Geological interpretation of whole-rock isochron dates from high grade gneiss terrains

MANY Rb–Sr whole-rock isochron dates have been reported on extensive terrains of quartzo–feldspathic orthogneisses. Most are of Precambrian age. In most cases the date is either regarded simply as the "age" of the gneiss complex (with no specific interpretation), or as the age of regional metamorphism. The latter interpretation naturally implies large scale regional homogenisation of Sr isotopes at the isochron date. I find such an interpretation improbable.

First, good "primary" Rb–Sr whole-rock isochrons are commonly observed in gneiss terrains which underwent much later intense metamorphism (at least up to amphibolite facies) indicating isochemical behaviour with respect to Rb and Sr on a whole-rock scale. Thus, Scourian gneisses of north-west Scotland yield Rb–Sr whole-rock dates of about 2,700 Myr, in spite of being subjected to intense Laxfordian metamorphism and deformation nearly 1,000 Myr later, as shown by mineral dates[1,2]. Similarly, the Amîtsoq gneisses of West Greenland have preserved their 3,700 Myr Rb–Sr whole-rock isochron systematics in spite of amphibolite facies metamorphism and intense deformation at about 2,600–2,800 Myr ago[3,4]. Many analogous cases have been reported.

Second, Krogh and Davis[5] have demonstrated unequivocally from Rb–Sr laboratory studies on gneisses of the French River area of the Grenville Province of Ontario that isotopic and chemical equilibrium was not reached over distances of even a few centimetres during a regional amphibolite facies metamorphism which occurred some 800 Myr after their "formation".

Why, then, do extensive gneiss terrains frequently yield such good Rb–Sr whole-rock isochrons, and what do these isochrons really mean? I have suggested that low, upper mantle type, initial $^{87}Sr/^{86}Sr$ ratios of many ancient gneisses indicate that their immediate precursors are predominantly juvenile additions to the continental crust at, or close to, the measured age[6]. The interval between times of extraction of juvenile igneous material from the upper mantle and/or subducted basic lithosphere and time of production of the regional metamorphic characteristics of the derived gneiss complex may be less than 50–100 Myr, which falls within the analytical uncertainty of most age measurements on Precambrian rocks. In my model major crustal accretion is regarded[6] as essentially contemporaneous with the profound geochemical and petrological differentiation required to yield a compositionally gradational crust, in which the raw materials of granite (*sensu lato*), as well as geochemically incompatible elements and water, migrate upwards, leaving behind depleted granulite facies rocks at depth[7,8].

On such a model, Rb–Sr whole-rock isochrons on orthogneisses simply give the age of the accretion–differentiation event. The best isochrons are obtained when the duration of the latter event is short in relation to its actual age. A low, homogeneous, initial $^{87}Sr/^{86}Sr$ ratio is inherited directly from the upper mantle or basic lithosphere source region, while local and regional dispersion in Rb/Sr ratios within the gneiss complex results from synchronous geochemical differentiation processes. Significant deviations from ideal Rb–Sr isochron behaviour are quite common, and may be attributed to source region heterogeneities, to interactions of the gneiss precursors with pre-existing crust, or to lack of closed system behaviour on a whole-rock scale with respect to Rb and/or Sr during subsequent metamorphism and tectonism.

These considerations also apply to Pb–Pb whole-rock isochron dates on ancient orthogneisses, which are frequently in good agreement with corresponding Rb–Sr dates [2,9,10]. In such cases, simplicity of the Pb–Pb isotope systematics suggests derivation from a homogeneous U–Pb (usually expressed as $^{238}U/^{204}Pb$) source region approximating to single stage evolution from time of formation of the Earth to the measured isochron date[11], although small deviations from ideal behaviour are common. Consideration of the actual $^{238}U/^{204}Pb$ value of the source region (about 7.3–8.0, using the model parameters of Oversby[12]) as calculated from the primary Pb isotope growth curve and of the customarily close agreement of a given Pb–Pb isochron date with that obtained from the intersection of the Pb–Pb isochron with the primary growth curve, suggests that the source region of the gneiss precursors was upper mantle or basic lithosphere.

