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Sm-Nd isotopic systematics in whole rocks of the Kathmandu and Nawakot complexes, central Nepal Himalaya

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ABSTRACT

In central Nepal, medium- to high-grade rocks of the Kathmandu Complex overlie lower-grade metamorphic rocks of the Nawakot Complex. These two units are separated by a clear high strain thrust belt marked by mature dynamic recrystallisation. These rock sequences have been folded to form the NW-SE trending, essentially upright Mahabharat Synclinorium.

Whole rock Sm-Nd isotopic analysis was carried out in thirteen samples collected from the Nawakot Complex, Kathmandu Complex, and the thrust zone between these two rock sequences from different parts of central Nepal. This analysis demonstrates important distinctions between the two rock packages. Results show a clear linear array of the data points from the different units in a $^{143}Nd/^{144}Nd$ vs. $^{147}Sm/^{144}Nd$ isochron plot with lowest values in the Nawakot Complex phyllite and highest values in the Kathmandu Complex gneiss while ε(0) Nd values show a marked difference with Nawakot Complex rocks ranging at -20 or higher, while the Kathmandu Complex rocks range at about -13 in schist and at about -6 in gneiss giving rise to major differences in their model ages. The comparison of the obtained data from the previous one clearly shows the affinity of the Nawakot Complex rocks with the Lesser Himalayan Sequence and of the Kathmandu Complex with the Higher Himalayan Sequence.

Keywords: Central Nepal Himalaya, Sm-Nd isotope, MCT, Kathmandu Complex, Nawakot Complex

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INTRODUCTION

The Himalayan orogen is a product of Palaeocene–Holocene collision between India and Eurasia (Le Fort 1975). Much of the Neogene shortening within the Himalaya has been concentrated on a few major fault systems, one of which is the Main Central Thrust (MCT). The nature and position of the MCT is a matter of controversy among the Himalayan geologists. Hagen (1969) introduced the term Nappe in the Himalaya and showed the affinity of the Kathmandu Complex rocks with the Higher Himalayan Crystalline. Stöcklin and Bhattarai (1977) and Stöcklin (1980) followed the concept of Hagen. According to them the thrust that passes south of the Kathmandu Valley, which they named the Mahabharat Thrust (MT), is a southward extension of the MCT. Later, Rai et al. (1998), Upreti and Le Fort (1999), and Rai (2001) advancad new concept than that of previous researchers and mentioned that the MCT passes from north of the Kathmandu Valley and the MT is an out-of-sequence thrust. They clearly declined the affinity of the Kathmandu Complex rocks with the Higher Himalayan Crystalline but are the rocks squeezed between two thrust systems, MCT in the north and MT in the south. In the meantime Dhital et al. (2000) proposed a model and support the earlier concept. Similarly Johnson et al. (2001) also refuted the concept and map prepared by Rai et al. (1998). As there is a debate for the nature and origin of the Kathmandu Complex rocks, the present study is focused to clarify whether there is a affinity of the Kathmandu Complex rocks with the Higher Himalayan Crystalline or not.

Samarium (Sm)-Neodymium (Nd) Isotopes from the Himalayan belt are useful for distinguishing between Himalayan tectonostratigraphic zones. Limited isotopic studies were carried out in the Himalaya (Whittington et al. 1999 in Pakistan; Ahmad et al. 2000 in northern India; and Parish and Hodges 1996 and Robinson et al. 2001 in Nepal). These results show a clear demarcation between different tectonostratigraphic units of rock. So this technique is used in the rocks of the central Nepal (Fig. 1).

