

ISOCHRON TRANSLATION, MANTLE MAPPING AND SRI LANKAN MODEL AGES

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ABSTRACT

In late 1980s, U-Pb zircon ages of metasediments were combined with Nd-model ages of high-grade gneisses to suggest that the Sri Lankan Precambrian consists of four lithotectonic units which evolved independently from one another. The amalgamation of the units during a period of tectonism around 600-550 Ma is believed to have led to multiple deformation and granulite- to amphibolite-facies metamorphism observed in these gneisses. Recent detailed Sm-Nd and Rb-Sr isotopic studies of the high-grade gneisses suggest that, (a) those have been subjected incomplete isotopic resetting, thus, Nd-model ages and U-Pb zircon ages do not necessarily represent crust formation ages and zircon crystallization ages of the orthogneisses and in the sources of detritus of metasediments, respectively, (b) their isotopic composition is unusual as indicated by extremely positive initial ϵ_{Nd} (+7.6 at 2800 Ma) of data alignments of Highland Complex orthogneisses.

The Sm-Nd and Rb-Sr isotopic data of the studied gneisses suggest that isochron translation has occurred during incomplete isotopic resetting and that has produced a scatter of data in the isochron diagrams. Computer simulations confirm that isotopic resetting in these isotopic systems is leading to isochron translation but not to isochron rotation as envisaged thus far, and that isochron translation is controlled by the field relations of the lithologies in the volume of rocks striving for isotopic equilibration. The above observations made on the basis natural data and computer simulations suggest that crust-mantle isotopic interaction during repeated lower crustal metamorphism and deformation has strongly modified the Sri Lankan lower crust to produce HC lithologies with ϵ_{Nd} (+7.6). However, to understand the extent of the said isotopic modification one has to use isochron translation to map the crust-mantle volume that interacted, and estimate its isotopic composition. Then, one can resolve the geological relations between HC, VC and WC and explain how a range of Nd-model ages from 1.0-3.2 Ga was produced by isochron translation during a long period of crustal residence of the Sri Lankan high-grade gneisses.

Key words: Isochron translation, Zircon, Lithotectonic, Isotopic, Orthogneiss

INTRODUCTION

Our understanding of the Geology of Sri Lanka was significantly revised/ reviewed after two publications in 1987 and 1988. (a). Zircon ion-microprobe dating of high-grade gneisses in Sri Lanka (Kröner et al., 1987), (b) Isotopic mapping of age provinces in Precambrian high-grade terrains, Sri Lanka (Milisenda et al., 1988). In the first paper, ages of zircons in metasediments from the central granulite belt and the Vijayan Complex were determined using the Sensitive High Resolution Ion Microprobe (SHRIMP). In the second paper,

Nd-model ages of regionally collected samples were determined with respect to the Depleted mantle in an attempt to infer age of crust formation within granulite- and amphibolite-facies areas. A revised nomenclature and a sub-division (Fig. 1) of the Precambrian of Sri Lanka was introduced (Kröner et al., 1991) after the publication of these two papers. The new sub-division took into account crust formation ages in addition to lithology, structure, and metamorphism, which were the basis of previous sub-divisions. Geological evolution of the Sri Lankan Precambrian envisaged and followed since then painted a picture where, (a)

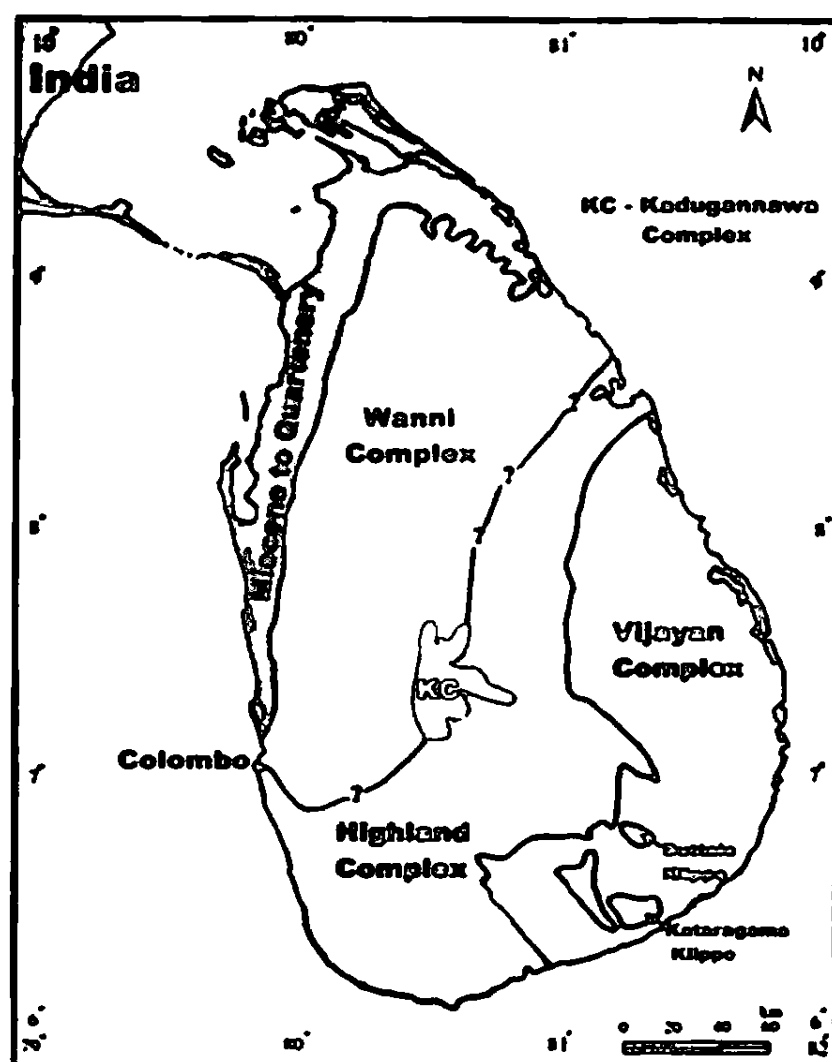


Fig. 1 Subdivision of the Precambrian of Sri Lanka (Modified after Cooray, 1994)

Sri Lankan high-grade gneisses are believed to consist of three (or four) litho-tectonic units, (b) Highland Complex (HC) preserved crust formation ages of 2.0-3.2 Ga and its meta-sediments derived detritus from 2.0-3.2 Ga sources, (c) Vijayan Complex (VC), Wannai Complex (WC) and Kadugannawa Complex (KC) preserved crust formation ages of 1.0-2.0 Ga and metasediments of the WC and VC derived detritus from terrains ≤ 1.0 Ga, (d) the four lithotectonic units are believed to have evolved as independent entities which collided, deformed and metamorphosed at 600-550 Ma and uplifted from depths and eroded to give the present-day exposure. Isotopic, geochemical and petrologic studies that followed continued to hold this picture without objectively analyzing it. A fresh attempt has been made by the author to investigate Nd- and Sr- model ages by detailed studies (Perera and Kagami, 2011, and unpublished data) and understand their true significance.

