# 19. The origin of the glaciotectonised lacustrine sediments in Gleann Ballach

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Controversy has surrounded the origin of the sediments that underlie the generally flat–topped asymmetric ridge, up to 60 m in height, which extends from the western side of Gleann Ballach into the valley floor at (NH 6513 0106) (Fig. 60A; Boston and Trelea-Newton, this guide: 17). The most recent description of the deposits by Gheorghiu *et al.* (2012) is based principally on the sequence exposed in a river cliff of the Allt Ballach at the eastern end of the ridge at c. 490 m OD. The 6 to 7 m-high exposure is dominated by well-sorted, fine- to medium–grained sands with planar lamination and ripple cross bedding, with lenses of till, laminated clay, and sparse dropstone cobbles; all indicating deposition in a glaciolacustrine setting. Gheorghiu *et al.* (2012, p. 137) supplemented the information from the exposed sequence by augering to the west of the exposure, which they suggest confirms that similar lacustrine sediments underlie the main part of the ridge. This reaches an elevation of c. 560 m OD and coincides in altitude with a 'horizontal notch cut into bedrock' that they interpret as an 'ice-marginal meltwater route'. Significantly, cosmogenic ages on boulders 'on top of the lake deposit at 550 m OD and 528 m OD' yielded exposure ages of 11.6 ± 1.1 ka and 10.9 ± 1.0 ka, with a mean age of 11.2 ± 1.1 ka. These ages have now been revised to 13.7 ± 0.8 ka and 12.8 ± 0.8 ka respectively, with a mean age of 13.2 ± 0.8 ka (Gheorghui and Fabel, this guide: 18).

Gheorghiu *et al.* (2012) also report exposure ages (corrected for erosion) of 11.6 ± 1.1 ka and 11.1 ± 1.0 ka (mean 11.0 ± 1.0) from boulders on the surface of a moraine, at 520 m OD, which crosses the glen higher up the valley from the ridge of lacustrine sediments (Location 6, Fig. 64; Gheorghui and Fabel, this guide: 18). These ages are now revised by Gheorghiu and Fabel (this guide: 18) to 13.3 ± 07 ka and 12.6 ± 0.7 ka; mean 13.0 ± 0.7 ka. Gheorghiu *et al.* (2012) also reported a further pair of ages (9.7 ± 0.9 ka and 9.9 ± 0.9 ka); from boulders on top of another arcuate moraine located between 580 and 680 m OD, higher still in the valley (Location 8, Fig. 64; Gheorghui and Fabel, this guide: 18). These have been revised to 11.3 ± 0.7 and 11.6 ± 0.7 (mean 11.4 ± 0.6 ka) by Gheorghiu and Fabel (this guide: 18). Importantly, all of the ages as originally reported by Gheorghiu *et al.* (2012) indicated that the sampled boulders, including those on top of the ridge underlain by lacustrine sediment, were emplaced during the Younger Dryas. Of the revised ages for sites in Gleann Ballach presented by Gheorghiu and Fabel (this guide: 18), only those from the moraine at Location 8 are consistent with a Younger Dryas origin.

## Previous interpretations

The sand-dominated sequence underlying the flat-topped/asymmetric ridge, was considered by Young (1978) to be an esker associated with meltwater channels occurring at 730 m on a col on the western side of the glen, north of Carn Macoul, and on a col at 550 m between Meall na Ceardaich and Craig Liath, to the east. This implies subglacial or englacial deposition during the main glaciation of the area, when ice was flowing eastwards. Merritt (1999) and Trelea (2008) also argued for deposition towards the end of the main glaciation of the district, suggesting that the ridge formed as a moraine emplaced by ice that impinged northwards from Glen Banchor, up Gleann Ballach, impounding a lake. A fourth interpretation was given by Gyte (2004) who argued for deposition as a moraine by ice flowing southwards down Gleann Ballach.

