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The significance of isotopic dates from the English Lake District for the Ordovician–Silurian time-scale

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SUMMARY: The Lower Palaeozoic time-scale is discussed in the light of a new date for the Threlkeld Microgranite and a reassessment of other published dates from the Lake District which suggest ages of *c.* 410 Ma for the base of the Devonian; *c.* 421 Ma for the Ashgill; *c.* 429 Ma for the late Caradoc; *c.* 439 Ma for the early Llandeilo, and *c.* 468 Ma for the early Llanvirn.

In a recent publication (McKerrow *et al.* 1980) concerning the Lower Palaeozoic time-scale, it is argued that the time-scale produced by Gale *et al* (1979), based largely on a new Rb-Sr isochron age for the (Ashgillian) Stockdale Rhyolite of the English Lake District, is in error due to the possibility that this age, and the Rb-Sr ages for several other acid volcanic rocks used in their scale, are recording metamorphic episodes rather than the times of extrusion.

It is the purpose of this note to present a new date for the Threlkeld Microgranite and to cite other previously published dates from the Lake District which provide independent evidence in favour of the younger age and longer duration preferred by Gale *et al.* (1979) for the Ordovician System.

All ages quoted in this work have been calculated using the decay and other constants recommended by Steiger & Jager (1977) and errors on the ages are quoted at the 2 sigma level. The Rb-Sr isochron age was calculated using a least squares regression based on that of York (1969). Where replicate K-Ar determinations have been used to determine an age, the standard error of the mean ($\sigma \div \sqrt{n}$) is quoted.

A new date for the early Llandeilo?

The Threlkeld microgranite was previously dated by Wadge *et al.* (1974) at 445 ± 15 Ma and was thought by them to have been emplaced in earliest Caradoc times on the basis of 'The Caradoc being fairly well dated at 447 Ma'. However, it was noted by Rundle (1979) that recalculation of their data to conform with current practice yields an age of 459 ± 25 Ma, and it is evident from the conflicting time-scales mentioned above that there is still considerable dispute and uncertainty about the age of the Caradoc. Hence, there was a need for a new assessment of the age of this intrusion.

According to Wadge *et al.* (op. cit.) the microgranite is younger than the lowest part of the Borrowdale Volcanic Group sequence (which is post late Llanvirn and pre-early Caradoc in age (Wadge 1978)) and is pre-end-Silurian cleavage. Microgranite clasts, first described by Wadge *et al.* (1972), from the basal Borrowdale Bampton Conglomerate in the Tarn Moor tunnel, to the E of the Threlkeld area, resemble a variety of the Threlkeld Microgranite, both in hand specimen and thin section, and contain small garnets similar to those in the Threlkeld rock. These authors also noted clasts of locally derived 'Borrowdale Group lavas and tuffs and Skiddaw Group mudstones' and suggested that 'The Conglomerate accumulated on the flanks of a tumescent volcanic area as a detrital fan of torrent debris'.

In their discussion of 1974, Wadge *et al.* appeared to have been more strongly influenced by the coincidence of their age for the microgranite with the then current estimate of the age of the Caradoc Series, and hence rejected the evidence of the microgranite clasts. Despite the distinctive nature of this rock and the proximity of the exposed intrusion they suggested that the clasts originated from an older, unexposed and previously unrecognized intrusion. It is considered here that, in view of the uncertainties of both the age determined by Wadge *et al.* (1974) and of the age of the Caradoc Series, this special pleading is unjustified and unnecessary and that the alternative explanation—that the microgranite clasts are indeed derived from the Threlkeld intrusion—is the more plausible. Hence, it is suggested that the Threlkeld Microgranite is closely constrained stratigraphically to the Lower Llandeilo Series.

The results of new Rb-Sr analyses of 12 fresh samples of the microgranite from the Threlkeld (working) and Bram Crag (disused) quarries are given in Table 1. All twelve samples define a line on an isochron diagram with an MSWD of only 1.7, giving an age of 439 ± 8 Ma and intercept of 0.7056 ± 6.

This result is not significantly different from that quoted by Wadge *et al.* but, despite the new samples having a smaller range of Rb-Sr ratios, is far more precise, reflecting the improved analytical techniques and more localized sampling. As a check on the earlier work, and also in an attempt to improve the new result, sample WG404 was re-analysed during this study. This sample was chosen because it was the only one collected by Wadge *et al.* from the working quarry

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TABLE 1. *Rb-Sr analytical results for Threlkeld Microgranite*

