

Letters to the Editors

LEWISIAN CHRONOLOGY

SIRS, The discussion by Park (1970) of aspects of Lewisian chronology centres around an assessment of the general review and interpretative papers of Bowes (1968*a*, *b*, 1969) which dealt mainly with the Lewisian of the North-west Highlands of Scotland. However, neither much of the original evidence on which these syntheses are based, nor other significant information relating to the Lewisian of the North-west Highlands and the Outer Hebrides (e.g. Bennison and Wright 1969, pp. 41–6; Hopgood 1964) are taken into account. In addition, a considerable amount of information now published, or being published, was not available to Dr Park. This is particularly the case for the central region of the Lewisian of the North-west Highlands (*cf.* Bowes 1969, figs. 1, 2; Park 1970, fig. 1) which includes the type areas for the Scourian and Inverian orogenies ('cycles' of Bennison and Wright 1969) and for the Scourie dyke. The evidence presented by Bowes and Khoury (1965) that basic minor intrusions were emplaced during *both* the Inverian and Laxfordian orogenies is rejected by Park (1970, p. 388) together with the relevant chronology of the central belt (Bowes 1968*b*, table 1; 1969, table 1) as if this were the sole evidence available (*cf.* Park 1970, table 1, note 2). Without the detailed evidence of Khoury (1965, 1968*a*, *b*) and Barooah (1967), hypothetical correlations are made of events separated by Bowes (1968*b*, 1969) and a 'simplified' chronology is presented by Park (1970, table 2). But the field evidence for the district between Kylesku and Scourie (Bowes 1969, fig. 2), based on systematic mapping, is clear. One set of basic dykes was emplaced *during* the Inverian orogeny about 2190 m.y. ago (*cf.* Park 1970, p. 381). This dyke set is deformed by the pre-Torridonian fold belts which are generally accepted as representing Laxfordian deformation (F of Park 1970, table 1). Another set of basic dykes intrude the deformed dykes (*cf.* Bowes and Khoury 1965) *and* cross-cut the fold belts. Their emplacement during the Laxfordian orogeny is shown by their deformation by late Laxfordian movements. 'Correlation' of these different suites on the assumption that there is only one suite of basic dykes in the central region ('the so-called Scourie dyke suite'—Park 1970, p. 387), the extension of this assumption to include basic intrusions in the southern region as members of the 'main Scourie dyke suite' (Park 1970, p. 388), and the related assumption that a strong foliation formed immediately preceding basic dyke injection in a sequence is the dominant Inverian foliation (Park 1970, p. 388) explains much of the confusion and the differences in interpretation of Park (1970) and Bowes (1968*b*, 1969). Evidence against these assumptions is not confined to the central belt of mainland Lewisian. Both Dash (1967; 1969, p. 349)

and Chowdhary (1969) have demonstrated in the northern region, between Loch Laxford and Strath Dionard, that basic minor intrusions cross-cut Dionard phase folds which deform gneisses dated at about 1850 m.y. (*cf.* Lambert and Holland *in press*). In the southern region, on Rona, there are at least four phases of basic minor intrusion separated by metamorphic and structural events (Gillen *et al.* 1969; Hopgood 1971*b*). In the Outer Hebrides, on Barra, Hopgood (1970, 1971*b*) has shown the existence of more than one phase of basic minor intrusions separated by phases of structural deformation, and similar relationships can be demonstrated in other parts of the Outer Hebrides. The evidence obtained throughout the Lewisian since the compilations of Bowes (1968*a, b*, 1969) is that Lewisian structural, metamorphic and igneous sequences are more extensive than had previously been determined (*cf.* Hopgood 1971*b*). Hence the suggestion of Park (1970, p. 380), that because the solution presented is 'simpler' that it is 'therefore more acceptable', is both lacking in logic and without support from field evidence. And the rejection of the three-fold orogenic subdivision into Scourian, Inverian and Laxfordian is not in accord with the evidence of Khoury (1965, 1968*a, b*), Barooah (1967) and Bennison and Wright (1969 *e.g.* fig. 3.3), which is not considered by Park (1970).

