Seismological evidence for shallow crystalline basement in Southern Uplands, Scotland

HALL *et al.*[1] propose that the Southern Uplands contain crystalline rocks of continental affinity at shallow depths (~1–5 km). We suggest that the same seismic data can, in fact, be used to strengthen the argument for a thick accretionary prism[2].

It has been inferred that prehnite–pumpellyite facies metamorphism in the Southern Uplands is related to tectonic burial and rotation of the various slices of the prism as they were accreted during closure of the Iapetus Ocean, and that isograds in the prism are now subparallel to the present day erosion surface[3–6]. The colour alteration of conodonts in the Northern Belt indicates temperatures between 300 °C and 400 °C (refs 7, 8). The transition of the prehnite–pumpellyite to the greenschist facies lies between 300 °C and 350 °C (ref. 9), thus it has been suggested[4,5] that greenschist facies is present not far below the present day surface over much of the Southern Uplands.

The LISPB seismic profile for the Grampian sector shows P-wave velocities similar to the Southern Uplands Seismic Profile (SUSP[1], that is, 6 km s^{-1} at the surface increasing to 6.05 km s^{-1} at 12 km depth[10]. Mainly amphibolite facies sediments (and granite) occur in the northern part and foliated greenschist facies greywackes occur in the south[11]. In New Zealand, the seismic profile for the Otago greenschist terrane shows a velocity of 6 km s^{-1} for the depth range 1–10 km, lying above a velocity of 6.7 km s^{-1} (ref. 12). In Otago the transition from prehnite–pumpellyite facies to greenschist facies is marked by a transition of poorly foliated greywackes to strongly foliated quartzo-feldspathic schists[13]. Individual mica- and chlorite-schists from Vermont, USA, have experimentally determined velocities (at the appropriate pressures) similar to SUSP[14]. We conclude that the SUSP velocities are compatible with the occurrence of foliated greenschist facies metagreywackes at depths 1–5 km below the present surface.

Velocity anisotropism in foliated metamorphic rocks is well known[12,15] and the 15% anisotropy measured at Eskdalemuir (EKA)[1] is very similar to that in slate, chlorite-schist and mica-schist measured experimentally[14,16] at the appropriate pressure. Similar anisotropism is present at the Broughton array (BTN)[1] if the contribution of arrivals from the Midland Valley is ignored. We conclude that the seismic evidence from the BTN and EKA arrays supports the existence of sub-vertical, NE–SW foliated greenschists at a shallow depth.

Hall *et al.*[1] reinterpreted the Southern Uplands LISPB sector[10] in terms of block-faulting of crystalline crust. We are not competent to quantify a seismic model involving the block-faulting of a thin layer of isotropic greywackes lying above anisotropic greenschists but we point out that the boundaries between the seismic blocks[1] correspond well with existing block faults[5].

The geological arguments of Hall *et al.*[1] are equivocal: the xenoliths could originate from English continental crust subducted below the Southern Uplands[2]; the Midland Valley conglomerates may have come from the upper 11–17 km of the prism (Cockburnland[17]) which has since been stripped off[4].

We conclude that the seismic evidence supports a thick accretionary prism in the Southern Uplands. We predict that a suitably positioned borehole sited in blocks F2 or F3 will penetrate greenschist facies metagreywackes rather than crystalline continental basement.

G. J. H. OLIVER
Department of Geology,
University of St Andrews,
St Andrews, Fife KY16 9ST, UK

W. S. MCKERROW
Geology and Mineralogy Department,
Oxford University,
Oxford OX1 3PR, UK

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HALL *ET AL.* REPLY—Oliver and McKerrow accept our conclusions that there are crystalline rocks at shallow depth in the Southern Uplands. Their suggestion that the rocks are greenschist facies metagreywackes, part of an accretionary wedge occupying nearly all the present crustal pile, represents an unlikely possibility rather than a probability more central to all the evidence.

Shots on LISPB[1] and the Otago line[2] are too far apart to provide good control on shallow velocities. Inspection of the original LISPB data from shot 1 suggests that the velocity of Dalradian greenschist metasediments is significantly less than 6 km s^{-1} at 1 km depth (in the fast direction—along the horizontal banding of the 'flat belt'). From this and other field measurements across banding, we estimate that at 1 km depth these rocks would have a mean velocity of ~5.6 km s^{-1} and anisotropy of less than 7%. The Otago data may be modelled similarly.

Laboratory data[3–5] show average values for anisotropy in small cores of schists and associated rocks at pressures corresponding to 3 km depth to be only 7–9%, although higher individual values are found. Less anisotropy would be expected in the field. The 15% anisotropy sought by Oliver and McKerrow is likely to require the rocks to have a 40% content of mica[4] oriented consistently throughout the region.

Thus, Oliver and McKerrow's claim that greenschist facies metagreywacke at 1 km depth would have a mean velocity of 6 km s^{-1} and 15% anisotropy is at the limit of possibility.

Turning to the geological evidence, it is unlikely that a 'regional' metamorphic transition from a greywacke with little or no fabric to a wholly reconstituted mica schist occurs over only 1 km depth, despite the 'dynamic' example near the Alpine Fault[6]. Oliver and McKerrow themselves imply elsewhere[7,8] that the transition in the Southern Uplands takes place over a depth range of 7–12 km.

Oliver and McKerrow imply that the accretionary wedge occupies more or less the whole crust north of the subduction zone indicated on WINCH[9] and with at least 10 km already removed by erosion, the stack must have reached a thickness of 40 km or so, far in excess of present-day examples[10].

Xenoliths from post-Caledonide vents in the Southern Uplands are sufficiently similar to those of the Midland Valley to suggest derivation from a similar crust[11]. It has yet to be established if the English continental crust could supply xenoliths of this type, and whether such crust extends far enough north (interpretation of the Iapetus Suture on WINCH suggests that it does not).

Northward translation[12] of the Southern Uplands is required to account for the missing Ordovician fore-arc basin, and to cover the source of the Silurian conglomerates. We cannot seriously entertain the idea that the substantial thickness of Silurian rocks in the southern Midland Valley came from Cockburnland which, in addition, has to supply sediment to a coeval trench to the south yet is rarely more than 5 km wide[12], and occasionally substantially less[13]. The conglomerates