Sample	*ppm Rb**	*ppm Sr**	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
TH1	126	83	4.423	0.73312
TH2	158	126	3.638	0.72868
TH3	153	67	6.678	0.74730
TH4	141	86	4.791	0.73549
TH5	134	86	4.561	0.73416
TH6	121	71	4.951	0.73713
BMC1	121	91	3.856	0.72964
BMC2	128	55	6.700	0.74726
BMC3	141	66	6.172	0.74433
BMC4	126	82	4.453	0.73365
BMC5	122	87	4.060	0.73052
BMC6	122	106	3.330	0.72639
WG404	129	36	10.510	0.77123

* Approximate values. Analytical and calculation details as given in Rundle (1979) except that all strontium isotopic analyses were made with a VG-Micromass MM30, fully automatic spectrometer, 6 samples being analysed overnight without operator intervention. 1 sigma errors are ±0.5% on Rb/Sr ratios and ±0.02% on $Sr^{87/86}$

TH = Threlkeld Quarry; BMC = Bram Crag Quarry.

at Threlkeld and also because of its relatively high Rb-Sr ratio.

The new value for the $^{87}Rb/^{86}Sr$ ratio (10.5) is 3.4% higher than that obtained by Wadge *et al.* (1974) but, because of the high errors associated with the earlier analyses, is not significantly different at the 95% confidence level. Similarly the new value for the $^{87}Sr/^{86}Sr$ ratio (0.77123) is also just within error of the earlier result (0.21% lower).

These new values both tend to move the point closer to the best fit line on the isochron diagram for the new samples and if this point is included in the regression there is a significant increase in precision because of the increased spread in Rb-Sr ratios.

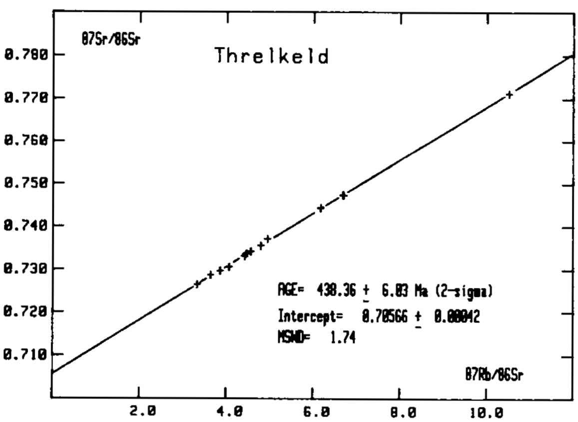

FIG. 1. Isochron diagram for new data from the Threlkeld Microgranite.

The age produced by all 13 samples is 438 ± 6 Ma with an intercept of 0.7057 ± 4, MSWD = 1.74 (Fig. 1). It is proposed that this date represents a better estimate of the age of the early Llandeilo than any previously published data.

A new date for the Caradoc?

The age of the Eskdale Granite is now well established both by Rb-Sr and K-Ar dates (429 ± 4 Ma, 427 ± 8 Ma (Rundle 1979)) and by U-Pb on zircons (*c.* 425 Ma Pidgeon & Aftalion 1978). It is widely accepted that the granite is a syntectonic intrusion (e.g. Dwerryhouse 1908; Simpson 1934; Trotter *et al.* 1937; Firman 1960) but the age is considerably older than the main Caledonian deformation (*c.* 400 Ma, see later). Hence, since the granite intrudes the Borrowdale Volcanic Group of Llandeilo age and since no major intra-Silurian folding has been recorded in the area, it is concluded that intrusion occurred during the widely recognised pre-Ashgillian deformation (e.g. see Moseley 1972; Ingham & McNamara 1978; Soper & Moseley 1978; Wadge 1978). Consequently, it is suggested that the best date for the Eskdale granite (429 ± 4 Ma) may also be taken as a good estimate of the age of the late Caradoc Series.

A new date for the early Llanvirn?

In the northern Lake District, the Great Cockup Picrite has given a K-Ar hornblende date of 458 ± 9 Ma (Rundle 1979). The stratigraphic age of this rock is somewhat uncertain. Eastwood *et al.* (1968) suggested that it is consanguineous with the Embleton quartz-diorite and Firman (1978) presented geochemical data from which he concluded that the diorite is related to the Eycott Volcanic Group; but Rundle (1979) disputed Firman's conclusion on the grounds that the diorite was 'emplaced after the development of a major fold in the Skiddaw Slates, whereas the Eycott lavas are conformably interbedded with the Skiddaw Slates sequence'. However, the recent division of the Skiddaw Slates into the 'Skiddaw Group' and the overlying 'Eycott Group' (Wadge 1978) and the recognition of an early pre-Eycott Group phase of nappe formation (Banham *et al.*, in press) invalidates this argument. The fold cut by the intrusion at Embleton is in Skiddaw Group slates and there is now no good reason why the Eycott lavas should not be related to the Great Cockup rock.