In view of both the insecure basis for the assumptions made by Park (1970) and the omission of important evidence, detailed point by point discussion would not serve any useful purpose. However, there are three fields of investigation which, in combination, throw light on the confused picture resulting from concentration on dykes as a means of chronological subdivision in the Lewisian, *viz.* (1) correlation by structural sequences, (2) geochronological studies in relation to determined structural/metamorphic/igneous sequences and (3) regional geochemical/lithological studies. These must be considered together with the discussion of Park (1970), particularly in view of the considerable amount of new information available.

(1) Correlation of structural sequences has been used with considerable success in the Caledonian orogenic belt (*e.g.* Tobisch *et al.* 1970) and despite the scepticism of the method expressed by Park (1970, p. 390) correlation by structural sequence in the Lewisian is both possible and important. The structural/metamorphic histories of Mingulay (Bowes and Hopgood 1969) and Barra (Hopgood 1964, 1971*a*) in the Outer Hebrides, which were not considered by Park (1970), show so many features of correspondence that correlation can be made with a considerable degree of certainty (Hopgood 1971*b*). There is similar correspondence with the sequence in Rona in the southern region of the Lewisian of the North-west Highlands (Hopgood 1971*b*) while sequences in the Loch Laxford-Strath Dionard-Durness district of the northern region (Chowdhary and Bowes *in press*; Dash 1969; D. Findlay personal communication) permit further correlation. These structural/metamorphic sequences are so extensive and the consequent number of parameters so numerous that the likelihood of coincidence is remote. The framework provided means that sequences in the central belt can

be compared, and contrasted, with those of the northern and southern belts and so the positions of the various dyke suites in the overall Lewisian chronology assessed. The existence of metamorphic/structural/igneous sequences in the Lewisian gneisses throughout the Outer Hebrides, which correspond with the Barra-Mingulay sequence, means that correlation throughout the whole Lewisian outcrop—mainland and Hebridean—appears practicable.

(2) Geochronological studies do not support the suggestion of Park (1970, p. 397) that the effects of the Laxfordian orogeny are not as widespread as previously considered to be the case, a suggestion largely dependent upon correlation of basic dykes in the southern region with the 'Scourie dykes' of the central region rather than with dykes emplaced during the Laxfordian orogeny in both central and northern regions (*cf.* Bowes 1969). In the southern region the dominant mica growth in schists of the Loch Maree Series took place during the Laxfordian orogeny (Keppie 1967, 1969). In the northern region Lambert and Holland (*in press*) and T. D. B. Lyon (personal communication) have determined ages indicative of the Laxfordian orogeny and the regional studies of Chowdhary and Bowes (*in press*), Dash (1969) and D. Findlay (personal communication) suggest that the effects of this orogeny are widespread. In the Outer Hebrides van Breemen *et al.* (1971) have shown that the granitic injection complex of Harris is *c.* 1750 m.y. old. This, together with other geochronological evidence obtained in conjunction with the Isotope Geology Unit at the Scottish Research Reactor Centre means that structural/metamorphic/igneous sequences and isotopic data can be compared and evaluated and the 'rather inconclusive' evidence of the published isotopic dates (Park 1970, p. 381) greatly strengthened.

(3) It is implicit in much of the discussion of Park (1970) that the northern and southern regions of mainland Lewisian represent 'reworked' equivalents of the pyroxene granulites and other rocks now seen in the central region. However, most of the Kylesku group, which shows the effects of the Scourian orogeny in the central region, has a chemical composition consistent with derivation from a volcanic assemblage of basalts, andesites and dacites (Bowes *et al.* 1971; *cf.* Sheraton 1970), while the Rhiconich group of the northern region contains a considerable proportion of metasediments (Chowdhary *et al.* 1971) and zircon populations consistent with the gneisses of the group being of sedimentary derivation (Chowdhary 1971). The small proportion of metasediments that do occur in the Kylesku group (Barooah 1970) show marked chemical differences from the Rhiconich group metasediments. For example, calc-silicate rocks from the two groups contain, respectively, Ce 420–675 p.p.m. and 50–70 p.p.m., and La 165–270 p.p.m. and 50–95 p.p.m. (Bowes *et al.* 1971; Chowdhary *et al.* 1971). The evidence is clear that the Kylesku group of the central region and the Rhiconich group of the northern region are different in *kind*, with the Kylesku group possibly representing part of the lower crust during Archaean times (Bowes *et al.* 1971). Whether they, the Loch Maree Series, the metasediments of Rona and the metasediments of the

