

## a22 Unconformities interpreted by Hutton < Siccar Point, Playfair >

... some drill and bore / The solid earth, and from the strata there / Extract a register, by which we learn / That he who made it, and reveal'd its date / To Moses, was mistaken in its age. —Cowper, 1785.<sup>1</sup>

The deformed and hardened rocks of the Southern Uplands [of Scotland] and the [English] Lake District were generally supposed to be relics of the early crust of the Earth, but this conjecture was refuted when Hutton and Clerk found fossils in the Lake District [slaty rocks] (1788) ... In a letter to James Watt in December 1791, [Joseph] Black reported that Hutton had been very ill [he survived an operation to relieve a urinary blockage] ... Although it is unlikely he did any further fieldwork, he wrote a prodigious amount between 1791 and his death in 1797, including: *Dissertations ... in Natural Philosophy* (740 pages in length); ... *Principles of Knowledge ...* (2,138 pages); ... *the Philosophy of Light, Heat, and Fire* (326 pages); the two-volume *Theory of the Earth ...* (1,187 pages) with additional chapters which remained in manuscript until 1899 (267 printed pages); the manuscript of his still unpublished *Elements of Agriculture* (1,045 pages); and various shorter contributions. —McIntyre & McKirdy.<sup>2</sup>

Horizontal strata resting atop the eroded edges of inclined strata were originally recognized by John Strachy (1671-1743) as indicative that a significant period of erosion and non-deposition had occurred before the younger formation came to bury the older formation. James Hutton reasoned similarly in 1787. In 1805, Prof. Robert Jameson (Edinburgh University) sketched an example at Burnswark Hill, Scotland,<sup>3</sup> and using Wernerian reasoning (that even young Darwin his student, 1826-1827, saw as cultish for its fantastical beliefs flaunted as proofs of piety) called the surface that separates two discordant formations (the Flötz upon the Transition) an *unconformity*.<sup>4</sup> Since then, American geologists recognized that the key point be that an unconformity is an erosion surface separating bodies of greatly different ages. It need not cut across inclined or folded strata. When it does, the unconformity is called an *angular unconformity*.

Dunglass estate in East Lothian, 40 miles (65 km) east of Edinburgh has to its north the Midland Valley underlain by sedimentary rocks and to its south the relatively resistant-to-erosion Southern Uplands graywacke crops out. Donald B. McIntyre and Alan McKirdy in *James Hutton*, 1997, write that at his request, “Sir James Hall’s uncle searched for and found the contact [of these] in the Tour [Tower] burn [small stream]. Hutton and Playfair then joined Sir James Hall at Dunglass. Under the heading *The Theory confirmed from Observations made on purpose to elucidate the subject*, Hutton described what happened: ‘Having taken boat at Dunglass burn, we set out to explore the coast. At Siccar Point, we found [in 1788] a beautiful picture of this junction washed bare by the sea.’”<sup>2</sup>

In the cliff section of the headland are exposed two formations (**Figure a22.1**). The uppermost is comprised of gently inclined strata of red sedimentary sandstones with, elsewhere, (Devonian) fish fossils. These red sandstone strata are called the *Old Red Sandstone* (ORS) because elsewhere stratigraphically higher (younger) red sandstones exist. The ORS formation rests on a gray one below comprised of steeply inclined strata of slaty sediments with, elsewhere, (Silurian) shellfish fossils.

The present elevation of the ORS and the inclination of its strata (here to an angle of about 15 degrees to the horizontal), implies uplift and tilting of its strata which had accumulated originally on the ocean floor as horizontal layers. Hutton’s reasoning was that “...moveable materials, delivered into the sea, cannot, for a long continuance, rest upon the shore; for, by the agitation of the winds, the tides and currents, every moveable thing is carried farther and farther along the shelving bottom of the sea, towards the unfathomable regions of the ocean.” Accumulations are of flat lying strata on the floor of the ocean. Subsequent uplift can raise these to view above sealevel.

The floor on which the ORS rests is underlain by folded strata of gray sediments. Hutton realized that before the deposition of the (Devonian) ORS this floor must have been cut across the upended, locally vertical, gray (Silurian) strata. The floor (angular unconformity) had been prepared by erosional truncation to sealevel of land formerly exposed above that datum by uplifting deformation. This general principle was later expressed by Hutton as:

... 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 washed away, by the continual circulation of the water, running from the summits of the mountains towards the general receptacle of that fluid [the ocean basins].

THE heights of our land are thus levelled with the shores; our fertile plains are formed from the ruins of the mountains; ...<sup>5</sup>

The vertical strata of gray sediments long before these were raised, tilted, and planed off by erosion can be reasoned to have once been horizontally bedded accumulations of marine sand and mud.