GEOLOGY OF THE AREA

The tectonics of the Kathmandu region was first studied by Hagen (1969) who recognized the Kathmandu Nappe in

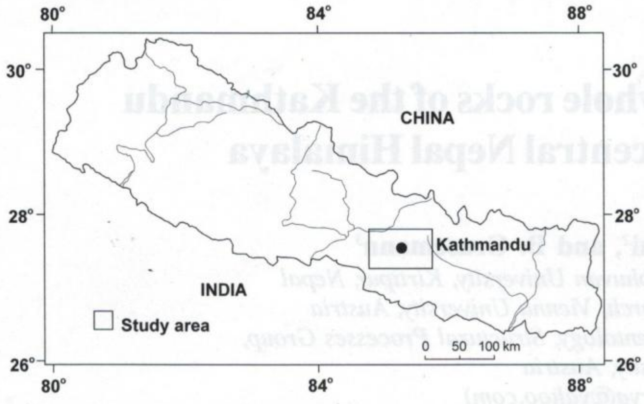

Fig. 1: Map of Nepal showing the study area. The study area is in central Nepal around the Kathmandu Valley.

the vicinity of Kathmandu. Stöcklin and Bhattarai (1977) prepared the aerial photo based geological map of the central Nepal (Fig. 2). Following the stratigraphic nomenclature of Stöcklin and Bhattarai (1977) and Stöcklin (1980), the Nawakot Complex comprises eight formations; these are, from bottom to top, the Kuncha Formation, Fagfog Quartzite, Dandagaon Phyllite, Nourpul Formation, Dhading Dolomite, Benighat Slate, Malekhu Limestone, and the Robang Formation (Fig. 3). The structurally overlying Kathmandu Complex comprises a bedded sequence of metasediments that have been divided into the older Bhimphedi Group and the younger Phulchauki Group and granitic and migmatitic rocks associated with the former. Kyanite-sillimanite gneiss observed mainly in the northern part of the area is named as Sheopuri Injection Gneiss (Fig. 2). The meta-sedimentary sequence consists of high to low grade schist, quartzite and carbonate rocks and has a total apparent thickness of about 12-15 km. The Bhimphedi Group consists of, from bottom to top, the Raduwa Formation, Bhainsedobhan Marble, Kalitar Formation, Chisapani Quartzite, Kulikhani Formation and the Markhu Formation while the Phulchauki Group comprises the Tistung Formation, Sopyang Formation, Chandragiri Limestone, Chitlang Formation and the Godavari Limestone, in ascending order (Fig. 3).

Between these two complexes, a clear high strain thrust belt marked by mature dynamic recrysallization encompasses a structural thickness of few tens meters. Acharya et al. (2006) mentioned the thickness of the thrust zone is >600 m along the Roshi Khola in north east part of the study area. The amphibolite facies Kathmandu Complex rocks containing garnet-kyanite-sillimanite schist and gneiss, quartzite, marble, and mica schist ± garnet forms the hanging wall of the thrust. The thrust belt footwall (Nawakot Complex) comprises greenschist facies phyllites, slates, carbonates, and quartzites.

In the frontal part, rocks of the Kathmandu Complex reach almost to the MBT. A narrow zone of the Nawakot Complex rocks separates the crystalline rocks of the Kathmandu Complex with the Siwalik. Rocks of the area are folded into a synform named as Mahabharat Synclinorium (Stöcklin 1980). The trend and plunge of the Synclinorium is 099°/06° (Acharya 2008).

SAMPLE PREPARATION

All of the sample preparation and analytical work were performed at the Laboratory of Geochronology, Department of Lithospheric Research, University of Vienna. Samples were cleaned by removing the outer weathered portion. After crushing the samples, whole-rock splits were taken. For whole-rock (wr) analysis, about 50–100 gm of sample crushate was ground in an agate mill, producing a fine powder for analysis. The whole-rock powders were dissolved for 3 weeks in a mixture of ultrapure HF-HClO4 (5:1) to ensure complete leaching of Rare Earth Elements (REEs) from refractory materials. After evaporating the acids, repeated treatment of the residue using 5.8 N HCl was carried out. After cooling, the sample solution was split off and spiked for Sm and Nd concentration determination by isotopic dilution (ID) using a mixed REE tracer (^{147}Sm-^{150}Nd spike). The REE fraction was extracted using AG 50 W-X8 (200–400 mesh, Bio-Rad) resin and 4.0 N HCl. Nd and Sm were separated from the REE fraction using Teflon-coated HdEHP and 0.24 N and 0.8 N HCl, respectively, as elution media. Sm and Nd ID were measured as a metal species from a Re double filament, using a Finnigan MAT262 for Sm and Nd ID and a ThermoFinnigan Triton TI TIMS for ND IC. A ^{143}Nd/^{144}Nd ratio of 0.511847 ± 0.000005 (n = 35) was determined for the La Jolla (Nd) international standard during the period of investigation, using the Triton instrument.