Outer Hebrides (Hopgood 1964; Coward *et al.* 1969) correspond, or differ, in age, remains to be demonstrated. This is being actively investigated at present. A solution to this problem, considered together with known structural sequences, will greatly assist in establishing a generally accepted Lewisian chronology.

The existence of a considerable amount of information recently published, or being prepared for publication, together with geochronological evidence about the age of the Kylesku group, the Rhiconich group and the rocks of Rona now being evaluated, provide a basis for further advances in our understanding of the Lewisian. When these data are available, another review to follow Bowes (1968*a, b*, 1969) will be appropriate.

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STRS, In a review of the chronology of the Lewisian that is aimed at setting out 'as objectively as possible' the evidence on which any attempt at a Lewisian chronology 'must be based', Park (1970) discards, as overelaborate, the sequence of events proposed by Bowes (1968*a, b*, 1969) and advances what appears to be a simplified two-fold orogenic classification. His argument rests, in great part, on the geology of the Central Region of the Lewisian (Park 1970, fig. 1). Surprisingly, however, he fails to report on detailed studies which have been completed in that region (Barooah 1967, 1970 and Khoury, 1965, 1968*a* and *b*). As a result, not only does he give an oversimplified account of the geology of the Central Region, but he also leaves the reader under the impression that the evidence he presents is up to date and constitutes the sole basis on which the so-called 'overelaborate' classification is based. The three-fold orogenic classification, Scourian, Inverian and Laxfordian, used by Khoury (1965, 1968*a*, p. 43), Bowes (1968*a, b*, 1969) and others is based on detailed structural, metamorphic and igneous relationships observed in the field.

Dr Park favours placing a major orogenic break between what he terms 'Badcallian' (Scourian of Bowes 1968*a*, 1969 and Khoury 1965, 1968*a*) and the Inverian because it is at this interval, he believes, that the main tectonic re-orientation occurs and the new tectonic grain imposed (Park 1970, p. 397). In the central region, the NW.-SE. Inverian foliation does not represent a new trend; it is rather a controlled orientation parallel to the axial plane of the Kylesku fold, which was formed towards the end of the Scourian orogeny (Khoury 1965, 1968*a*, pl. 2, Barooah 1967 and Bowes 1969, fig. 2). The beginning of the Inverian orogeny cannot be pushed back to include the formation of the Kylesku fold because this fold and the NW.-SE. belts formed under markedly different tectonic régimes. The association of cross-joints (extension joints) and axial planar joints (release

joints) with the Kylesku fold (Khoury 1968, pp. 68–9) imply the prevalence of little or no confirming pressure during the formation of this structure. Furthermore, the formation of the axial planar joints implies the release of the regional tectonic stresses. In contrast, the plastic deformation of the NW.–SE. belts (Khoury 1968*b*) necessitates the prevalence of tectonic stresses under relatively high confining pressure. A marked break between the Kylesku fold and the Inverian structures is thus implied. Hence, a period of sedimentation, not yet recognized, was proposed by Khoury (1968*a*, p. 43). This inferred period of sedimentation corresponds with the interval between the end of the Scourian and beginning of the Inverian cycles.

