Journal of Nepal Geological Society, 2011, Vol. 43 (Special Issue), pp. 29–36

Review of detrital zircon age and Sm-Nd isotopic data from Himalaya: Support to the Mesoproterozoic formation of East Gondwana

***M. Yoshida[1,2] and B. N. Upreti[2]**

[1] *Gondwana Institute for Geology and Environment, 147-2 Hashiramoto, Hashimoto 648-0091, Japan*
[2] *Department of Geology, Trichandra Campus, Tribhuvan University, Ghantaghar, Kathmandu, Nepal*
*(*Email: gondwana@gaia.eonet.ne.jp)*

ABSTRACT

Published detrital zircon ages and Sm-Nd isotopic data from the Himalayan orogen suggest that the protolith of the Higher Himalayan Gneisses received its material mostly from the Circum-East Antarctic Orogen and adjacent Archaean blocks including Western Australia and East Antarctica, and partly from the Lesser Himalayan Metasediments. The original material of late Proterozoic to early Paleozoic clastic strata in the northern fringe of the Indian craton including those of the Tethys Sedimentary Sequence is considered to be mostly derived from the Higher Himalayan Gneisses, and for some amount, possibly from the Circum-East Antarctic Orogen and the Lesser Himalayan Metasediments, and only small amount, in the western area, from the Arabian Nubian Shield. The above results do not support the isolated block of the Indian craton apart from other crustal blocks during the Neoproterozoic, but is in support of the juxtaposition of the Indian craton with the Mesoproterozoic Circum-East Antarctic Orogen during the Neoproterozoic, and thus support the Mesoproterozoic assembly of East Gondwana.

Keywords: Higher Himalayan gneisses, provenance of Himalayan rocks, origin of Himalayan gneisses, East Gondwana assembly, detrital zircon ages of Himalayan rocks

Received: 5 January 2011 **revision accepted:** 10 June 2011

INTRODUCTION

East Gondwana is regarded to have assembled during the Pan-African (ca 450-700 Ma) orogeny according to recent studies (Li et al. 2008), in contrast to the classical model that it assembled during the Mesoproterozoic Grenvillian orogeny (the Circum-East Antarctic orogeny) and suffered strong reworking events during the Pan-African times (Unrug 1992; Yoshida 1995). Objection to the classical idea mostly born from palaeomagnetic studies. Here we give a review of detrital zircon age studies from the Himalaya to constrain the above topics; either East Gondwana was born by the Pan-African or the Grenvillian orogenies.

Detrital zircon U-Pb/Pb-Pb ages and rock Sm-Nd isotopic data from rocks of major geologic units of the Himalayan orogen (Fig. 1) so far published provide some constraints on the time of the assembly of East Gondwana. Parrish and Hodges (1996) pointed out a distinct difference in both the detrital zircon ages and $^{\varepsilon}$Nd values between the Lesser Himalayan Metasediments (LHM) and the Higher Himalayan Gneisses (HHG, also referred as the Higher Himalayan Crystalline Sequence). Their conclusion was further supported by later studies (DeCelles et al. 2000; Robinson et al. 2001; Argles et al. 2003; Myrow et al. 2003; Martin et al. 2005; Gehrels et al. 2006a, 2006b). Yoshida and Upreti (2006), by analyzing existing geochronologic data, pointed out that the provenance of the HHG is most possibly the Circum East Antarctic Orogen (Yoshida 1995, Yoshida et al. 2003). They (Yoshida et al. 2006) further examined areal and temporal polarities in the variation of detrital zircon age populations of the upper Proterozoic to lower Paleozoic formations including the Tethys Sediments (TTS, also referred as the Tibetan Tethys Sedimentary Sequence) and pointed out a possibility that although most part of detrital zircons are considered to have been derived from the HHG, some part of zircons in the TTS and related formations might have been derived from the CEAO and a small part from the Arabian Nubian Shield (ANS). They also pointed out that the population of zircon ages thought to have been derived from the ANS increased both in the western areas and in the upper horizons of the TTS. The geochronologic data and arguments from the Himalayan orogen cited above clearly show that during the Neoproterozoic, the Himalayan belt (hereafter referred as the proto-Himalayan belt) was juxtaposed with the CEAO. This indicates that the Indian craton was not an isolated block apart from other cratonic blocks, but was juxtaposed with the CEAO, since the proto-Himalayan belt is generally regarded to have constituted the northern fringe of the Indian craton during the Proterozoic - Paleozoic times (Myrow et al. 2003, 2006). The data and arguments above have given a constraint to the past location of the Indian craton in relation to East Antarctica as well as East Gondwana (Fig. 2). The present paper reviews above studies and stresses that the proto-Himalayan belt as well as the Indian craton was a part of East Gondwana during the Neoproterozoic.

