Hassness and Goat Crags

[NY 189 163]

B.C. Webb

Highlights

This well-exposed section, showing some 350 m of the Buttermere Formation of the Skiddaw Group, demonstrates the distinction between the disruption and folding produced by slump or gravity-slide movements during Llanvirn times and the superimposed Early Devonian tectonic deformation.

Introduction

The Skiddaw Group (Lower Ordovician) rocks exposed here are disposed on a major anticline, overturned broadly westwards. The uninverted limb of this fold has suffered severe extension, leading to disruption of the beds and the formation of mélange lithologies.

The site lies within ground described by Rose (1954), Jackson (1961, 1962, 1978), Simpson (1967) and Webb (1972, 1975). Because of the complex structure and lack of chronostratigraphical control, the results of these earlier workers were controversial and problematic. The recent resurveying of the western part of the main Skiddaw Group inlier by the British Geological Survey has resolved the structural problems and clarified the stratigraphy (Webb and Cooper, 1988).

It should be noted that, in the description below, the gravity-driven folds labelled F_0 and the tectonic deformation labelled D_1 are differently assigned by Webb and Cooper (1988) — see (Table 3.1). This merely results from an attempt, in this volume, to reserve the notation D_1 for the Early Devonian deformation phase, which was broadly contemporaneous throughout the non-metamorphic Caledonides.

Description

The strata at the site belong to the Buttermere Formation of the Skiddaw Group comprising, in ascending stratigraphical order:

1. The Goat Gills Member, a marine breccia which has yielded a Trernadoc microflora.
2. The Robinson Member, a sequence of interbedded turbidite sandstone and siltstone.
3. Undifferentiated silty mudstone, largely of Late Arenig age.

Two generations of folds are clearly visible in the rocks cropping out over the site area, designated F_1 and F_2 by Simpson (1967), but are here designated F_0 and F_1, in accordance with the regional deformation sequence (F_1 and F_3 in Webb and Cooper, 1988). Both sets of folds are displayed in the Robinson Member, where bedding is clearly visible and the 'way-up' of the strata can be easily ascertained from sedimentary structures (Figure 3.5). The Robinson Member exhibits a strong ductility contrast with the surrounding silty mudstone, and this facilitates the study of deformation structures associated with slumping and with the generation of mélange structures (Figure 3.5) and (Figure 3.6).

Both major and minor F_0 folds are present. The trace of a major F_0 anticline descends from near the top of Goat Crags, south-eastwards through Goat Gills (Figure 3.5). This anticline is overturned, broadly westwards, so that the beds cropping out over most of the site dip eastwards and are inverted. Minor F_0 folds with amplitudes of a few metres, or less, are common. They are intrafolial periclines with curvilinear hinges, which plunge south-eastwards and are congruous with the major fold. On the inverted limb of the major F_0 fold, turbidite sandstones of the Robinson Member crop out extensively (Figure 3.6). The sandstones are hardly disrupted except close to their junction with the stratigraphically underlying Goat Gills Member, which crops out in the core of the major fold. Near to this junction, sandstone beds are

irregularly and disharmonically folded and sheared and only very locally does the junction appear to be undisturbed. On the more gently dipping, uninverted limb of the major fold, the Robinson Member is highly disrupted and forms a mélange of sandstone rafts and boudins suspended in a silty-mudstone matrix (Figure 3.7). Sandstone 'rafts' are well exposed near the summit of Goat Crags, where they range, in length and thickness, from a little over 1 m to several tens of metres.

The F_1 folds occur, most commonly, as minor structures with amplitudes of only 1 or 2 m. Larger F_1 folds, a few tens of metres in amplitude, affect the Robinson Member on the inverted F_1 major fold limb towards the west end of the site and in the buttress between Goat Gill and Hassnesshow Beck (Figure 3.5). The main cleavage (S_1) is well developed in the finer-grained lithologies. It dips steeply to the SSE, axial planar to the F_1 folds. Interference between F_0 and F_1 folds is well displayed at Hassness. The F_0 fold hinges, with gentle plunges, are visible in the small cliffs overlooking the lake, and F_1 folds, with axial-planar S_1 cleavage, can be seen plunging steeply in the glacially scoured rock surface above the cliffs.