ANALYSIS

Sm-Nd isotopic analysis was carried out for thirteen samples collected from different parts of the central Nepal (Fig. 2). Among these samples, six are phyllites from the Robang Formation of the Nawakot Complex, two amphibolite samples from the Robang Formation, two highly deformed phyllites from the thrust zone, two schists of the Raduwa Formation of the Kathmandu Complex, and one sample of Shivapuri Injection Gneiss. The obtained Sm-Nd analytical results are shown in Table 1.

The isotopic evolution of Nd in the earth is described in terms of a model called CHUR, which stands for Chondritic Uniform Reservoir (Depaolo and Wasserburg 1976). This model assumes that terrestrial Nd has evolved in a uniform reservoir whose Sm/Nd ratio is equal to that of chondritic meteorites. The present value of the ^{143}Nd/^{144}Nd ratio of this reservoir is 0.512638 while the present ^{147}Nd/^{144}Nd (CHUR) is 0.1967. This information can be used to calculate the ^{143}Nd/^{144}Nd ratio of CHUR at any other time. The isotopic evolution of Nd in the earth according to CHUR is illustrated in Fig. 4.

The differences in the isotopic ratios we want to compare are quite small. For this reason Depaolo and Wasserburg (1976) introduced the Epsilon Parameter $\varepsilon(0)$ Nd which is defined as

