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Alpine influences on Scottish geology: sketches by Albert Heim in Henry Cadell's 1894 notebook

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In 1894 the Scottish geologist and industrialist Henry Moubray Cadell (1860–1934) visited Switzerland and met with the doyen of Alpine geology, Professor Albert Heim (1849–1937). Cadell may have arranged his trip to coincide with the 6th International Geological Congress, held that year in Zurich. Heim played a leading role in the organisation of the Congress and led a field excursion to the Glarus region, for the geological structure of which he had a controversial interpretation. Whatever the circumstances, that the two men discussed details of Alpine structural geology is made clear by sketches that Heim drew in Cadell's notebook (Figure 1), recently rediscovered in section 5381.70 of the extensive Cadell archive held by the National Library of Scotland. Some of the sketches suggest fascinating links with contemporary developments in Scottish geology.

Cadell had studied at Edinburgh University and the Clausthal Royal Mining Academy in Germany before joining the Geological Survey in Scotland in 1883 (Mendum 2010). With the Survey he was a member of the team examining the complex geology of the NW Highlands, and to support the field investigations performed in 1885 his remarkable experiments into fold and thrust propagation utilising a mechanical 'squeeze box' (Figure 2). He came from a wealthy family and in 1888, on the death of his father, he resigned his position to manage the family's business affairs in coal mining and manufacturing. Thereafter he travelled extensively and remained scientifically well-connected by virtue of fellowship of the Royal Society of Edinburgh. In 1894 he was the secretary of the Edinburgh Geological Society.

Heim's magnum opus, published in 1878, was a 3-volume, beautifully illustrated atlas showing his interpretations of Alpine structural geology: large-scale overfolding was much in evidence but he regarded thrust faulting as a subordinate feature developed by the shearing-out of the lower limb of overturned anticlines. In the Glarus region, wary of the prodigious lateral displacement inherent in a single thrust interpretation, he proposed instead two huge overfolds facing each other, one directed southward and the other northward, this was his *Glarus Doppelfalte* [Double Fold] (Figure 1). A more detailed view of part of the northern 'wing' [*Nordflügel*] of the *Doppelfalte* (Figure 3) shows the *Verrucana*, Permian red beds, lying above Jurassic strata with a zone of *quartenschiefer* [quartz-schist?] marking the thrust plane where the lower limb of the putative anticline has been sheared out. By the time of Cadell's 1894 visit, most Alpine geologists had accepted a single, major north-directed thrust to explain the Glarus relationships, doing away with the south-directed overfold, the *Nordflügel*, but Heim clung to his interpretation until the end of the century (Oldroyd 1990, p. 237).

It is generally recognised that Heim's Alpine work influenced the resolution of structural problems in the NW Highlands of Scotland – 'The Highlands Controversy' (Oldroyd 1990) – but Heim's sketches also suggest a link to interpretations of Southern Uplands geology. There, Charles Lapworth (1842–1920), having established the Lower Palaeozoic stratigraphy with the pioneering use of graptolites (and decisively intervened in the NW Highlands) next assessed the region's overall structure.

The Heim sketch of most relevance (Figure 4) illustrates the concept of fan-shaped anticlinal and synclinal arrangements, compound structures of tight folds with axial planes dipping either outwards or inwards relative to the overall structure. This idealises the structures shown in Figure 1, for which Heim had included a similar diagram in his 1878 atlas. Although he doesn't acknowledge Heim, Lapworth (1889) utilises the same approach to explain the structure of the Southern Uplands. His cross-sections (a fold-out in the 1889 paper) show the repeated, multiple tight folding of a relatively thin succession, strike and fold hinges trending NE-SW, but with the fold envelope domed in the NW and dropping to the SE (Figure 5). Consequently, "we must naturally expect to find the deepest strata in the "fan structure" (endocline) or pseudo-synclinal form and the highest in the folds of the inverted fan structure (exocline) or pseudo-anticlinal form" (Lapworth 1889, p. 62).