EARLY IDEAS ON THE GEOLOGY OF SRI LANKA AND MODEL AGES

Although early ideas on the geological evolution of Sri Lanka were revisited after the Nd-model age data set of Milisenda et al (1988), it was Crawford and Oliver (1969) who first calculated Sr-model ages of Sri Lankan gneisses on the

basis of their whole-rock Rb-Sr data set, assuming an initial ratio of 0.700 for all analysed samples. However, they placed more emphasis to calculate Rb-Sr isochrons based on the data of regionally collected samples, but the Sr-model ages were not given any significance. Only Katz (1971) used the Sr-model ages to assign an age of 3.0 Ga to the Vijayan basement. If calculated with respect to the Depleted mantle, Sr-model ages show a range that closely resembles the range of Nd-model ages suggesting that both Nd- and Sr- isotopes may have been mobile to similar extents during crustal processes.

Early ideas on the geological evolution of high-grade gneisses of Sri Lanka were rejected outright by the Nd-model age based proposed new scheme of evolution. These include the notions that: (a) VC and WC are retrogressed equivalents of the HC (Cooray, 1961, Hapuarachchi, 1975), (b) VC and WC formed a basement for the HC (Katz, 1971), (c) HC formed as a sedimentary basin between two crustal plates, the VC and WC (Munasinghe and Dissanayake, 1982). These early ideas were totally based on the Rb-Sr whole-rock data set of Crawford and Oliver (1969). The models of retrogression of the HC to form the VC and WC, and the Plate Tectonic model of Munasinghe and Dissanayake (1982) did not find support in the Nd-model ages because the HC model ages are older (2.0-3.2 Ga) than the VC & WC model ages (1.0-2.0 Ga). Crustal processes like metamorphism cannot account for the near 1.0 Ga age difference between HC & WC/VC Nd-model ages.

However, the proposed new scheme of geological evolution of the late 80s made the tiny island of Sri Lanka an unusual high-grade terrain where (1) a continuum of crust formation ages from 1.0-3.2 Ga are preserved, (2) UHT & UHP granulite-facies metamorphism (Sajeev and Osanai, 2004) E-W and N-S directed tectonic transport and deformation occurred during a short period between 600-550 Ma (due to collision of HC, WC & VC). (3) The long time gap (around 1.4 Ga) between sedimentation in the HC basin (~2.0 Ga) and its granulite-facies metamorphism (600-550Ma). Apparently, it had to wait until WC and VC originate elsewhere. Contrary, Peninsular India preserving evidence of geological evolution since early Archaean to Neo-Proterozoic and later remained a single land mass throughout that history,

although it has been affected by several orogenic belts and sub-continent wide tectonic zones of shear deformation.

NEW ISOTOPIC DATA AND TRUE SIGNIFICANCE OF MODEL AGES

Detailed Rb-Sr and Sm-Nd studies were undertaken in selected fresh quarries in the HC and KC to test Milisenda et al's (1988, 1994) assumption that isotopic re-distribution occurred only across several centimeters during metamorphism and deformation preserving crust formation ages. If their assumption is valid, one should see isochrons of the protoliths of the gneisses preserved. But most HC and KC samples studied did not give isochrons, instead, the isotopic data showed scatter on isochron diagrams suggesting incomplete isotopic resetting and the samples contain evidence of repeated metamorphism and deformation.

ISOCHRON TRANSLATION IN THE KADUGANNAWA COMPLEX

In some quarries where detailed sampling was carried-out across several lithologies, both Sm-Nd and Rb-Sr isotopic data fell on sub-parallel linear alignments suggesting that an isochron has been translated on the isochron diagram during isotopic resetting (Fig. 2A). Although some samples could be grouped according to their lithology, the samples from an adjacent lithology showed severe scatter but still their data could be put on several alignments sub-parallel to one another and parallel to the alignments shown by the other lithologies. Thus, one could not give a unique basis for selection of data to put on the sub-parallel alignments, however, their slopes indicated the age of a Pb-loss event that was first reported in the SHRIMP zircon study of Kröner et al (1987) but not recorded in later studies.

Where detailed isotopic analyses have been carried-out, scatter of isotopic data of KC samples within a single quarry produces a significant range of the known Nd- and Sr-model ages of samples reported from the VC, WC and KC by Milisenda et al (1988, 1994). In the Oodillawe quarry a range of Nd- and Sr-model ages up to 1 Ga long has been caused by incomplete isotopic resetting. The translated data alignments in isochron diagrams suggesting a reference age of ~1100 Ma in the KC (and individual samples) (Figs. 2A,B) and similar

alignments in the VC (Milisenda et al 1994) show large ranges of ϵ_{Nd} at 1.05 Ga due to isochron translation (Fig. 3). These variations are responsible for the 1.1 – 2.2 Ga range of model ages in the WC, VC and KC. Where isochrons younger than 1.1 Ga were noted from the KC (Perera and Kagami, 2011) the spread of model ages in individual quarries is limited (eg. Boyagama 1 & 2, Table 1). There, metre-scale Nd- and Sr- isotopic homogenization is noted when a fluid is present. However, KC isochrons contradicted with previous interpretations. i.e. Early charnockites gave a younger age than late (arrested) charnockites (Perera and Kagami, 2011).

NEW Sm-Nd AND Rb-Sr DATA FROM THE HIGHLAND COMPLEX

Sm-Nd and Rb-Sr isotopic data from HC orthogneisses analysed at Paradeka (Figs. 4A,B) and Bambarakelle (Figs. 5A,B) also indicated that both isotopic systems too have been partially reset. Although the data are scattered on isochron diagrams the number of samples analysed is insufficient to delineate translated data alignments as done for the KC. However, the analysed whole-rock cube samples give linear data alignments suggesting older ages for the samples but they show very unusual initial Nd isotopic ratios, particularly at Paradeka. Those initial ratios plot above the depleted mantle Nd-evolution line, therefore the model ages are younger than the age indicated by the data alignments (Table 1). The analysed whole-rock slabs indicate severe scatter of data suggesting continued disturbance of the whole-rock systems at small scales. As a result, the whole-rock slab samples give the extremes of the Nd-model ages at Paradeka locality and at Bambarakelle the Nd-model ages of the slabs are older than those of the cube samples. A garnet biotite sillimanite gneiss from Tambilideniya in the northwestern HC also gave Rb-Sr data alignments (Fig. 6) showing isochron translation, but the Sm-Nd data of those samples are clustered on a data plot and their Nd-model ages are older than 2.5 Ga (Table 1). Another garnet-biotite-sillimanite gneiss and an orthogneiss from the central HC gave Nd- and Sr²-model ages that are typical of the VC, WC and KC, and those demand valid explanations to justify model-age based sub-division of geological terrains. Similar occurrences have been reported from other granulite terrains.

