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Lower boundary of the Caledonian Barrovian metamorphic belt at Loch Leven, Scotland: Phengite K-Ar ages of metapelites

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Since the Barrow's report (1893), the Barrovian metamorphic belt in the Caledonides of Scotland has become one of the best-studied orogenic belts in the world. Based on many geological and isotopic studies, this belt has long been considered to be formed by arc-continental collision in the Ordovician-Silurian (the Grampian orogeny: ca. 480-430 Ma) (Dewey and Bird, 1999; Oliver, 2008). However, many controversies and fundamental uncertainties remain. For example, in terms of the polarity of subduction, Ryan and Dewey (1991) and Oliver (2008) assumed that the polarity of subduction was toward the NW, but Clift et al. (2004) proposed the opposite. Also, the main reason for the "orogeny" and metamorphism for several decades has been just burial at depth caused by thrusting, which we consider to be a dated, unlikely concept.

The Barrovian metamorphic rocks in Loch Leven belong to the biotite zone, have been folded and thrusted northwestwards (e.g., Treagus, 1974; Piasecki, 1980), and they overlie weakly metamorphosed rocks (Eilde Flags). Inferring from our understandings of the occurrence and exhumation of HP rocks in Japan (Aoki et al., 2008; 2009), and in many Barrovian orogenic belts worldwide (Agard et al., 2009), we predicted that the lower tectonic boundary of the Barrovian metamorphic rocks should have occurred at Loch Leven. In order to examine this model, we determined K-Ar ages of phengite-rich mineral separates from 6 metapelites in the area.

Our new phengite K-Ar ages are 398.2 +/- 10.4 (sample no. LL46), 406.4 +/- 10.6 (LL20), 405 +/- 10.5 (LL19), 399.7 +/- 10.5 (LL24) and 445.0 +/- 11.6 Ma (LL16). One samples (LL13) has an "anomalously young" age of 340 +/- 8.9 Ma, probably because of its low K2O content (1.3 wt%). The main results indicate a K-Ar age-gap between ca. 445 Ma and ca. 400 Ma, which, when integrated with previous metamorphic-age (e.g., Oliver, 2008) and structural data from Loch Leven (Roverts, 1976; Atherton, 1977) suggest that the lower boundary of the Barrovian metamorphic belt formed at 445-400 Ma.

The lower boundary of the E-dipping, Barrovian metamorphic belt at Loch Leven has long been considered to be an extension of the 430-413 Ma Moine Thrust (MT) displaced by the Great Glen Fault. The shear sense of the E-dipping MT is top-to-the-WNW/NNW (Butler, 2004). Moreover, we have recently discovered that the upper boundary of the originally E-dipping Barrovian metamorphic belt crops out near Portsoy in NE Scotland, the shear sense of which was top-to-the-SW (Kawai et al., in prep.). In terms of the internal thermobaric Barrovian zones of Scotland, the grade of metamorphism decreases symmetrically upwards and downwards from a central highest-grade zone (Kennedy, 1948), which contains relicts of retrogressed HP rocks. Integration of all multi-disciplinary data provides robust evidence that the Barrovian metamorphic zones were exhumed from a HP depth by N-directed wedge extrusion. The lower wedge boundary was the Moine thrust-Loch Leven thrust, and the upper extensional boundary at Portsoy enabled the downward emplacement of the overlying, lower pressure Buchan metamorphic zonal belt. Thus, formation of the whole Caledonian orogenic belt of Scotland was controlled by wedge extrusion.