The Scourian pegmatites of the central region, which were dated at 2,460 m.y. by Giletti *et al.* (1961, table 3), are considered problematic (Park 1970, pp. 382–3) in spite of the fact that, on the basis of field evidence, the spread of ages and time of intrusion had already been discussed by Khoury (1965, 1968*a*, p. 48 and pp. 60–1). Since it is the igneous rocks which are the most likely to be radiometrically dated, particular emphasis should be given to the relationship between igneous activity and structure (Khoury 1968*a*).

In the central region, the NW.–SE. foliation is not characteristic of the Laxfordian (Park 1970, table 1). The orientation of this foliation is consistently E.–W., cross-cutting all pre-existing trends (Khoury 1968*a*, pl. 1 and 2). Therefore, it is between the Inverian and the Laxfordian that a regional re-orientation of stresses took place, resulting in the imposition of a new grain. However, the control of pre-existing structures on the development of the E.–W. fold belts has also been demonstrated. A variety of interference patterns result when an E.–W. fold belt crosses a NW.–SE. fold belt. All stages of cross-cutting, partial and total re-orientation of the E.–W. fold belts, parallel to the NW.–SE. trend, occur. Where the NW.–SE. Inverian trend is well developed, the structural control on later structures is complete (Khoury 1968*a*, pp. 67–8 and Bowes 1969, fig. 2).

The geologic relationships in the Precambrian are commonly obscure and quite complex and occasional comparisons with younger orogenic belts often prove to be quite fruitful. In Eastern North America the Taconian, Acadian and Appalachian are recognized as three separate Paleozoic orogenies. Since there has been no major tectonic re-orientation or imposition of a new grain, should these events be considered as phases of a 'Mega-orogeny'? The answer to this question depends on the total geologic history of the individual tectonic belts rather than on the imposition of a new tectonic grain. The same would appear to be the case for the Scourian, Inverian and Laxfordian orogenies.

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SIRS, Dr Bowes's criticism of my paper (Park 1970) can be summarized thus:

(1) That in preferring a 'simpler' sequence of events based on the traditional view of a single Scourie dyke suite to the sequence proposed by Bowes (1968*a*, *b*, 1969) including four dyke suites, all post-Scourian (i.e. post-Badcallian in my terminology), I have ignored, rejected or been unaware of certain published and unpublished evidence relating to the dykes.

(2) That the three-fold orogenic sub-division of the Lewisian proposed by Dr Bowes and argued against in my paper can be supported by (a) structural correlation, (b) geochronological data, and (c) regional 'geochemical/lithological' studies.

I will take these points in order.

(1) As far as I know, there is no direct evidence anywhere in the mainland Lewisian of post-Badcallian dykes of one set being folded and cut by those of even *one* later set (although *three* are proposed). I tried to show that the evidence from the locality described by Bowes and Khoury (1965) together with the indirect evidence depending on structural correlation and isotopic dates could be explained in a much simpler and, to me, more satisfactory way. Surely, if there had been four episodes of dyke intrusion separated by episodes of deformation, there would be some examples of folded dykes cutting each other, as there are for instance in Greenland and Sweden? Yet I have examined quite extensive areas of the Lewisian without seeing any, as have many other geologists including such observers as Peach, Horne and Clough. Nor is there any record of this phenomenon in the extensive literature. If evidence of this kind exists, let Dr Bowes give the locality so that it can be checked by others. As stated in my paper, post-Badcallian pre-Inverian dykes might be expected to occur although none have been proved and the only other firmly established episode of basic intrusion is pre-Badcallian.

(2)a. Dr Bowes claims that my scepticism of structural correlation as used to establish his tripartite orogenic succession is unjustified, and cites the 'success' of such methods in the Caledonian orogenic belt. Leaving aside the question of how one might objectively judge the 'success' of such correlation in the Caledonides, the important point here is that we are supposed to be dealing in the Lewisian with *three* orogenies, not one, having, according to Dr Bowes, almost identical structural sequences. Surely it must be admitted that, without employing additional criteria, there is at least a strong possibility of confusing them?

