Classic Papers in the History of Geology (1)

James Hutton's "Theory of the Earth" (1788)

The International Commission for the History of Geological Sciences (INHIGEO) has been invited by the IUGS to publish a series of articles on papers of fundamental importance in the history of geology. The articles will consist of extracts from "classic" papers, together with exegesis or commentary, and background biographical or cultural information as appropriate. Some secondary sources will also be listed, and bibliographical information concerning the papers will be provided as appropriate. Most topics will be selected from the nineteenth and twentieth centuries, but James Hutton's foundational "Theory of the Earth" paper (1788) has been selected to start off the series. The series will not, however, follow strict chronological order.

Background

James Hutton (1726–1797) was a Scottish farmer, businessman, chemist, philosopher, philologist, and geologist. His formal education was in the humanities and science at Edinburgh University and in chemistry and anatomy in Paris. He took a degree in medicine at Leyden, with a thesis on the circulation of the blood (1749). In his later life in Edinburgh, Hutton was friends with such persons as the chemist Joseph Black, the economist Adam Smith, and the mathematician John Playfair. His special friend during his geological travels was John Clerk of Eldin. With reason, Hutton has often been referred to as the "founder of modern geology".

Not long after returning to Edinburgh from the Continent, Hutton became involved in a successful business manufacturing sal ammoniac, which provided a steady income. But he also developed an interest in the new agricultural techniques then being developed in England, and in 1752 moved from Edinburgh to Norfolk, where he studied the up-to-date farming methods, making also journeys on foot to inspect other parts of England. In 1754, he travelled to the Low Countries, also in search of agricultural information. Later that year, he returned to Scotland, and decided to apply himself to farming. He worked two small farms that he owned, about forty miles from Edinburgh, residing in one of them. For several years he laboured manfully, applying his knowledge to the improvement of his properties, and making a success of his agricultural enterprises.

But Hutton did not remain for ever a farmer and he returned to Edinburgh about 1767, engaging in such matters as the business of the construction of the canal linking Edinburgh and Glasgow, philosophising, geologising, making chemical experiments and meteorological observations, and writing an unpublished treatise on agriculture (which contained an early intimation of the principle of natural selection). In his later years Hutton, by then comfortably off, travelled much and wrote extensively, and was active in the intellectual life of Edinburgh in its great period of "Enlightenment".

It is evident from Hutton's writings that he believed that the earth and its living organisms were produced by a wise and intelligent "Designer", as appeared from examination of the earth, which he thought admirably created for human habitation. Yet in Norfolk, and on his farms in Berwickshire, Hutton saw good soil being washed away into the sea. However, he also realised that fresh soil was being formed by the weathering and erosion of rock. So he felt

it necessary to think of a cyclic process whereby the good soil might be replenished; and this idea seems to have lain at the back of his geological theorising.

Hutton's Geological Writings

There was apparently an early geological manuscript, mentioned by Hutton's biographer John Playfair, but this has not survived. From 1867, Hutton was active in the Edinburgh Philosophical Society and he assisted in founding the Royal Society of Edinburgh in 1783. His great paper, expounding his geological theory, was presented to the Society in two parts in 1785, and an abstract of the paper was published the same year. The full text appeared as a separate in 1787, and in the Society's *Transactions* in 1788. The paper was subsequently extended to two substantial volumes: his celebrated *Theory of the Earth* (1795). A third volume remained in manuscript for many years. It was only published in 1899 by Archibald Geikie, but has recently been reprinted. It gives much information about Hutton's geological travels and observations. Hutton also published "Observations on Granite" and "On the Flexibility of the Brazilian Stone" in the *Transactions of the Royal Society of Edinburgh* (1791). His geological ideas were discussed and expounded in his biography by Playfair (1805), and at book length in Playfair's *Illustrations of the Huttonian Theory of the Earth* (1802).

Hutton's Geological Theory

Hutton had to explain how rocks could be replaced, thereby providing material that could be eroded and weathered—yielding soil that could allow the continuance of plant and animal life and of soil for agriculture. Thus (perhaps in keeping with his early ideas about the circulation of the blood) he devised a *cyclic* theory, in which the changes were driven by the internal heat of the earth, and by the activities of living organisms (with plants collecting sunlight). He presumed that there was unlimited time for geological cycles to occur, and thought that the philosophical naturalist should not attempt to say anything about the origins of the earth.