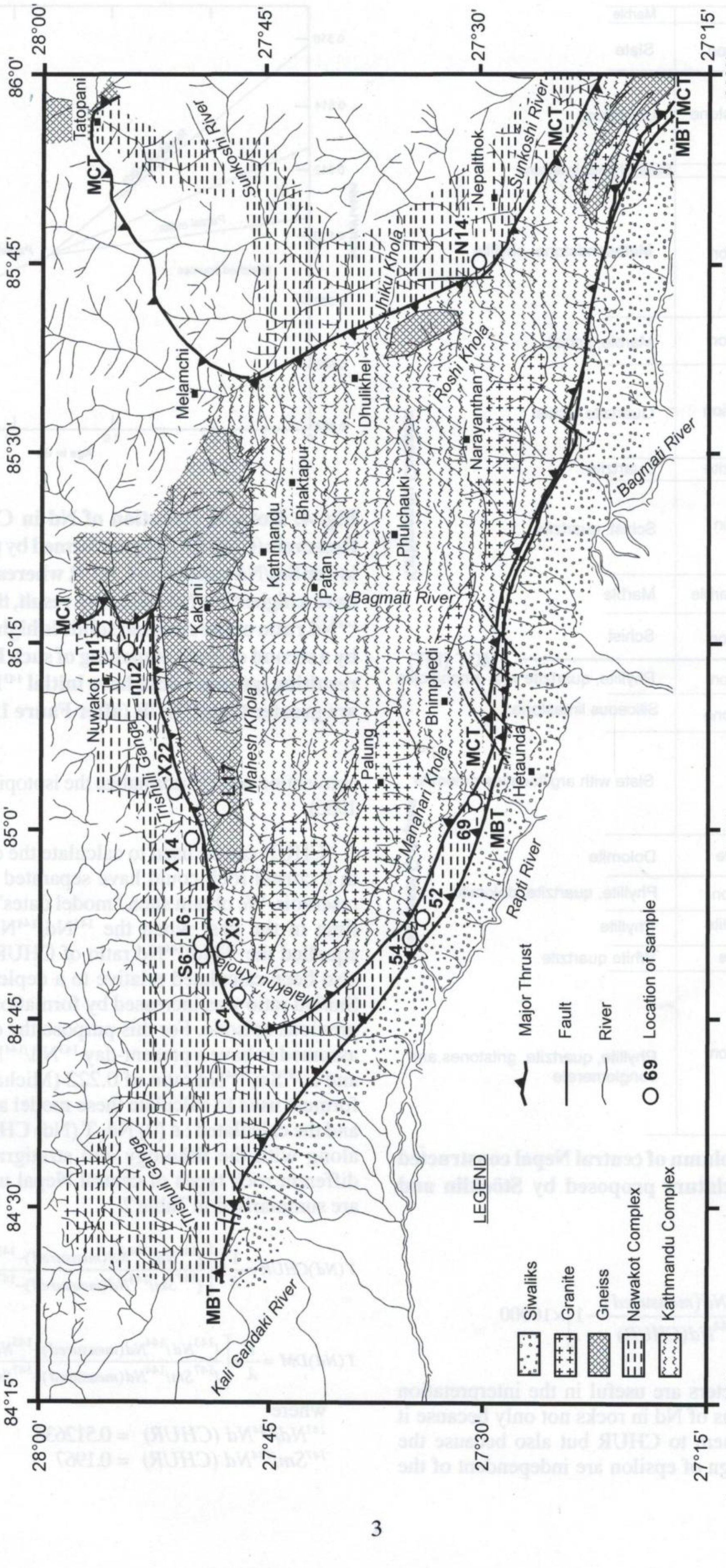

Fig. 2: Geological map of the central Nepal showing the location of samples for Sm-Nd isotopic analysis (After Stöcklin and Bhattarai 1977)

