

Rb-Sr ages of granites and gneisses from the Precambrian of Sri Lanka

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Abstract. The major problem of the Precambrian rocks of Sri Lanka is the age and stratigraphic relationships between the four major units: Highland Series (HS), South-western Group (SWG), Vijayan Complex (VC) (previously known as the 'eastern Vijayan Complex') and Wannai Complex (WC) (previously known as the 'western Vijayan Complex'). Previous Rb-Sr ages, though systematically older than they should be, supported the concept that the Highland Series is older than the Vijayan; and more recent work on U-Pb ages of zircons supports this relationship. The present work, which was begun in 1981, is an attempt to understand better the regional geological evolution of the island through Rb-Sr age determinations of samples collected from many parts of it.

Laboratory determinations carried out at the Geochronology Research Centre of the University of Sao Paulo, Brazil, by the first-named author gave the following results:

- (a) ages of granites sampled are between 920 and 1050 Ma and their analytical points define a best-fit line of about 1010 Ma;
- (b) ages of rocks from the Highland Series do not define a clear isochron and though some lie close to Crawford and Oliver's Kataragama Complex 2055 Ma isochron, others suggest much older ages;
- (c) rocks of the Wannai Complex show anomalous ages, which may be due to rejuvenation;
- (d) the Gallodai gneisses suggest a redistribution of Sr.

The few conclusions that can be drawn are that :

- (i) a first episode of sialic crust formation took place at about 2000 Ma or earlier;
- (ii) a second episode of crustal formation took place about 1000-1100 Ma, and two zones can be recognized in the rocks formed at this time :
A-a high-grade metamorphic zone, viz. Highland Series and Southwestern Group,
B-a medium-grade zone in which rejuvenation and crustal addition took place, i. e. Vijayan and Wannai Complex rocks.
- (iii) A third episode at about 600 Ma was mainly a thermal event of 'pan-Gondwana' distribution.

This is a simplified picture of a terrain with a complicated evolutionary history, and more U-Pb work on zircons should give a truer picture. It now seems likely that the HS (+ WC) came together with the VC either by collision or thrusting at about 1150 Ma.

GEOLOGICAL BACKGROUND

The Precambrian rocks of Sri Lanka are conventionally divided regionally into four major units, largely on the basis of lithology and structure. These units are: the **Highland Series (HS)** (granulite facies metasediments and charnockitic gneisses); the **Vijayan Complex (VC)** east of the Highland Series (previously known as the 'Eastern Vijayan Complex'); the **Wanni Complex (WC)** (previously known as the 'Western Vijayan' but with a dominance of pink, microcline-bearing gneisses and granitoid rocks); and the **South-western Group (SWG)** (metasediments and charnockitic gneisses, together with migmatites, granitic gneisses and granites). The assumption by early workers that the rocks on either side of the central metasedimentary-charnockitic gneiss belt of the island belonged to the same unit, the Vijayan, now seems unjustified. Affinities between the Highland Series and

the 'West Vijayan' warrant a renaming of the latter. This we have done reverting, in part, to the name used by Coates (1935) (i. e. 'Wanni Gneiss') and naming it the 'Wanni Complex'.

The major problem concerning these Precambrian rocks has been, and still is, their stratigraphic relationships to each other. Several attempts have been made over the past six decades to explain their relationships, but not one has yet found general acceptance. The principal alternative concepts can be summarized as follows:

- A. That the previously named 'east' and 'west' Vijayan formed the gneissic basement or floor on which the precursors of the Highland Series were laid down, and is, therefore, the older (Adams 1929, Coates 1935, Wadia 1945, Fernando 1948 and Katz 1971). This concept was based largely on similarities between the Sri Lankan Precambrian and the Indian Shield, of which the island once formed a part.
- B. That the (E) Vijayan rocks are younger than the Highland Series, being, in fact, the granitized and migmatized equivalents of the Highland Series rocks (Cooray 1961). This idea was based on field relationships, especially the presence of scattered Highland Series-like metasediments in some of the (E) Vijayan migmatitic complexes.
- C. That the Highland Series, originally a volcanic-sedimentary succession, was formed by the collision of two 'Vijayan' microplates (Munasinghe and Dissanayake 1982). This idea is inferred from the presence of shear zones, hot springs and serpentinite bodies in the vicinity of the boundary between the Highland Series and the (eastern) Vijayan Complex.
- D. That the HS was thrust to the east and south-east over the largely migmatitic and granitoid, younger (E) VC (Kroner *et al.* 1987).

