Chapter 7 Controls on the location and evolution of the Glencoe Caldera-volcano Complex

The volcano developed at the intersection of substantial crustal discontinuities, and movements occurred on these immediately before and during caldera-forming volcanism. Caldera subsidence involved numerous crustal blocks that subsided incrementally and in various ways before the ring-fault system formed. During caldera-volcano development the sites of both magmatic plumbing and maximum volcanotectonic subsidence shifted south or south-westwards; this can be deduced from the thickness variation of successive eruptive units, preserved vents and buried fault scarps. The succession also demonstrates marked changes in eruption style related to faulting, including punctuation by distinctive phreatomagmatic explosive eruptions, and distinct intervals of erosion and sedimentation between eruptions. The Glencoe Caldera-volcano Complex shows ample evidence of strong tectonic control of piecemeal subsidence during its evolution (Moore and Kokelaar, 1997, 1998).

The orientation and some of the subsidence of the Glencoe Graben were tectonically controlled. Following its establishment, development of the graben was incremental, with faulting commonly unrelated to magma withdrawal. Fluvial drainage was consistently reinstated along the graben at least nine times (Table 2). Furthermore, the structure must have extended and been active outside the volcano complex towards the south-east, in order to maintain the capture of the river system. There is evidence of only minor uplift within the volcano complex, which was due to shallow emplacement of sills (see pp.57; 74); had there been major uplift, either due to tectonism or by large-scale magmatic resurgence, the fluvial system would have been deflected from its rather narrow course across the volcano. The development and persistence of cross-graben structures, along which rivers originating to the north-east of the Glencoe volcano complex were topographically confined, indicate one or more (closely spaced) tectonic faults at right angles to the Glencoe Graben.

Substantial tectonic faulting during the span of volcanic activity at the Glencoe Caldera-volcano Complex is indicated by:

- the repeated switches from fluvial incision to fluvial or lacustrine sedimentation
- the abrupt switches from fairly normal fluvial-channel and overbank sedimentation to relatively catastrophic and widespread aggradation of coarse-grained alluvial-fan breccias
- the collapse of fault scarps to form very coarse debris-avalanche breccias, including megabreccias.

All of these phenomena occurred without contemporary eruption. Such sedimentation is similar to that known from the most actively subsiding strike-slip sedimentary basins, where time-averaged subsidence rates may approach 2 to 3 km per million years (e.g. see Nilsen and Sylvester, 1995). Given that the Glencoe Graben trended at a right angle to the major regional faults on which substantial (sinistral) strike slip is inferred to have occurred during the magmatism (e.g. the Great Glen Fault; (Plate 1)), subsidence along the graben may have been induced, at least in part, by a pull-apart mechanism. Although the volcanic deposits were accommodated mainly by volcanotectonic faulting and downsag, episodes of marked localised subsidence recurrently preceded explosive volcanism. Many volcanotectonic faults originated as tectonic faults and were reactivated so that displacements were accentuated during eruptions. Several sets of closely spaced volcanotectonic faults probably represent splays of tectonic faults (e.g. The Chasm step-fault system). Because many explosive eruptions were preceded by tectonic subsidence in near-vent areas, it seems likely that magma ascent from depth was, in some cases at least, triggered or facilitated by regional tectonism. Tectonism also influenced eruption cycles indirectly so as to lead to formation of contrasting intra-caldera deposits. Each of the Etive rhyolite eruptions, for example, was initiated with phreatomagmatic explosions before switching to magmatic activity, because each ascending magma batch was channelled through water-saturated sediments that accumulated within a tectonically controlled centre of deposition. Thus the location and evolution of the Glencoe Caldera-volcano Complex evidently were strongly influenced by the regional tectonic regime and crustal structure.