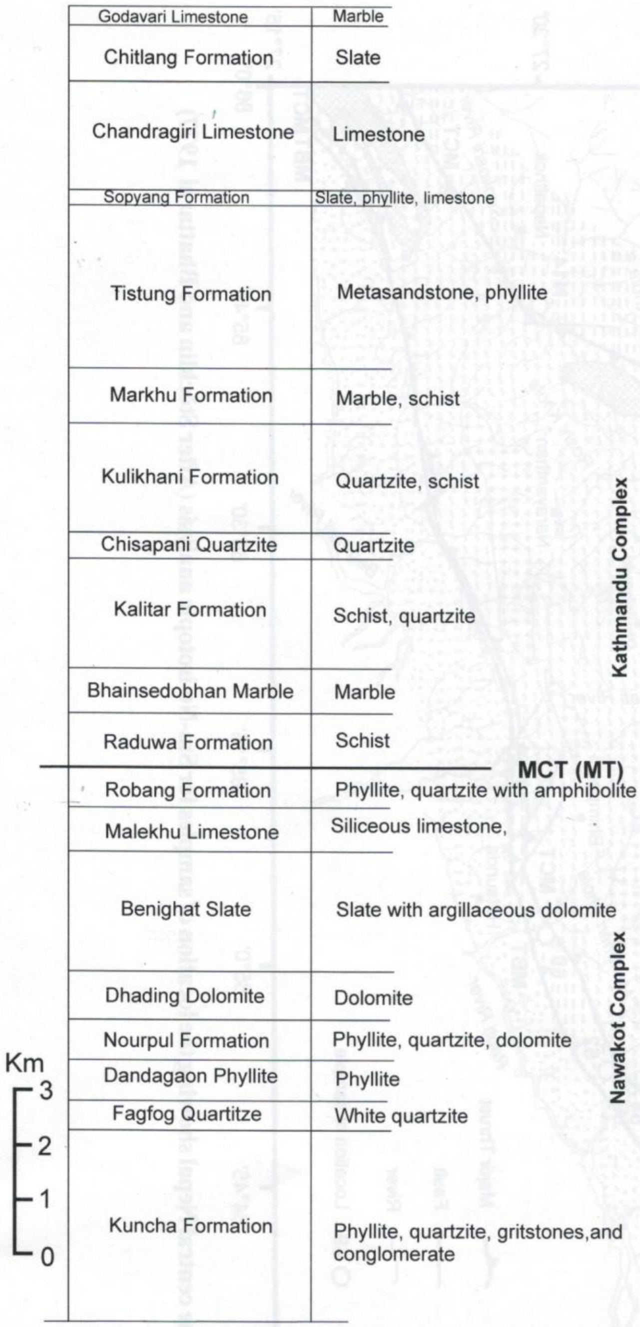

Fig. 3: Stratigraphic column of central Nepal constructed following the nomenclature proposed by Stöcklin and Bhattarai (1977)

$$\varepsilon(0)Nd = \left[\frac{^{143}Nd/^{144}Nd(measured)}{^{143}Nd/^{144}Nd(CHUR)} - 1 \right] \times 10000$$

The epsilon parameters are useful in the interpretation of isotopic compositions of Nd in rocks not only because it helps us to compare them to CHUR but also because the numerical value and sign of epsilon are independent of the convention used to normalize the isotopic ratios of Nd (Faure 1986).

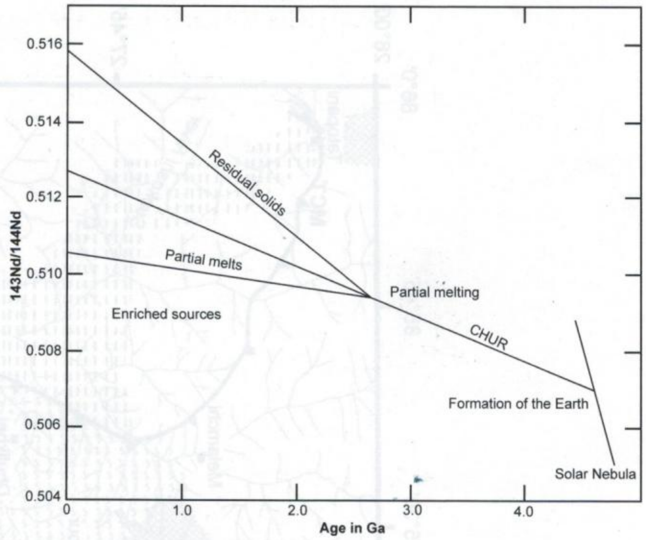

Fig. 4: Isotopic evolution of Nd in Chondritic Uniform Reservoir (CHUR). Magma formed by partial melting has a lower Sm/Nd ratio than CHUR whereas the residual solids have a higher Sm/Nd ratio. As a result, the present-day $^{143}Nd/^{144}Nd$ ratio of the residual solids is higher. If magma forms by a second episode of melting of such Depleted Mantle the resulting igneous rocks have initial $^{143}Nd/^{144}Nd$ ratios that are greater than CHUR (after Faure 1986).

CHUR can be used to calculate the date at which the Nd in a crustal rock could have separated from the chondritic reservoir. We obtain such "model dates" by determining the time in the past when the $^{143}Nd/^{144}Nd$ ratio of the rock equalled the $^{143}Nd/^{144}Nd$ ratio of CHUR. Model dates have also been calculated relative to a depleted reservoir whose Sm/Nd ratio was increased by formation of partial melt in a previous episode. For this purpose the depleted reservoir is assumed to have a present-day $^{143}Nd/^{144}Nd$ ratio of 0.513114 and a $^{147}Sm/^{144}Nd$ ratio of 0.222 (Michard et al. 1985). The formula used to calculate these model ages are given below and the calculated : ε (0) Nd, T (Nd) CHUR, and T (Nd) DM along with the lithology and stratigraphic formation for different rock types of central Nepal using these formulas are summarised in Table 2.