The field evidence for each of these ideas is either scanty or lacking completely, and, what isotopic ages there are seem to support the alternatives B and D.

PREVIOUS WORK

Apart from ages determined by Holmes (1955) from pebbles of zircon, thoriumite and monazite, the first significant attempt at dating the Sri Lankan rocks was a series of K-Ar ages of micas and hornblendes from the HS and VC rocks

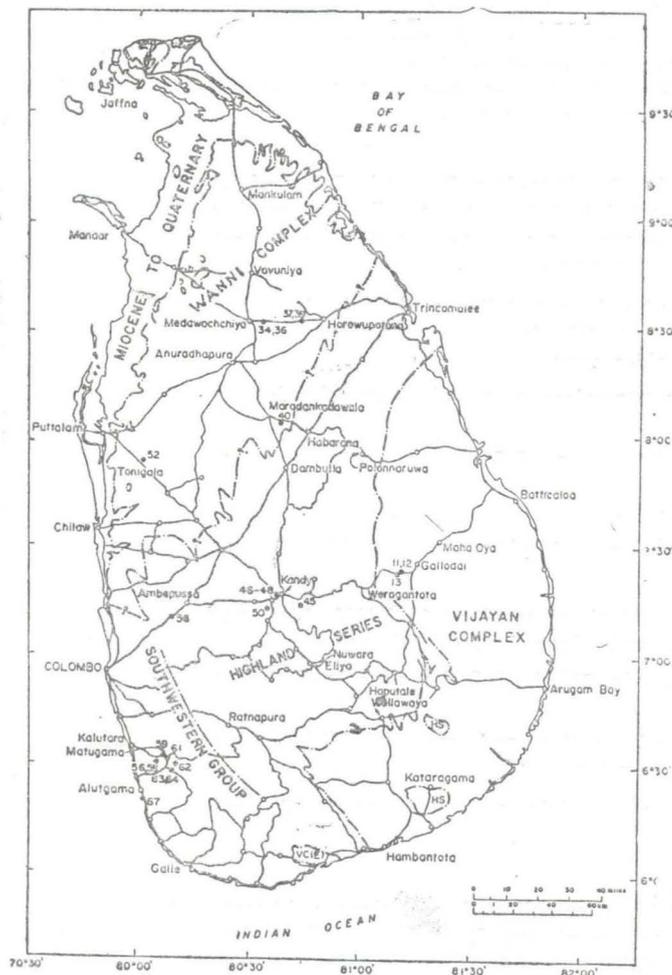


Fig. 1. Sketch map showing main geological divisions of Sri Lanka and locations of samples used in this study.

(Cooray 1969). Unfortunately these showed only that a major 'event' had affected nearly all the rocks in the period 450 to 600 ma.

The second attempt was by Crawford and Oliver (1969) who reported several Rb-Sr determinations carried out on separated minerals and whole-rock samples. Their data could not be treated adequately by means of isochron diagrams because of the lack of congeneticity of most samples. The results were thus reported as conventional Rb-Sr ages, but these authors selected an extremely low value of 0.7000 for the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio. Nevertheless, although they obtained calculated ages that are systematically older than they should be, Crawford and Oliver came up with a general picture that supported the age relationships implied in concept B. Additional isolated determinations (e. g. Wickremasinghe 1969, Jayawardena and Carswell 1976) support the sequence suggested by Crawford and Oliver's work.