b. Dr Bowes also cites geochronological studies in support of his case, but it is precisely in this area that his arguments are most open to question, depending as they do on the identification of a 'Laxfordian' date with Laxfordian *orogeny* (rather than with Laxfordian *re-heating* as suggested by the geochronologists). This point has I think been adequately discussed in my paper. In fact the relatively large number of dates from the southern region of the Lewisian shortly to be published by Dr Moorbath and myself supports the arguments presented in the paper that the Inverian metamorphism had much stronger, more pervasive and more widespread effects on the Lewisian complex than had the Laxfordian. As

for the evidence that the dominant mica growth in the Loch Maree schists is Laxfordian, this 'evidence' is a date of 1550 m.y. obtained from a sample of sheared and recrystallised muscovite-gneiss of Scourian age and has very little bearing on the real age of the Loch Maree metasediments.

c. Regarding the evidence of regional geochemical/lithologic differences in the Lewisian, it is certainly not implied in my paper that the northern and southern regions of the mainland Lewisian represent reworked *pyroxene granulites*. What I do say is that the evidence points to the bulk of the gneisses of these regions being composed of reworked Badcallian (Early Scourian) rocks, and that this is confirmed by the lead isotope study of Moorbath *et al.* (1969). But the bulk of these may not necessarily have been in granulite facies. The chemical differences which, I agree, exist between these gneisses and those of the central region may well be due to the existence of an older basement and younger supracrustal series but both would require to be *pre-Badcallian* in age as suggested by Coward *et al.* (1969) for the Lewisian of the Outer Hebrides. So that for the purpose of Dr Bowes' argument the geochemical evidence is neutral.

In response to Dr Khoury's comments, my paper (Park 1970) was not intended as a comprehensive review and I did not consider that an exhaustive treatment of the Lewisian literature was necessary. I assure Dr Khoury, however, that I have read his paper and that of Dr Barooah but that they do not seem to me to offer any evidence different in kind from that used by Bowes (1968*a,b*, 1969) which was discussed by me.

Regarding the orogenic sub-division of the Lewisian, I agree that NW.-SE.-oriented folds were in existence before the Inverian (the Kylesku fold is only one of these) and also that locally the Laxfordian structures are not concordant with the Inverian ones. However, taking a regional view, I believe that there is a major difference in the *degree* of tectonic re-orientation between the Badcallian and Inverian on the one hand and the Inverian and Laxfordian on the other.

A significant point made by Dr Khoury in relation to the central region is that 'where the NW.-SE. Inverian trend is well developed, the structural control on later structures is complete'. In the northern and southern regions of the mainland I would maintain that this condition is *general* and that, in contrast, the degree of control exerted by a relatively large-scale open fold like the Kylesku fold on the subsequent Inverian structures is much less important.

I would suggest to Dr Khoury that his closing remarks on the criteria for recognizing orogenies imply that we should be very wary of establishing orogenies in the Precambrian in the absence of good stratigraphic evidence—with which I entirely agree! (I deliberately use the term 'major break' in my paper rather than 'division between two orogenies'.)

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REFERENCES

Editorial note.—To avoid duplication, all references cited in the correspondence on the Lewisian are grouped below. Only the latest references are quoted in full and readers are referred to the bibliography in Bowes (1969) for the asterisked papers.