Lapworth's terminology is a bit cryptic but in essence it explains the distribution of strata in the Southern Uplands: oldest in the NW, youngest in the SE, despite the tight folding imagined across the whole region. In another respect Lapworth's terminology appears surprisingly modern: "we find that almost the whole of the Lower Palæozoic strata of the Uplands are naturally grouped in two grand lithological terranes, viz. (I.) a *Lower Terrane* (*Moffat Terrane*), including strata ranging from the Upper Llandeilo to the Upper Llandovery; and (II.) an *Upper Terrane* (*Gala or Queensberry Terrane*), embracing strata generally of Tarannon [about Upper Llandovery to Wenlock] age (Lapworth 1889, p. 59). Does anyone know of an earlier use of 'Terrane' with something approaching its current geological meaning?

Following Lapworth's lead, Ben Peach (1842–1926) and John Horne (1848–1928) had in 1888 commenced their re-examination of the Southern Uplands for the Geological Survey. They expanded Lapworth's model of a relatively thin sequence 'corrugated' by a repetition of tight folds and in their subsequent monumental memoir (Peach & Horne, 1899, p.72) illustrated the 'fan structures' incorporating the folds, adopting the terms 'anticlinorium' and 'synclinorium' for, respectively, Lapworth's endocline and exocline (Figure 6). The terminology was credited to the American geologist James Dwight Dana (1813–1895), but is it coincidence that the anticlinorium shown broadly matches the structure created by Cadell in Figure 2?

It has puzzled many commentators that after successfully invoking large-scale thrusting as the key to geological structure in the NW Highlands of Scotland, Lapworth, Peach and Horne fell back on folding as the principal tectonic mechanism in the Southern Uplands. For example, Kelling (2001, p. 330): "Given their ready acceptance of thrusting to explain the repetition of stratigraphic units in the NW Highlands, why was *faulting*, and especially reverse and thrust faulting, so conspicuously ignored as a regionally important structural element in the Southern Uplands?" Geology there is now seen in terms of a subduction-related accretionary complex of imbricate thrust zones repetitively stacking-up the sedimentary succession, but in those earlier interpretations, "though reversed faults are not infrequent, there is here no evidence of great horizontal displacement as in the North-west Highlands" (Peach & Horne 1899, p. 73).

Of course, there were mitigating factors. The major Southern Uplands thrusts are now sub-vertical, so to think of them as rotated near-horizontal originals was perhaps counterintuitive, and as sedimentary 'way-up' indicators were unappreciated, tight folds could be imaginatively introduced into the steeply inclined greywacke successions. But perhaps most important of all were the broad geological models that provided the context for the interpretations: we now have

plate tectonics to accommodate accretionary thrust complexes, but for Lapworth and the others, zones of tight folding were prominent in the influential mountain building interpretations developed by Heim and colleagues for the Alps.

References

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And for background to the Alpine controversies see Chapter 8 in Greene, M. T. 1982. *Geology in the Nineteenth Century*. Cornell University Press.

Figures

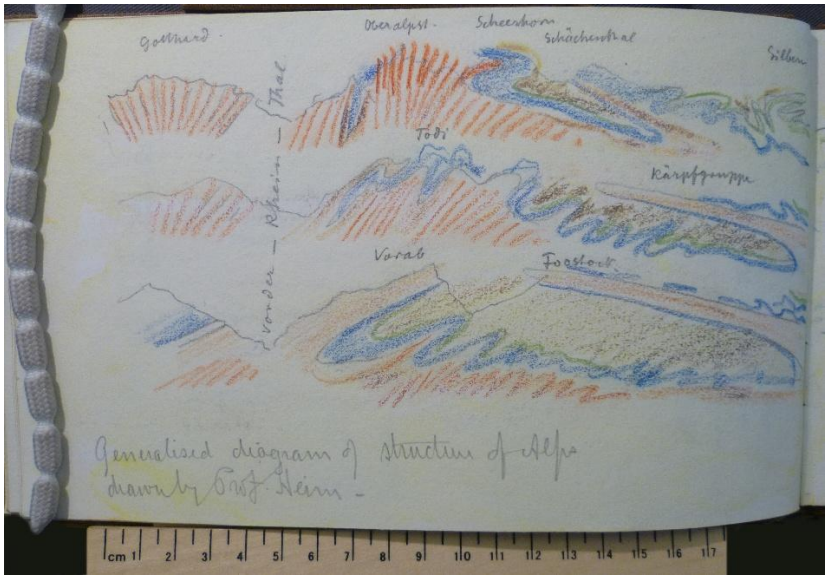

Figure 1. The first of Heim's Alpine geology sketches in Cadell's notebook. The assignment to Heim is in Cadell's handwriting. From an original held by the National Library of Scotland.