In the paper focused on here, which provided his first extended statement of his geological ideas, Hutton provided evidence for the existence of the internal heat of the earth, but did not speculate on its causes. His basic idea was that sediment was washed into the oceans, and consolidated, with the help of heat, on the ocean floors. Then by some expansive, heat-generated, process the consolidated sediments were upheaved to form new land, which in time would undergo erosion and weathering, forming fresh soil. In their upheaval, strata might be broken and tilted, and the resulting inclined strata might be planed off, and at some later time (after subsidence) they might receive further deposits of layered sediments. Hence unconformities might be produced; but apparently Hutton had not actually seen unconformable strata when he produced his paper of 1785/1788. He did so in the years following, at celebrated sites such as Siccar Point and Jedburgh in southeast Scotland, and they were described in his *Theory of the Earth*. These localities displayed unconformities between what came to be known as Old Red Sandstone and Silurian greywacke. Playfair described Hutton and his friends as having discovered the unconformity at Siccar Point in 1788 by sailing along the Berwickshire coast until the junction between the two rock types was reached; and, when they saw it and recognised its geological significance, they felt, as Playfair put it, as if they were looking into the "abyss of time". But possibly Hutton

knew what he might find at the coastal exposure, for his lowland farm had been situated on the Old Red while his hill farm was on greywacke and the contact ran towards the coast approximately along the eastern boundary of the latter farm. Hutton's work always involved an intricate interplay between reasoning from his field knowledge and the specimens in his collection, and the formulation of hypotheses which he sought to test in the field.

Neither in his paper (1785/1788) nor in his *Theory of the Earth* did Hutton give an explanation of the earth's internal heat, nor why places on the ocean floor might be variously upheaved to form new land. Rather, he was concerned to argue from the evidence of hand specimens and field observations that the earth's interior was hot and that many phenomena could only be accounted for satisfactorily on the basis of the action of heat rather than water. His arguments were ingenious, but some, such as those to do with the formation of crystals within cavities, have not stood the test of time. Regardless of this, it was known in Hutton's day that a gas becomes heated under compression. Perhaps he thought that the compressed strata on the ocean floors likewise acquired additional heat and thereby entered an expansive phase? In the exposition of his theory (1785/1788), Hutton laid much stress on the notion that the earth behaved like a machine, and it is possible that his thoughts were thus directed by his acquaintance with the heat engines, then coming into use, where complicated mechanisms were driven by the energy of a hot fire. But he was also interested in the importance of the sun for plant growth, in the dependence of animals on plants, and the role of living organisms in the formation of sediments. Some modern "Gaia" theorists regard Hutton as one of their founding fathers.

Extracts

Here follow extracts from Hutton's classic paper of 1788, with emphasis on his arguments for the internal heat of the earth. The original page numbering is given in parentheses.

- [209] Extracts from: James Hutton, "THEORY of the EARTH; Or an INVESTIGATION of the Laws Observable in the Composition, Dissolution, and Restoration of Land upon the Globe. ... [Read March 7. and April 4. 1785]", *Transactions of the Royal Society of Edinburgh*, 1788, Volume 1, 209–304 and plates.

PART I.

Prospect of the Subject to be treated of.

[Hutton begins with an argument that the earth behaves like a machine, and with an assumption that it is designed for the existence and well-being of living organisms, especially humans.]

WHEN we trace the parts of which this terrestrial system is composed, ... , the whole presents a machine of a peculiar construction by which it is adapted to a certain end. We perceive a fabric, erected in wisdom, to obtain a purpose worthy of the power that is apparent in the production of it.

- [210] IN taking this view of things, ... , we may hope to find a principle upon which the comparative importance of parts in the system of nature may be estimated, and also a rule for selecting the object of our enquiries. Under this direction, science may find a fit subject of investigation in every particular, whether of *form*, *quality*, or *active power*, that presents itself in this system of motion and of life; and which, without a proper attention to this character of the system, might appear ... incomprehensible.

IT is not only by seeing those general operations of the globe which depend upon its peculiar construction as a machine, but also by perceiving how far the particulars, ... , depend upon the general operations of the globe, that we are enabled to understand the constitution of this earth as a thing formed by design

- [211] TO acquire a general or comprehensive view of this mechanism of the globe, by which it is adapted to the purpose of being a habitable world, it is necessary to distinguish three different bodies which compose the whole. These are, a solid body of earth, an aqueous body of sea, and an elastic fluid of air.

1st, THERE is a central body in the globe. This body supports those parts ... which may be examined by our sense and observation

2dly, WE find a fluid body of water. This, by gravitation, is reduced to a spherical form, and by the centrifugal force of the earth's rotation, is become oblate [B]esides affording the means of life and motion to a multifarious race of animals, it is the source of growth and circulation to the organized bodies of this earth, in being the receptacle of the rivers, and the fountain of our vapours.

- [212] *3dly*, WE have an irregular body of land, raised above the level of the ocean

Lastly, WE have a surrounding body of atmosphere, which completes the globe

SUCH is the mechanism of the globe; let us now mention some of those powers by which motion is produced, and activity procured to the mere machine.

FIRST, There is the progressive force, or moving power [inertia], by which this planetary body, if solely actuated, would depart continually from the path which it now pursues

BUT this moving body is also actuated by gravitation, which inclines it directly to the central body of the sun. Thus it is made to revolve about that luminary, and to preserve its path.

- [213] WE next observe the influence of light and heat, of cold and condensation. It is by means of these two powers that the various operations of this living world are more immediately transacted .

WE are thus bountifully provided with the necessaries of life; we are supplied with things conducive to the growth and preservation of our animal nature, and with fit subjects to employ and to nourish our intellectual powers.

- [214] [LET] us now confine our view, more particularly, to that part of the machine on which we dwell, that so we may consider the natural consequences of those operations which being within our view, we are better qualified to examine.