$$T(Nd)CHUR = \frac{1}{\lambda} \ln \left[\frac{\{^{143}Nd/^{144}Nd(measured) - ^{143}Nd/^{144}Nd(CHUR)\}}{\{^{147}Sm/^{144}Nd(measured) - ^{147}Sm/^{144}Nd(CHUR)\}} + 1 \right]$$

$$T(Nd)DM = \frac{1}{\lambda} \ln \left[\frac{\{^{143}Nd/^{144}Nd(measured) - ^{143}Nd/^{144}Nd(DM)\}}{\{^{147}Sm/^{144}Nd(measured) - ^{147}Sm/^{144}Nd(DM)\}} + 1 \right]$$

where

$^{143}Nd/^{144}Nd\ (CHUR) = 0.512638$

$^{147}Sm/^{144}Nd\ (CHUR) = 0.1967$

Table 1: Sm-Nd analytical results of whole-rock samples from central Nepal

Sample	Sm, ppm	Nd, ppm	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	2σm
Nawakot Complex phyllite					
52	6.91	37.5	0.11130	0.511562	0.000004
54	6.29	32.3	0.11774	0.511571	0.000003
56	3.14	15.1	0.12569	0.511550	0.000003
nu1	3.79	19.5	0.11753	0.511533	0.000004
N14	4.96	27.2	0.11005	0.511418	0.000005
X14	9.67	54.5	0.10725	0.511349	0.000004
Amphibolite of the Nawakot Complex					
nu2	3.16	13.3	0.14331	0.511993	0.000003
L6	4.77	21.0	0.13738	0.511927	0.000003
Rocks of thrust zone					
69	8.50	39.6	0.12952	0.511800	0.000003
X22	6.50	29.8	0.13175	0.511861	0.000004
Kathmandu Complex schist					
C4	3.13	14.6	0.12955	0.511963	0.000003
X3	7.47	37.6	0.11991	0.511999	0.000002
Kathmandu Complex gneiss					
L17	2.54	9.84	0.15602	0.512317	0.000004
La Jolla International standard				0.511846	0.000005

Table 2: Calculated ε (0) Nd, T (Nd) DM, T (Nd) CHUR for whole-rock samples of central Nepal

Sample	Lithology	Stratigraphy	ε (0) Nd	T (Nd) DM (Ga)	T (Nd) CHUR (Ga)
Nawakot Complex Phyllite					
52	Phyllite	Robang Fm	-20.99	2.12	1.91
54	Phyllite	Robang Fm	-20.82	2.46	2.05
56	Phyllite	Robang Fm	-21.23	2.44	2.32
nu1	Phyllite	Robang Fm	-21.56	2.29	2.11
N14	Phyllite	Robang Fm	-23.80	2.29	2.13
X14	Phyllite	Robang Fm	-25.15	2.33	2.18
Amphibolite of the Nawakot Complex					
nu2	Amphibolite	Robang Fm	-12.58	2.16	1.83
L6	Amphibolite	Robang Fm	-13.86	2.12	1.82
Rocks of thrust zone					
69	Phyllite		-16.34	2.15	1.89
X22	Phyllite		-15.16	2.11	1.82
Kathmandu Complex Schist					
X3	Garnet schist	Raduwa Fm	-12.47	1.66	1.27
C4	Mica schist	Raduwa Fm	-13.17	1.89	1.53
Kathmandu Complex Gneiss					
L17	Gneiss	Sheopuri Gneiss	-6.26	1.83	1.20

$^{143}Nd/^{144}Nd\ (DM) = 0.513114$
$^{147}Sm/^{144}Nd\ (DM) = 0.222$ (Michard et al. 1985)

DISCUSSIONS

The Sm-Nd analysis gives the contrasting ^{147}Sm/^{144}Nd ratios, ε(0) Nd values, T(Nd)CHUR and T(Nd)DM for different rock types and different rock units of the central Nepal. Based on the values obtained and comparing these values from the previous literatures, the nature of evolution of these units and their affinity are discussed in following paragraphs.