The most recent dating of Sri Lankan rocks has been the U-Pb ages of zircons by Kroner *et al.* (1987). Ion microprobe of zircons have given the following results:

- (a) detrital grains from metaquartzite of the HS gave:
 - (i) U-Pb ages of 3.17 and 2.4 Ga, indicating derivation of sediments from an unidentified source terrain;
 - (ii) Pb-loss patterns suggest severe disturbance at 1100 Ma ago, probably a period of high-grade metamorphism;
 - (iii) the sediments were laid down at about 2.0 - 2.5 Ga ago.
- (b) detrital grains from pelitic gneisses gave zircons with ages up to 2.4 Ga and also recorded an 1100 Ma event;
- (c) granitic intrusives into the HS show an emplacement age of 1000 - 1100 Ma and a metamorphic disturbance at about 550 Ma; they contain older, crustally derived xenocrysts;
- (d) a metaquartzite xenolith in the VC is not older than 1100 Ma, showing that the VC is not Archaean and was not the basement for the HS.

On the basis of the above results, Kroner *et al.* suggest that the Vijayan Complex formed significantly later than the Highland Series, and that the two units were brought into contact through post-1.1 Ga thrusting.

Another recent result is given by Baur *et al.* (1987) who record widespread retrogression at about 550 Ma ago.

PRESENT WORK

In view of the importance of this major problem of the Precambrian geology of Sri Lanka, the present authors, together with Prof. J. F. Lovering, presently of Flinders University, Australia, drew up a programme of age determination which, it was hoped, would produce additional relevant evidence towards a better understanding of the regional geologic evolution. The samples were collected by Lovering and Cooray in 1981, all of which were taken by the former for fission-track dating and work on apatites, the results of which are awaited. Selected samples were sent to Cordani in Sao Paulo for Rb-Sr determinations, and the results of that work are presented here.

Suitable unweathered specimens were collected, mostly from quarries, and Rb-Sr determinations were made on samples selected after careful petrographic study. The analytical data are reported in Table 1. Total Rb and Sr contents were measured by X-ray fluorescence, with an overall precision better than 1 percent for the Rb/Sr ratio. For rocks with low Rb or Sr contents, below 20 ppm, a mass spectrometer isotope-dilution technique was employed, using $^{84}\text{Sr}/^{87}\text{Rb}$ tracers.

Sr isotopic measurements were carried out in the Varian-Mat TH-5 solid source mass spectrometer of the Centre for Geochronological Research, University of Sao Paulo, Brazil. They were normalized to an $^{86}\text{Sr}/^{86}\text{Sr}$ value of 0.1194, and a set of measurements on standard samples run concurrently in the same instrument were as follows:

NBS-987 Sr carbonate (6 measurements)
- 0.71028 ± 0.00036 (1 sigma)
Eimer and Amend Sr carbonate (9 measurements)
- 0.7081 ± 0.0004 .

Regression analyses of the Rb-Sr isotopic data were carried out using the method of Williamson (1968). The ^{87}Sr decay constant employed was $\text{Rb} = 1.42 \times 10^{-11} \text{ year}^{-1}$.

All measurements at 1 sigma (67% confidence level) were duplicated in order to check internal reproductibility, and all results fell within experimental error, assumed to be of the order of 10^{-3} on the basis of laboratory experimental statistical data. Relative standard deviations of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio at 1 sigma level were around 2.5%. Individual errors for each determination are included in Table 1.

The locations of the samples analysed are shown in Figure 1 and the analytical data are given in Table 1.