[A] solid body of land could not have answered the purpose of a habitable world; for a soil is necessary to the growth of plants; and a soil is nothing but the materials collected from the destruction of the solid land. Therefore, the surface of this land, ... is made by nature to decay, in dissolving from that hard and compact state in which it is found below the soil; and this soil is necessarily wasted away, by the continual circulation of the water, running from the summits of the mountains towards the general receptacle of that fluid.

- [215] THE heights of our land are thus levelled with the shores; our fertile plains are formed from the ruins of the mountains; and those travelling materials are still pursued by the moving water, and propelled along the inclined surface of the earth. These moveable materials, delivered into the sea, cannot, for a long continuance, rest upon the shore; for, ... , every moveable thing is carried ... along the shelving bottom of the sea; towards the unfathomable regions of the ocean.

IF the vegetable soil is thus constantly removed from the surface of the land, and if its place is thus to be supplied from the dissolution of the solid earth, ... , we may perceive an end to this beautiful machine; ... arising ... from that destructibility of its land which is so necessary ... in the oeconomy of life and vegetation.

THE immense time necessarily required for this total destruction of the land, must not be opposed to that view of future

events, which is indicated by the surest facts and most approved principles. Time, which measures everything in our idea, and is often deficient to our schemes, is to nature endless and as nothing; ...

[216] [WE] are now to examine the globe; to see if there be, ... , a reproductive operation, by which a ruined constitution may be again repaired, and a duration or stability thus procured to the machine, considered as a world sustaining plants and animals.

THE globe of this earth is evidently made for man. He ... alone is capable of knowing the nature of this world, which he thus possesses in virtue of his proper right; and he alone can make the knowledge of this system a source of pleasure and the means of happiness.

[217] NOW, if we are to take the written history of man for the rule by which we should judge of the time when the species first began, that period would be but little removed from the present state of things. The Mosaic history places this beginning of man at no great distance; and there has not been found, in natural history, any document by which a high antiquity might be attributed to the human race. But this is not the case with regard to the inferior species of animals, particularly those which inhabit the ocean and its shores. We find in natural history monuments which prove that those animals had long existed; and we thus procure a measure for the computation of a period of time extremely remote, though far from being precisely ascertained.

IN examining things present, we have data from which to reason with regard to what has been; and, from what has actually been, we have data for concluding with regard to that which is to happen hereafter ...

IT is thus that, in finding the relics of sea-animals of every kind in the solid body of our earth, a natural history of those animals is formed, ... [218] We shall thus arrive at facts which indicate a period to which no other species of chronology is able to remount.

THE solid parts of the globe are, in general, composed of sand, of gravel, of argillaceous and calcareous strata, or of the various compositions of these with some other substances, ...

BUT that which renders the original of our land clear and evident, is the immense quantities of calcareous bodies which had belonged to animals, ... For ... all these calcareous bodies, from the collection of the strata were formed, ... were produced in [the sea].

[219] *1st*, THERE are few beds of marble or limestone, in which may not be found some of those objects which indicate the marine origin of the mass. If, for example, in a mass of marble, taken from ... the top of the Alps or Andes, there shall be found one cockle-shell, or piece of coral, it must be concluded, that this bed of stone had been originally formed at the bottom of the sea, as much as another bed which is evidently composed almost altogether of cockle-shells and coral ...

[220] *2dly*, IN those calcareous strata, which are evidently of marine origin, there are many parts that are of a sparry structure; that is to say, the original texture of those beds, in such places, has been dissolved, and a new structure has been assumed, which is peculiar to a certain state of the calcareous earth. This change is produced by crystallization, in consequence of a previous state of fluidity, which has so disposed the concreting parts, as to allow them to assume a regular shape and structure proper to that substance. A body, whose external form has [221] been modified by this process, is called a *crystal*; one whose internal arrangement of parts is determined by it, is said to be of a *sparry structure*; and this is known from its fracture.

3dly, THERE are, in all the regions of the earth huge masses of calcareous matter, in that crystalline form or sparry state, in which perhaps no vestige can be found of any organised body,

nor any indication that such calcareous matter had belonged to animals; but as, in other masses, this sparry structure, or crystalline state, is evidently assumed by the marine calcareous substances, ... , it does not appear, that the sparry masses, in which no figured body is formed, have been originally different from other masses, which being only crystallized in part, and in part still retaining their original form leave ample evidence of their marine origin.

WE are [thus] led, ..., to conclude, that all the strata ... , not only those consisting of such calcareous masses, ... , have had their origin at the bottom of the sea, by the collection of sand and gravel, of shells, of coralline and crustaceous bodies, and of earths and clays, variously mixed, or separated and accumulated ...

THERE is a part of the solid earth which we may at present neglect, not, as being persuaded that this part may not also be [222] found to come under the general rule of formation with the rest, ... This excluded part consists of certain mountains and masses of granite. These are thought to be still older in their formation, and are very rarely, at least, found superincumbent on strata which must be acknowledged as the productions of the sea.