To summarize: The ORS strata were deposited in the Devonian Period, a remote past time often called the “Age of fishes” (though marine invertebrates are abundantly the commoner fossils).<sup>6</sup> The base on which these red sands were deposited is an erosion surface cut at sealevel across of the underlying vertical strata that had originated long before (during, what would later come to be called, the *Silurian Period*) as horizontal sedimentary marine strata. Hutton could explain that the time of erosion, which is represented physically by the contact boundary of no thickness (the unconformity) between formations of greatly different age, was sufficient for a great mountain range to be reduced by erosion to sealevel (**Footnote a22.1**). We now know that the interval recorded by this buried erosion surface (unconformity) and mountain building (deformation) that preceded it, is about 80 million years. Inconceivably long on a human time scale, yet less than 2 percent of geological time.

The angular unconformity of Hutton, which is a buried erosion surface cut across older deformed strata, was of a quite different origin to the collapse unconformity of Steno. It gave evidence for burial of an erosion surface after prolonged erosion to a plain of the exposed parts of up-tilted or folded, formerly horizontal, strata. Hutton’s contribution was limited to the realization that uplift can raise the land anew with respect to sealevel. In his view, mountains expose deep structures in their up-bent and rent parts. He did not perceive that these same structures, by the direct application of Steno’s principle of lateral continuity, could be used to reconstruct, in the minds eye, the mountains that had once existed (A. C. Ramsay would in 1846, *see* Topic a24).

Hutton thought beyond the model of four Earth formations (*see* Topic a26) that Werner’s teachings had implanted in the informed minds of his time. He argued, on the basis of inclusions, for an endless succession of once formations. In Scotland, schists mapped as Primitive contained pebbles of altered or metamorphosed sediments that themselves could be described as Primitive. “... nothing in the strict sense [is] primitive.” wrote Hutton and in the rock record he saw “no vestige of a beginning, no prospect of an end.” Also, Primitive rocks that contained pebbles of diverse other rocks are thereby not entirely of chemical origin as Werner had envisaged.

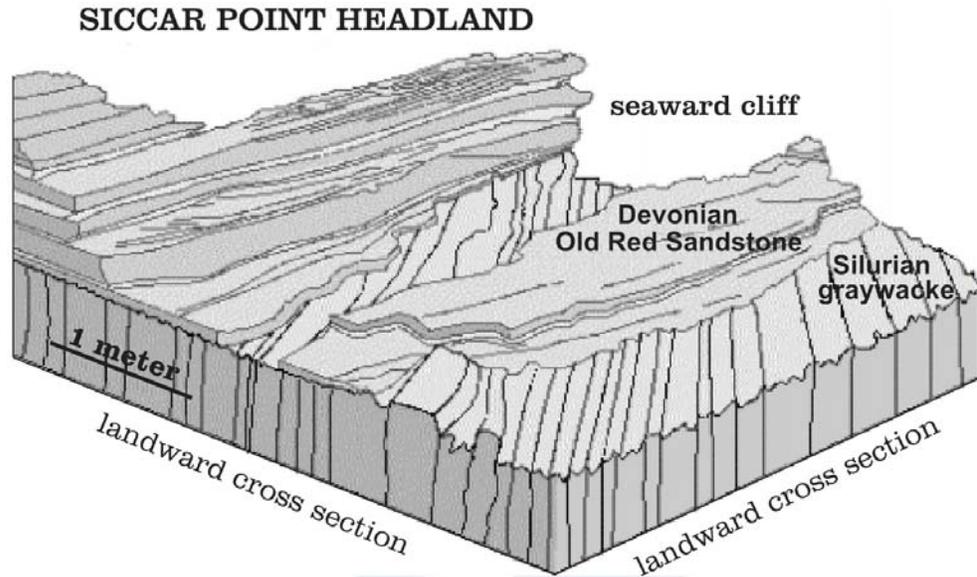
High standing areas of Earth’s surface are cut deeply by erosion. Hutton supposed mountain to be the result of uplift. As a result, mountains expose to weathering strata formerly in Earth’s depths. The voluminous detrital sediments of the Secondary are evidence of weathering and erosion. The Secondary he had predicted should, in some places, unconformably bury deeply-eroded older strata. Field work in 1787, had provided Hutton with two examples (**Figures a22.2, a22.3**) which corroborated his theory of uplift of mountainous lands.

Steno’s mechanism of episodic collapse to explain the attitude of strata (carried forward by such as Saussure, John Whitehead, and Jean-André Deluc)<sup>7</sup> is in Hutton’s interpretation replaced by episodic uplift due to the emplacement of granite that makes room for itself. Also, rather than break rock strata, as would collapse, Hutton’s envisioned uplift slow enough for strata to yield by bending (to fold). Following from his novel insights, destruction of once mountains by weathering to soil and erosion of this soil by rivers, could be appreciated from the very bulk of detrital sedimentary rocks.