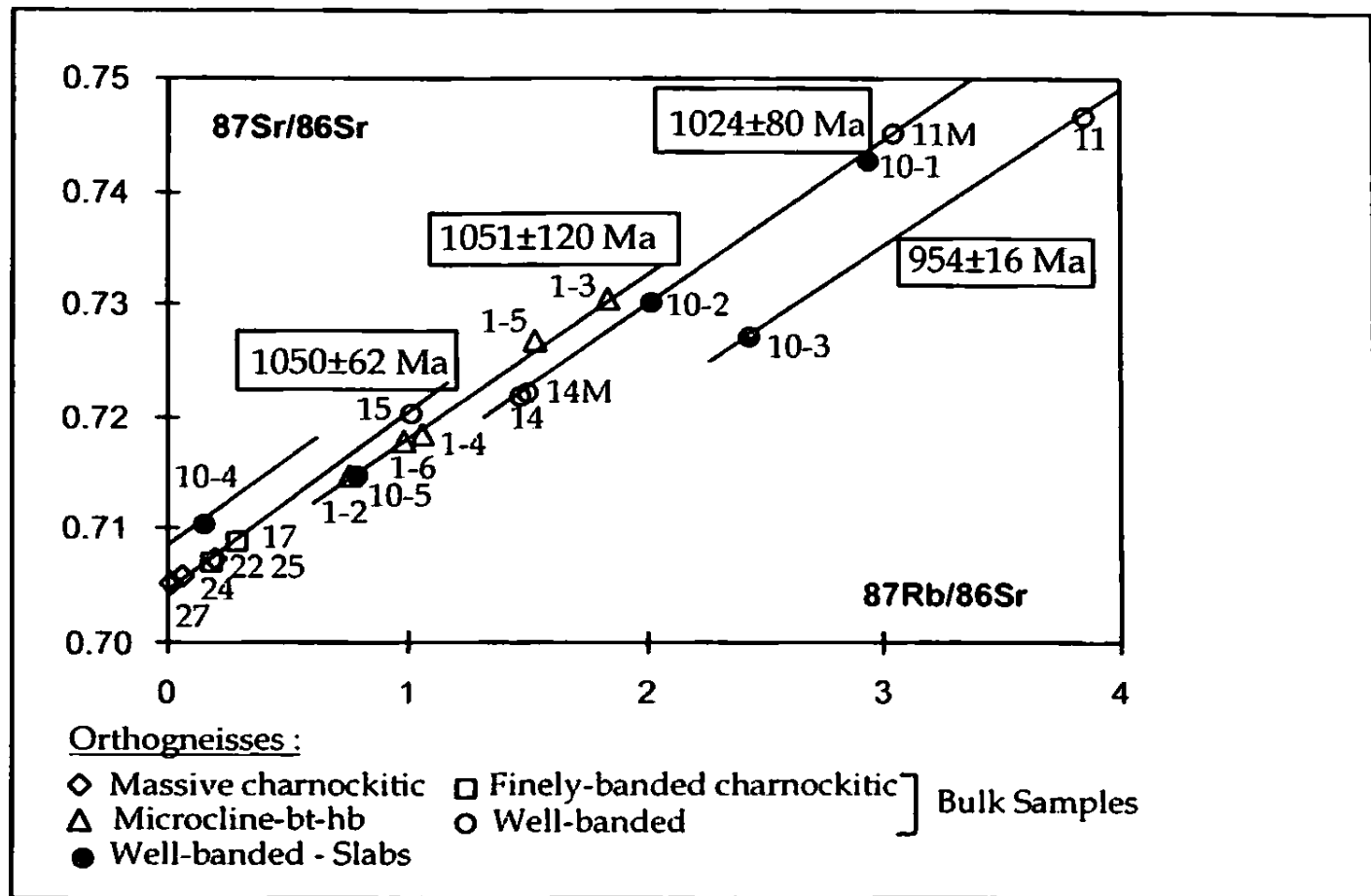


Fig. 2A Rb-Sr isochron diagram for samples from the Oodillawe quarry located in the Dumbara synform of the Kadugannawa Complex. The samples represent four adjacent lithological layers as described. Note that the data lie on sub-parallel alignments of similar slope and samples of the well-banded gneiss is highly disturbed. The letter M after the label indicates that slightly larger sample has been analysed compared to the normal sample