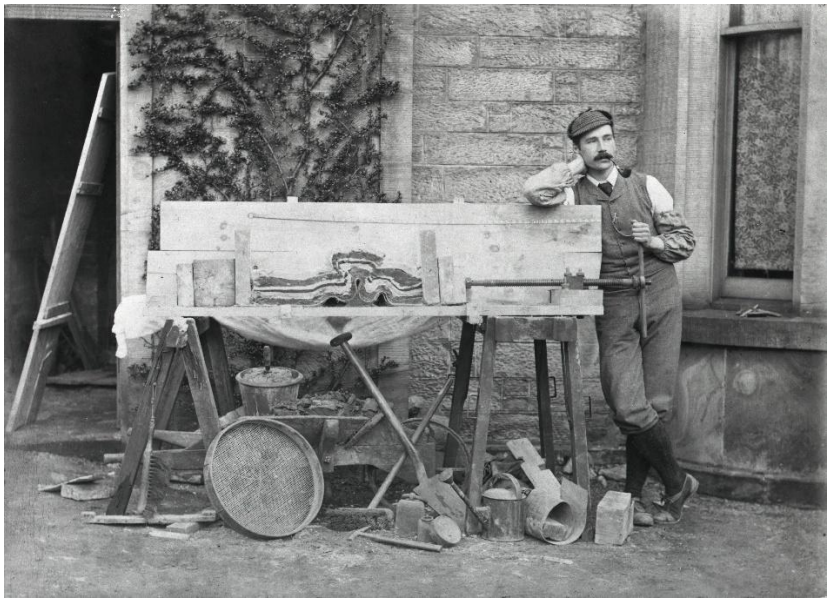

Figure 2. Cadell in 1885 experimenting with his ‘squeeze box’ to model fold and thrust development. British Geological Survey image P240116 © UKRI.

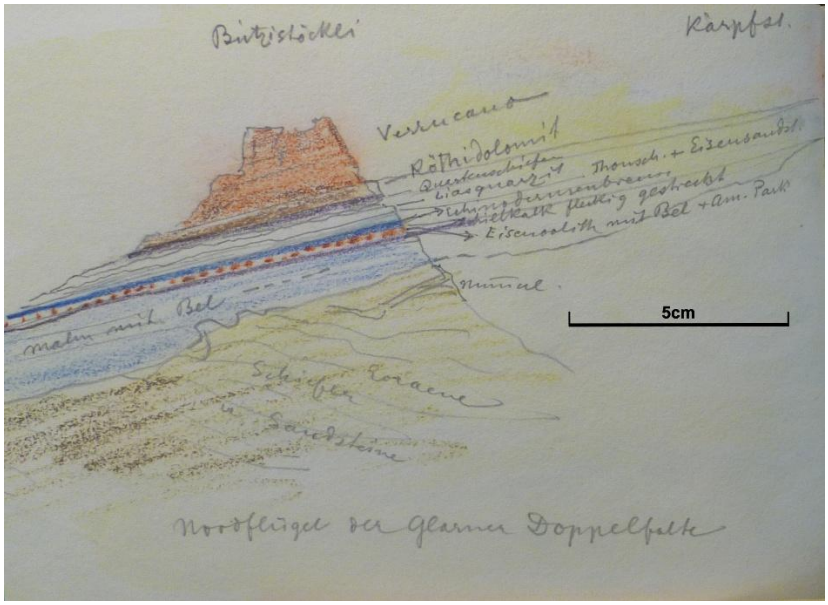

Figure 3. Heim’s sketch of part of his Glarus *Doppelfalte*, with Permian red beds (*Verrucana*) thrust over Jurassic strata. From an original held by the National Library of Scotland.