Other minor structures in the Skiddaw Group are poorly represented in the site area. These include late, sideways-closing minor folds (F_2) with an associated, axial-planar, crenulation cleavage (S_2) which commonly affect S_1 or bedding, where this is steeply inclined. Sporadic, steeply inclined, NNW-trending joints are the local expression of north- or north-west-trending joints and cleavage, which are better developed elsewhere.

Rose (1954) recognized 'severe overfolding and thrusting' in the Goat Crags area. Using 'way-up' evidence, from the sedimentary structures in the turbidite sandstone, he correlated the Robinson Member with the lithologically similar Loweswater Formation (Early Arenig) of the fells further north. Jackson (1961, 1962) initially agreed with this correlation, having obtained graptolites from near the summit of Robinson [NY 202 168] which, elsewhere, occur at the base of the Loweswater Formation. Rose correlated the silty mudstone with the Kirkstile Formation, which overlies the Loweswater Formation. Later, however, Jackson changed his correlation (Jackson, 1978). Ignoring the 'way-up' evidence but taking into account graptolites reported from near Buttermere Village (Simpson, 1967), he reassigned the silty mudstone to the Hope Beck Formation which underlies the Loweswater Formation. Simpson, too, largely ignored the 'way-up' evidence placing the silty mudstone, which he named the Buttermere Slates, stratigraphically below the Robinson Member. He did not correlate the Robinson Member with the Loweswater Formation, but considered it to be older, naming it the Buttermere Flags.

Interpretation

Simpson (1967) recognized the polyphase nature of Skiddaw Group deformation, identifying the main, ENE-trending cleavage and folds (the present S_1 and F_1) as the earliest structures. He considered that these were originally inclined towards the SSE, but were reorientated by the later sideways-closing folds (the present F_2). He considered that both of these deformations pre-dated the Borrow-dale Volcanic Group, which unconformably overlies the Skiddaw Group. Since the ENE-trending, main cleavage and associated folds at Goat Crags affect previously inverted strata, they cannot be the earliest folds. Simpson referred them to a later, post-volcanic deformation phase even though, elsewhere, he considered a north-westerly trend to be characteristic of this phase. Simpson's deformation sequence and the nature of the junction with the overlying volcanic rocks were the subjects of controversy during the late 1960s and early 1970s (see Soper and Moseley, 1978; and the Introduction to this chapter). No major structures relatable to Simpson's second and third deformation phases could be substantiated, and his first two deformations were shown to be Early Devonian in age and thus not related to pre-Borrowdale unconformity. Early, north-trending, pre-cleavage folds (the present F_o) were, however, discovered at various localities in the Skiddaw Group.

Webb (1972, 1975) mapped the major and minor pre-cleavage folds in Goat Crags and described, in detail, the interference between minor, pre-cleavage folds and later, cleavage-related folds at Hassness. Since the later folds and cleavage trend ENE, parallel to the main cleavage elsewhere in the Lake District, he considered these to be the Early Devonian structures.

The recent remapping was done by the Geological Survey, when a more detailed palaeontological investigation was undertaken. This demonstrated abrupt changes in the age of contiguous strata in the Buttermere area, indicating severe