HAVING thus found the greater part, ... , of the solid land to have been originally composed at the bottom of the sea, we may now, ... , suppose the whole of this sea-born land to be again dispersed along the bottom of the ocean, the surface of which would rise proportionally over the globe. We would thus have a spheroid of water, with granite rocks and islands scattered here and there. But this would not be the world which we inhabit; therefore, the question now is, how such continents, as we actually have upon the globe, could be erected above the level of the sea.

[223] CONSEQUENTLY, besides an operation, by which the earth at the bottom of the sea should be converted into an elevated land, ... , there is required, ... , a consolidating power, by which the loose materials that had subsided from water, should be formed into masses of the most perfect solidity, ...

[224] FROM every view of the subject, therefore, we are directed to look into those consolidated masses themselves, in order to find principles from whence to judge of those operations by which they had attained their hardness or consolidated state.

[225]

PART II

An Investigation of the Natural Operations employed in consolidating the Strata of the Globe.

THERE are just two ways in which porous or spongy bodies can be consolidated, and by which substances may be formed into masses of a natural shape and regular structure, the one of these is simple *congelation* from a fluid state, by means of cold; the other is *accretion*; and this includes a separatory operation, as well as that by which the solid body is to be produced. But, in whichever of these ways solidity is to be procured, it must be brought about by first inducing fluidity, either ... by the action of heat, or ... with the assistance of a solvent, ...

THUS, fire and water may be considered as the general agents in this operation which we would explore ...

THE strata, formed at the bottom of the sea, are to be considered as having been consolidated, either by aqueous solution and crystallization, or by the effect of heat and fusion. If it is in the first of these two ways, there will be a certain uniformity observable in the effects; and there will be general laws, by which the operation must have been concluded. Therefore, knowing those general laws, and making just observations ... , a philosopher, in his closet [study], should be able to determine, what may, and what may not have been transacted in the bowels of the earth, or below the bottom of the ocean.

...

THE action of water upon all the different substances is an operation with which we are familiar. We have it in our power to apply water in different degrees of heat for the solution of bodies, and under various degrees of compression; consequently, there is no reason to conclude anything mysterious in the operations of the globe, which are to be performed by means of water, unless an immense compressing power should alter the nature of those operations ...

...

WATER being the general medium in which bodies collected at the bottom of the sea are always contained, if those masses of collected matter are to be consolidated by solution, it must be by the dissolution of those bodies in that water as a men[227]struum [solvent], and by the concretion or crystallization of this dissolved matter, that the spaces, first occupied by water in those masses, are afterwards to be filled with a hard and solid substance; but without some other power, by which the water contained in those cavities ... , should be separated in proportion as it had performed its task, it is inconceivable how those masses, ... should be absolutely consolidated, without a particle of fluid water in their composition.

...

[IF], therefore, the cavities of the strata are to be filled with solid matter, by means of water, there must be made to pass through those porous masses, water impregnated with some other substances in a dissolved state; and the aqueous menstruum must be made to separate from the dissolved substance, and to deposit the same in those cavities through which the solution moves.

BY such a supposition as this, we might perhaps explain a partial consolidation of those strata; but this is a supposition, of which the case under consideration does not admit; for in the present case, which is that of materials accumulated at the bottom of the ocean, there is not proper means for separating the dissolved matter from the water included in those enormous masses; nor are there any means by which a circula[228]tion in those masses may be formed ...

...

IF water had been the menstruum by which the consolidating matter was introduced into the interstices of strata, masses of those bodies could only be found consolidated with such substances as water is capable of dissolving; ...

IN this case, the consolidation of strata would be extremely limited; for we cannot allow more power to water than we find it has in nature; ... Let us, therefore, attend, with every possible circumspection, to the appearances of those bodies, by means of which we are to investigate the principles of mineralogy, and know the laws of nature.

...

[229] WE have strata consolidated by calcareous spar, ... We have strata made solid by the formation of fluor, a substance not soluble, ... , by water. We have strata consolidated with sulphureous and bituminous substances, which do not correspond to the solution of water. We have strata consolidated with siliceous matter, in a state totally different from that under which it has been observed, on certain occasions, to be deposited by water. We have strata consolidated by feld-spar, a substance insoluble in water. We have strata consolidated by almost all the various metallic substances, ... [W]e find, perhaps, every different substance introduced into the interstices of strata which had been formed by subsidence at the bottom of the sea.

IF it is by means of water that those interstices have been filled with those materials, water must be, like fire, an universal solvent, ... , and we must change entirely our opinion of water in relation to its chemical character. But there is no necessity thus to violate our chemical principles, in order to explain certain natural appearances; more especially if those appearances may be explained in another manner, confidently with the known laws of nature.

IF, again, it is by means of heat and fusion that the loose and porous structure of strata shall be supposed to have been consol-

idated, then every difficulty which had occurred in reasoning upon the power or agency of water is at once removed. The loose and discontinuous body of a stratum may be closed by means of softness and compression; the porous structure of the [230] materials may be consolidated, in a similar manner, by the fusion of their substance; and foreign matter may be introduced into the open structure of strata, in form of steam or exhalation, as well as in the fluid state of fusion; consequently, heat is an agent competent for the consolidation of strata, which water alone is not. If, therefore, such an agent could be found acting in the natural place of strata, we must pronounce it proper to bring about that end.