Nawakot Complex phyllite

All of the six samples collected from the Robang Formation show very similar ^{147}Sm/^{144}Nd ratios, between 0.10 and 0.12, a typical continental crustal signature with a homogenous source. Measured ε(0) Nd values show a rather narrow range, between -20.82 to -25.15 and Depleted Mantle (DM) model ages range from 2.1 to 2.4 Ga. This result is very similar to the data of Lesser Himalayan Sequence of Parish and Hodges (1996) who performed similar work in the Langtang area (north of the present study area). They obtained ε(0) Nd between -21.4 and -25.9 and DM model ages of 2.12 to 2.33 Ga. Robinson et al. (2001) published data with an average ε(0) Nd value in the Lesser Himalayan zone of -21.5 (Fig. 5).

Amphibolite of the Nawakot Complex

Two samples (nu2 and L6) of amphibolite from two different areas of the Robang Formation were analysed. Both amphibolites show similar and somewhat higher Sm-Nd ratios (0.14 and 0.13) than the phyllites and strongly negative ε(0) Nd values of -12.6 and -13.9. Although it is proven that these two amphibolite bodies are of the same origin and derived from the same protolith, the origin of these rocks can not be confirmed by this analysis alone. The rocks could have been derived either from sedimentary material (marl metasediments) or from igneous material where the primary chemical composition was completely changed during the metamorphism or metamorphic alteration.

Kathmandu Complex schist

Two schists (X3 and C4) from the Kathmandu Complex show ε(0) Nd of -12.5 and -13.2 and DM model ages of 1.7 and 1.9 Ga respectively. None of these samples showed evidence of partial melting. The measured Sm-Nd isotopic characteristics are considered to be representative for sedimentary protolith. The results support a homogenized sedimentary source comparable to the Lesser Himalayan rocks, but both samples show negative Nd values and the DM model ages are different compared to the Lesser Himalayan rocks. ε(0) Nd values of Parish and Hodges (1996) and Robinson et al. (2001) are slightly higher than the present value calculated for this unit but are comparable with their Higher Himalayan Zone (Fig. 5).

Kathmandu Complex gneiss

One sample of Higher Himalayan gneiss (L17) showed ε(0) Nd value of -6.3 and the DM model age of 1.8 Ga. The ^{147}Sm/^{144}Nd ratio is lower (0.15) than that of mantle value (0.222) but higher than that of typical crustal material (0.11). This is probably due to the influence fractionation of REE during melt formation from crustal sources.

Phyllite of thrust zone

Two samples collected from the MCT zone (69 and X22) show ε(0) Nd values of -15.2 and -16.3 with the DM model ages of 2.10 and 2.15 Ga, respectively. The samples show ε(0) Nd value higher than that of the Kathmandu Complex schist and lower than that of the Nawakot Complex phyllite. The ε(0) Nd values for the rock of the MCT zone lies between the values of the Higher Himalayan Crystalline and the Lesser Himalayan sequence (Parrish and Hodges 1996, Robinson et al. 2001). Similar nature is shown by the mapped thrust of this area and is comparable to the MCT.

^{143}Nd/^{144}Nd vs ^{147}Sm/^{144}Nd plot shows a linear trend with lowest values in the Nawakot Complex phyllite and highest value in the Kathmandu Complex schist and Sheopuri Injection gneiss (Fig. 5). The comparison of plots made from the data of present study and data obtained by Parrish and Hodges (1996) and Robinson et al. (2001) show the affinity of the Nawakot Complex rocks with the Lesser Himalayan Sequence and the Kathmandu Complex rocks with the Higher Himalayan Crystalline (Fig. 5).

