
Raven Crag, Mungrisdale

[NY 363 306]–[NY 360 311]

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Highlights

Raven Crag provides one of the best-displayed examples of Caledonian folds in the Lake District Skiddaw Group. At least four episodes of crustal deformation can be recognized here. These outcrops expose some of the most complex fold structures documented in the region, and they have produced important information on the sequence of events during the Caledonian Orogeny.

Introduction

The site extends for some 500 m north of School-House Quarry, Mungrisdale, on the eastern flank of the Northern Fells. The crags themselves comprise a set of vertical and steeply inclined exposures, separated by relatively flat ground with no exposures. They expose rocks which have been assigned to the Loweswater Flags division (now Loweswater Formation) of the Skiddaw Group (Jackson, 1961) and are, here, a part of a small triangular-shaped fault-bounded inlier almost 2 km long, the eastern margin of which is the major Carrock-End Fault. A number of prominent hollows more or less perpendicular to the crags themselves represent the lines of faults or master joints.

The Loweswater Formation is a group of alternating greywacke sandstones, siltstones, and slates. On many of the crag exposures, small-scale sedimentary structures are clearly visible on weathered surfaces in the more arenaceous beds, indicating their origins as turbidity flows.

The sections reveal three sets of structures, which post-date the D_0 folds described above in the description of the Caldew River site. In this account they are labelled D_1 , D_2 , and D_3 (but see (Table 3.1) for other attributions). The D_1 structures dominate the crag sections; upright folds with steeply inclined slaty cleavage generally have anomalous north-westerly trends. The D_2 structures comprise subhorizontal folds and gently inclined cleavage, whereas D_3 structures, only recorded at the south-west end of the crags, are minor N–S flexures with rare fracture cleavage.

Some aspects of the site are referred to in the Memoir of the Geological Survey (Eastwood *et al.*, 1968). Various opinions of the structures, now superseded, are mentioned by Mitchell *et al.* (1972), but the definitive paper on the section is that of Roberts (1977b) which formed part of a fuller study of the Skiddaw Group of the Northern Fells (Roberts, 1973, 1977a).

Description

The general structure of Raven Crag is shown in (Figure 3.11). They can be divided into a southern section where the structure follows the regional E–W trend, for approximately 100 m to the north of the quarry, and a northern section, where asymmetrical folds with a gentle WSW limbs and a steep ENE limbs have an anomalous north-westerly trend. The plunge of the folds, which can be traced for distances up to 100 m, is gently inclined to the north-west and the axial planes are steeply inclined to the south-west.

At School-House Quarry, Mungrisdale [NY 363 306], black slates containing *D. deflexus*, (Jackson, 1961) dip steeply to the south, and have a weak S_1 E–W cleavage, subparallel to the bedding. Two gently inclined E–W thrusts, with associated subhorizontal folds, dominate the structure, and a faint crenulation parallel to the thrust is also visible on bedding planes over most of the quarry. These are all D_2 structures and the thrusts are most likely to be accommodation structures for stresses acting during the formation of the subhorizontal open D_2 folds. At the eastern end of the quarry, two highly altered quartz-dolerite dykes occur parallel to the bedding and are visible, both in the side wall and in the

quarry floor where they have been displaced along minor N–S faults. Steeply plunging N–S minor folds, with a steeply inclined associated fracture cleavage, occur in the slates adjacent to the dykes along the lines of the faults, and these are regarded as being D₃ structures. The dykes reacted to the D₃ stresses by brittle fracture, whereas the more ductile slates accommodated the stresses by folding and the development of the fracture cleavage.

Immediately to the north-west of Mungrisdale Quarry, D₁ structures dominate, with, in parts, a strong overprint of D₂. The D₀ structures are not common and, although they follow the D₁ trend, can be distinguished from them by their steep plunge. D₃ structures are also uncommon outside School-House Quarry. Good examples of asymmetrical folds, with a NW–SE trend, occur over the entire crags. One hundred metres to the northwest of the north-east end of Undercrag Farm, at the base of the crags, a prominent, upright open syncline occurs with associated minor folds and a cleavage. This last approximates to a true slaty cleavage in the mudrocks, but with an accompanying cleavage refraction it becomes a spaced cleavage in the sandstones.

The anomalously trending folds are identified as D₁ structures on account of their similarity in style to D₁ structures elsewhere in the Northern Fells, their associated, well-displayed, slaty cleavage, and the gradual change in their trend from W–E to NW–SE immediately to the west.

Interpretation

At this locality, structures occur that are clearly attributable to four deformation phases, related to the Caledonian Orogeny. However, the anomalous trend of structures assigned to the main structural event is something of a problem, since it is NW–SE compared with NE–SW for the Caledonides as a whole, and W–E for the same structures in the surrounding area.

The author at one time, and others (Mitchell *et al.*, 1972), considered that these folds were the result of an early-Caledonian deformation phase of the Skiddaw Group. Early deformation structures (D₀) are clearly visible in the nearby Caldew Valley, but the folds on Raven Crags bear no resemblance to these in either style or orientation. These folds have a gentle plunge, whereas D₀ folds have a steep plunge (as is seen locally at this site), and their associated cleavage is typical of S₁.