Table 1. Analytical Data

SPR	Sample No.	Sample locality and type	Rb (ppm)	Sr (ppm)	$^{87}\text{Sr}/^{86}\text{Sr}$	$^{87}\text{Rb}/^{86}\text{Sr}$
		Vijayan Complex (East)				
6493	SLK-11A (3)	Biotite gneiss. Mst. 54, Weragantota-Maha Oya road, quarry S of road. 81°06'00"E, 7°26'00"N.	211.3	248.3	0.0705±0.0002	2.471±0.070
6495	11A (1)	Pink gneiss. Same locality.	147.4	276.4	0.7324±0.0005	1.547±0.044
6496	11A (1)	Gneiss. Same locality.	246.6	204.0	0.7465±0.0004	3.512±0.099
6494	12	Grey biotite gneiss with granitic veins. Wettewa, near mst. 58, Weragantota-Maha Oya rd, quarry S of road. 81°09'30"E, 7°23'30"N.	172.4	457.1	0.7227±0.0000	1.092±0.031
6497	13	Pinkish gneissic granite. Near mst. 53½, Weragantota-Maha Oya rd, S of road. 81°05'20"E, 7°23'30"N	142.3	110.9	0.7546±0.0007	3.731±0.105
		Wanni Complex (=W. Vijayan C.)				
7102	34A	Charnockitic gneiss Mst. 4¼, Madawachchiya-Horowupotana rd, 80°33'20"E, 8°32'20"N	8.5≠	455.8	0.7101±0.0003	0.054±0.002
6516	34B*	Charnockitic gneiss, same locality	101.8	379.2	0.7171±0.0003	0.778±0.022
6815			101.8	379.2	0.7170±0.0003	0.778±0.022
6517	36*	Granite, locality as for 34 B	149.7	378.7	0.7201±0.0002	1.145±0.032
6816			149.7	378.7	0.7202±0.0003	1.145±0.032
6518	37*	Garnet-biotite gneiss	94.9	177.5	0.7689±0.0002	1.557±0.044
6817		Near mst. 86, Horowupotana-Trincomalee rd, 80°54'20"E, 8°35'30"N	94.9	177.5	0.7678±0.0002	1.557±0.044
6519	39*	Gneiss (garnetiferous pegmatite)	94.3	195.0	0.7733±0.0007	1.409±0.040
7105		Locality as for 37.	94.3	195.0	0.7730±0.0005	1.409±0.040
6570	40L	Leucogranite, foliated About ½ mile S of Ganewalpola on Kekirawa rd. 80°37'30"E, 8°05'00"N	141	24.8≠	1.1221±0.0022	28.862±0.784
6492	52	Pink, microcline granite Tonigala, mst. 65½, on Puttalam-Kurunegala rd, 79°56'00"E, 7°54'20"N	140.1	656.5	0.7108±0.0002	0.618±0.017
		Southwestern Group				
6437	57	Charnockitic gneiss, with biotite Yatagalawatte quarry 80°04'40"E, 6°31'00"N	61.0	252.2	0.7294±0.0002	0.702±0.020
6438	58	Charnockitic Pegmatite Locality as for SLK-57	97.6	62.5	0.7734±0.0004	4.549±0.128

TABLE 1. Analytical Data

SPR	Sample No.	Sample locality and type	Rb (ppm)	Sr (ppm)	$^{87}\text{Sr}/^{86}\text{Sr}$	$^{87}\text{Rb}/^{86}\text{S}$
6439	SLK-59	Southwestern Group Garnetiferous augen gneiss Matugama, behind Central College 80°06'40"E, 6°31'20"N	239.8	153.3	0.8416±0.0002	4.587±0.128
6440	61	Garnet-cordierite-biotite gneiss Wettewa quarry, Matugama- Agalawatte rd, 80°07'40"E, 6°30'00"N	214.7	148.2	0.8471±0.0004	4.250±0.119
7103	62	Charnockitic gneiss Kitulgoda, Matugama-Agalawatte rd, 2 mls from Ragedera fork junction 80°10'00"E, 6°30'00"N	14.7*	66.0	0.7200±0.0003	0.065±0.002
6572	63	Garnet-biotite gneiss About 2½ mls from Horawela junction on Moragala road. 80°09'00"E, 6°28'20"N	11.9*	160.0	0.7451±0.0005	0.216±0.006
6441	64A	Charnockitic gneiss - Locality as for SLK-63	141.8	197.7	0.7950±0.0002	2.094±0.059
6442	64B	Charnockitic gneiss - Locality as for SLK-63	83.0	136.2	0.7715±0.0002	1.775±0.050
6443	67	Zircon-hornblende granite Arangala, Colombo-Galle rd. 80°00'40"E, 6°21'30"N	193.9	188.8	0.7720±0.0010	2.991±0.084
		Highland Series				
6498	SLK-45	Pink granite, foliated, lineated Haragama Estate, Kandy-Hanguranketa rd, 80°43'40"E, 7°14'40"N	233.8	73.1	0.8386±0.0006	9.376±0.262
6499	46	Garnet-biotite gneiss, fine-grained Getambe quarry, Kandy, east bank of Mahaweli Ganga 80°36'20"E, 7°16'30"N	116.2	144.5	0.7948±0.0003	2.347±0.066
6500	47	Garnet-biotite gneiss, coarse-grained. Locality as for SLK-46 (‘granite gneiss’)	55.2	228.4	0.7740±0.0004	0.704±0.020
6501	48	Granite gneiss Locality as for SLK-46	93.3	145.1	0.7619±0.0004	1.871±0.053
6491	50	Biotite gneiss. Daulagala junction quarry, (Gadaladeniya synform) 80°34'30"E, 7°13'30"N	80.4	490.7	0.7106±0.0004	0.474±0.013
6436	56	Charnockitic gneiss Mst 30¼, Colombo-Kandy road, 80°09'00"E, 7°11'00"N	227.4	249.7	0.7796±0.0004	2.654±0.075

