# Interpretation of Rb-Sr dates from the Western Gneiss Region: a cautionary note

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Some Precambrian Rb-Sr whole-rock isochrons from the Western Gneiss Region have been interpreted as recording the age of the metamorphism, and some recent geologic models have in turn considered the Caledonian influence in the region to be relatively minor. However, data from the basement rocks of the Alps clearly show that Rb-Sr whole-rock isochrons survived intense Alpine metamorphism and deformation. Thus, the Precambrian dates from western Norway may record meaningful ages of the Precambrian basement, even though the effects of the Caledonian orogenesis may have been considerable.

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The conclusions that recumbently folded and metamorphosed rocks of the Oppdal area represent a Caledonian tectonostratigraphy (Krill 1980), and that Sm-Nd dates on eclogites indicate high-grade Caledonian metamorphism followed by deformation and retrogression (Griffin & Brueckner 1980), support earlier geologic models that the Western Gneiss Region is the structural and metamorphic core of the Scandinavian Caledonides. These conclusions challenge recently suggested revisions that would question or severely limit the degree of Caledonian influence in the region (Krogh 1977, Bryhni & Brastad 1980, Roberts & Sturt 1980, Oftedahl 1980). Such models, which suggest that the main metamorphism and deformation of the Western Gneiss Region was Precambrian, were developed largely from interpretations of Rb-Sr whole-rock dates as representing the age of the last major metamorphic event (eg. Råheim 1977, Skjerlie & Pringle 1978). These geochronologic interpretations, however, are debatable. The dates may instead record primary igneous/metamorphic ages related to the original formation of this segment of the continental crust. This interpretation resolves the apparent 'Caledonian' vs. 'Precambrian' contradictions in the geology of western Norway, and agrees better with data from gneiss regions of other orogens, where geochronologic interpretations are more closely constrained by stratigraphic and fossil evidence.

Within the Western Gneiss Region Rb-Sr whole-rock isochrons of gneisses typically give Precambrian dates. Some investigators have interpreted such isochrons as recording the magmatic or primary events (Priem et al. 1973, Brueckner 1972, 1979, Abdel-Monem & Bryhni 1978, Lappin et al. 1979). Others have interpreted similar isochrons as recording metamorphic or secondary events (Mysen & Heier 1972, Pidgeon & Råheim 1972, Råheim 1977, Skjerlie & Pringle 1978, Råheim et al. 1979, Solheim 1980).

These isochrons generally have low (<. 706) initial $^{87}Sr/^{86}Sr$ ratios. They can only be interpreted as giving metamorphic ages if: (a) the metamorphism occurred within a relatively short period (ca. 100 Ma?) after separation of the rock from a 'mantle' source, or (b) selective removal of radiogenic $^{87}Sr$ from *all* analyzed rocks occurred during the later metamorphism. The first alternative implies that the isochron date records some late stage in a crustal acretion-differentiation 'super-event' (Moorbath 1975). The second requires a process that has been suggested (Heier & Compston 1969) but never, to our knowledge, clearly demonstrated.

Several recent interpretations of the Western Gneiss Region suggest that the preservation of Precambrian Rb-Sr whole-rock isochrons *excludes* the possibility of major Caledonian metamorphism of the dated rocks (Pidgeon & Råheim 1972, Råheim 1977, Skjerlie & Pringle 1978, Råheim et al. 1979, Solheim 1980). These interpretations rest largely on two assumptions:

(a) It is assumed that any strong deformation and metamorphism would reset Rb-Sr whole-rock systems, so that the Precambrian isochrons could not have survived a strong Caledonian recrystallization. (b) Because of the lack of obvious structural and metamorphic breaks within the Western Gneiss Region, it is assumed that only one orogeny was significant here.

Thus, following the first assumption, the orogeny must be dated by the oldest preserved isochrons in the region (Svecofennian) and younger isochrons must record isotopic disturbance and resetting due to secondary events of relatively minor geologic significance.

A close look at geochronologic and geologic studies of other orogens discredits these assumptions. The Alps are especially suited for such a comparison and for understanding the meaning of geochronologic data (cf. Jäger 1977). Many Rb-Sr studies have been made in the Alps and, because of the young age of the Alpine orogeny, absolute errors of isochrons are relatively small. Furthermore, abundant fossil evidence provides independent control on the age interpretations. The degree of Alpine deformation and metamorphism of the basement and cover is well documented, and the influence of the Alpine orogenesis on the Rb-Sr mineral and whole-rock systems of basement rocks has been studied in detail. The results from many studies of basement rocks show that Rb-Sr whole-rock systems remained closed despite deformation and recrystallization, even in the staurolite, kyanite, and sillimanite zones of regional metamorphism (Jäger 1970, 1977).

