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Palaeomagnetism of the Loch Doon Granite Complex, Southern Uplands of Scotland: The Late Caledonian palaeomagnetic record and an Early Devonian episode of True Polar Wander

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Abstract

The Southern Uplands terrane is an Ordovician–Silurian back-arc/foreland basin emplaced at the northern margin of the Iapetus Ocean and intruded by granite complexes including Loch Doon (408.3 ± 1.5 Ma) during Early Devonian times. Protracted cooling of this 130 km^3 intrusion recorded magnetic remanence comprising a predominant ('A') magnetisation linked to initial cooling with dual polarity and mean direction D/I=237/64° (α_{95}=4°, palaeopole at 316°E, 21°N). Subsidiary magnetisations include Mesozoic remanence correlating with extensional tectonism in the adjoining Irish Sea Basin ('B', D/I=234/−59°) and minority populations ('C', D/I=106/−2° and 'D', D/I=199/1°) recording emplacement of younger (~395 Ma) granites in adjoining terranes and the Variscan orogenic event. The 'A' directions have an arcuate distribution identifying anticlockwise rotation during cooling. A comparable rotation is identified in the Orthotectonic Caledonides to the north and the Paratectonic Caledonides to the south following closure of Iapetus. Continental motion from midsoutherly latitudes (~40°S) at 408 Ma to equatorial palaeolatitudes by ~395 Ma is identified and implies minimum rates of continental movement between 430 and 390 Ma of 30–70 cm/year, more than double maximum rates induced by plate forces and interpreted as a signature of true polar wander. Silurian–Devonian palaeomagnetic data from the British–Scandinavian Caledonides define a 430–385 Ma closed loop comparable to the distributed contemporaneous palaeomagnetic poles from Gondwana. They reconcile pre-430 Ma and post-380 Ma APW from this supercontinent and show that Laurentia–Baltica–Avalonia lay to the west of South America with a relict Rheic Ocean opening to the north which closed to produce Variscan orogeny by a combination of pivotal closure and right lateral transpression.

Keywords: Palaeomagnetism; Caledonides; Scotland; Southern Uplands; Loch Doon; Devonian; Tectonic rotation; Gondwana; True polar wander

1. Introduction

Formation of the British Caledonides in Lower Palaeozoic times involved the consumption of a major ocean basin, the Iapetus, in Late Ordovician and Early Silurian times and orogenic deformation within a collisional zone between the Laurentian continent comprising Greenland and cratonic North America in the north, and Gondwana and bordering terranes in the south. The latter included the basement of England and Wales north of the Variscan suture and formerly-adjoining parts of the Maritime Provinces of North America (Avalonia) composed of rock suites with a history commencing during Neoproterozoic times. The ensuing orogeny was accompanied by terrane emplacement and deformation of arc-related sedimentary-

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volcanic sequences (Soper and Woodcock, 1990), whilst block rotations and strike slip motions along major orogen-parallel faults continued into Silurian and Devonian times (Hutton, 1987). The end result was the juxtaposition of medium grade metamorphic terranes comprising the Grampian and Northern Highlands of Scotland (the Orthotectonic Caledonides) against low-grade terranes (the Paratectonic Caledonides) including the Southern Uplands of Scotland, the Lake District and Wales (Fig. 1).

Resolution of the relative movements resulting in emplacement of these terranes has been complicated by widespread partial or complete overprinting of older magnetisations by Carboniferous–Permian remanence. However, older Ordovician igneous suites have generally yielded an integral primary record that identifies a history of terrane rotation following consumption of the Iapetus Ocean (McCabe and Channell, 1990; Trench et al., 1991; Piper, 1997a; Piper et al., 1997). The granitic rocks, which form a major component of the subsequent Caledonian igneous record, are not intrinsically satisfactory palaeomagnetic material because they tend to have a ferromagnetic content dominated by only small amounts of magnetite, typically with multidomain properties. However the thermal aureoles can often provide a useful palaeomagnetic record of the granite magnetisation where mudrocks have been recrystallised into hornfels (Piper, 1997b).