The deep north-west-trending fault or fault-zone that controlled the development of the Glencoe Graben is inferred to have been linked at a high angle to the Great Glen Fault (Moore and Kokelaar, 1997, 1998). In the vicinity of Glen Coe there are several north-east-trending faults or shear zones (Figure 3), including the Etive–Laggan Fault, which cuts the volcano complex, and the Ericht–Laidon Fault to the south-east (Hinxman et al., 1923; Treagus, 1991; Jacques and Reavy, 1994). These lie parallel to the Great Glen Fault and were involved in both normal dip-slip and strike-slip displacements during activity on the major fault. Two north-west-trending lineaments have also been recognised, and are believed to mark deep pre-Caledonian crustal structures that influenced Dalradian sedimentation and magmatism as well as subsequent development of tectonometamorphic domains (Fettes et al., 1986): the Cruachan Lineament in the vicinity of the Pass of Brander Fault (Hall, 1985; Graham, 1986) and, parallel to the Strath Ossian Pluton, the Strath Ossian Lineament (Forrest and Key, 1989; (Figure 3)). The developments of the Glencoe Graben and its fluvial system are strong evidence of a further north-west-trending deep crustal discontinuity, possibly another pre-Caledonian fault or shear zone. This fundamental crustal discontinuity beneath the caldera-volcano complex is named the Glencoe Lineament.

The orthogonal system of faults (and fault splays) at Glen Coe, and the piecemeal and spatially variable subsidence, are considered to reflect a structurally complex response to crustal extension or transtension primarily focused above the intersection of the Glencoe Lineament and the north-east-trending Etive–Laggan Fault (Figure 3). The Devil’s Staircase Fault, which bisects the caldera volcano, is part of the main surface trace of the Etive–Laggan Fault, and the Queen’s Cairn and Glen Etive faults probably formed as splays from depth on this major discontinuity. Subsidence was greatest on the Glencoe Graben axis between the Queen’s Cairn Fault and the Glen Etive Fault (Figure 7). The repeated plumbing of magmas to locations along the Glencoe Graben indicates that magma ascent was focused or accommodated in concert with the extension or transtension at Glen Coe. Interestingly, the few Permian dykes that cut the caldera-volcano complex (see British Geological Survey, 2005) lie parallel to the Glencoe Graben; the most continuous one lies along the graben axis and extends north-west for 2 km beyond the ring-fault.

The base levels of the successive major rivers in the Glencoe Graben were probably controlled by structural developments outside the Glencoe Caldera-volcano Complex, and, as the drainage was to the north-west, these may have involved movements and base-level changes on the Great Glen Fault. Contemporary sedimentary rocks along the Great Glen towards the south-west, for example on Kerrera (Figure 3), include coarse conglomerates with abundant andesite and fewer silicic fragments. These show derivation from the north-east and must have been derived by fluvial input from volcano complexes on lateral drainages, such as towards Ben Nevis and towards Glen Coe.

Throughout the south-west Highlands there are close spatial and temporal relationships between ‘late-Caledonian’ granitic plutons, strike-slip and dip-slip faults, and major tectonic lineaments (Watson, 1984; Hutton and Reavy, 1992; Jacques and Reavy, 1994; Jacques, 1995). Several of the plutons (e.g. Etive and Ben Nevis) truncate and thus postdate volcanic formations, while others preserve no vestige of a central volcano. It appears that the plutons tended to exploit crustal discontinuities that had in places previously focused magmatic plumbing to volcanic centres. It is probable that other ‘late-Caledonian’ plutons succeeded central volcanoes that consequently became obliterated by intrusion or were removed by erosion. Thus caldera-volcano complexes like that at Glen Coe were probably more numerous than is presently apparent in the south-west Highlands; the same applies in the continuation of the magmatic province to the south-west into Ireland (Donegal) and north-eastwards towards the Shetland Isles.