It was considered that the anomalous NW–SE-trending folds at Raven Crags might be the Skiddaw Group equivalent to supposed north-trending folds affecting the Borrowdale Volcanic Group. However, as outlined in the introduction to this chapter, such folds do not exist (Soper and Numan, 1974) and Borrowdale Group deformation is related to volcanotectonic processes (Branney and Soper, 1988). Roberts (1977b) believed these folds to be late-Caledonian D₁ structures, and he suggested three alternative causes for their anomalous trends:

1. A continued arcuate swing from NE–SW to E–W to NW–SE across the Lake District; against this suggestion are E–W structures further east at Troutbeck [NY 385 270] and even at the southern end of the crags themselves in School-House Quarry.
2. Drag associated with the right lateral movement along the Carrock-End Fault. However, the NW–SE trend is not consistent along the length of the fault and so this suggestion should also be rejected.
3. Reorientation during the D₃ phase. Minor refolding of earlier structures, by the D₃ event, is a common feature throughout much of the Northern Fells, but it is generally on a minor scale. The suggestion is that the more competent Loweswater Formation within the fault bounded inlier was re-oriented as a mass, whereas minor D₃ structures were formed in the less-competent slates. Roberts (1977b) considers this to be the most likely explanation, although it does not explain why such a large-scale change in trend has not been recorded in competent Skiddaw Group rocks elsewhere in the area. To the south-east, across the drift-covered plain, the volcanic rocks of Eycott Hill have a N–S strike, and there may be some connection between this and the trend on Raven Crags, but that has still to be established.

Conclusions

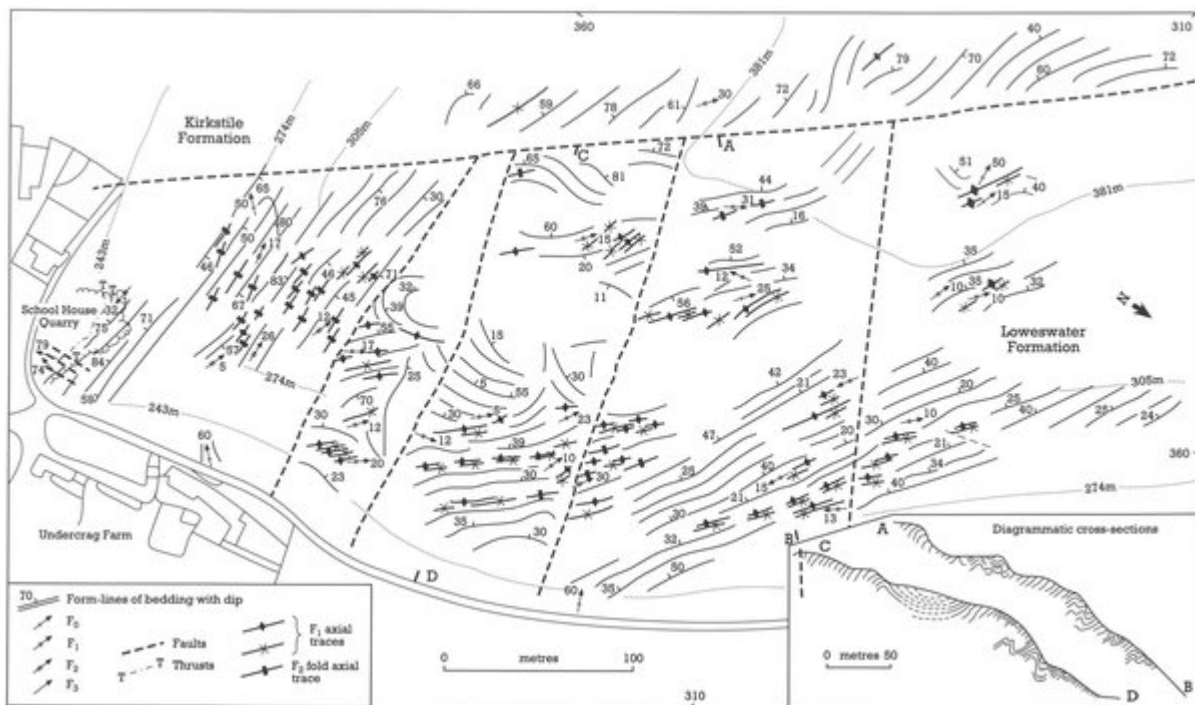
The exposures of the Loweswater Formation, in the fault-bounded inlier of Raven Crag, show, with remarkable clarity, some of the most complex fold structures documented in the region, and they have provided important contributions to an understanding of the Caledonian Orogeny in north-west England. Four phases of deformation are recognized (D_0 and D_{1-3}): the first (D_0) the product of slumping and crumpling of sediments on a sloping Ordovician (Arenig) sea-bed; the second, the dominant regional structure (probable Devonian– D_1); the third (D_2), dominant here, includes the thrust faults in the site, and the fourth formed next to a pair of dolerite dykes which are also displaced by some later, small faults.

Here there was clearly a long history of strain and deformation in the form of crustal shortening and folding, and also faulting. These are some of the most complex and informative outcrops in the region, providing graphic evidence of the length and intensity of the Caledonian mountain-building episode. The main Caledonian phase has a NW–SE trend which is anomalous to that of other tracts of Skiddaw Group rocks in 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 (398Ma) 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 (Llandovery) ↓	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?							
(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 3.11) Map of the structures in the Loweswater Formation on Raven Crag, Mungrisdale. A–B and C–D are the lines of the cross-sections illustrated in the inset (modified from Roberts, 1977b).