Timing of deposition, orogenesis and glaciation within the Dalradian rocks of Scotland: constraints from U–Pb zircon ages

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Abstract: The stratigraphical and structural continuity of the Late Proterozoic Dalradian rocks of the Scottish Highlands is re-examined in the light of new U–Pb zircon ages on the tuffs belonging to the Tayvallich Volcanic Formation (601 ± 4 Ma), and on the late Grampian ‘Newer Gabbros’ (470 ± 9 Ma) of Insch and Morven-Cabrach in Aberdeenshire. These data age, together with the existing 590 ± 2 Ma age for the Ben Vuirich Granite, provide key radiometric constraints on the evolution of the Dalradian block, and the implications arising from these ages are critically assessed. Three main conclusions are drawn.

(1) The entire Caledonian orogeny, although short-lived, is unlikely to have affected sediments of Arenig age and a break probably occurs between those Dalradian sediments of late Proterozoic (<600 Ma) age and the Ordovician rocks of the Highland Border Complex.

(2) A period of crustal thickening probably affected some Dalradian rocks prior to 590 Ma. Such an event is indicated by both the polymetamorphic histories of the lower parts of the Dalradian pile and the contact metamorphic assemblages within the aureole of the Ben Vuirich Granite, which are incompatible with sedimentary thicknesses.

(3) Age constraints on global Late Proterozoic glacial activity also suggest that the Dalradian stratigraphy is broken into discrete smaller units. Models involving continuous deposition of Dalradian sediments from pre-750 Ma to 470 Ma are rejected.

Keywords: Dalradian Orogeny, Neoproterozoic, glaciation, U–Pb, zircons.

Understanding the evolution of orogenic belts critically depends upon having reliable geochronological constraints. This is particularly important in Precambrian orogenic belts, which lack fossiliferous successions, and in which interpretations rely only on isotopic ages and correlations with global events. The dating of late orogenic events is relatively straightforward, using Rb-Sr, 39Ar–40Ar or K–Ar techniques on micas (e.g. Cliff 1985). However, such systems typically only record cooling after the last thermal pulse, and the dating of peak metamorphic and prograde events directly is more difficult (e.g. Vance et al. 1999). An alternative way of constraining the timing of both deposition, and the early parts of orogenic history is to date igneous bodies whose emplacement relative to tectonothermal events can be established (e.g. Long 1964; Pidgeon & Johnson 1974; Rogers & Dunning 1991). In these cases, geochronological systems with high closure temperatures, such as U–Pb on zircon, must be used in order to minimize effects of resetting by later events.

There is considerable uncertainty in both the age of deposition of the Dalradian sediments in the Scottish Highlands and their subsequent metamorphism (Tanner & Bluck 1999; Soper et al. 1999; Prave 1999). The accepted stratigraphy of the Dalradian block is presented in Figure 1. Although there is evidence that the Central Highland Division rocks are not part of the ‘Dalradian Supergroup’ and have experienced a c. 800 Ma orogenic event (Pasecki & van Bremen 1983; Noble et al. 1996; Highton et al. 1999), the extent to which Precambrian tectonothermal events have affected the ‘higher’ stratigraphic levels is uncertain (e.g. Phillips et al. 1999). The uppermost boundary of the Dalradian is similarly controversial (e.g. Tanner 1995; Bluck & Ingham 1997). A single Early Ordovician microfossil specimen is reported to be from the Macduff Slate (Downie et al. 1971; re-examined by Molyneux 1998) but no fossils have been found in these rocks by any later study (Bliss 1977). Some workers use this unconfirmed palaeontological evidence to argue that Southern Highland Group deposition continued through to the Arenig and that the Dalradian rocks were affected by a single short-lived Caledonian orogeny soon afterwards (Soper et al. 1999; Dewey & Mange 1999). Continued Dalradian deposition into