In the Pennine zone of the Alps, basement rocks were strongly foliated, recumbently folded with cover rocks, and strongly metamorphosed, locally forming Alpine eclogites, yet Rb-Sr whole-rock isochrons commonly yield meaningful pre-Alpine ages (e.g. Hunziker 1979, Jäger 1970, Gulson 1973, Satir 1974). It is reasonable to compare the Western Gneiss Region to the Pennine Zone (Holtedahl 1938, Muret 1960), and to interpret the Precambrian dates as meaningful ages for the pre-Caledonian basement.

Isotopic disturbance of whole-rock specimens is common in the Alps, and isolated cases of completely reset or secondary whole-rock isochrons are known (Hanson et al. 1969, Hunziker 1970). As with secondary mineral isochrons, the well documented secondary whole-rock isochrons are characterized by higher initial ratios. Common models of isotopic behavior require that secondary isochrons should indeed have high initial ratios, since isotopic resetting involves homogenization of $^{87}Sr/^{86}Sr$ to the average value for the reset system, and this average value is necessarily higher than the initial value (cf. Faure & Powell 1972).

In any case, the old isochrons cannot exclude the possibility of a younger metamorphism in the Western Gneiss Region. The resetting of whole-rock isochrons requires the movement and homogenization of Sr isotopes on a scale equivalent to the maximum distance between samples. Evidence from other polymetamorphic orogens demonstrates that this requirement is seldom met, especially in orthogneisses. The consensus among geochronologists working in such terrains is that extensive movement of a fluid phase is necessary for the resetting of Rb-Sr systems. Dehydration during the original igneous/metamorphic event would therefore greatly reduce the likelihood of isotopic resetting of whole-rock systems during subsequent events (Jäger 1979).

It is important to note that all known Rb-Sr mineral dates from the Western Gneiss Region (north of Sognefjorden) are 'Caledonian' (350–500 Ma). These data have been widely disregarded in the interpretation of whole-rock data, on the assumption that mineral dates record only weak reheating, rather than metamorphic recrystallization. This asumption is based largely on the relatively low 'blocking temperatures' recorded in some mineral Rb-Sr systems (and K-Ar systems) in studies of contact metamorphism. However, other arguments may be advanced. (a) Muscovite 'blocking temperatures' are as high as 500°C (Purdy & Jäger 1976, Jäger 1979), suggesting *minimum* temperatures on this order throughout the Western Gneiss Region in Caledonian time. (b) Regional metamorphism to temperatures up to 100°C *above* the assumed 'blocking temperature' may not reset Rb-Sr and K-Ar systems in biotite and muscovite (cf. Verschure et al. 1980, Chopin & Maluski 1980). Recrystallization, rather than simply heating, appears to be the critical factor. (c) Small, late- to post-tectonic granite or granite-pegmatite dikes are common in the western parts of the Gneiss Region, and give Caledonian (< 400 Ma) Rb-Sr whole-rock dates with high inital $^{87}Sr/^{86}Sr$ (i.e. ⩾ .712) (Pidgeon & Råheim 1972, S. Ilebekk, pers. comm. 1981). The existence of these dikes implies local anatexis of older rocks not far from the site of emplacement. These data thus suggest that the Caledonian Rb-Sr mineral dates from the Western Gneiss Region reflect high temperatures (>600°C) and probably extensive recrystallization during the Caledonian event.

The absence of obvious structural and metamorphic breaks within the Western Gneiss Region does not eliminate the possibility of both Precambrian and Caledonian orogenic events. Tectonized basement-cover relationships without obvious breaks are common in the Alps (e.g. Chatterjee 1961, Chadwick 1968, Thakur 1973, Huber et al. 1980) and in other orogens. Basement-cover unconformities are locally observed in eastern parts of the Western Gneiss Region (Rosenqvist 1941, Santarelli & Brunel 1979, Krill 1980), but toward the west the unconformable relationships are tectonized beyond recognition. Furthermore, basement and cover rocks with different ages and geologic histories have been intimately interlayered by thrusting and recumbent folding, so that ages of each rock unit must be considered independently. Old dates from one rock unit cannot be considered to also date adjacent units.

A form of circular reasoning appears to have developed in recent interpretations of the geologic age and isotopic behavior of rocks of the Western Gneiss Region. Rather unusual interpretations of isotopic behavior – that Sveconorwegian and Caledonian whole-rock dates represent isotopic resetting due to relatively minor secondary events (Råheim 1977, Solheim 1980) – have been accepted by geochronologists on the assumption that the interpretations are demanded by the regional geology. However, the same geochronologic interpretations have in turn led to revisions of regional geologic models on the assumption that the revisions are demanded by the geochronology. We know of no geochronologic data that discredit the earlier models of intense Caledonian orogenesis in the Western Gneiss Region.

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