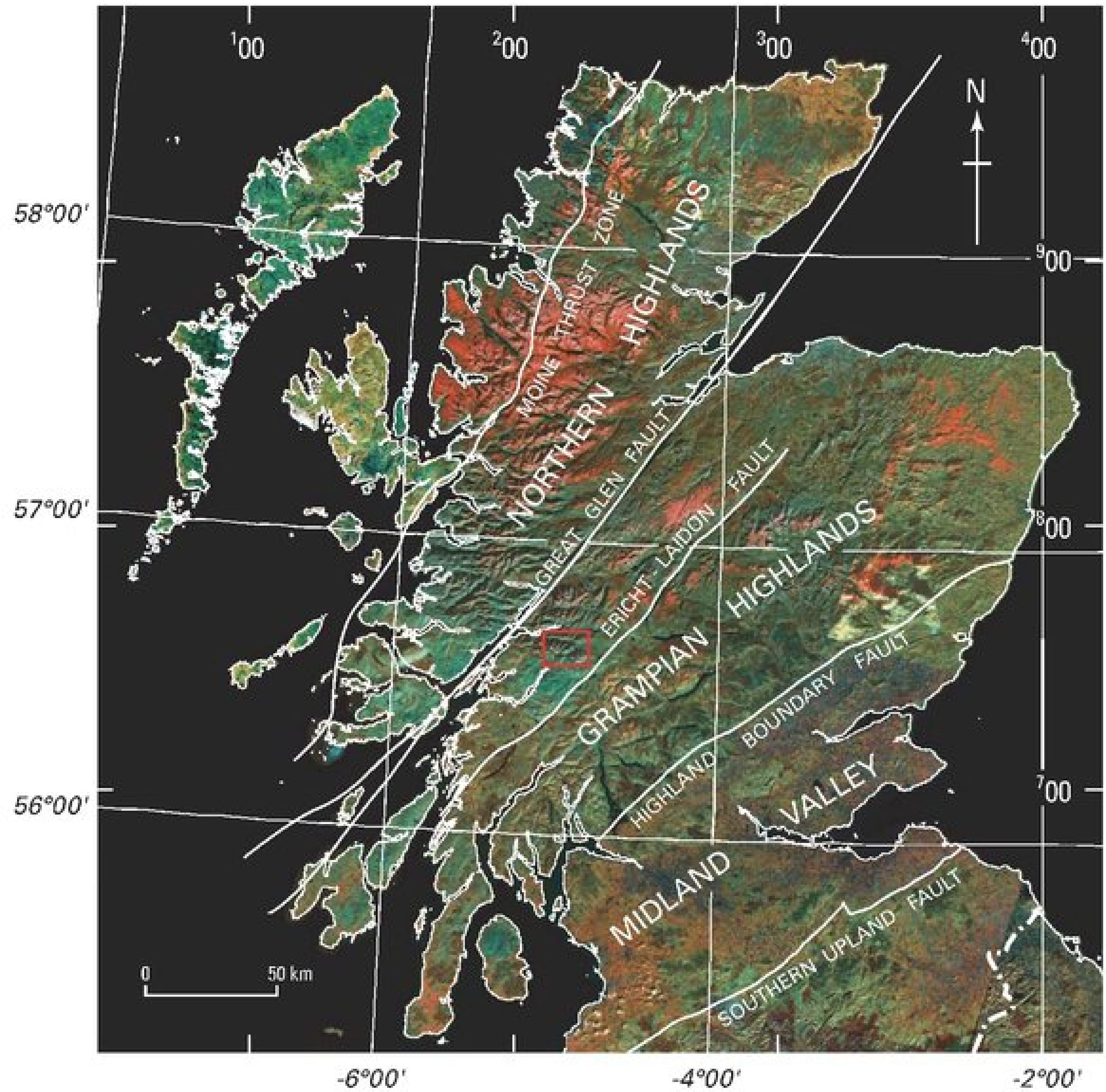
References

Glencoe Volcanic Formation (this report)		Roberts (1974)	Clough et al. (1909)
Upper Dalness Ignimbrite	Dalness Ignimbrite Member	Group 7 Andesite and rhyolite lavas, with thin ignimbrite	Group 7 Andesites and rhyolites
Coire nan Easan Tuffs ↓		Group 6 Grits and shales	Group 6 Shales and grits
Lower Dalness Ignimbrite Coir Eilde Tuffs ↓		Group 5 Rhyodacitic ignimbrite	Group 5 Rhyolite
Bidean nam Bian andesites	Bidean nam Bian Andesite Member	Group 4 Hornblende-andesite lavas	Group 4 Hornblende-andesites
Glas Choire sandstones ↓	Glas Choire Sandstone Member	Group 3 Breccias, grits and shales	Group 3 Agglomerates and shales
Upper Streaky andesites ↓			
Church Door Buttress Breccias Upper Queen's Cairn Breccias Upper Three Sisters Ignimbrite Lower Queen's Cairn Breccias * Queen's Cairn Conglomerates ↓ White Corries Breccias Lower Three Sisters Ignimbrite ↓	Three Sisters Ignimbrite Member	Upper Group 2 Rhyodacitic ignimbrite	Group 2 Rhyolites and andesites
Lower Streaky Andesites		Lower Group 2 Andesite and rhyolite lavas, with thin ignimbrite	
Upper Etive Rhyolite Crowberry Ridge Tuffs ↓ Middle Etive Rhyolite Raven's Gully Tuffs ↓ Lower Etive Rhyolite Kingshouse Tuffs Kingshouse Breccias ↓	Etive Rhyolite Member		
Basal Andesite Sill-complex ↓		Group 1 Basalts and pyroxene-andesite lavas	Group 1 Augite-andesites