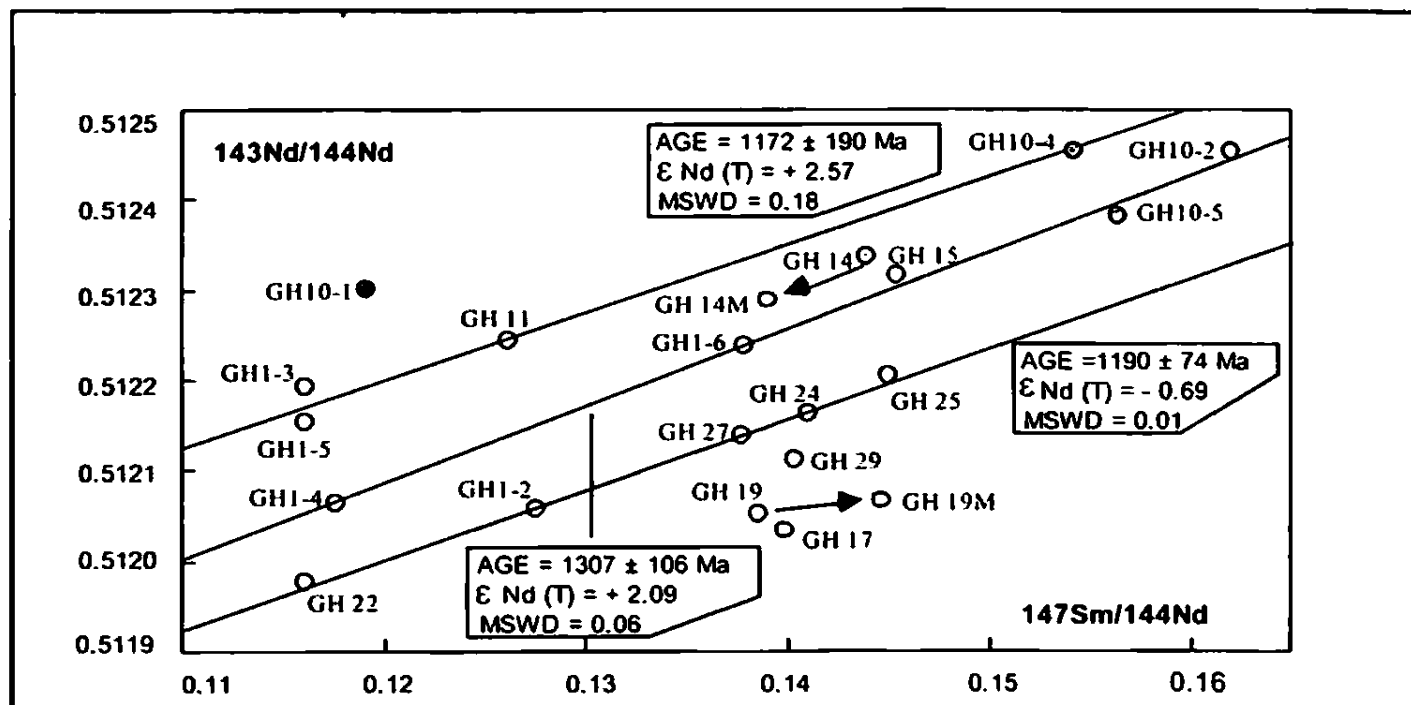


Fig. 2B Sm-Nd isochron diagram for samples from the Oodillawe quarry. Note that it is the same samples as in Fig. 2A but the letters GH have been removed from that figure for clarity. Also the initial ϵNd (1.05 Ga) range for this quarry shown in Fig. 3 include both bulk (cube) samples and slabs, and in total it give rise to a ~1.0 Ga range of model ages from this quarry. See Table 1

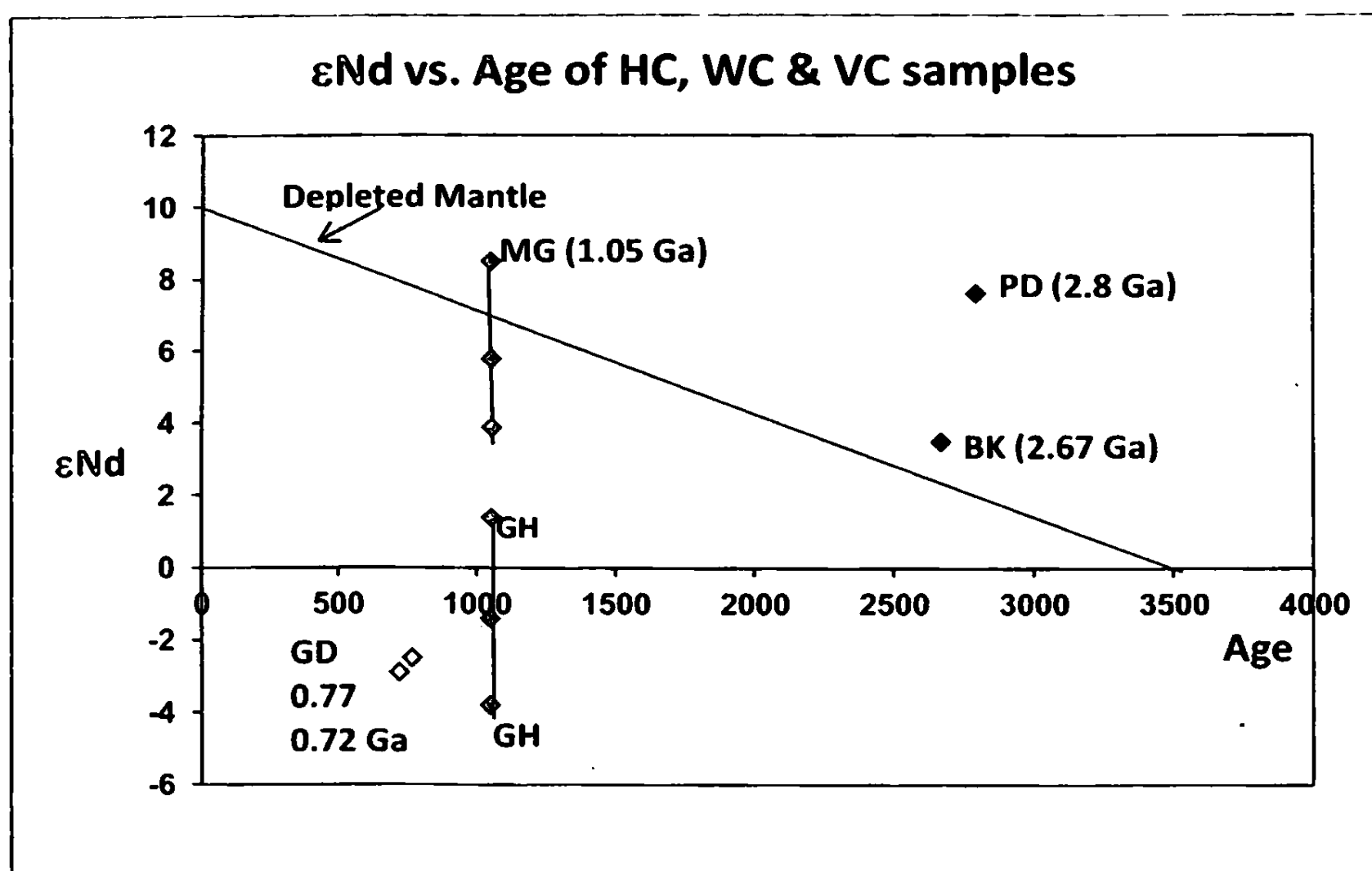


Fig. 3 ϵNd of HC, WC and VC sample at the ages indicated by translated data alignments in isochron diagrams. Note the very unusual ϵNd values of BK and PD quarries plotting above the deplete mantle evolution line. As a result their Nd-model ages are younger than the age indicated by the data alignments in isochron diagram. Spread of ϵNd of GH quarry is equivalent to a ~ 1.0 Ga range of model ages. BK-Bambarakelle quarry, GD-Boyagama quarries 1 & 2, GH-Oodillawe quarry, MG-Mahiyangana quarry, PD-Paradeka quarry

Table 1 Ranges of Nd- and Sr-model ages observed in geological units and individual quarries