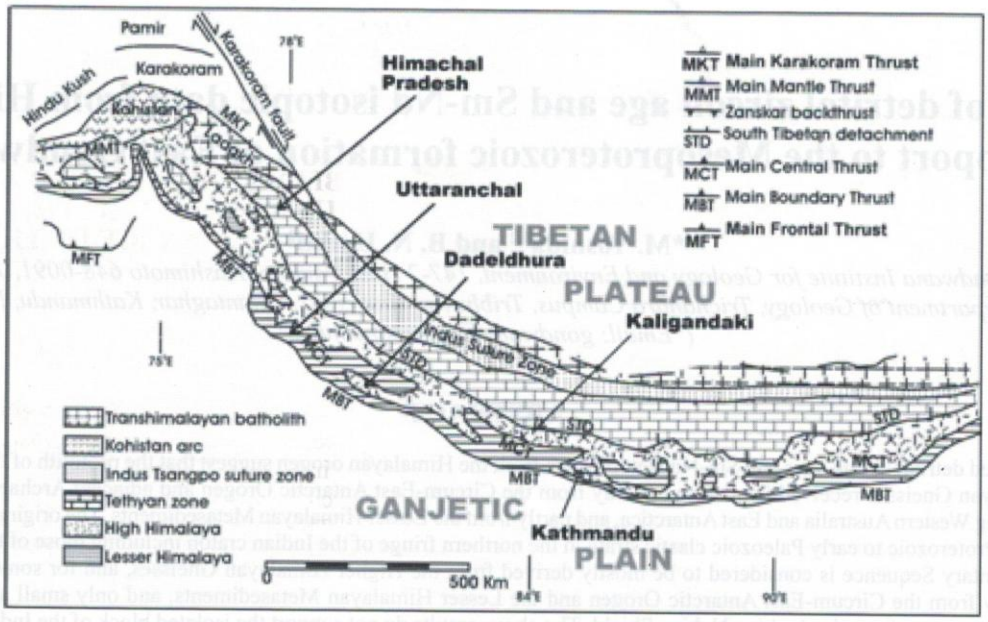

Fig. 1: Geological outline of the Himalayan Orogen (Modified after Searle et al. 2003)

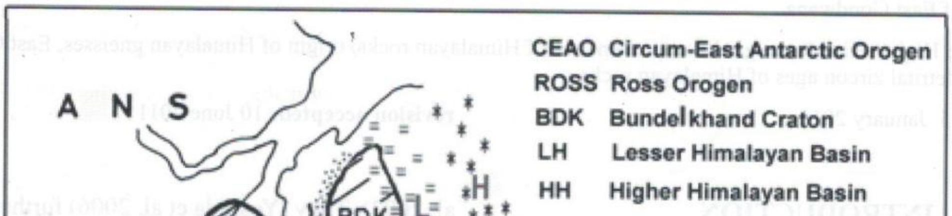

Fig. 2: Gondwana assembly and the Himalayan basins (proto-Himalayan belt) after ca 1000 Ma Circum-East Antarctic orogeny (CEAO) for India-Australia-Antarctic sector and after ca 550 Ma for Africa-Indian sector (cited from Yoshida and Upreti 2006). HH and ROSS are the late Pan-African orogens and not the rejuvenated craton.