disruption of the normal stratigraphical sequence. Disruption of the Robinson Member had been noted by Webb (1975) but, at that time, major submarine gravity slide deposits (olistostromes) had yet to be described in detail and he considered the deformation to be 'orogenic'. The importance of slump folding associated with major, gravity sliding of the Skiddaw Group was first clearly demonstrated by Webb and Cooper (1988). They showed not only that the north-trending folds were slump-generated, but also that many of the ENE-trending folds were early slump structures modified by later, Early Devonian deformation. They proposed the current stratigraphy, defining the Buttermere Formation as an olistostrome, or submarine slump mass. Evidence from near Causey Pike [NY 218 209], further north, indicates that the olistostrome was emplaced during the Early Llanvirn. The geometry of the slump folds within it indicate that it slid westwards. This section is situated to the south-east of the Crummock Water–Causey Pike Line and the sense of overturning here is contrary to the southeasterly overturning observed north-west of that structural line (for example, at Gasgale Crags), suggesting that the line represents the axis of a local Ordovician depositional basin.

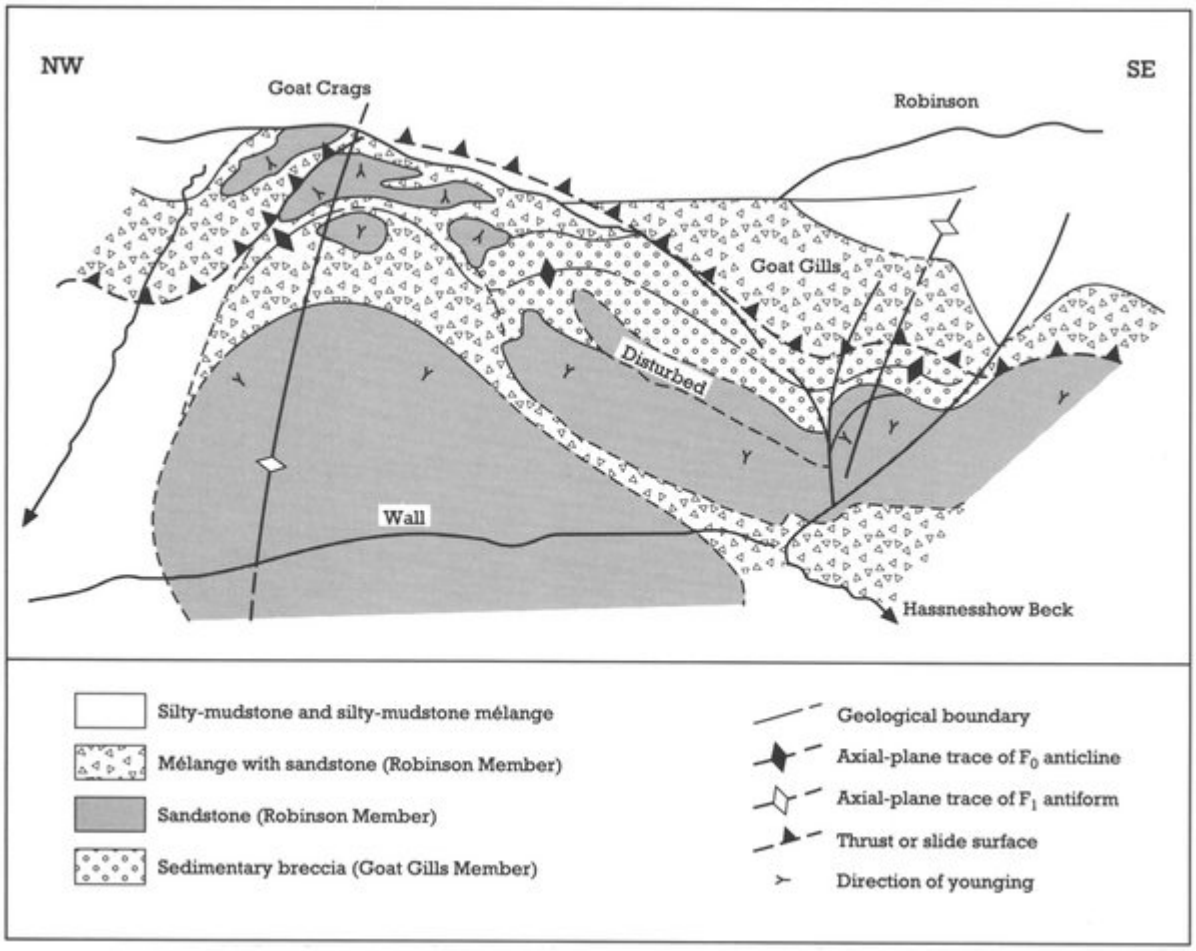
Conclusions

The fellside at Goat Crags affords an excellent section through a major olistostrome or submarine slump mass. This was formed by massive lateral movement of material on a sloping sea-bed during the early Ordovician Period, in Llanvirn times. Deposits of this type, on this scale, have not been recorded elsewhere in Britain. Primary minor structures, developed during the emplacement of the slump mass, are clearly displayed. These folds are referred to as D_0 folds in the classification of folds used in this volume. A degree of stratigraphical control within the slump mass is provided by the sandstone of the Robinson Member, whose sediments provide way-up evidence. In contrast to the south-easterly movements recorded at Gasgale Crags (see below), the slump folding here was directed to the west, towards the centre of the Ordovician marine depositional basin. The slump structures are clearly overprinted, that is, refolded, by others formed during the Early Devonian Caledonian deformation (D_1). It was here that these two generations of folding were first recognized and explained. They provide an important key to the understanding of the geological structure and history of the Lake District.