The Southern Uplands Terrane lies at the northern margin of the Iapetus suture; with the exception of the Midland Valley block where the basement is largely buried, all other Caledonian terranes of the Paratectonic Caledonides in Britain (the Lake District and Wales) occur to the south of the suture. The kinematics of the Southern Uplands is currently constrained only by some relatively old palaeomagnetic data from the ca. 396 Ma Cheviot Complex (Thorning, 1974). To determine the wider palaeomagnetic signature and evaluate its relationship to adjoining Caledonian orthotectonic terranes to the north and paratectonic terranes to the south, this study reports a palaeomagnetic study of the Loch Doon granite complex. This is one of four major granitic plutons emplaced into the terrane following the bulk of Caledonian tectonism (Fig. 1).

2. Geological framework

The Southern Uplands of Scotland is a strongly deformed terrane of early Ordovician to late Silurian (at least until Wenlock, 428–423 Ma) mudrocks. It was formerly interpreted as an example of an ancient accretionary prism (McKerrow et al., 1977; Leggett et al., 1979; Leggett and Soper, 1983; Knipe and Needham, 1986) developed at the northern margin of the Iapetus Ocean although later assessments have tended to consider it as a back-arc and foreland basin thrust duplex formed when the Iapetus Ocean was already small, particularly in view of partial derivation of material from the south and the recognition that this was the site of an ensialic Late Ordovician basin (Stone et al., 1987). The Ordovician and Silurian rocks are mostly mudstones, shales and greywackes showing a complex deformational history. Structures fall into four sequential divisions comprising (a) down slope gravity-driven structures in poorly lithified sediment, (b) structures developed during accretion in rocks with the cementation and compaction essentially complete, (c) late accretion or collision-related structures associated with arrival of continental crust at the subduction zone, and (d) post-collisional adjustments in the accretionary complex mainly associated with strike shortening and strike slip faulting (Knipe and Needham, 1986). Phase (d) comprises the last episode of major deformation and was complete before large-scale granite emplacement occurred in Early Devonian times.

The latter magmatism is recorded by three major granitoid plutons (Loch Doon, Cairnsmoor of Fleet and Criffel-Dalbeattie) and a volcanic-intrusive complex in the Cheviot Hills (Fig. 1). The Loch Doon Complex has yielded a mean Rb–Sr biotite age of 408 ± 2 Ma (Halliday et al., 1980) and three small high-level complexes at Cockburn Law, Priestlaw and Cairnsmore of Carsphairn close to the Southern Uplands Fault (SUF in Fig. 1) show similar whole rock and mineral Rb–Sr age determinations of 413 ± 4.2, 408.5 ± 5.6 and 410.4 ± 4 Ma respectively (Thirlwall, 1988). These ages collectively identify acid magmatism along the northern part of the block as Early Devonian (Lochkovian to Pragian) in age, which is similar to the age of comparable magmatism in the adjoining Midland Valley (Thirlwall, 1988). In the southern part of the Southern Uplands Block radiometric ages of magmatism are younger: biotite-whole rock-plagioclase isochrons on the Criffel-Dalbeattie and Cairnsmoor of Fleet plutons (see Fig. 1) are 397 ± 2 and 392 ± 2 Ma respectively (Halliday et al., 1980). Rb–Sr (Thirlwall, 1988) and K–Ar ages (Mitchell, 1972) from the Cheviot Complex yield estimates of 395.9 ± 2.9 Ma for granite and 395.9 ± 3.8 Ma for lavas consistent with a comagmatic origin. These ages suggest that magmatism in the southern part of the block was contemporaneous with the younger granites of the Lake District on the south side of the Iapetus Suture (IU in Fig. 1) including the Shap (397 ± 7 Ma, Wadge et al., 1978; Rundle, 1992) and Skiddaw (399 ± 8 Ma, Shepherd et al., 1976; Rundle, 1992) plutons.