Synchronous geochemical differentiation of newly accreted sial produces severe U–Pb fractionation at the measured isochron date[13]. The wide range of measured $^{238}U/^{204}Pb$ values in gneisses contrasts strongly with the homogeneous $^{238}U/^{204}Pb$ value calculated for the source region of the gneiss precursors. Profound uranium depletion is characteristic of many gneisses, yielding present-day unradiogenic Pb isotope ratios close to the primary growth curve[10,11].

By close analogy with the Rb–Sr system, homogeneity of initial Pb isotopes ratios in a gneiss terrain is thus regarded as being inherited from the source region of the gneiss precursors, whereas geochemical differentiation results in dispersion of U–Pb ratios. The necessary conditions for isochron behaviour may thus be met. A good Pb–Pb whole-rock isochron can date the primary accretion-differentiation event, which is usually constrained to a time interval of not more than about 50–100 Myr.

The above interpretation of Rb–Sr and Pb/Pb whole-rock isochron dates in ancient quartzo–feldspathic orthogneisses obviates the necessity for invoking the popular, but highly implausible, process of large scale homogenisation of Sr and Pb isotopes throughout extensive volumes of metamorphic basement rocks.

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1. Lyon, T. D. B., Pidgeon, R. T., Bowes, D. R., and Hopgood, A. M., *J. geol. Soc. Lond.*, **129**, 389 (1973).
2. Moorbath, S., Powell, J. L., and Taylor, P. N., *J. geol. Soc. Lond.*, **131**, 213 (1975).
3. Moorbath, S., O'Nions, R. K., Pankhurst, R. J., Gale, N. H., and McGregor, V. R., *Nature phys. Sci.*, **240**, 78 (1972).
4. Pankhurst, R. J., Moorbath, S., Rex, D. C., and Turner, G., *Earth planet. Sci. Lett.*, **20**, 157 (1973).
5. Krogh, T. E., and Davis, G. L., *Yb. Carnegie Instn Wash.*, **72**, 601 (1973).
6. Moorbath, S., *Nature*, **254**, 395 (1975).
7. Fyfe, W. S., *Phil. Trans. R. Soc.*, **A273**, 457 (1973).
8. Heier, K. S., *Phil. Trans. R. Soc.*, **A273**, 429 (1973).
9. Rosholt, J. N., Zartman, R. E., and Nkomo, I. T., *Bull. Geol. Soc. Am.*, **84**, 989 (1973).
10. Black, L. P., Gale, N. H., Moorbath, S., Pankhurst, R. J., and McGregor, V. R., *Earth planet. Sci. Lett.*, **12**, 245 (1971).
11. Moorbath, S., Welke, H., and Gale, N. H., *Earth planet. Sci. Lett.*, **6**, 245 (1969).
12. Oversby, V. M., *Nature*, **248**, 132 (1974).
13. Moorbath, S., in *The Early History of the Earth* (edit. by Windley, B. F.) (J. Wiley, in the press).

Depths of origin of Kenyan basalts and implications for the Gregory Rift

THE Gregory Rift of Kenya, part of the eastern branch of the Afro-Arabian rift system, has received much attention in recent years as an exceptionally well exposed example of an intracontinental rift. It exhibits a variety of lavas and ignimbrites related to one another in time and space in patterns that can be clearly defined[1–3]. Explicit models of the crust and upper mantle in and near the Gregory Rift, have been derived, largely from gravity surveys[4,5].

Two petrogenetic models for suites of basalts found in and near the Gregory Rift have been developed. One of these models, for the Chyulu Basalts found east of the rift, overlying Precambrian metamorphic rocks, suggests that the parental basalts of this suite effectively equilibrated with mantle rocks at a temperature of ~ 1,450 °C and pressures of substantially less than 25 kbar[6]. Analytical data on abundances of rare earth elements in the Chyulu Basalts show that assimilation of crustal materials has had at most a very minor effect on the compositions of these rocks, suggesting that the magmas they represent