# Rb/Sr ages from the Arequipa Massif, southern Peru

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The Rb/Sr whole rock isochron age of 1960 ± 33 m.a. obtained from the gneisses of the Arequipa Massif which lies between the Chile-Peru trench and the Andean chain is interpreted as the age of a metamorphic event in which partial melting was followed by static granulite-facies metamorphism. During the Ordovician-Silurian the gneisses were intruded by at least two series of granites from which dates of 449 ± 15 m.a. and 400 ± 22 m.a. have been obtained. The earlier granites are overlain by, and the later granites cut, the Marcona Formation sediments, the age of which can now be given as Ordovician.

The Andean chain in Peru is flanked by basement gneisses which give Precambrian radiometric ages: to the east is the Brazilian Shield (Cordani *et al.* 1973) and to the west the Arequipa Massif. The Arequipa Massif is approximately 200 km. wide and crops out along the coast of Peru between latitudes 14° and 18° (Figure 1). This strip of crystalline rocks, which lies between the Chile-Peru trench and the Andean chain, must either be part of the Brazilian Sheild or a fragment of another plate now on the opposite side of the Pacific Ocean. In 1975 a Royal Society sponsored expedition foom the University of Leeds (Robert Shackleton, Mike Coward, Peter Cobbold and the author) visited the Arequipa Massif to try to find out about the age and origin of the block using structural, petrological, geochronological and palaeomagnetic techniques. This report is concerned only with the geochronological results.

The basement rocks of the Arequipa Massif are gneisses, generally of sedimentary origin, intruded by several sets of acid and basic sheets which have undergone a series of deformational and metamorphic events. Gneisses collected from the Mollendo area (Figure 1) give a Rb/Sr whole rock isochron age of 1960 ± 33 m.a. (all errors quoted are 2σ) with an initial Sr ratio of 0.704 ± 2 and a MSWD = 10.7 (Figure 2).

Both from field evidence and microscope studies the Mollendo gneisses show a metamorphic history the first stage of which was partial melting followed by a static recrystallisation in granulite facies. Very little subsequent retrogression is in evidence. It is likely that the partial melting and granulite-facies recrystallisation were closely connected and that the 1960 m.a. isochron represents this event. The high average $^{87}Rb/^{86}Sr$ ratio (2.27) of the samples suggests that very little of the melt has left the system. The low initial $^{87}Sr/^{86}Sr$ ratio (0.704) implies that these rocks cannot have had a long previous crustal history. Cobbing *et al.* (in press) obtained a Rb/Sr whole rock isochron age of 1922 ± 74 m.a. with an initial Sr ratio of 0.7084 ± 3 and MSWD = 3.69 (the five points are plotted on Figure 2) from the Mollendo gneisses which they interpreted as the age of the granulite-facies metamorphism (age has been recalculated using the decay constant, sigma value and regression model described in the appendix).

In places the gneisses are cut by an intrusive igneous complex which at Atico varies in composition from grey homogeneous granite to a quartz diorite. Five samples collected from the Atico igneous complex and one sample collected from one of the red granites east of Camana, which from field evidence appears to be of similar age to the Atico complex, give an Rb/Sr whole rock isochron age of 449 ± 7 m.a. (Middle Ordovician*) with an initial Sr ratio of 0.7097 ± 4 and MSWD = 5.52 (Figure 3). Stewart *et al.* (1974) obtained K/Ar biotite dates of 447 and 395 m.a. from two of the red granites east of Camana which taken together with the isochron age imply rapid cooling. Cobbing *et al.* (in press) plotted Rb/Sr data from two samples of the red granites east of Camana and one sample of the Atico igneous complex and obtained a best fit line of 539 ± 90 m.a. and an initial Sr ratio of 0.7084 ± 0.0013 (MSWD = 16). K/Ar analyses produced younger dates of 374 ± 6 m.a. (K. feldspar), 365 ± 6 m.a. (biotite) and 339 ± 5 m.a. (muscovite) from the same three samples, which dates Cobbing *et al.* (in press) attributed to argon loss. Field or further radiometric evidence to support this early Phanerozoic event is not yet available.

These intrusive igneous complexes cut the

*The time scale used is the Phanerozoic Time-Scale (Harland *et al.*, 1964).