Geological Unit or Quarry (Data)	TNd (Ga)	TSr (Ga)	Remarks
HC (All)	1.92-3.78	1.97-4.31	A few unrealistic Sr-ages
HC (Milisenda et al 1988)	1.96-3.78	2.08-3.01	
HC (Crawford & Oliver, 1969)	-	2.06-3.06	One unrealistic age
Paradeka (Unpublished data)	2.20-2.52	1.97-3.47	1.73 - 3.20 (Nd-slabs)
Bambarakelle (- do -)	2.41-2.71	3.37-4.31	2.82 - 3.55 (Nd-Slabs)
Tambilideniya (- do -)	2.50-2.70	2.21-3.30	
VC (All)	0.97-1.77	0.83-2.48	
VC (Milisenda et al 1988, 1994)	0.97-1.77	0.83-1.34	
VC (Crawford & Oliver, 1969)	-	0.86-1.66	Note similar Nd-, Sr-ages
Mahiyangana (Milisenda et al 1994)	0.97-1.48	-	
WC (All)	1.31-1.99	0.52-1.74	
WC (Crawford & Oliver, 1969)	-	0.52-1.47	
WC (Milisenda et al 1988,1994)	1.31-1.99	0.88-1.74	
KC (All)	1.30-2.21	0.73-2.57	03 Sr-samples > 3.0 Ga
Oodillawe (Unpublished data)	1.39-2.21 (cubes)	0.73-2.57	1.3-1.87 (Nd-slabs)
Boyagama 1 (Perera & Kagami)	1.43-1.82 (slabs)	2.35-3.56 (cubes)	1.83-3.75 (Sr-slabs),
Boyagama 2 (Perera & Kagami)	1.37-1.75 (cubes)	1.47-2.77 (cubes)	0.90-2.73 (Sr-slabs)

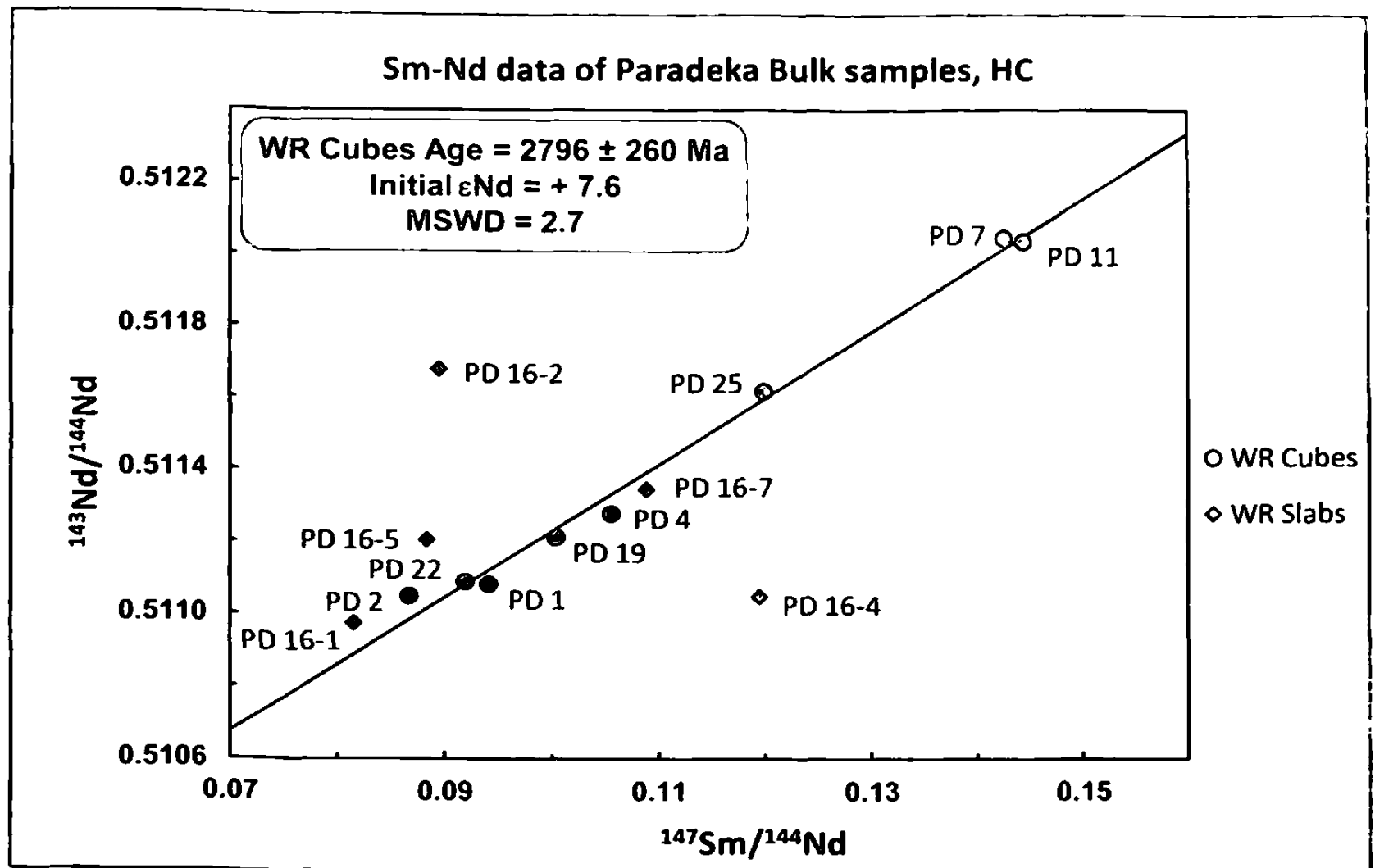


Fig. 4A Sm-Nd isochron diagram for Paradeka whole-rock cube and slab samples. Note that slab samples show large scatter (Perera, unpublished data)