...

[231] THERE are to be found among the various strata of the globe, bodies, formed of two different kinds of substances, *siliceous* bodies, and those which may be termed *sulphureous*. With one or other or both of those two substances, every different consolidated stratum of the globe will be found so intimately mixed, or closely connected, that it must be concluded, by whatever cause those bodies of siliceous and sulphureous matter had been changed from a fluid to a concreted state, the strata must have been similarly affected by the same cause.

...

SILICEOUS matter, ... , is not soluble in water; ...

...

[232] IT may be, therefore, asserted, that no siliceous body having the hardness of flint, nor any crystallization of that substance, has ever been formed, except by fusion ...

BESIDES this proof for the fusion of siliceous bodies, which is indirect, arising from the indissolubility of that substance in water, there is another, which is more direct, being founded upon appearances which are plainly inconsistent with any other supposition, except that of simple fluidity induced by heat. The proof I mean is, the penetration of many bodies with a flinty substance, which, ... , must have been performed by the flinty matter in a simply fluid state, and not in a state of dissolution by a solvent.

THESE are flinty bodies perfectly insulated in strata both of chalk and sand. It requires but inspection to be convinced. It is not possible that flinty matter could be conveyed into the middle of those strata, by a menstruum in which it was dissolved, and thus deposited in that place, without the smallest trace of deposition in the surrounding parts.

BUT, besides this argument taken from what does not appear, the actual form in which those flinty masses are found, demon [233] strates, *first*, That, they have been introduced among those strata in a fluid state, by injection from some other place. *2dly*, That they have been dispersed in a variety of ways among those strata, then deeply immersed at the bottom of the sea, and, *lastly*, That they have been there congealed from the state of fusion, and have remained in that situation, while those strata have been removed from the bottom of the ocean to the surface of the present land.

...

[234] NOW, ... , we have the most convincing proofs, that it had been flint in a simple fluid state which had penetrated the wood, and not in a state of solution.

First, BECAUSE, however little of the wood is left unpenetrated, the division is always distinct between the injected part and that which is not penetrated by the fluid flint. In this case, the flinty matter has proceeded a certain length, which is marked, and no farther; and, beyond this boundary, there is no partial impregnation, nor a gradation of the flintifying operation, as must have been the case if siliceous matter had been deposited from a solution. *2dly*, The termination of the flinty impregnation has assumed such a form, precisely, as would naturally happen from a fluid flint penetrating that body.

IN other specimens of this mineralizing operation, fossil wood, penetrated, more or less, with ferruginous and calcareous substances, has been afterwards penetrated with a flinty substance. In this case, with whatever different substances the woody body shall be supposed to have been penetrated in a state of solution by water, the regular structure of the plant would still

have remained, with its vacuities variously filled with the petrifying substances, separated from the aqueous menstruum, and deposited in the vascular structure of the wood.

THERE cannot be a doubt with regard to the truth of this proposition; for as it is, we frequently find parts of the consolidated wood, with the vascular structure remaining perfectly [235] in its natural shape and situation; but if it had been by aqueous solution that the wood had been penetrated and consolidated, all the parts of that body would be found in the same natural shape and situation.

THIS, however, is a far from being the case; for while, in some parts, the vascular structure is preserved entire, it is also evident, that, in general, the woody structure is variously broken and dissolved by the fusion and crystallization of the flint ...

WE may now proceed to consider sulphureous substances, ...

THE sulphureous substances ... [are] not soluble in water, ... , but fusible by heat, and inflammable These substances are of two kinds, ...

THE most: simple kind is composed of two different substances, viz. phlogiston, with acid or metallic substances; from which result, on the one hand, sulphur, and, on the other, metals, ... The more compound sort, again, is oily matter, produced by vegetables, and forming bituminous bodies.

THE *first* of these is found naturally combined with almost all metallic substances, which are then said to be mineralized with sulphur. Now, it is well known, that this mineralizing operation is performed by means of heat or fusion; ... The combination of iron and sulphur, for example, may easily be performed by fusion; ...

- [236] THE variety of these ... substances ... is almost indefinite; but unless they were all soluble in water, this could not have happened by the action of that solvent. If we shall allow any of those solid bodies to have been formed by the fluidity of heat, they must all have been formed in the same manner; ...

HERE, for example, are crystallized together in one mass ... *Pyrites, ... Blend, ... Galena, ... Marmor metallicum* [Barytes], ... *Fluor, ... Calcareous spar, ... Quartz* ...

... [IT] is in vain to look for the explanation of these appearances in the operations of nature, by means of aqueous solution.

- [237] ON the other hand, heat being capable of rendering all these substances fluid, they may be, with greatest simplicity, transported from one place to another; and they may be made to congregate altogether, at the same time, and distinctly separate in any place ...

- [239] WE now come to the *second* species of inflammable bodies called oily or bituminous ...