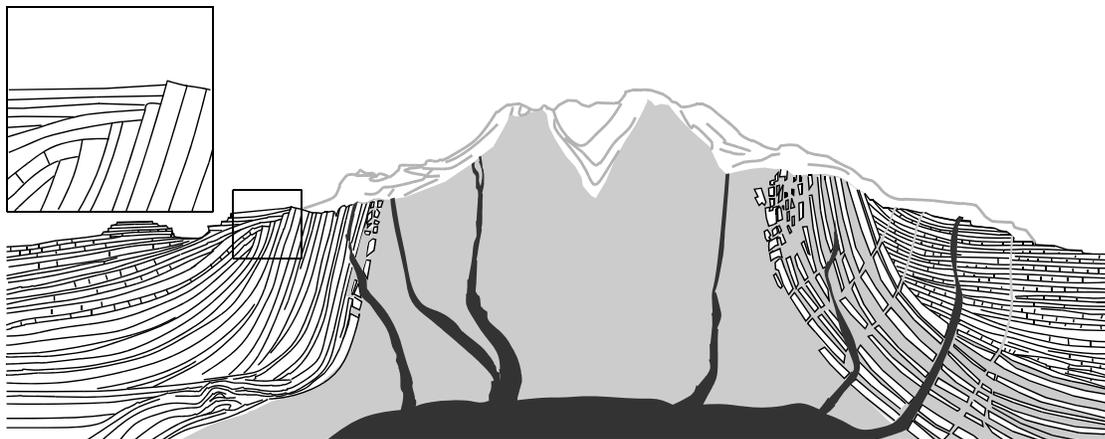
Not clear to Hutton, even by 1787, was that uplift had been elsewhere than in existing mountainous terrains. However, in 1788 he generalized his understanding: The scenery has been cyclic in its nature. Mountains come and go. Uplift creates a mountain, and erosion removes it. This has happened often we know and in continental areas everywhere in the long course of geologic history. □

**Figure a22.1**<sup>8</sup>

Angular unconformity at Siccar Point, Berwickshire, Scotland, between almost horizontal beds of Upper Devonian "Old Red Sandstone" and almost vertical beds of Lower Silurian "greywacke" (graywacke).

**Figure a22.2**<sup>9</sup>

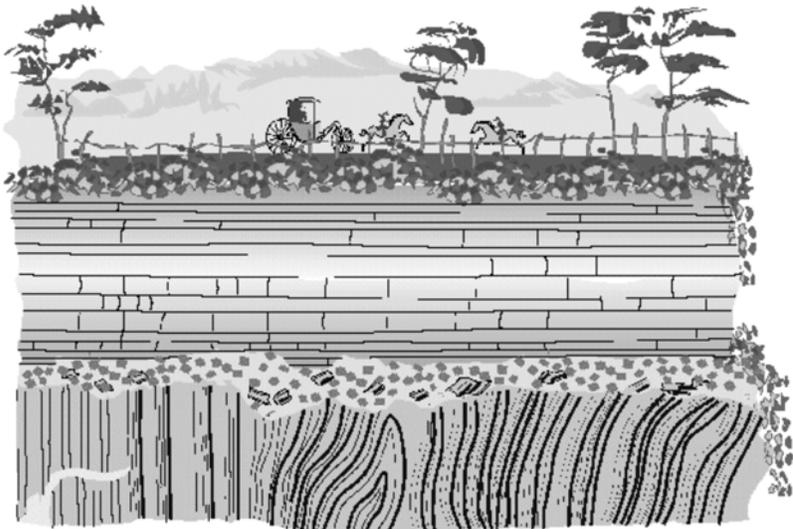
East-west cross section of the Northern Granite (pale gray), Isle of Arran in the Firth of Clyde, after one drawn (probably by John Clerk of Eldin) for Hutton and published in 1787. Scenic elements are in gray line. The uppermost sedimentary formation oversteps (in box) the erosionally truncated, upended, strata of the underlying "schistus" formation; itself older than (cut by) apophyses of an inferred underlying body of granite (black). The buried erosion surface (visible in a small outcrop at Newton Point, Arran) is the unconformity Hutton examined in 1787. His description of it in *Theory of the Earth* (1795, p. 429, and 1899, pp. 235-236) is (from the latter): "Here the first thing that occurs is the intermediate junction of the inclined strata of schistus [folded graywacke strata that in this local dip about 30° NNW] and the other strata, which here appear to be a composition of sandstone and limestone; these strata are equally inclined with the schistus, but in the opposite direction [dip 40-50° SSW]. These two different kinds of stratified bodies rise to meet each other; they are somewhat confused [basal conglomerate with clasts of underlying rock] at the immediate junction, but some of the sandstone [Old Red Sandstone] or calcareous strata overlap the ends of the alpine schistus."