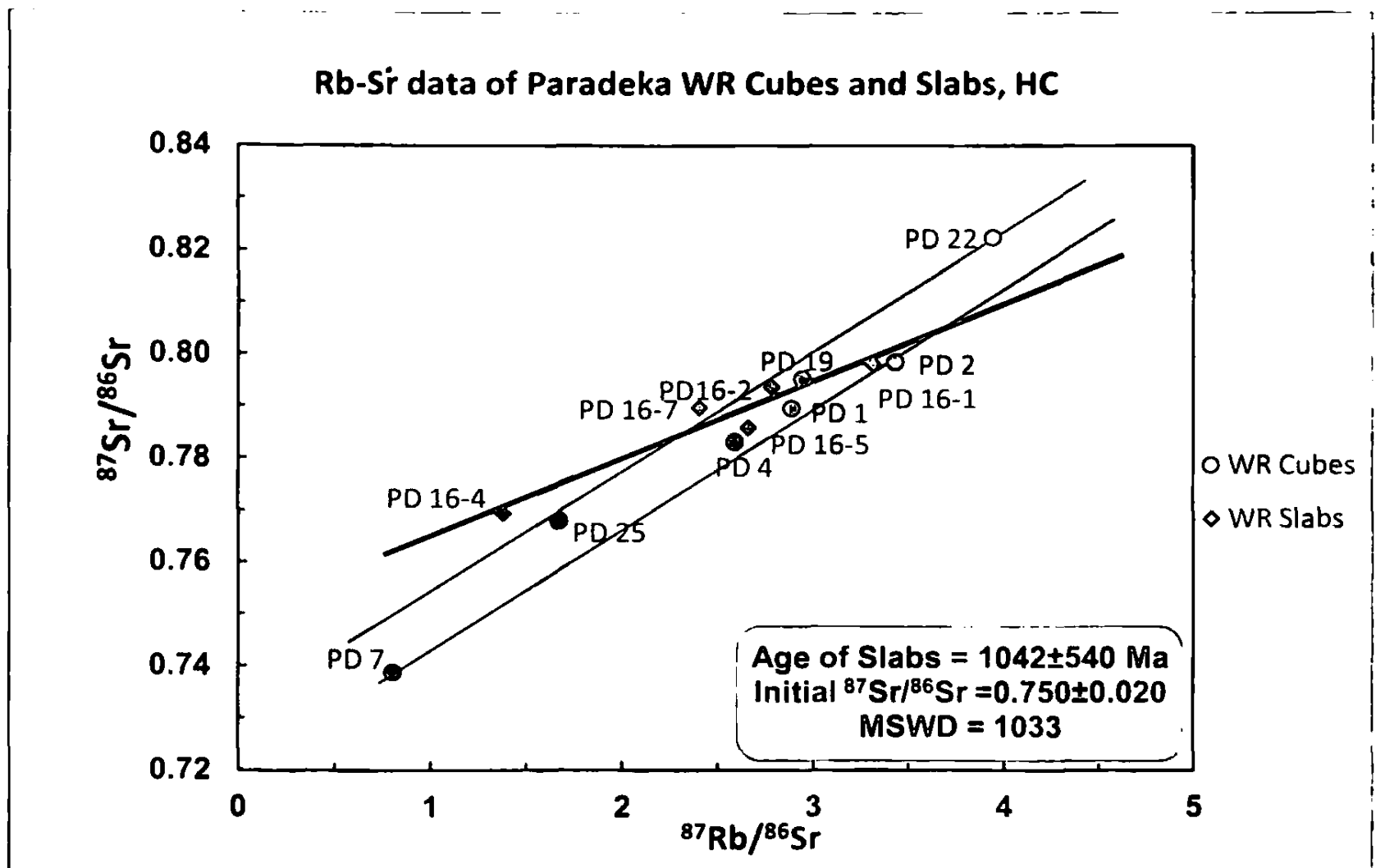


Fig. 4B Rb-Sr isochron diagram for Paradeka whole-rock cube and slab samples. Note that slab samples suggest a younger age (Perera, unpublished data)

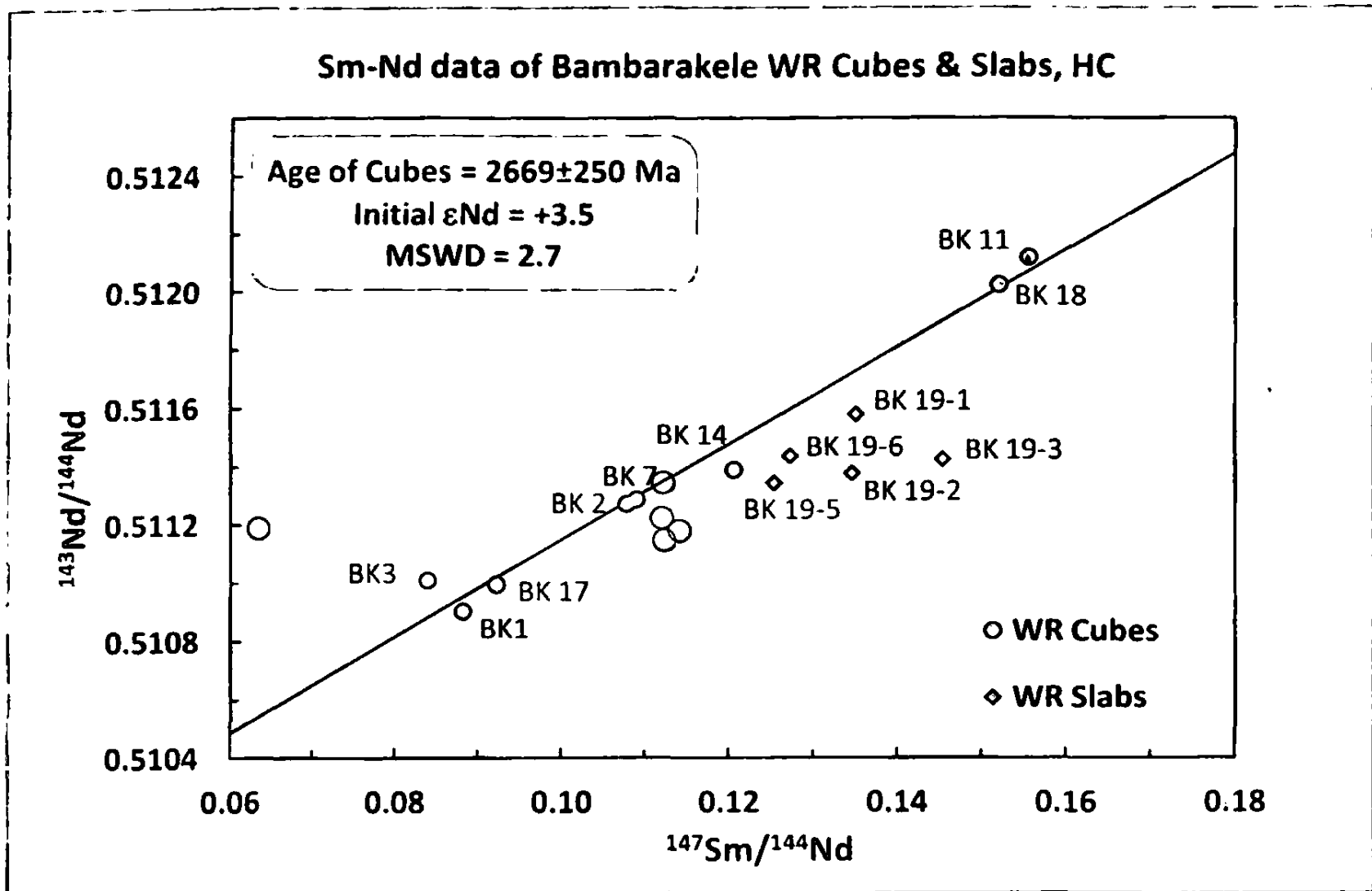


Fig. 5A Sm-Nd isochron diagram for Bambarakelle whole-rock cube and slab samples. (Perera, unpublished data) Open circles Kagami et al (1995) data