- BAROOAH, B. C. 1967.*
 — 1970. Significance of calc-silicate rocks and meta-arkose in the Lewisian complex south-east of Scourie. *Scott. J. Geol.* **6**, 221–5.
- BENNISON, G. M. and WRIGHT, A. E. 1969. *The geological history of the British Isles*. London.
- BOWES, D. R. 1968a.*
 — 1968b.*
 — 1969. The Lewisian of Northwest Highlands of Scotland. In Kay, M. (ed.), *North Atlantic—geology and continental drift, a symposium*. *Mem. Amer. Assoc. Petrol. Geol.* **12**, 575–94.
- BAROOAH, B. C. and KHOURY, S. G. 1971. Original nature of Archaean rocks of North-West Scotland. *Spec. Publ. Geol. Soc. Aust.* **3** (in press).
- and HOPGOOD, A. M. 1969. The Lewisian gneiss complex of Mingulay, Outer Hebrides, Scotland. In Larsen, L. (ed.), *Igneous and Metamorphic Geology*. *Mem. Geol. Soc. Amer.*, **115**, 317–60.
- and KHOURY, S. G. 1965.*
- CHOWDHARY, P. K. 1969. Geology of Lewisian rocks south of Loch Inchard Sutherland. *Univ. Glasgow, Ph.D. thesis* (unpubl.) (in press).
- 1971. Zircon populations in Lewisian quartzite, gneiss and granite north of Loch Laxford, Sutherland. *Geol. Mag.* **108** (in press).
- and BOWES, D. R. (in press). Structure of Lewisian rocks between Loch Inchard and Loch Laxford, Sutherland, Scotland. *Krystalinikum*, **9**.
- , DASH, B. and FINDLAY, D. 1971. Metasediments in the Rhiconich group of the Lewisian between Loch Laxford and Durmess, Sutherland. *Scott. J. Geol.* **7**, 1–9.
- COWARD, M. P., FRANCIS, P. W., GRAHAM, R. H., MYERS, J. S. and WATSON, J. 1969. Remnants of an early metasedimentary assemblage in the Lewisian complex of the Outer Hebrides. *Proc. Geol. Ass.* **80**, 387–408.
- DASH, B. 1967.*
 — 1969. Structure of the Lewisian rocks between Strath Dionard and Rhiconich, Sutherland, Scotland. *Scott. J. Geol.* **5**, 347–74.
- GILLEN, C., BOWES, D. R. and HOPGOOD, A. M. 1969. Glasgow University Exploration Society Expedition to Rona, 1968 and 1969. *Outcrop, Univ. of Glasgow*, **2**, 49–56.
- HOPGOOD, A. M. 1964. Structure and tectonic history of Lewisian Gneiss, Isle of Barra. *Univ. St. Andrews, Ph.D. thesis* (unpubl.).
- 1970. Written discussion of paper taken as read: 4 July 1969. *Proc. Geol. Ass.* **81**, 399–400.
- 1971a. Structure and tectonic history of Lewisian Gneiss, Isle of Barra, Scotland. *Krystalinikum*, **7**, 27–60.
- 1971b. Correlation by tectonic sequence in Precambrian gneiss terrains. *Spec. Publ. Geol. Soc. Aust.* **3** (in press).
- KEPPIE, J. D. 1967.*
 — 1969.*
- KHOURY, S. G. 1965. The geology of the Lewisian rocks north of Kylesku, Sutherland. *Univ. Glasgow, Ph.D. thesis* (unpubl.).
- 1968a.*
 — 1968b.*
- LAMBERT, R. ST J. and HOLLAND, J. G. (in press). A geochronological study of the Lewisian of the Laxford area, north-west Scotland. *Q. Jl geol. Soc. Lond.*
- MOORBATH, S., WELKE, H. and GALE, N. H. 1969. The significance of lead isotope studies in ancient high-grade metamorphic basement complexes, as exemplified by the Lewisian rocks of Northwest Scotland. *Earth Planet. Sci. Letters*, **6**, 245–56.

- PARK, R. G. 1970. Observations on Lewisian chronology. *Scott. J. Geol.* **6**, 379-99.
- SHERATON, J. W. 1970. The origin of the Lewisian gneisses of North-west Scotland, with particular reference to the Drumbeg area, Sutherland. *Earth Planet. Sci. Letters*, **8**, 301-10.
- TOBISCH, O. T., FLEUTY, M. J., MERH, S. S., MUKHOPADHYAY, D. and RAMSAY, J. 1970. Deformational and metamorphic history of Moinian and Lewisian rocks between Strath Conon and Glen Affric. *Scott. J. Geol.* **6**, 243-65.
- van BREEMEN, O., AFTALION, M. and PIDGEON, R. T. 1971. The age of the granitic injection complex of Harris, Outer Hebrides. *Scott. J. Geol.* **7**, 139-52.