Gheorghiu *et al.* (2012, p. 140) argue against these interpretations, suggesting that the deposit was laid down in a proglacial lake that formed when a glacier occupying Gleann Ballach decoupled from an ice lobe in Glen Banchor, towards the end of the Late Devensian. They cite the presence of dropstones in the fine-grained sands as indicating a low energy environment incompatible with the high gradient necessary for deposition in a subglacial channel. They also suggest that genesis as a moraine is difficult to reconcile with what they regard as 'the entirely lacustrine stratigraphy of the deposit' and state that 'we found no evidence of lacustrine sediments in stream sections south of the main deposit and no evidence of a morainic plug downvalley against which any lake would have impounded'. They recognise that stillstands were common during the deglaciation of the Spey valley and that ice-dammed lakes formed between the retreating ice sheet and local glaciers. They suggest that when the deposit was laid down, ice to the south in Glen Banchor must have been sufficiently thick to obstruct water from the retreating glaciers to the north, from infiltrating within or beneath it, or 'spilling over the terminus'.

Ice limits reconstructed by Gheorghiu *et al*., (2012, Fig. 10a) show a lake in Gleann Ballach, impounded between a Gleann Ballach ice lobe to the north, and a Glen Banchor ice lobe to the south. They suggest that the lake was fed from meltwater channels on the western valley wall and that it 'drained towards Gleann Fionndrigh over the eastern col, incising it in the process'. Their final reconstruction (Gheorghiu *et al*., 2012, Fig. 10c) indicates that during the Younger Dryas, ice within Gleann Ballach advanced to the northern margin of the lake, but did not impinge across it.

Gheorghiu *et al.* (2012) explain the apparent contradiction of having boulders with exposure ages of 11.6 ± 1.1 ka and 10.9 ± 1.0 ka on top of an older Late

Devensian lake deposit, by a rather unlikely method. They envisage emplacement of the boulders on top of the ridge, by erosion and transport from the nearby Younger Dryas ice margin to the north, by meltwater that only deposited the boulders and no associated gravelly outwash.

**New evidence**

Detailed logging of the upper part of the river cliff exposure at NH 6513 0106 has provided further information on the nature of the sedimentary sequence underlying the eastern portion of the asymmetric ridge (Fig. 66a). In particular, the recognition of progressive deformation of the sequence, which passes upwards from a sequence of boudinaged diamictons and silty olive grey clays within a matrix of deformed fine-grained sands (Fig. 66e), into asymmetric tightly folded interbedded sands and silts (Fig. 66c), provides compelling evidence of glaciotectonism. The folded sediments are directly overlain by fine-to medium-grained sands showing evidence of dewatering, in the form of flames and ball and pillow structures (Fig. 66b). These in turn, are overlain by flat-lying interbedded sands and sandy silts with low angle tabular cross bedding, as well as horizontal and ripple lamination.

Sparse dropstone cobbles are present in the boudinaged sequence, which is cut by low-angle reverse faults (thrusts T3-T4) showing a northeastwardly directed sense of movement (Fig. 66d). Oversteepened bedding (> 40° dips) within the sandy matrix of the boudinaged unit also suggests glaciotectonic displacement. The asymmetry of the upright tight folds in the overlying unit again indicates a sense of movement towards the northeast. Bedding planes within the sands showing soft sediment deformation, and those of the flat lying sequence above, are also displaced along small-scale thrusts (T1-T2). These less prominent thrusts have a southwesterly directed sense of movement.

**Interpretation and conclusions**

The recognition of pervasive deformation in the upper portion of the sequence forming the asymmetric ridge indicates a complex origin for the landform and the sediments that comprise it. The tectonic folding, boudinage and thrusting, as well as the soft sediment deformation argue against an origin for the ridge as an erosional, *in situ* remnant of an undeformed glaciolacustrine succession. The asymmetry of the ridge and the absence of similar sediments in exposures in the valley of the Allt Ballach, downstream and presumably upstream of the section, suggest that the maximum width of the outcrop of the lake sediments is probably no more than about 100 m (the approximate width of the ridge at its widest point). However, Gheorghiu and Fabel (this guide) postulate an outcrop width of c. 600 m of lake sediment. If one accepts the interpretation of the auger samples reported by Gheorghiu *et al*. (2012), that they indicate that the whole ridge is composed of in situ lake sediments, then the former lake was very narrow (even at 600 m) for 60 m of glaciolacustrine sediment to have accumulated within it, unless a considerable amount of lake sediment has been removed by subsequent erosion, leaving no other scattered remnants. Such a thickness of fine-grained lacustrine sediment is about three of four times that of even the thickest glaciolacustrine successions in adjacent areas.