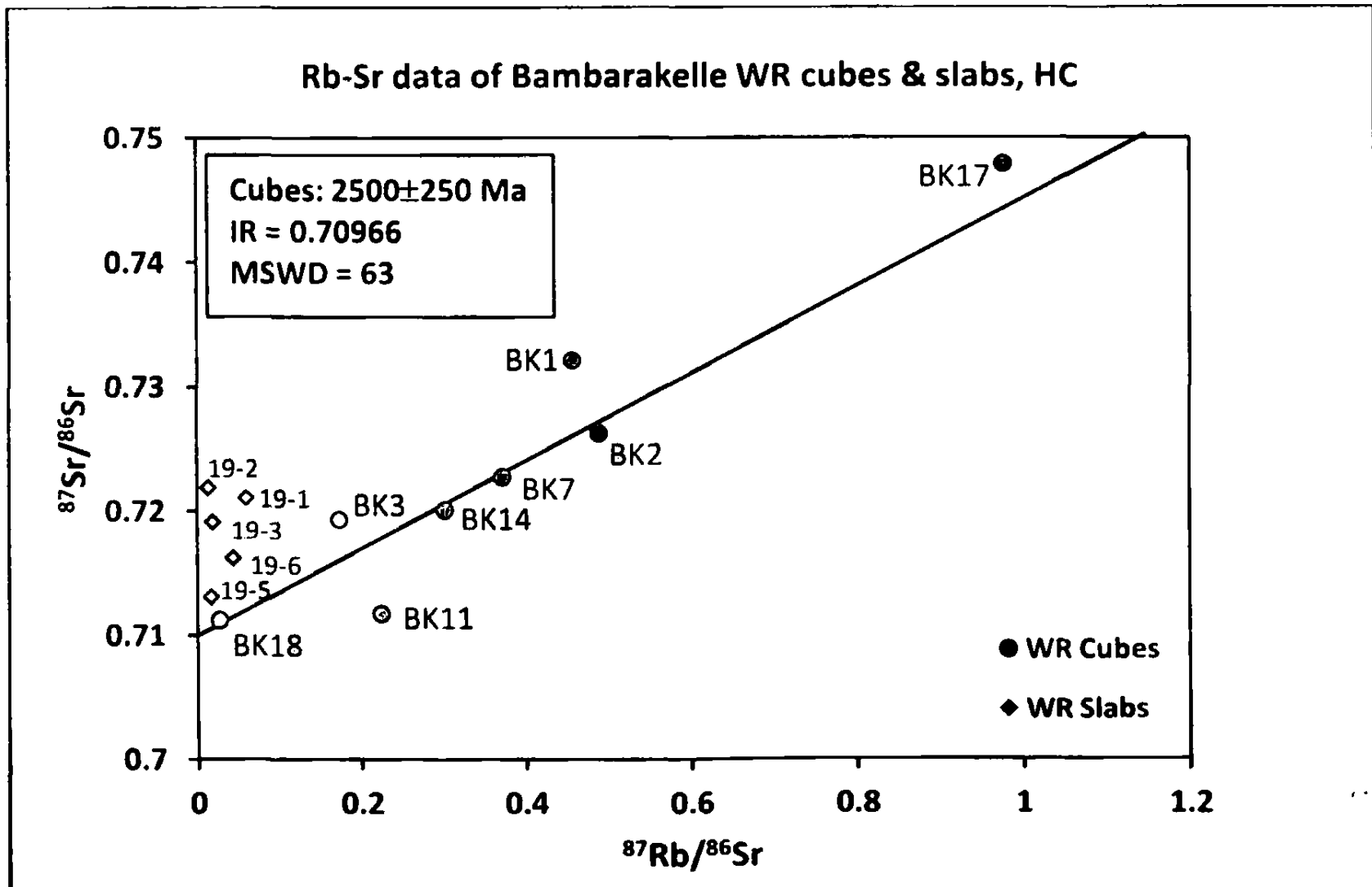


Fig. 5B Rb-Sr isochron diagram for Bambarakelle whole-rock cube and slab samples (Perera, unpublished data)