* duplicate analyses

≠ isotope dilution

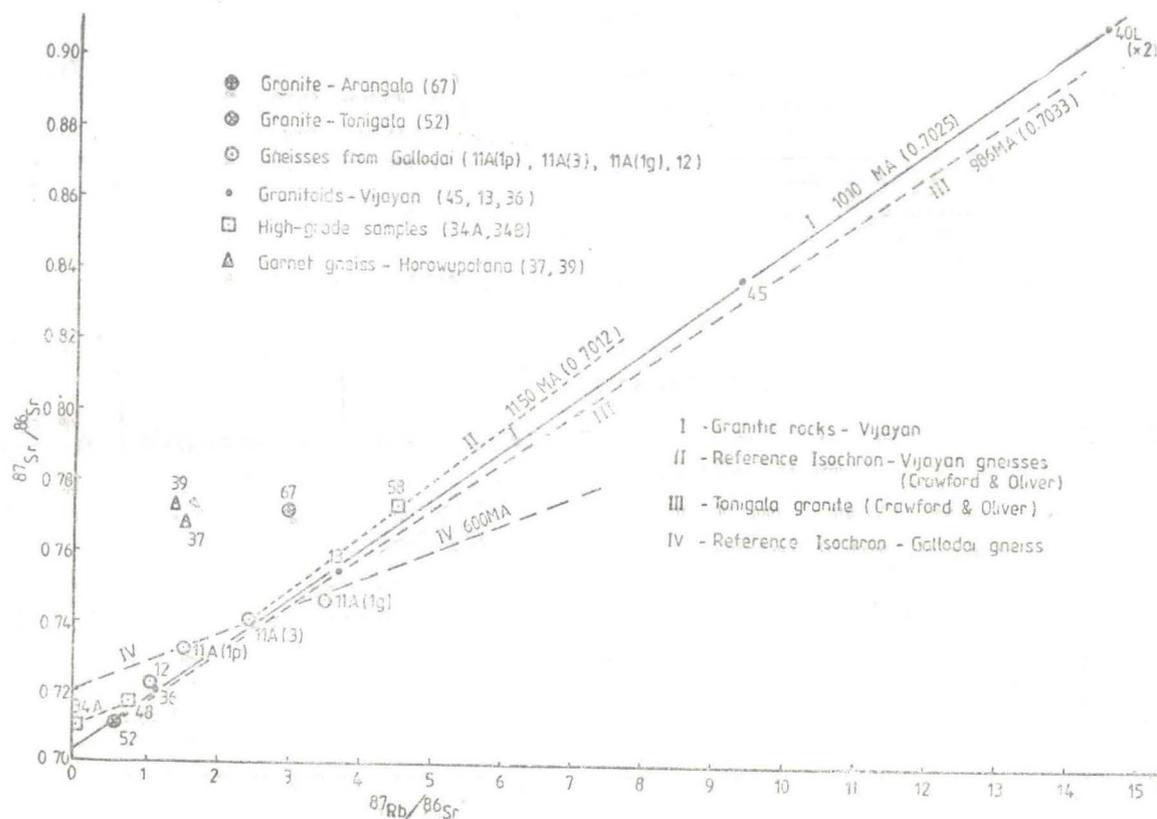


Fig. 2. Reference isochron for Vijayan rocks.

INTERPRETATION OF RESULTS

The above data show that the Vijayan orogeny took place at about 1000-1100 Ma, as indicated by the clear tendency of samples of granites, gneisses and related types of cluster around a reference isochron (I) of about 1010 Ma, with $^{87}\text{Sr}/^{86}\text{Sr} = 0.7025$, as shown in Figure 2. It is apparent that there are a number of rocks with a fairly simple geological history and reasonably high $^{87}\text{Sr}/^{86}\text{Sr}$ values whose calculated ages are of geological significance. These are:

SLK, 40L ... Ganewalpola leucogranite ...	1010 \pm 30Ma ... WC
SLK. 45 ... Haragama granite	966 \pm 32Ma — HS
SLK. 58 ... Yatagalawatte pegmatite	1051 \pm 43Ma — SWG
SLK. 13 ... Granite near Gallodai	930 \pm 47Ma — VC
SLK. 36 ... Granite near Madawachchiya ...	921 \pm 125Ma — WC
SLK. 67 ... Granite, Arangala	1560 \pm 68Ma — SWG

The above ages support the conclusion of Crawford and Oliver (1969) that a single event took place at about 1000 Ma during the evolution

of Sri Lanka, and that it involved the formation of granites, migmatites and gneisses, the latter of amphibolite-facies grade.

In Figure 2, the samples of granitoid rocks from Ganewalpola, Haragama, Gallodai and Madawachchiya, referred to above, exhibit a clear alignment, together with the sample from the Tonigala intrusion. They characterize a best-fit line (isochron I in Figure 2), with 1010 Ma and $(^{87}\text{Sr}/^{86}\text{Sr}) = 0.7025$. This is considered here to be the best possible figure for the age of formation of granitoid rocks in association with the Vijayan orogeny. This age value should be considered only