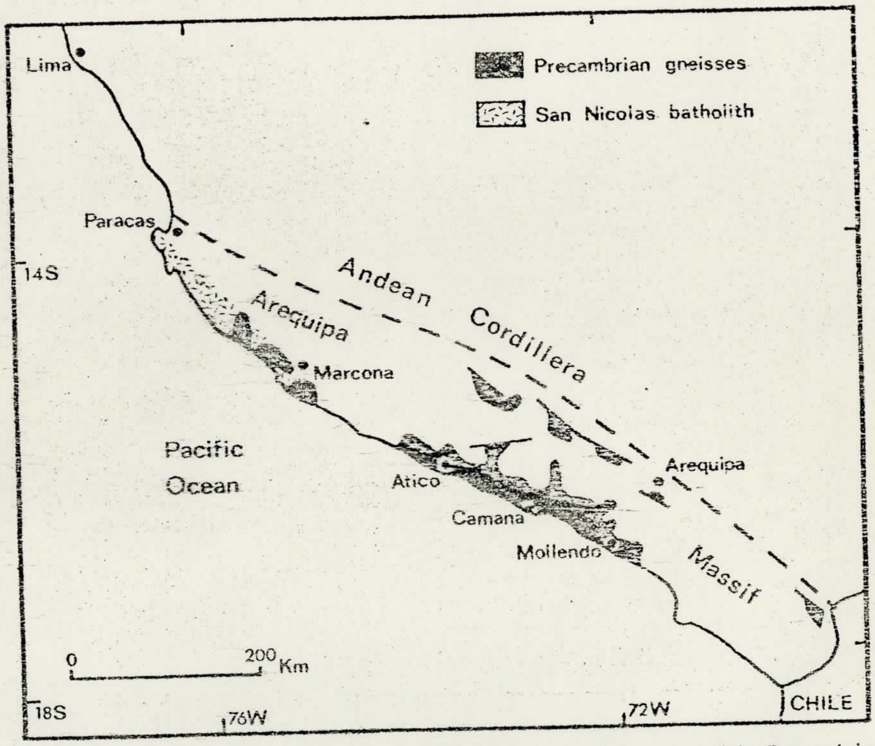


*Figure 1.* Locality map of the Arequipa Massif, southern Peru. Outcrops of the Precambrian gneisses taken from Mégard *et al.* (1971).

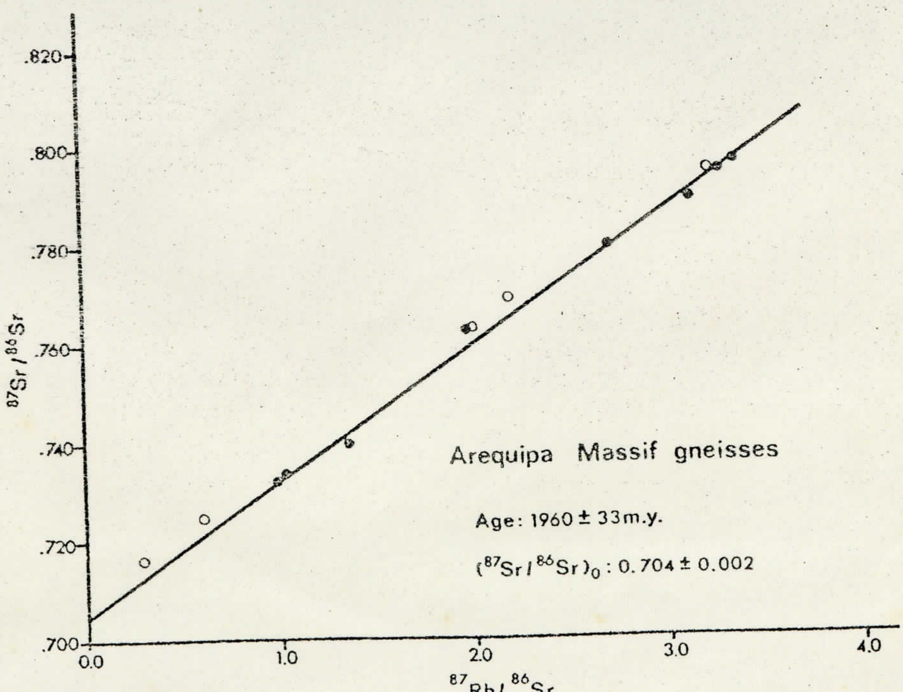


*Figure 2.* Rb/Sr whole rock isochron plot for the gneisses of the Arequipa Massif. Filled circles represent results from the present study and define the isochron. Open circles are analyses reported by Cobbing *et al.*, (in press).