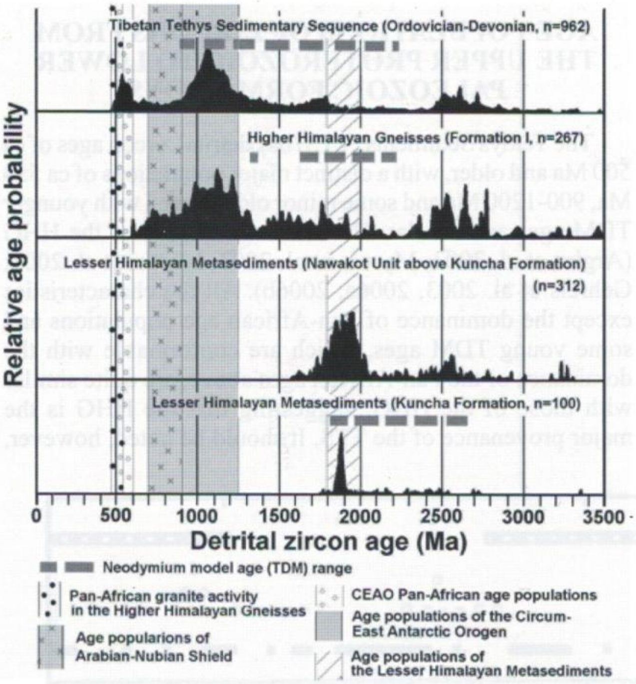

Fig. 3: Characteristics of Detrital zircon ages and TDM ages from the Himalayan rocks. The figure is compiled from data after Martin et al. (2005), Parrish and Hodges (1996), Robinson et al. (2001) and Argles et al. (2003). The base figure is extracted from Martin et al. (2005)

CHARACTERISTICS OF DETRITAL ZIRCON AGE POPULATIONS AND ND ISOTOPIC RATIOS OF MAJOR GEOLOGIC UNITS OF THE HIMALAYAN OROGEN

A summary of geochronologic characteristics of the major three geologic units of the Himalayan orogen is shown in Fig. 3, modified after Martin et al. (2005), along with characteristic age ranges of major orogenic peaks of the ANS and the CEAO and age range of characteristic geologic events in the HHG and LHG. In addition, there are several important geochronological studies from the Himalayan orogen (Parrish and Hodges 1996, DeCelles et al. 2000, Robinson et al. 2001; Argles et al. 2003, Myrow et al. 2003, Martin et al. 2005, Gehrels et al. 2003, 2006a, 2006b, Martin et al. 2011). Summarizing all these studies, characteristics of detrital zircon ages and Sm-Nd isotopic systematics of major geologic units of the Himalayan orogen are given as follows.

The Lesser Himalayan Metasediments (LHM) gives detrital zircon ages mostly older than ca 1.6 Ga with major populations of ca 1.8-2.0 Ga and TDM of rocks ranges from 1.8 to 2.6 Ga with low initial Nd ratios from -15 to -30, with an average of -23. The Neoproterozoic Higher Himalayan Gneisses (HHG) shows major populations of detrital zircon ages of ca 950 – 1250 Ma (Grenvillian ages) and TDM ages of 1.3-2.2 Ga with initial Nd ratios of +1 to -20. The Tethys Sediments (TTS) shows mostly similar characteristics with the HHG, except the addition of ca 500 - 600 Ma Pan-African age populations of detrital zircons and slightly younger TDM ages ranging from ca 0.9 Ga to 2.2 Ga.

GEOCHRONOLOGIC DATA FROM THE ARABIAN NUBIAN SHIELD AND THE CIRCUM EAST ANTARCTIC OROGEN AND THE PROVENANCE OF THE HIGHER HIMALAYAN GNEISSES