It may be noted that the picrite date is the mean of three separate determinations on three different samples and the oldest of these, on the hornblende with the highest K content, is 468 ± 15 Ma (Rundle 1979); identical to that determined for the Carrock Fell gabbro (468 ± 10 Ma, Ibid) which has also been related to the Eycott Group lavas (Firman 1978).

It is concluded here that the best estimate of the age of the Eycott Group, and hence of the *D. bifidus* zone of the Llanvirn (Downie & Soper 1972) is currently 468 ± 9 Ma (the mean of the determinations from Carrock Fell and Great Cockup).

The Lower Devonian

According to Wadge *et al.* (1978) the main Caledonian cleavage in the Lake District affected strata up to the Scout Hill Flags of Downtonian age (= early Gedinnian). The emplacement of the Skiddaw granite is thought to have overlapped this Caledonian deformation (Soper & Roberts 1971) and hence the K-Ar age of 399 ± 9 Ma determined by Shepherd *et al.* (1976) for this intrusion can be taken as a minimum estimate of the age of the early Gedinnian and suggests that the base of the Devonian is somewhat in excess of 400 Ma.

The Lower Palaeozoic time-scale

In recent publications (Gale *et al.* 1979, 1980; McKerrow *et al.* 1980) the authors considered it necessary to erect some independent scale proportional to the absolute duration of the stratigraphic divisions in order to make a statistical correlation between these divisions and the radiometric dates. In view of the uncertainty of the stage lengths used by Gale *et al.* (based on rates of animal evolution) and of the discussion by McKerrow *et al.* of what ratio to use for the relative lengths of the Caradoc and Ashgill Series (2 : 1 or 8.5 : 1) it is considered here that this attempted correlation is unjustified and gives a false impression of the accuracy of the interpolated points.

This is demonstrated admirably by the latter authors who, after noting the uncertainty of establishing a relative stratigraphic time-scale 'especially for the Ordovician', then present a table which assigns an age (with no error estimates) to the base of every stage of the Lower Palaeozoic. In the author's opinion it would be far more useful and less misleading if geochronologists applied themselves to producing a list of reliable data points for the stratigraphic column and left the interpolations to the imagination and predilection of those who wish to use the data.

Conclusion

The new ages presented here (see Table 2) are more in accord with the time-scale produced by Gale *et al.* (1979) than any other version and support the lowering of the Ordovician–Silurian boundary to something less than about 420 Ma. If the date for the Stockdale Rhyolite is accepted then there is no justification for placing the boundary older than this (as Gale *et al.* 1980, have done in their revised scale).

Only for the Silurian–Devonian boundary is there

TABLE 2. *Comparison of time-scales (ages in Ma)*

	This work	*Gale et al* 1979*	*Gale et al* 1980*	*McKerrow et al* 1980*
DEVONIAN				
Gedinne	399 ± 8 (Skiddaw)	394	400	411
SILURIAN				
Pridoli				415
Ludlow				422
Wenlock				428
Llandovery		418	425	440
ORDOVICIAN				
Ashgill	421 ± 9 (Stockdale)			447
Late Caradoc	429 ± 9 (Eskdale)			
Early Caradoc		434		469
Llandeilo	439 ± 9 (Threlkeld)	453		478
Llanvirn	468 ± 10 (Eycotts)	464		488
Arenig		482		504
Tremadoc	490 ± 10 (Bohemia)	490	500	519

* Ages to base of divisions.

Following Rundle (1979) and Gale *et al.* (1979) a minimum absolute error of ±2% (2 sigma) has been assigned to all ages in order to allow for possible errors in decay and other constants and inter-laboratory differences. The resolution between particular data points determined by the same method in the same laboratory may be considerably less than this.

any disagreement between the new data and the scale of Gale *et al.* (1979). The Skiddaw granite age clearly indicates that the early Gedinnian must be older than about 400 Ma and hence, in this case, the estimate of 411 Ma by McKerrow *et al.* appears to be the more reasonable.

The time-scale preferred here suggests that a reasonable estimate of the duration of the Silurian period is only some 10–15 Ma compared with perhaps 70 Ma for the Ordovician. (However, it should be noted that if one accepts the interpolated values for the boundaries and assumes a 2% error on them at the 95% confidence level, the Silurian could be anywhere between minus 9 and plus 23 Ma in length; beware stratigraphic interpolations and statistics!). That this is not unreasonable can be demonstrated by the geological history of the Lake District during these periods. The Ordovician is characterized by at least three periods of deformation, four periods of magmatic activity and a wide variation in depositional environments producing in excess of 11 000 m (Moseley 1978) of deep sea turbidites, sub-aereal lavas, volcaniclastics and limestones. In contrast the Silurian was a remarkably quiescent period of tranquil marine sedimentation producing only c. 3–4000 m of beds, with little evidence of major magmatic or tectonic activity.

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