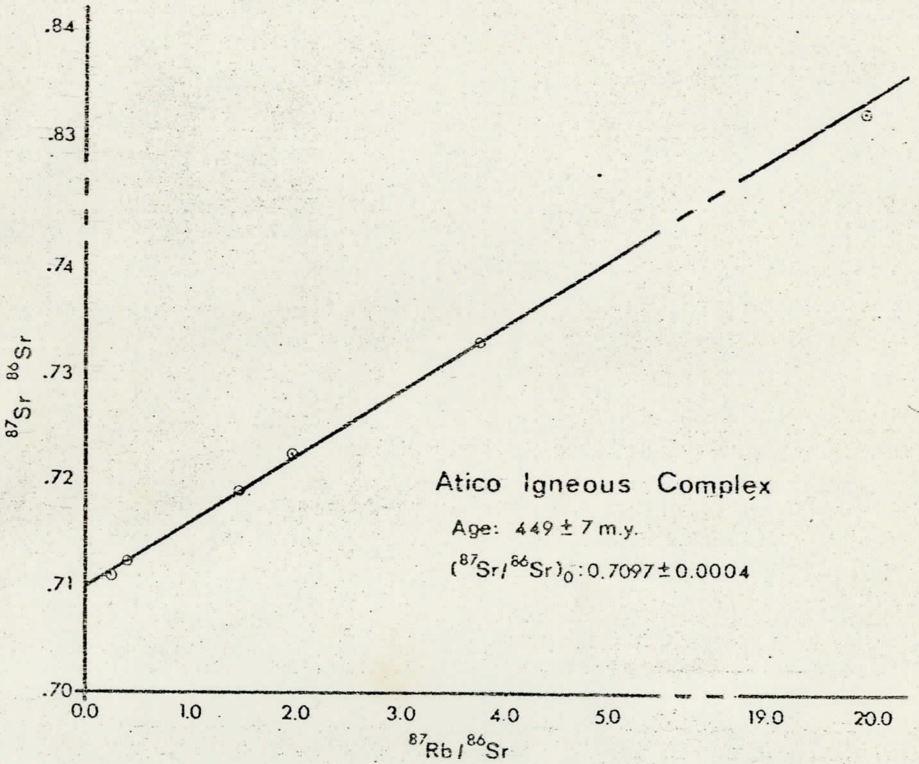


*Figure 3.* Rb/Sr whole rock isochron plot for the Atico igneous complex.