Extensive geologic and geochronologic data from the Arabian Nubian Shield (ANS) have been given by Johnson and Woldehaimanot (2003) and are summarized in Fig. 4. According to them the basement geology of the ANS is mostly composed of Neoproterozoic crystalline rocks, and older rocks including Mesoproterozoic, Paleoproterozoic and latest Archaean rocks are only sporadically cropped out. U-Pb/Pb-Pb/Th-Pb detrital zircon and Rb-Sr whole-rock ages range mostly from 550 to 900 Ma that form only one main peak distribution. Nd model ages (TDM) are mostly younger than ca 1.4 Ga, with mostly positive $^{\varepsilon}$Nd values. Older TDM ages than ca 2.5 Ga and negative $^{\varepsilon}$Nd values occur only rarely at scattered older blocks. The ANS is considered to be in juxtaposition with the Indian craton during ca 550 Ma (Johnson and Woldehaimanot 2003) and Cretaceous (Acharyya 2000). It is pointed out that although DeCelles et al. (2000) suggested the provenance of the HHG to be the ANS, the juxtaposition ages as well as the characteristics of this shield mentioned above do not support their suggestion.

The late Mesoproterozoic Circum-East Antarctic Orogen (CEAO) fringes most of the East Antarctic shield. It also develops at the eastern margin of India, and continues to western and southwestern margins of Australia (cf. Fig. 2, referred after Yoshida et al. 2003). All areas of this orogen are mostly composed of medium-high grade metamorphites and plutonic rocks (Yoshida 1995; Yoshida et al. 2003). Geochronologic data from some areas of this orogen near by the proto-Himalayan belt in East Gondwana assembly (Fig. 2) are summarized in Fig. 5. Extensive areas of this orogen are superimposed by the ca 500-600 Ma Pan-African orogeny. The earlier orogenic peaks of the belt are mostly of the Grenvillian ages ranging from ca 1000Ma to -1400 Ma, with 800 - 1000 Ma ages in some areas. The Archaean ca 2600-2800 Ma ages develop extensively in the Archaean Yilgarn block and adjacent areas (Myers, 1993) and ca 2400-2500 Ma ages are found generally in near-by Archaean blocks of East Antarctica (Tingey 1991). TDM ages of the CEAO range mostly from 1.6 Ga to 3.0 Ga, with the exception of 1.1-1.6 Ga and 3.0-4.0 Ga for the western margin of Western Australia and Enderby Land in East Antarctica respectively. These data are quite consistent with the detrital zircon age data from the HHG and in favour of considering the source material of these rocks almost totally to have been derived from the CEAO and adjacent terrains as pointed out by Yoshida and Upreti (2006), although the contribution from the LHM for the older age populations is considered possible (DeCelles et al. 2000).

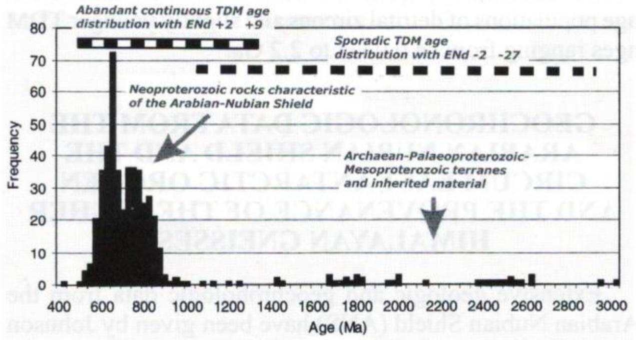

Fig. 4: Geochronologic data from the Arabian-Nubian Shield (Modified after Johnson and Woldehaimanot 2003)

AGE POPULATIONS OF ZIRCONS FROM THE UPPER PROTEROZOIC TO LOWER PALEOZOIC FORMATIONS

The Tethys Sediments (TTS) has detrital zircon ages of ca 500 Ma and older, with a distinct major populations of ca 550 Ma, 900-1200 Ma and some minor older peaks, with younger TDM ages and similar εNd values with those of the HHG (Argles et al. 2003; Myrow et al. 2003; Martin et al. 2005; Gehrels et al. 2003, 2006a, 2006b). All the characteristics except the dominance of Pan-African age populations and some young TDM ages, which are conformable with the dominance of the Pan-African ages above, are quite similar with those of the HHG, suggesting that the HHG is the major provenance of the TTS. It should be noted, however,