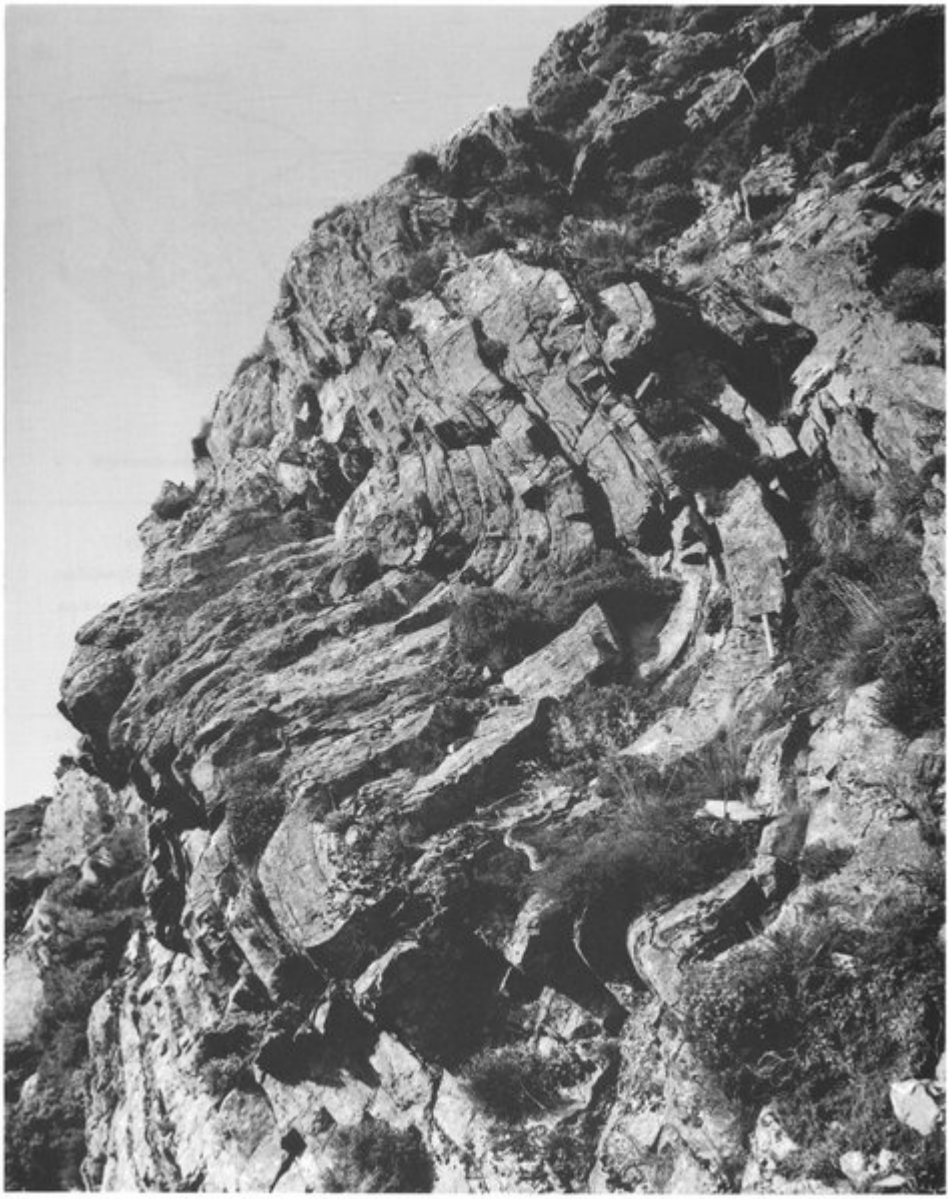
References

Stratigraphy and timing of events	Description of deformation phase	Phase numbering and contributions by various workers					
		Simpson (1967)	Soper (1970) and others (see text)	Moseley (1972)	Roberts (1977)	Webb and Cooper (1988)	This volume
	FAULTING dominantly N and NW trends						
	N-S FLEXURES with weak fracture cleavage				D_4		D_3
	RECLINED FOLDS with flat crenulation cleavage		D_2		D_3		D_2
Late Early Devonian intrusion of Shap (394Ma) and Skiddaw (399Ma) Granites							
MAIN END-CALEDONIAN PHASE: (Pridoli) WINDERMERE GROUP (Mid-Caradoc)	UPRIGHT FOLDS Major and minor, with transecting cleavage, trending NE to E	F_3	D_1	Phase 3 Related to collision	D_2	D_3	D_1
VOLCANO-TECTONIC FLEXURING AND TILTING (Early Caradoc) BORROWDALE VOLCANIC GROUP (Llandeilo)	Open E-W folding, block faulting		E-W folds large scale, no cleavage	Phase 2 Related to subduction and closure	Not recognised in Skiddaw Group	D_2	Volcano-tectonic deformation (Branney and Soper, 1988)
VOLCANO-TECTONIC UPLIFT BEGINS?	INITIATION OF ENE-TRENDING LAKE DISTRICT ANTICLINE?						