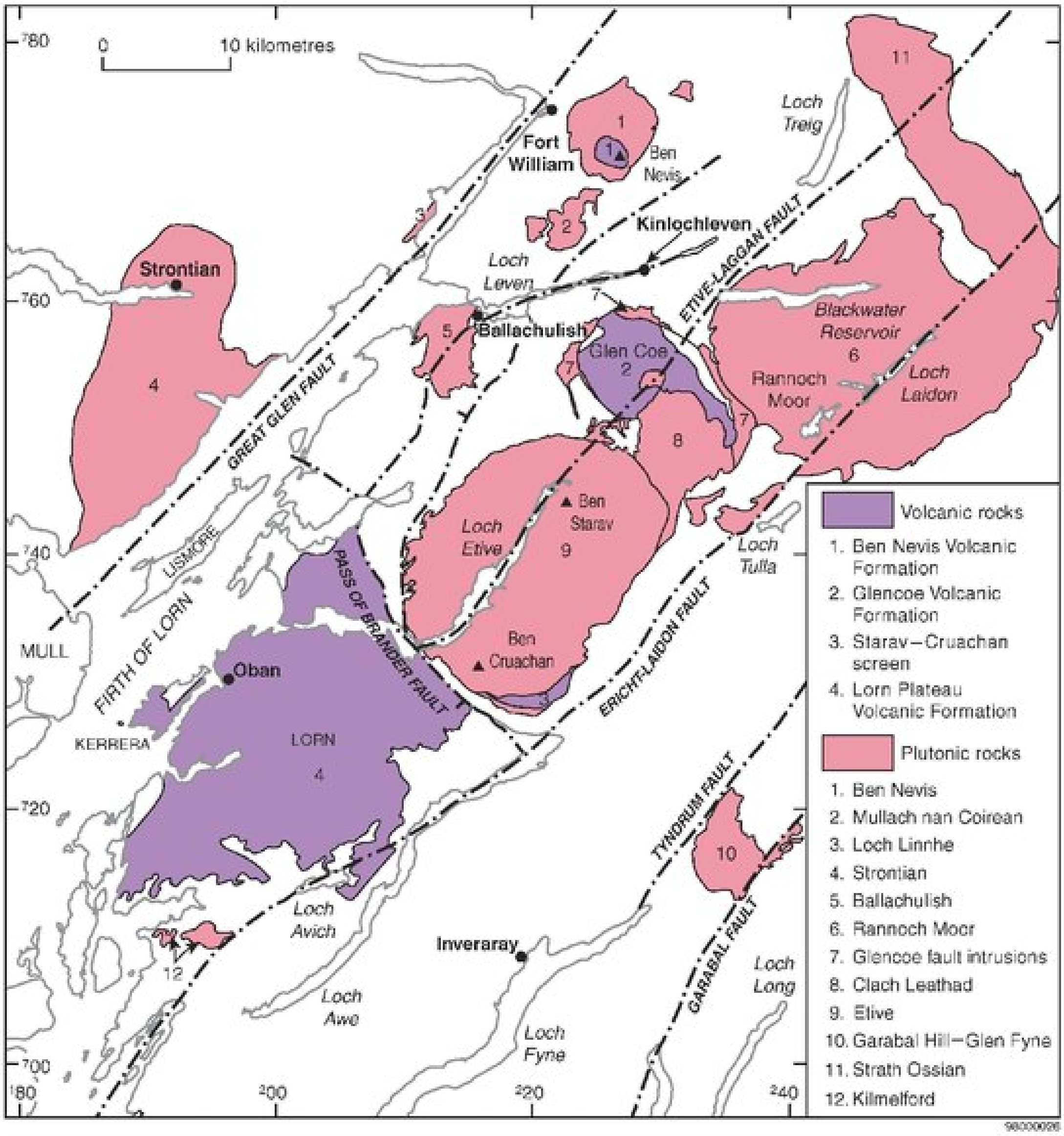
↓ *indicates unit that rests on fluvial sediments and an erosional unconformity*