- [240] ... [IN] order to decide the point, with regard to what is the power in nature by which mineral bodies have become solid, we have but to find bituminous substances in the most complete state of coal, immediately connected with some other substance, which is more generally found consolidating the strata, and assisting in the concretion of mineral substances. But I have in my possession the most undoubted proof of this kind. It is a mineral vein, or cavity, in which are blended together coal of the most fixed [non-volatile] kind, quartz, and marmor metallicum ...

- [242] THUS, ... , from the facts relating to the bituminous substances, conspiring with that from the phaenomena of other bodies, affords the strongest corroboration ... that the various concretions found in the internal parts of strata have not been occasioned by means of aqueous solution, but by the power of heat and operation of simple fusion, ...

[Hutton next argues along somewhat similar lines from the evidence of rock salt; and then turns to consider the evidence provided by certain concretionary iron-stone nodules from East Lothian.]

- ...
[246] THE form of these iron-stones is that of an oblate or much compressed sphere, and the size from two or three inches diameter to more than a foot. In ... section, they present the most elegant septarium; ... [from which one may conclude]

First, THAT the septa have been formed by the uniform contraction of the internal parts of the stone, ...

2d, THAT there are only two ways in which the septa must have received the spar with which they are filled, more or less, either, *first*, By insinuation into the cavity of the septa after these were first formed; or, *2dly*, By separation from the substance of the stone, at the time the septa were forming.

- ...
[247] [BUT] the septa reach not the circumference; the surface of the stone is solid and uniform in every part; and there is not any appearance of the spar in the argillaceous bed around the stone.

IT, therefore, necessarily follows, that the contraction of the iron-stone, in order to form septa, and the filling of these cavities with spar, had proceeded *pari passu* [simultaneously]; and that this operation must have been brought about by means of fusion, or by congelation from a state of simple fluidity and expansion.

[Hutton then argues similarly for the production of crystals in other rock cavities, and for the formation of agates. Next he considers the consolidation of siliceous and calcareous strata by heat. The interlocking grains of sand in a sandstone or quartzite exemplified the formation of the former by heat. A specimen of marble from Spain, consisting of interlocking pieces of different calcareous matter is held to exemplify the latter. Gravel and sand are held to "graduate" into granite.]

- ...
[255] [WE] shall, ... , now consider one particular species of granite *[a graphic specimen from near Portsoy, on the coast of the Moray Firth, northeast Scotland]*; ...

...
THE singularity of this specimen consists, not in the nature of the proportions of its constituent parts, but in the uniformity of the sparry ground, and the regular shape of the quartz mixture. This siliceous substance, viewed ... longitudinally, may be considered as columnar, prismatical, or continued in lines running nearly parallel. These columnar bodies of quartz are beautifully impressed with a figure on the sides, where they are in contact with the spar ...

- ...
[256] IT is evident ... that the sparry and siliceous substances had been mixed together in a fluid state; and the crystallization of the sparry substance, which is rhombic, had determined the regular structure of the quartz, ...

THUS, the siliceous substance is to be considered as included in the spar, and as figured according to the laws of crystallization proper to the sparry ground; but the spar is also to be found included in the quartz Now it is not possible to conceive any other way in which these two substances, quartz and feldspar, could be thus concreted, except by congelation from a fluid state, in which they had been mixed. *[This cannot have been water as the two substances are insoluble in water.]*

- ...
[257] UPON the whole, therefore, whether we shall consider granite as a stratum or as an irregular mass, ..., there is sufficient evidence of this body having been consolidated by means of fusion, and in no other manner.

- [258] WE are thus led to suppose, that the power of heat and operation of fusion must have been employed in consolidating strata of loose materials, which had been collected together and amassed at the bottom of the ocean ...

...
IF, again, strata have been consolidated by means of heat, acting in such a manner as to soften their substance, then, in [259] cooling, they must have formed rents or separations of their substance, by the unequal degrees of contraction which the contiguous

ous strata may have suffered. Here is a most decisive mark by which the present question may be determined.

THERE is not in nature any appearance more distinct than this of the perpendicular fissures and separations in strata. They are generally known to workmen by the terms veins or backs [*joints in coal seams, oblique to bedding*] and cutters [*joints in coal, perpendicular to principal joints*]; and there is no consolidated stratum that wants these appearances ...

[261]

PART III.

Investigation of the Natural Operations employed in the Production of Land above the Surface of the Sea.

WE seek to know that operation by means of which masses of loose materials, collected at the bottom of the sea, were raised above its surface, and transformed into solid land.

[262] WE may, perhaps, account for the elevation of land, by the same cause with that of the consolidation of strata, already investigated, without [actually] explaining the means employed by nature in procuring the power of heat, ...

[263] ... [IF] there is no other way in which we can conceive this event to have been brought about, consistent with the present state of things, ... , we shall have a right to conclude, that such had been the order of procedure in natural things, and that the strata formed at the bottom of the sea had been elevated, as well as consolidated, by means of subterraneous heat.

[Hutton considers that alterations of the level of land might involve subsidence, but he has no mechanism to explain such changes; and subsidences would exhibit "little wisdom" in that they would not yield sources of new rock for the production of soil.]