(Llanvirn) (Arenig) SKIDDAW GROUP (Tremadoc) ?	N-TRENDING FOLDS no cleavage	F_1 and F_2 (descriptions as D_1 and D_2 this volume)	N-S folds minor, no cleavage	Phase 1 N-S folds, minor in largely unconsolidated sediments	D_1 N-S folds, recumbent and minor, in largely unconsolidated sediments	D_1 N-S folds (but variable), large and small scale submarine slides and slumps	D_0 Large and small scale slumps as Webb and Cooper (1988), early small scale slumps

(Table 3.1) Deformation sequences in the Lake District as interpreted by various authors; the last column shows the system adopted in the present volume.



(Figure 3.5) Hassness and Goat Crags. Sketch view from the south-west, showing outcrop pattern and axial-plane traces. Length of foreground is approximately 500 m.



(Figure 3.6) Goat Crag, Buttermere. Slump-generated minor folds on the inverted limb of a major slump fold in the Skiddaw Group (hammer for scale, middle right). (Photo: reproduced by permission of the Director, British Geological Survey: NERC copyright reserved, D 3843.)

(Figure 3.7) Goat Crag, Buttermere. The sandstone lens is part of a slump-generated mélange which has been folded by minor D_1 folds with a poorly developed axial-planar cleavage. (Photo: reproduced by permission of the Director, British Geological Survey: NERC copyright reserved, D 3849.)