* *The Dalness Breccias may, in part, correlate with the Lower Queen's Cairn Breccias. They are overlain by the Upper Three Sisters Ignimbrite, but rest upon the Basal Andesite Sill-complex and could have formed in part during development of the Etive Rhyolite Member*

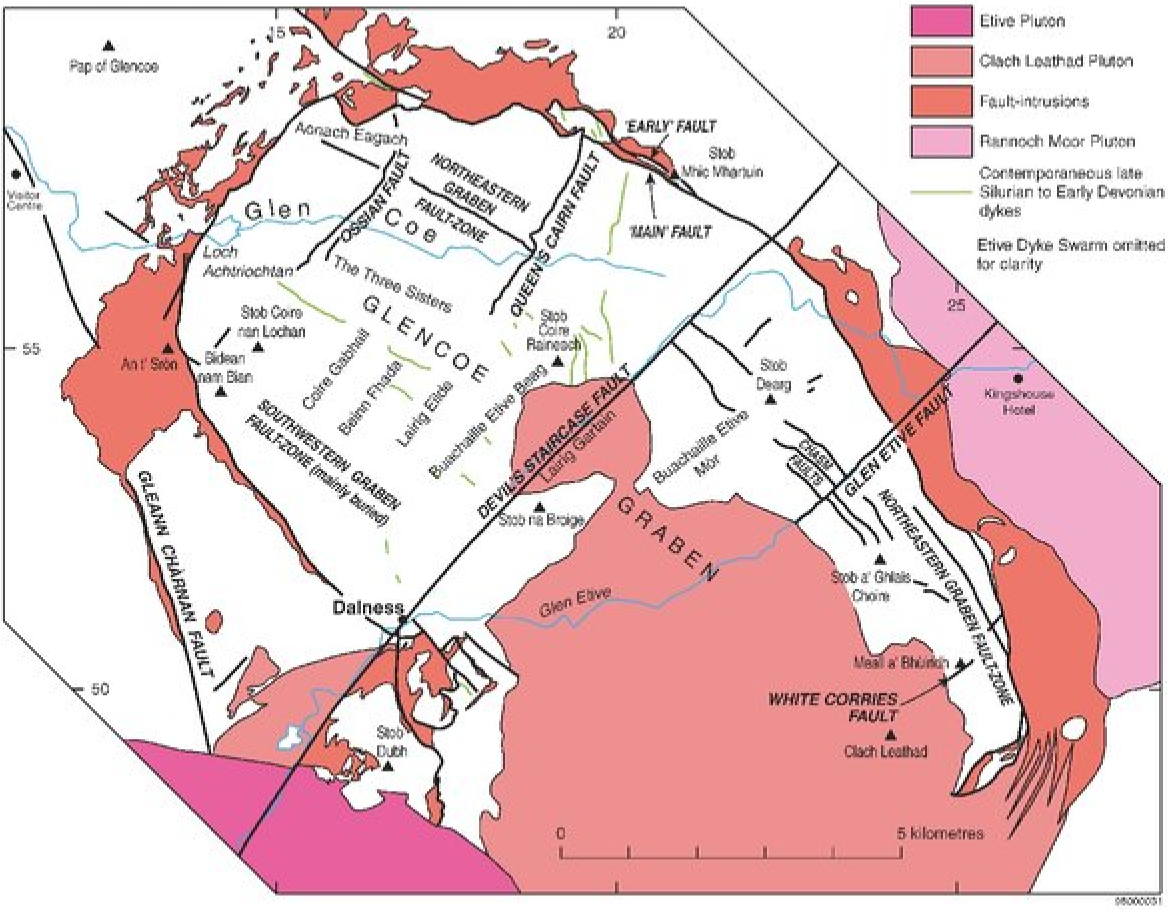
(Table 2] Lithostratigraphical and lithodemic nomenclature used in the Glencoe Caldera-volcano Complex.



(Plate 1) A Satellite view showing the location of the Glencoe area in Scotland. BGS enhanced image © NERC, 2005. Grid lines in white show latitude and longitude; National Grid is indicated along the margin of the image.



(Figure 3) Distribution of Siluro-Devonian volcanic and plutonic rocks showing faults that were active during the magmatic activity.



(Figure 7) Major structural features of the Glencoe Caldera-volcano Complex, highlighting intrusions and faults active during volcanism (Etive Dyke Swarm not shown).