CONCLUSIONS

The Sm-Nd whole rock analysis shows clear distinctions between the different lithology and rock units of central Nepal. ^{147}Sm/^{144}Nd ratios of the Nawakot Complex demonstrate a typical continental crustal signature with a homogenous source. The results of the Kathmandu Complex support a homogenized sedimentary source comparable to the Lesser Himalayan rocks, but ε(0) Nd values and the DM model ages are different compared to the Lesser Himalayan rocks. Furthermore, the comparison of the present result with the previous data shows the affinity of the Nawakot Complex rocks with the Lesser Himalayan Sequence and rocks of the Kathmandu Complex with the Higher Himalayan Sequence. The mapped thrust belt between the Nawakot and Kathmandu Complexes show ε(0) Nd values more negative than the Kathmandu Complex rocks and less negative than the Nawakot Complex rocks (similar to the MCT in earlier research). So the mapped thrust between these two units is unquestionably the MCT and the Kathmandu Nappe is therefore required to be an MCT re-entrant.

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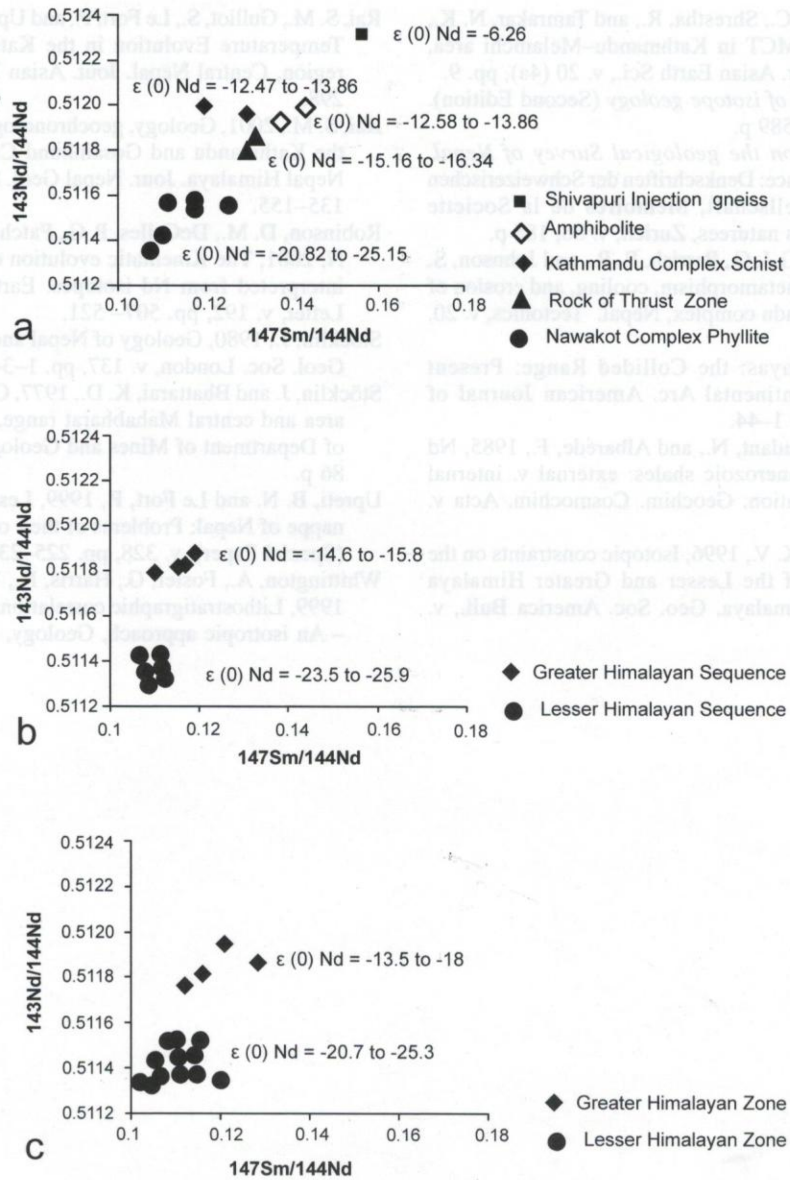

Fig. 5: $^{143}Nd/^{144}Nd$ vs. $^{147}Sm/^{144}Nd$ plot: (a) plot of data received from the present study, (b) plot of data obtained by Parrish and Hodges (1996), and (c) plot of data calculated by Robinson et al. (2001)

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