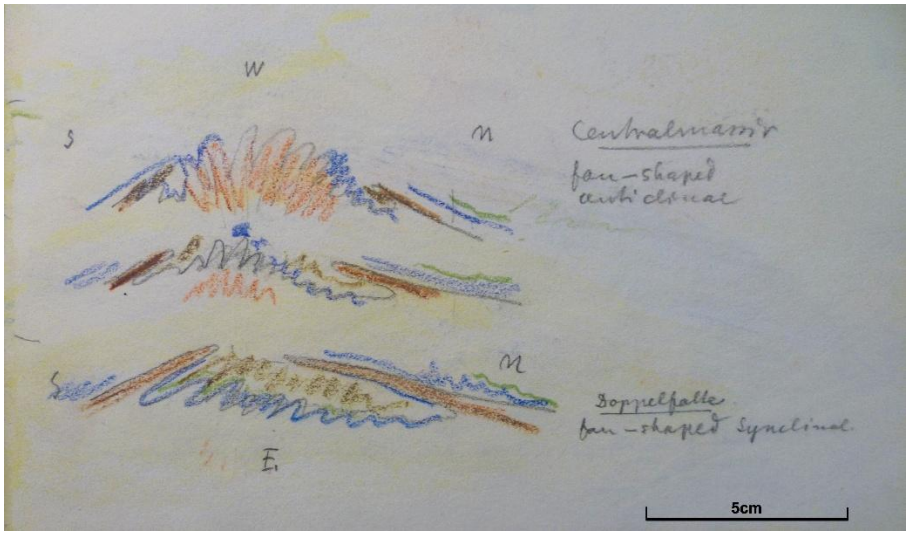

Figure 4. Heim's concept of fold fans, c.f. Figure 1. From an original held by the National Library of Scotland.

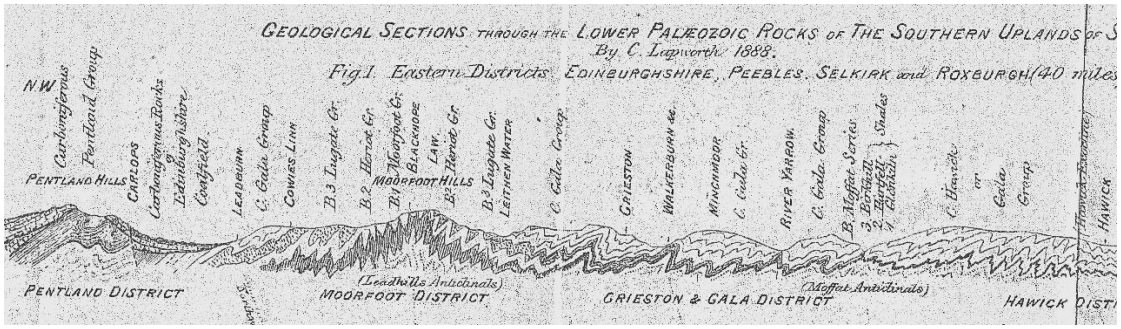

Figure 5. Part of Lapworth's (1889) fold-dominated interpretation of the Southern Uplands.

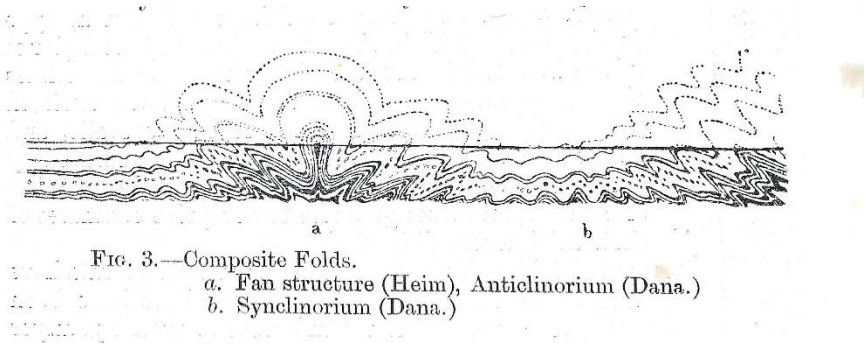

FIG. 3.—Composite Folds.
a. Fan structure (Heim), Anticlinorium (Dana.)
b. Synclinorium (Dana.)

Figure 6. The anticlinorium-synclinorium illustration from Peach & Horne (1899. p. 72).