At depth, the schematic cross section was drawn to show that uplift had been gradualistic, but also episodic, and Hutton's (incorrect) opinion that the (ORS) sandstone and the underlying strata (Late Precambrian Dalradian schists) are conformable at depth away from the area of intrusive granite (black). A Steno valley-fill buttress unconformity (at right) is entirely fanciful and such (as even in the box) plague illustrative cross sections as late as in Lyell's *Principles of Geology* 1st vol. 2nd ed., 1832.

**Figure a22.3** Plant and animal life is ongoing upon a landscape currently being eroded into horizontal (Upper Devonian) limestone strata that records a former time of gradual accumulation when a sea had flooded the area. It buries a "puddingstone" with angular pebble inclusions of an even older

formation. The puddingstone itself is a partial record of a time of prolonged subaerial erosion when erosion removed a former enormous mountain. The buried erosion surface is called an *angular unconformity*. Although cut off by this unconformity, the once mountain is proclaimed below by its roots of vertical, isoclinally folded, shistose (Silurian) graywacke strata and some igneous intrusion. This was the second such example discovered by Hutton in 1787. The exposure is a natural cross section (depicted in exaggerated scale and embellished by the artist, probably John Clerk of Eldin)<sup>10</sup> in the cut bank of the River Jedd, south of Edinburgh, Scotland.



**Footnote a22.1** (From *The Works of John Playfair*, 4:78-81. Archibald Constable & Co., 1822)<sup>11</sup>

The ridge of the Lammermuir Hills, in the south of Scotland, consists of primary micaceous schistus [folded Silurian graywacke], and extends from St Abb's Head westward, till it join the metalliferous mountains about the sources of the Clyde. The sea coast affords a transverse section of this alpine tract at its eastern extremity, and exhibits the change from the primary to the secondary strata, both on the south and on the north. Dr Hutton wished particularly to examine the latter of these, and on this occasion Sir James Hall and I had the pleasure to accompany him. We sailed in a boat from Dungleigh, on a day when the fineness of the weather permitted us to keep close to the foot of the rocks which line the shore in that quarter, directing our course southwards, in search of the termination of the secondary strata. We made for a high rocky point or head-land, the Siccar, near which, from our observations on shore, we knew that the object we were in search of was likely to be discovered. On landing at this point, we found that we actually trode on the primeval rock, which forms alternately the base and the summit of the present land. It is here a micaceous schistus, in beds nearly vertical, highly indurated, and stretching from S.E. to N.W. The surface of this rock runs with a moderate ascent from the level of low water, at which we landed, nearly to that of high-water, where the schistus has a thin covering of red horizontal [Devonian] sandstone laid over it; and this sandstone, at the distance of a few yards farther back, rises into a very high perpendicular cliff. Here, therefore, the immediate contact of the two rocks is not only visible, but is curiously dissected and laid open by the action of the waves. The rugged tops of the schistus are seen penetrating into the horizontal beds of sandstone, and the lowest of these last form a breccia containing fragments of schistus, some round and others angular, united by an arenaceous cement.

Dr Hutton was highly pleased with appearances that set in so clear a light the different formations of the parts which compose the exterior crust of the earth, and where all the circumstances were combined that could render the observation satisfactory and precise. On us who saw these phenomena for the first time, the impression made will not easily be forgotten. The palpable evidence presented to us, of one of the most extraordinary and important facts in the natural history of the earth, gave a reality and substance to those theoretical speculations which, however probable, had never till now been directly authenticated by the testimony of the senses. We often said to ourselves, What clearer evidence could we have had of the different formation of these rocks, and of the long interval which separated their formation, had we actually seen them emerging from the bosom of the deep? We felt ourselves necessarily carried back to the time when the schistus on which we stood was yet at the bottom of the sea, and when the sandstone before us was only beginning to be deposited, in the shape of sand or mud, from the waters of a superincumbent ocean. An epocha still more remote presented itself, when even the most ancient of these rocks, instead of standing upright in vertical beds lay in horizontal planes at the bottom of the sea and was not yet disturbed by that immeasurable force which has burst asunder the solid pavement of the globe. Revolutions still more remote appeared in the distance of this extraordinary perspective. The mind seemed to grow giddy by looking so far into the abyss of time; and while we listened with earnestness and admiration to the philosopher who was now unfolding to us the order and series of these wonderful events, we became sensible how much farther reason may sometimes go than imagination can venture to follow.