approximate as the samples are from different bodies and are not strictly cogenetic. A better understanding of the sequence of events within the Vijayan orogeny could be achieved when some zircon ages as well as Rb-Sr detailed studies with several samples from the granitoid complexes, collected from single outcrops, become available.

Some other conclusions can be drawn from the data shown in Figure 2. These are:

- (i) isochron I also agrees very closely with isochrons II and III from Crawford and Oliver (1969);
- (ii) the Gallodai gneisses suggest a redistribution of Sr, as shown by isochron IV;

- (iii) the Arangala granite (sample SLK. 67) is definitely pre-Vijayan in age;
- (iv) samples SLK. 37 and SLK. 39 from the Wannai Complex are anomalous points in Figure 2, and may possibly be reworked Highland Series rocks, i. e. pre-Vijayan rocks rejuvenated. There is an evident connection between the WC and the HS, which seems sufficient justification for the proposal to rename the 'West Vijayan' as the 'Wanni Complex'. Furthermore, the data demonstrate that the Vijayan rocks of the east could not have been derived from the Highland Series. This, therefore, disposes of Cooray's 1961 conception (B above) for the derivation of these rocks, and supports alternative concepts C and D above;
- (v) samples SLK. 34A and B, from the WC, show Sr redistribution, and therefore may also be rejuvenated rocks. Their isochron is parallel to that for the Gallodai gneisses at 600 Ma, which suggests Sr re-homogenization in a later event;
- (vi) sample SLK. 58 from a pegmatite of the SW Group is possibly of Vijayan age.

The high-grade gneisses and charnockitic gneisses are spread out on the isochron diagram (Figure 3) but do not define clear isochrons.