[265] THE strata formed at the bottom of the ocean are necessarily horizontal in their position, or nearly so, and continuous in their horizontal direction or extent. They may change, and gradually assume the nature of each other, so far as concerns the materials of which they are formed; but there cannot be any sudden change, fracture or displacement naturally in the body of a stratum. But if these strata are cemented by the heat of fusion, and erected with an expansive power acting below, we may expect to find every species of fracture, dislocation and contortion, in those bodies, and every degree of departure from a horizontal towards a vertical position.

THE strata of the globe are actually found in every possible position: For from horizontal, they are frequently found vertical; from continuous, they are broken and separated in every possible direction; and, from a plane, they are bent and doubled. It is impossible that they could have originally been formed, ... , in their present state and position; [266] and the power that has been necessarily required for their change, has not been inferior to that which might have been required for their elevation from the place in which they had been formed.

WE are now to conclude, that the land on which we dwell had been elevated from a lower situation by the same agent which had been employed in consolidating the strata, in giving them stability, and preparing them for the purpose of the living world. This agent is matter actuated by extreme heat, and expanded with amazing force.

IF this has been the case, it will be reasonable to expect, that some of the expanded matter might be found condensed in the bodies which have been heated by the igneous vapour; and that matter, foreign to the strata, may have been thus introduced into the fractures and separations of those indurated masses.

[Accordingly, Hutton offered an explanation of the

occurrence of mineral veins, and discussed the phenomena of volcanoes, still occurring at the present.]

[274] VOLCANOES are natural to the globe, as general operations; but we are not to consider nature as having a burning mountain for an end in her intention, or as a principal purpose in the general system of the world. The end of nature in placing an internal fire or power of heat, and a force of irresistible expansion, in the body of this earth, is to consolidate the sediment [275] collected at the bottom of the sea, and to form therefrom a mass of permanent land above the level of the ocean, for the purpose of maintaining plants and animals. The power appointed for this purpose is, as on all occasions, where the operation is important, and where there is any danger of a shortcoming, wisely provided in abundance; and there are contrived means for disposing of this redundancy. These, in the present case, are our volcanoes.

A VOLCANO is not made on purpose to frighten superstitious people into ... piety and devotion, nor to overwhelm devoted cities with destruction; a volcano should be considered as a spiracle to the subterranean furnace, in order to prevent the unnecessary elevation of land, and fatal effects of earthquakes; and we may rest assured, that they, in general, wisely answer the end of their intention, without being an end in themselves, for which nature had exerted such amazing power and excellent contrivance.

[Hutton then continues by describing outcrops of "whinstone" or basaltic material, found in dykes and sills and formed as "subterranean lavas". He suggests that such rock is similar to that associated with volcanoes, but is not introduced explosively as in an erupting volcano, since within the earth any contained calcareous spar cannot "effervesce by the explosion of its fixed air [carbon dioxide]".]

[284] IT is not meant to specify every particular in the means employed by nature for the elevation of our land. It is sufficient to have shewn, that there is, in nature, means employed for the consolidation of strata, formed originally of loose and incoherent materials; and those same means have also been employed in changing the place and situation of those strata. But how describe an operation which man cannot have any opportunity of perceiving? Or how imagine that, for which, perhaps, there are not proper data to be found? We only know, that the land [285] is raised by a power which has for principle subterraneous heat; but how that land is preserved in its elevated position, is a subject in which we have not even the means to form conjecture; at least, we ought to be cautious how we indulge conjecture in a subject where no means occur for trying that which is but supposition.

WE now proceed, from the facts which have been properly established, to reason with regard to the duration of this globe, or the general view of its operations, as a living world, maintaining plants and animals.

PART IV.

System of Decay and Renovation observed in the Earth

[Hutton describes the materials out of which sediments are formed: gravel, sand, clay, and organic remains. These suggest that sediments were formed at the bottom of the sea, and were derived from former land masses. Animals depend on plants, which provide the "pabulum (food) of life". Evidence for former vegetation is provided by fossil wood, etc.]

[294] ... [IT] may be enquired, why destroy one continent in order to erect another? The answer is plain; Nature does not destroy a continent from having wearied of a subject which had given pleasure, or changed her purpose, whether for better or a worse; neither does she erect a continent of land among the clouds, to show

her power, or to amaze the vulgar [common] man: Nature has contrived the productions of vegetable bodies, and the sustenance of animal life, to depend upon the gradual but sure destruction of a continent; that is to say, these two operations necessarily go hand in hand. But with such wisdom has nature ordered things in the oeconomy of this world, that the destruction of one continent is not brought about without the renovation of the earth in the production of another; and the animal and vegetable bodies, for which the world above the surface of the sea is levelled with its bottom, are among the means employed in those operations, as well as the sustenance of those living beings is the proper end in view.

...

[In continuation, Hutton offers a rather Kantian doctrine: and some students of Hutton have seen his philosophical works as having arrived independently at notions rather similar to those of Immanuel Kant.]