Younger Dryas ages for boulders on top of the ridge at 550 m OD and 528 m OD, and the presence of northwesterly directed thrusting and folding in the lower

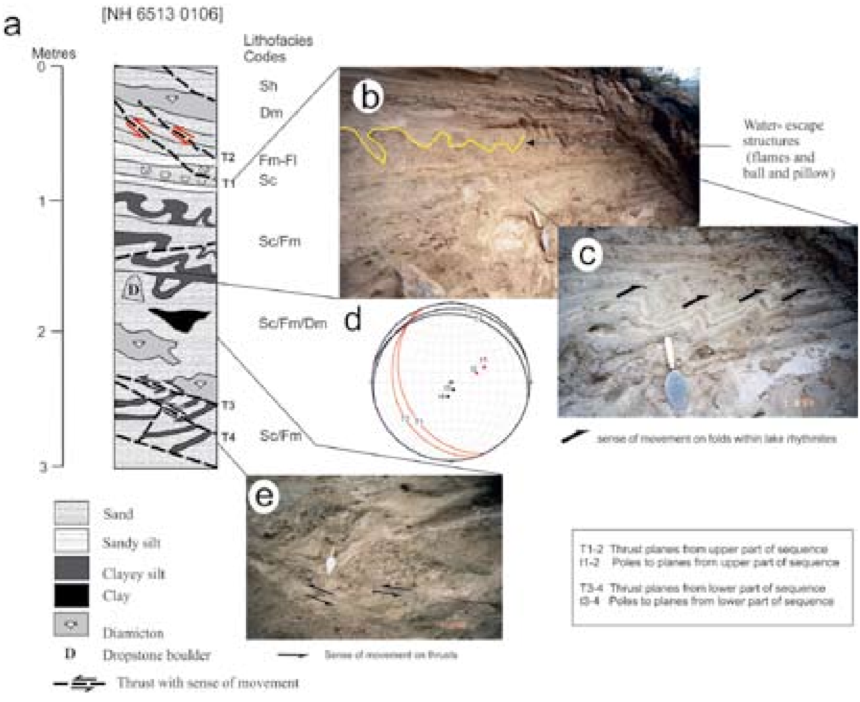


**Fig. 66.** The sediments and structures in the river cliff section of the Allt Ballach; a) sedimentary log of the uppermost 3 m of the section exposed in 1997; b) interbedded sands and silts showing soft sediment deformation and folding (0.8-1.5 m from the surface); c) detail of upright overfolds in interbedded sands and silts; d) equal area stereonet showing planes, and poles to planes, of thrust faults; e) thrusts T3 and T4 within the glaciotectonised sequence containing angular blocks of diamicton and silty clay in a matrix of fine-grained sand (2.2- 3.0 m depth). Lithofacies codes after Evans and Benn (2004).

part of the logged section, and of southwestwardly directed thrusting in the upper part of the section, might have indicated a composite origin for the ridge. These features could suggest that the sediments were first pushed by Glen Banchor ice from the southwest, towards the end of the main Late Devensian glaciation. This ice-push may have tectonically thickened the sequence, and compressed its outcrop width by thrust-stacking, perhaps enabling an almost 60m-thick sediment pile to form. The southwesterly directed thrusting, would then, suggest minor amounts of ice-push by southwestward flowing Gleann Ballach ice during the Younger Dryas. At its maximum extent, the Gleann Ballach glacier would have reached the ridge, which was already in existence, tectonising its upper part, rather than impinging upon the edge of a formerly more extensive glacial lake as indicated by the reconstruction by Gheorghiu *et al*. (2012).

However, the revised Lateglacial exposure ages from the boulders on the ridge crest presented by Gheorghiu and Fabel (this guide: 18) suggest that, although a composite origin might still be inferred for the ridge, the bimodal thrusting may be a result of ice push from Glen Banchor ice alone. The less prominent thrusts (T1-T2) in the top part of the sequence might simply be back thrusts associated with a single event.

Elements of most of the previous observations and interpretations of the origin of this prominent, asymmetrical ridge and its sediments are correct. However, a more complex picture has emerged indicating that the ridge is largely composed of glaciotectonised sediment and that it might be a composite feature. It marks a limit or stillstand (one simple definition of a moraine) during the advance of one or more glaciers. Micromorphological studies, using orientated soft sediment thin sections, in a manner similar to that employed at Raitts Burn (see Phillips and Auton, this guide: 18), are currently under way to further elucidate sedimentary history and glaciotectonic development of the sediments forming this enigmatic ridge.