Isochron I is that for the Kataragama rocks as determined by Crawford and Oliver, giving an age of 2055 Ma, with $(^{87}\text{Sr}/^{86}\text{Sr}) = 0.0793$. Points SLK. 56, 57, 59 and 61 from the western parts of Sri Lanka lie close to this line; it may be geologically significant, but the number of samples is small. Other samples seem to suggest still older ages, as found also by Crawford and Oliver (1969), and by Kroner *et al.* (1987), but again, an unequivocal interpretation is not possible. However, there is a strong likelihood that the HS contains relics of rocks significantly older than 2000 Ma. The Rb-Sr ages for the high-grade gneisses do not improve the existing evidence, but rather confirm the existing problem.

The following additional deductions can also be made from Figure 3;

- (a) there are many samples that show 'absurd ages' of more than 10 Ga, e. g. SLK. 62, SLK. 63, SLK. 47, SLK. 64 and SLK. 46. These have relatively low Rb and very high present-day $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and are located much to the left of all reference isochrons. This could be explained by severe Rb depletion during an episode of high-grade metamorphism after their formation. The starting condition could have been rocks of about 2000 Ma (Kataragama-type ages) but which suffered Rb depletion

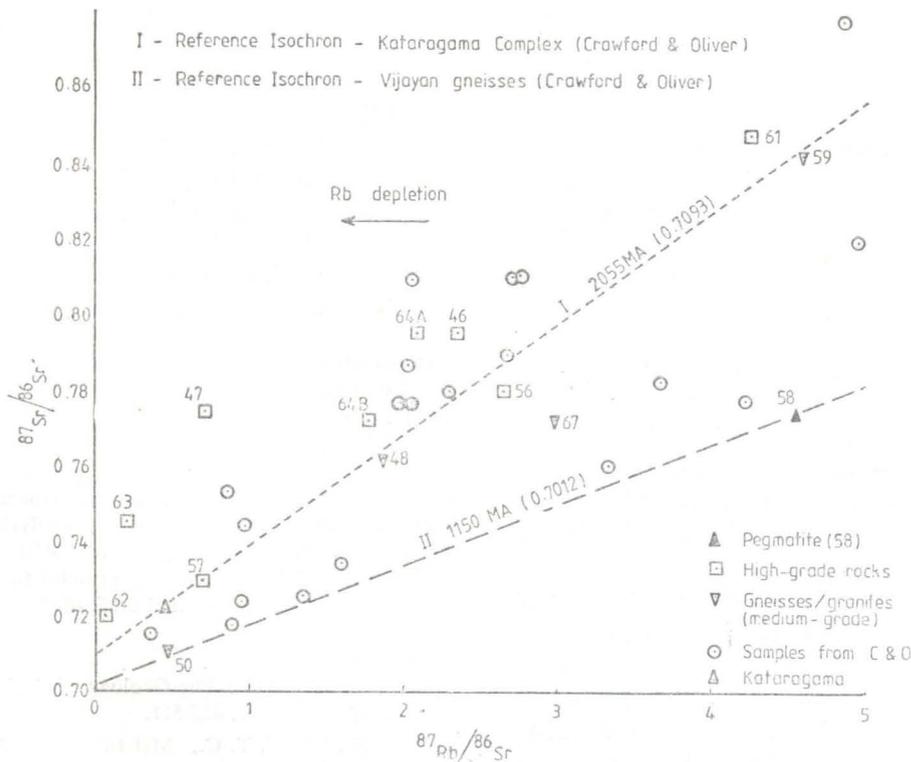


Fig. 3. Rb-Sr isochron diagram for pre-Vijayan rocks.

during the Vijayan orogeny at around 1000–1100 Ma, and perhaps again in the pan-Gondwana episode.

- (b) 'normal', unaffected (?) samples (with highest Rb contents) from the HS and SWG are close to the 2000 Ma reference isochron;
- (c) sample SLK. 58 is a pegmatite, probably from Vijayan times, as already shown;
- (d) sample SLK. 50 is anomalous, like some other points from Crawford and Oliver (1969). It could be VC or HS which was completely rejuvenated in Vijayan times by Rb gain (or Sr loss).