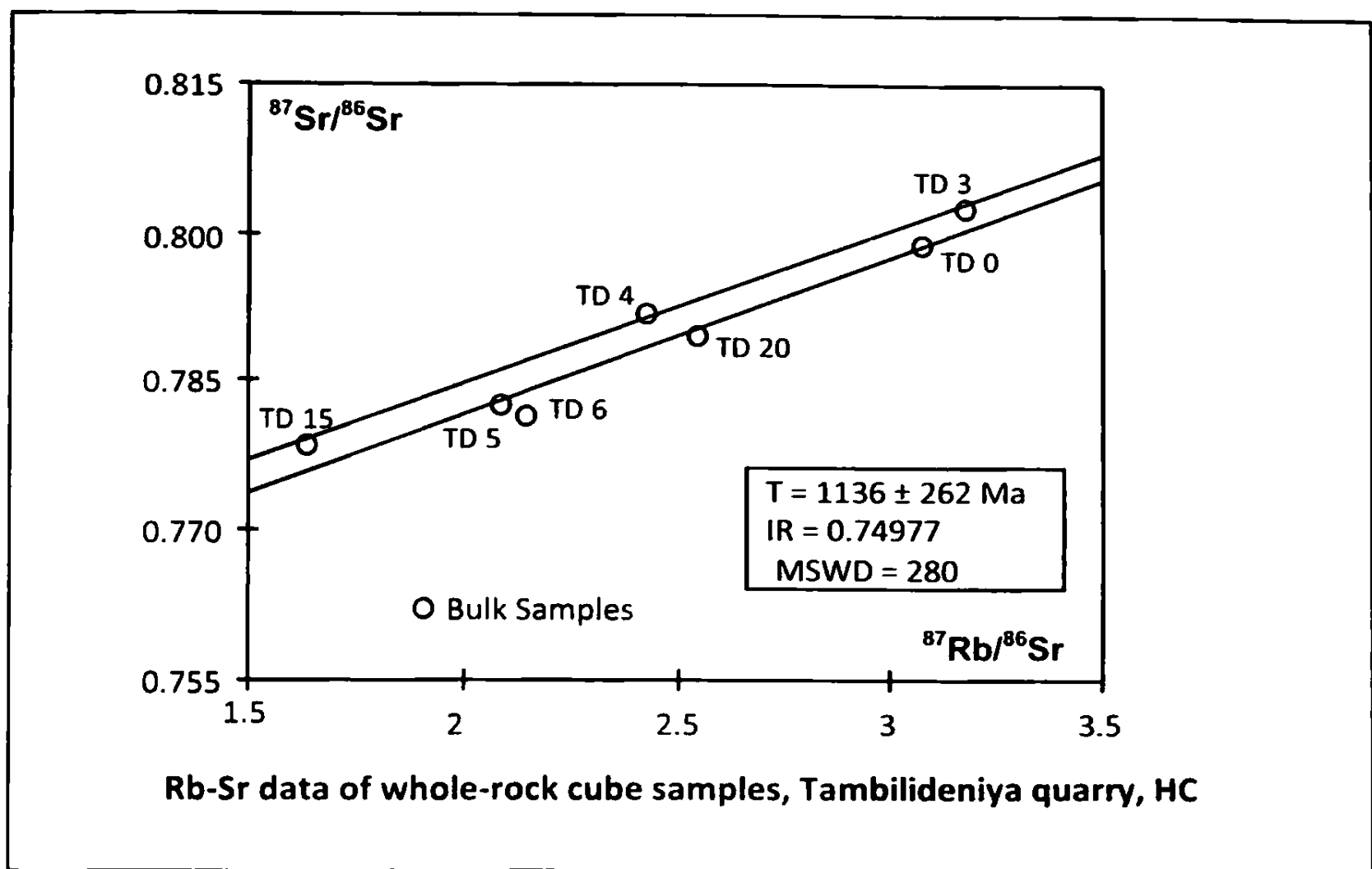


Fig. 6 Rb-Sr isochron diagram for garnet-biotite-sillimanite gneiss samples from Tambilideniya quarry in the northwestern Highland Complex. The Sm-Nd data of these samples are clustered together within an isochron diagram (Perera, unpublished data)

The detailed analyses of samples from single quarries in the HC and KC gave ranges of Nd-model ages similar to what Milisenda et al (1988, 1994) obtained during their regional sampling. In addition, the study of single quarries clearly indicates that the isotopic systems have been highly disturbed and the data are highly scattered on isochron diagrams. Moreover, irrespective of whether the samples analysed come from HC or KC, the new data indicate that whole-rock slab samples are even more disturbed than the whole-rock cube samples. This suggests that disturbances continued at centimeter scale even after the large whole-rock isotopic systems have been closed. As mentioned earlier, Crawford and Oliver were the first to calculate model ages of Sri Lankan high-grade gneisses assuming an initial Sr-isotopic ratio of 0.700. However, if their data are used to re-calculate Sr-model ages with respect to the present day Depleted Mantle assuming a parent $^{87}\text{Rb}/^{86}\text{Sr}$ of 0.052 and a daughter ratio of $^{87}\text{Sr}/^{86}\text{Sr} = 0.7025$ one ends up in Sr-model ages that are very similar to the Nd-model ages. This raises the question, Did the Rb-Sr system of the high-grade gneisses also preserve the time of crust formation? However, it is well known that Rb-Sr system is very vulnerable for isotopic

resetting during crustal processes like metamorphism, deformation and weathering. Perera and Kagami (2011) showed that both Rb-Sr and Sm-Nd systems have been severely reset in the presence of a hydrous fluid in some of the KC localities where detailed analyses have been carried-out. Thus, it is very likely that the consistency between Nd- and Sr-model ages has been brought about by similar disturbances to the Rb-Sr and Sm-Nd isotopic systems during the geological evolution of the high-grade gneisses. Thus, the new Sm-Nd and Rb-Sr data from HC and KC along with previous data from both regional and local scales of sampling suggest that Milisenda et al's (1988, 1994) inference of crust formation based on a regionally collected set of samples is not justified since the samples have been disturbed at all scales.

On the other hand in the Mahiyangana quarry of the VC where Milisenda et al (1994) analysed more samples, isochron translation is evident and initial ϵNd values (1.05 Ga) of those sub-parallel alignments straddle across the depleted mantle Nd-isotopic evolution line from +9 to -4. If the samples were derived from the depleted mantle with respect to which the Nd-model ages have been calculated, the initial Nd-isotopic

ratios of felsic gneisses can never plot above the mantle Nd-isotopic evolution line. Thus, taken together with HC samples having unusual initial Nd- isotopic ratios mentioned above, isotopic composition of VC samples also suggest that their isotopic composition cannot be accounted for by the normal depleted mantle evolution. If so, Were the Sri Lankan gneisses derived from an ultra-depleted mantle? Or alternatively, Were those severely isotopically modified due to isotopic interaction with an ultra depleted mantle while they were residing in the lower crust? One should find an explanation for the very unusual positive ϵ_{Nd} values shown by data alignments of HC orthogneisses at Paradeka and Bambarakelle. Isochron translation is a key to understand the isotopic modifications the Sri Lankan lower crust may have undergone during its lower crustal residence.

ISOCHRON TRANSLATION AND MANTLE MAPPING

Since isochron translation is evident from HC, KC and VC and is apparently responsible for scatter of isotopic data on isochron diagrams, the process of isotopic resetting was simulated on computer for Sm-Nd, Rb-Sr and Pb-Pb isotopic systems. The simulations involve isotopic exchanges between thousands of hypothetical samples distributed in three dimensional space making use a computer program developed by the author. The program perhaps closely executes the natural process taking place in rocks. The simulations clearly indicated that an isochron does not rotate in an isochron diagram during isotopic resetting as hitherto believed. Instead, translation of an isochron takes place during isotopic resetting in three distinct stages having their own characteristics. Most importantly it was noted that field relationship of the lithologies is the prime factor controlling isochron translation, and each and every field relationship is characterized by a unique pattern of isochron translation during the resetting of an isochron. Conversely, for a given pattern of isochron translation observed based on present-day data, one can infer the field relationship in the whole-rock volume that strived for isotopic equilibration. This technique of solving the inverse problem of explaining how the present-day isotopic compositions have been reached is useful to investigate the field relationships in the inaccessible areas of the earth like its mantle. Thus, mapping of the mantle was carried-out in

the light of isochron translation in order to explain the unusual initial isotopic ratios of data alignments observed in the HC of Sri Lanka. It is possible to generate the Nd-model ages of the high-grade gneisses of Sri Lanka on computer if one applies isochron translation to Sm-Nd and Rb-Sr systems. Isochron translation provides a sound basis to understand U-Pb zircon ages and mantle Pb-evolution, particularly to solve the Pb-paradox. Unfortunately, during the last seven decades of application of the isochron method of dating scientists have failed to identify isochron translation and the real strengths of the isochron method of dating. A comprehensive account on isochron translation and its applications will be presented elsewhere.

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