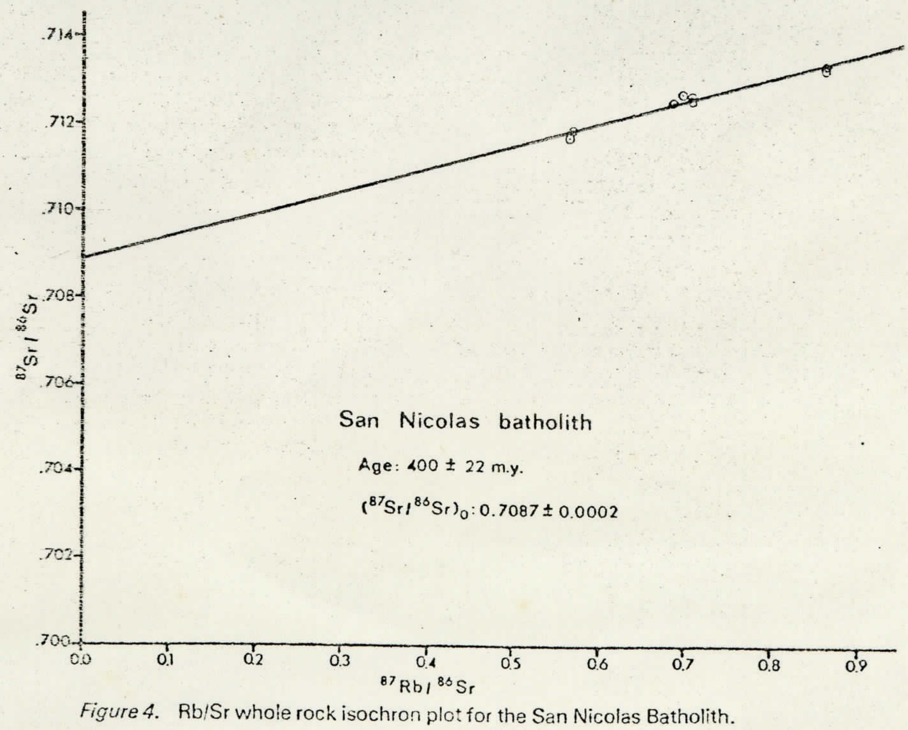


*Figure 4.* Rb/Sr whole rock isochron plot for the San Nicolas Batholith.

gneissic banding but are themselves in places affected by a schistosity associated with an amphibolite-facies metamorphism. The supposed equivalents of all these rocks are unconformably overlain by a group of unfossiliferous metasediments, the Marcona Formation, comprising tilloids at the base, followed by dolomites and limestones, pelites and quartzites. The age of the Marcona Formation was unknown; it unconformably overlies the crystalline basement which gives Precambrian ages and the nature of its deformation and metamorphism leaves no doubt that it is older than the undeformed and unmetamorphosed plant-bearing Carboniferous sediments cropping out approximately 300 km. south of Marcona and the undeformed and unmetamorphosed Devonian still farther south. It is likely that the Marcona Formation can be correlated with an Ordovician succession of pelites and greywackes with a few intercalations of sandstones and limestones and possible glacial deposits described from Northwest Argentina by Turner (1970).

The Marcona Formation is cut by the San Nicolas batholith, a post-tectonic complex ranging in composition from hornblende gabbro to granodiorite. Adrian (1958) thought that the granite was formed by granitisation of the basement gneisses and the Marcona Formation and was responsible for the Marcona magnetite deposits which are found both in the Marcona Formation and in the overlying Jurassic volcanics and sediments. The granite was thought by Pitcher (1974) to be probably Jurassic but Wilson (1975) produced two K/Ar biotite-hornblende mineral pairs of 442 ± 10.4 — 438 ± 9.4 m.a. and 428 ± 12.2 — 421 ± 10.9 m.a. from the batholith. A Rb/Sr whole rock isochron age of 400 ± 22 m.a. with an initial ratio of 0.7087 ± 6 (MSWD = 8.41) has now been obtained from eight samples collected from the Marcona region (Figure 4). The discrepancy between the Rb/Sr and the K/Ar data cannot be easily explained but it seems reasonable to conclude that the San Nicolas batholith is of the order of 400 m.a. old. This gives a minimum age for the Marcona Formation and the events which affected it. The Ordovician-Silurian thermal activity and regional metamorphism extends southwards into central Chile and northwest Argentina where McBride *et al.* (1976) have obtained K/Ar whole-rock and mineral age determinations concentrated between 400 and 500 m.a. The regional extent of this orogenic belt in South America is not yet known but these events cannot be correlated with the Hercynian orogeny recognised by Mégard *et al.* (1971) in the Andes, which reached a peak in the Upper Devonian.

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*Appendix*

The Rb/Sr ratios were measured by XRF (technique described by Pankhurst and O'Nions, 1973, modified by M. Bickle, University of Leeds) with estimated errors of 2% (2 ). The Sr isotope ratios plotted in Figure 2 and 3 were measured on an A.E.I. MS-5 mass spectrometer (results quoted in four figures) and the ratios in Figure 4 on a MM-30 mass spectrometer (results quoted in five figures). Average values of Eimer and Amend $SrCO_3$ of 0.70807 ± 1.3 (MM-30) and 0.7080 ± 3 (MS-5) were obtained during the period of study. The data has been regressed according to the recommendations of Brooks *et al.* (1972) using York Model II. The quoted errors are two sigma. The decay constant of $^{87}Rb$ used throughout is 1.39 $10^{-11} Yr^{-1}$.