A Reply. Reconnaissance Rb–Sr Investigation of Salic, Mafic and Ultramafic Rocks in the Øksfjord Area, Seiland Province, Northern Norway

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Pringle's comments on my work (Brueckner 1973) on rocks from the Øksfjord area start with a small, but significant, misquote. The sentence reads (last lines, page 11) that 'some portions of the Øksfjord area *may have had* a pre-*Caledonian* origin' (emphasis mine), not, as Pringle quotes '. . . some portions of the Øksfjord area *had* a pre-*Cambrian* origin'. This misquote and other misreadings generate the false impression that the Øksfjord paper had a biased and perhaps contrived viewpoint regarding the interpretation of the data. In fact, the paper was carefully presented as a reconnaissance investigation that provided new and surprising data (I, too, had initially assumed that all the rocks of the Seiland petrographic province originated during the Caledonian orogenic cycle) and some very cautious interpretations. Thus, numbers determined by the regression analyses of various groupings of samples were not labeled simply as 'ages' or 'isochrons', as quoted by Pringle, but rather as 'apparent ages', 'model ages', or 'apparent isochrons' which in most cases were rejected, or which were discussed with carefully outlined reservations. In fact, two of the three 'isochrons' with which Pringle takes issue are reference lines, as explicitly stated in the figure caption.

Pringle restates the three basic conditions (same age, same initial Sr^{87}/Sr^{86} ratio, no open system behavior) that must be fulfilled before an isochron plot will define an age. The only internal way to test for these conditions is to plot the data on an isochron diagram to see if the scatter of the data about a best-fit line is less than can be attributed to experimental error. This situation applies to the data plotted in fig. 3 of the Øksfjord paper for rocks with igneous textures. Based on internal Rb–Sr evidence only, there is no reason not to relate the perthosites to the other massive igneous rocks of the area. Naturally, the linearity of the data does not prove this possibility, and there may be geological reasons for rejecting it. Thus, a separate regression was presented and discussed using only points from a single perthosite body. Pringle focuses on the large error of the three point isochron, and then goes on to state that 15 subsequent analyses (Pringle & Sturt, in preparation) from two other widely separated perthosite bodies fall on the same linear trend. This gratifying confirmation of the 625 m.y. apparent isochron renders discussion of the error superfluous. The only significant question is the interpretation of the apparent age. The simplest procedure is simply to accept the age as the time of crystallization of the perthosite magma. The mixing line hypothesis advanced by Pringle is a time-honored procedure used to explain away an age that is unacceptable. This hypothesis may have to be given serious consideration, but the burden of proof will rest with Pringle. Since evidence for this model is still in preparation, there is no way to evaluate it. The only clue to date is that the perthosites on Seiland and Sørøy contain relict xenoliths of gabbroic rocks. Presumably, the hypothesis will suggest that these xenoliths partially mixed with a perthositic magma so that samples of the contaminated perthosite would plot with a positive slope (i.e. show an apparent age) on an isochron diagram at the time of initial crystallization. Generally, mixing points plot as diffuse bands (see, e.g. fig. VI.5 in *Strontium Isotope Geology* by Faure & Powell 1972) since one or both of the end members tend to have variable Rb/Sr and Sr^{87}/Sr^{86} ratios. The data from the Øksfjord area (table 2) show that the metamorphosed country rocks intruded by the perthosites had highly variable Rb/Sr and Sr^{87}/Sr^{86} ratios during the Caledonian Orogeny. Yet the data from the Øksfjord perthosites (including IV – 9, a monzonite perthosite) fall precisely on a single line. If the 15 subsequent analyses of Pringle fall as neatly on the same line, despite being from two other widely separated bodies, then the mixing model hypothesis will strain credibility. Further discussion of the model will have to await publication of Pringle's data. At present, accepting the 625 m.y. apparent age as the true time of crystallization is the simplest and least *ad hoc* of the two possibilities.

The rest of Pringle's comments refer to the data for the foliated (i.e. metamorphosed) rocks plotted in fig. 4. The data points do not fit about a best fit line within experimental error, and hence one or more of the basic conditions of the Rb–Sr whole-rock isochron technique have been violated. It should be pointed out that plots of metamorphic rocks from other parts of the Norwegian Caledonides have yielded a linear array of points with acceptable ages (see, e.g., Heier & Compston 1969, Pidgeon & Råheim 1972, Mysen & Heier 1972). Simply because metamorphism has not caused isotopic homogenization in whole-rock samples in northern Idaho (Hofmann 1972) does not mean it cannot or has not occurred elsewhere. However, because the foliate rocks from the Øksfjord area did not fall on a line, the best fit age was indeed rejected. Various groupings of samples (table 3) were then systematically considered (i.e. igneous rocks versus non-igneous rocks, sheared versus unsheared rocks) to see if any fulfilled the requirements of the isochron technique. None did, as explicitly stated in the paper. Two groupings give apparent ages (around 1645 and 1035 m.y.) that have some significance in the Norwegian Caledonides, and these were cautiously discussed. Pringle seems to feel the 1035 m.y. apparent date may have some validity. Precisely. So *may* the 1645 m.y. apparent age. More detailed work will be required to resolve these possibilities.

The value of the Øksfjord paper is simply that it shows there are samples in the Øksfjord area that are significantly more radiogenic than could be reasonably expected under the assumption that all the rocks in the area formed during the Caledonian Orogeny. The fact that its publication was delayed for almost two years by those who took exception to some of its findings no doubt diminished some of its value as a reconnaissance work. I do not wish to dismiss entirely the value of Pringle's comments. Sample IV–1–C is 0.7100, not 0.7010 as mistakenly printed in table 2. The reference lines in fig. 4 perhaps should not have error limits. There could well have been more geologic control, although I found Krauskopf's (1954) field mapping more than adequate. Nevertheless, I feel Pringle could have better served the orderly progression of knowledge about the Seiland Province by dealing with the data presented in the Øksfjord paper rather than trying to discredit its cautious conclusions. Perhaps he and other investigators are still unduly influenced by a ruling hypothesis that demands most of the rocks of the Seiland Petrographic Province originated during the Caledonian orogenic cycle. At this stage, I see no reason to change any of the findings of the Øksfjord paper, and I suggest the interested reader will gain the best understanding of its intent by reading it directly.

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