[297] OUR object is to know the time which had elapsed since the foundation of the present continent had been laid at the bottom of the ocean, ... The space is long; the data for the calculations are perhaps deficient: No matter; so far as we know our error, or the deficiency in our operation, we proceed in science, and shall conclude in reason. It is not given to man to know what things are truly in themselves, but only what things are in his thought ...

WE are investigating the age of the present earth, from the beginning of that body which was in the bottom of the sea, to the perfection of its nature, which we consider as in the moment of our existence; ...

THE formation of a future earth being in the bottom of the ocean, ... , here is a part of the process which cannot be taken as a principle in forming an estimate of the whole. But, in the destruction of the present earth, we have a process that is performed within the limits of our observation; therefore, in knowing the measure of this operation, we shall find the means of calculating what had passed on a former occasion, as well as what will happen in the [298] composition of a future earth ...

...

[But neither in a single human life-time, nor in the record of history from the Ancients, do we find evidence to estimate the rate of wastage of the land by the sea, as it is so slow. This objection notwithstanding, Hutton concludes his argument, considering cycles of formation and destruction of land, in unimaginable lengths of time.]

[303] ... [IF] the earth on which we live, began to appear in the ocean at the time when the last began to be resolved, it could not be from the materials of the continent immediately preceding this which we examine, that the present earth had been constructed; for the bottom of the ocean must have been filled with materials before land could be made to appear above its surface.

LET us suppose that the continent, which is to succeed our land, is at present beginning to appear above the water in ... the Pacific Ocean, it must be evident, that the materials of this great body, ... , must have been collected from the destruction of an earth which does not now appear [exist]. Consequently, ... , there is necessarily required the destruction of an animal and vegetable earth prior to the former land; and the materials of that earth which is first in our account, must have been collected at the bottom of the ocean, and begun to be concocted [made ready by heat] for the production of the present earth, when the land immediately preceding the present had arrived at its full extent.

[304] THIS, however, alters nothing with regard to the nature of those operations of the globe. The system is still the same. It only protracts the indefinite space of time in its existence, while it gives us a view of another distinct period of the living world; that is to say, the world which we inhabit is composed of the materials, not of the earth which was the immediate predecessor of the present, but of the earth which, in ascending from the present, we consider as the third, and which had preceded the land

that was above the surface of the sea, while our present land was yet beneath the water of the ocean ...

[It was evidence in favour of such cycles that Hutton eventually found at Siccar Point, etc., and which made his companions' minds "grow giddy by looking so far into the abyss of time". He concludes with a famous geological aphorism, summing up his belief that there was no necessity for natural philosophy to look for an agent to originate the earth: "it is in vain to look for anything higher in the origin of the earth".]

WE have now got to the end of our reasoning; we have no data further to conclude immediately from that which actually is: But we have got enough; we have the satisfaction to find, that in nature there is wisdom, system, and consistency. For having, in the natural history of this earth, seen a succession of worlds, we may from this conclude that there is a system in nature; in like manner as, from seeing revolutions of the planets, it is concluded, that there is a system by which they are intended to continue those revolutions. But if the succession of worlds is established in the system of nature, it is in vain to look for anything higher in the origin of the earth. The result, therefore, of our present enquiry is, that we find no vestige of a beginning,—no prospect of an end.

Select Bibliography

- Bailey, E.B., 1967, James Hutton—The Founder of Modern Geology: Elsevier Publishing Company, Amsterdam, London, and New York.
 Dean, D.R., 1992, James Hutton and the History of Geology: Cornell University Press, Ithaca and London.
 Gerstner, P.A., 1968, James Hutton's Theory of the Earth and his Theory of Matter: *Isis*, v. 59, 26–31.
 Jones, J., 1984, The Geological Collection of James Hutton: *Annals of Science*, v. 41, 223–244.
 Jones, J., 1985, James Hutton's Agricultural Research and his Life as a Farmer: *Annals of Science*, v. 42, pp. 573–601.
 Leveson, D.J., What was James Hutton's Methodology?: *Archives of Natural History*, v. 23, 61–77.
 McIntyre, D.B., 1997, James Hutton's Edinburgh: The Historical, Social, and Political Background: *Earth Sciences History*, v. 16, 100–157.
 McIntyre, D.B. and McKirdy, A., 1997, James Hutton: The Founder of Modern Geology: The Stationery Office, Edinburgh.
 Playfair, J., 1803, Biographical Account of the Late Dr James Hutton, F.R.S. *Edin.*: Transactions of the Royal Society of Edinburgh, v. 5, 39–99.
 Tomkeieff, S.I., 1962, Unconformity—An Historical Study: *Proceedings of the Geologists' Association*, v. 73, 383–417.

David Oldroyd,
 Secretary-General, INHIGEO,
 Honorary Visiting Professor,
 School of Science and Technology Studies,
 The University of New South Wales,
 Sydney 2052,
 AUSTRALIA
 Tel: 61 2 9449 5559;
 Fax: 61 2 9144 4529;
 E-mail: <D.Oldroyd@unsw.edu.au>

Acknowledgement

I am most grateful to Donald McIntyre and Norman Butcher for their valued and timely comments on the first draft of this paper.