CONCLUSIONS

The data presented here enable one firm conclusion, with good foundations, to be drawn. It is that a major event, the 'Vijayan' orogeny, led to the formation of the Vijayan Complex about 1000 to 1100 Ma ago. For the rest, we can only suggest a general picture for the evolution of the Precambrian of Sri Lanka. Greatly simplified, it suggests:

1. a first episode of sialic crust formation, including additions from the mantle, at about 2000 Ma or somewhat earlier;
2. a second episode of formation of crustal rocks at about 1000 to 1100 Ma. The rocks formed at this time comprise two zones;
 - A, a high-grade metamorphic zone, viz. High and Series and South-western Group, with considerable retrogression associated with Rb depletion; and B, a medium-grade zone in which some rejuvenation of older terrains (SLK. 37 and SLK. 39) and some addition to the crust (SLK. 50,) with low $^{87}\text{Sr}/^{86}\text{Sr}$ have taken place; these are mostly the Vijayan rocks;
3. a third episode, at about 600 Ma, which was largely a thermal event, shown only by the Gallodai samples (SLK. 34A, B) in the Rb-Sr systematics. This is undoubtedly a 'Pan-African' — or rather a 'Pan-Gondwana', — event, as it seems to have affected all the contiguous parts of the Gondwana continent.

Some of the U-Pb results obtained by Kroner and others enhance the value of this interpretation.

In Sri Lanka, rock-forming events are quite evident in the Lower Proterozoic (2000 Ma—HS) and in the Middle to Upper Proterozoic (1100 Ma—VC). The granulite metamorphism seems to have been associated with the 1100 Ma orogeny.

Another possibility is that the high-grade metamorphism belongs to the 600 Ma episode (Pan-African). Kroner *et al.* (1987) also indicate the possibility of two different phases of granulite-forming events.

The geologic evolution of Sri Lanka is thus somewhat similar to that of the Mozambique Belt of East Africa.

The data presented here give a very simplified picture of the geological evolution of Sri Lanka during the Precambrian. However, the available evidence suggests that Sri Lanka is a terrain with a very complicated history, as shown by the recognition of possibly four deformation episodes (Yoshida, personal communication). What is really needed in order to obtain a meaningful picture is for Rb-Sr work to be done on strictly cogenetic samples from single outcrops. But perhaps even the Rb-Sr method is not strictly applicable because of the great mobility of Rb and/or Sr during the Upper Proterozoic. For an adequate interpretation of the geologic evolution of Sri Lanka, U-Pb work on zircons such as that carried out by Kroner and others, seems to be essential; Sm-Nd determinations in basic rocks could also be applied with some success.

Returning to the alternatives set out at the beginning for the relationships of the major units, the results seem to show:

- (i) that hypothesis A must now be ruled out;
- (ii) that B could be valid in part, as the Vijayan must include material formed at 1100 Ma;
- (iii) that C or D may be the preferred hypothesis. This is that the Highland Series (+ Wannu Complex) came together with the Vijayan (and Southwestern terrain) at 1150 Ma. The possibility of an additional major collision at 600 Ma also remains open.

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Addendum: After this paper went to press, the following article has come to our notice:

"Preliminary geochronological study of Sri Lankan rocks" by H. Kagami, M. Owada, Y. Osanai and Y. Hiroi, in *Study of Geological Correlation between Sri Lanka and Antarctica (1988-1989)* (Editors: Y. Hiroi and Y. Motoyoshi), March 1990.

In it the author's report (using Rb-Sr and Sm-Nd systems):

- a) Highland Series rocks from Gampola-Nuwara Eliya have ages of 2300 to 2600 Ma and 400-500 Ma;
- b) rocks from Kurunegala have ages of 1000 Ma and 450 Ma;
- c) rocks from area north of Lake Victoria have ages similar to (b).

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