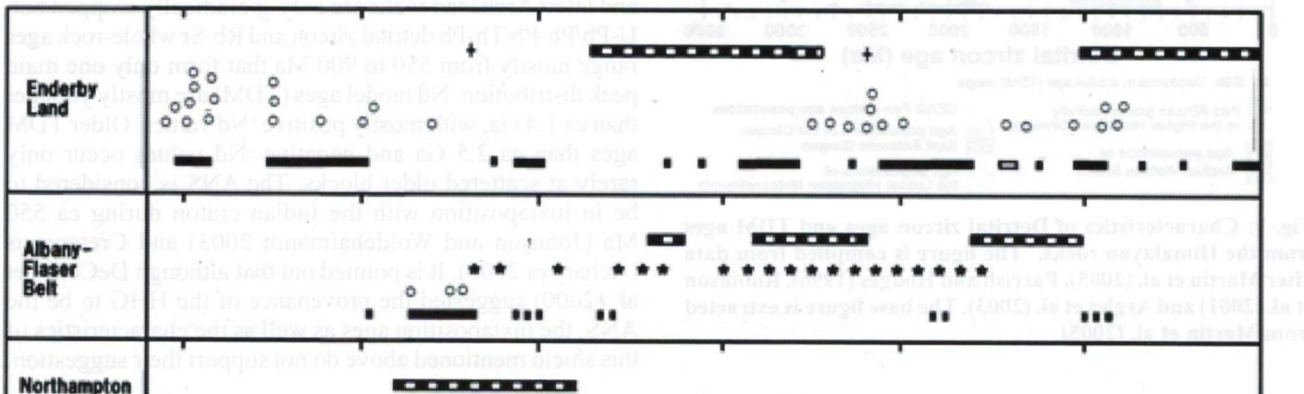

Fig. 5: Geochronologic data from a part of the Circum-East Antarctic Orogen. Data are referred to the following literatures. De Paulo et al. 1982; McCulloch and Black 1984; Collerson and Sheraton 1986; Black et al. 1987; Grew et al. 1988; Belyatsky et al. 1990; Tingey 1991; Black et al. 1992, a and b; Zhao et al. 1992, 1993, 1995, 2000, 2003; Clarke et al. 1995, 1999, 2000; Sheraton et al. 1992; Nelson et al. 1995; Carson et al. 1996; Kinny et al. 1993; Hensen and Zhou 1995; Zhang et al. 1996; Snape et al. 1997; Shiraishi et al. 1997; Young et al. 1997; Boger et al. 2001; Mikhalsky et al. 2001: Tong et al. 2002; Rasmussen et al. 2002, Fitzsimons 2003 and references therein.

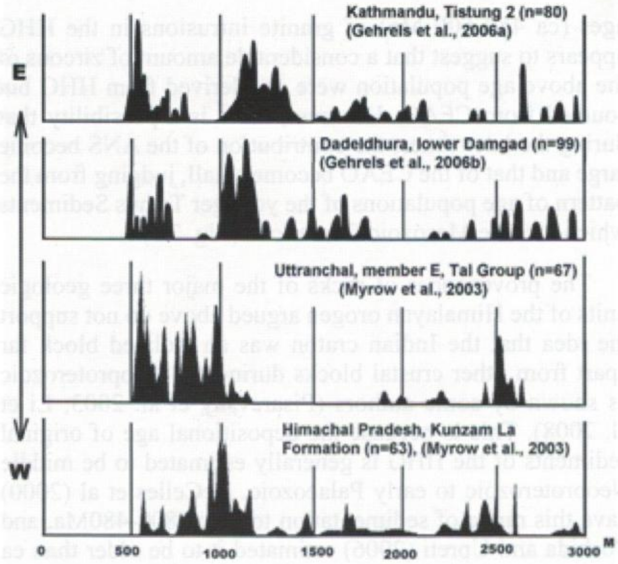

Fig. 6: Polarity of detrital zircon age populations in lower Teth sediments from east (E) to west (W) (Compilation after Myro et al. 2003; Gehrels et al. 2006a, 2006b)

that the peak 550 Ma age appears to be somewhat olde than early Paleozoic granite intrusions in the HHG, whic generally range from ca 470- 500 Ma (Gehrels et al. 2006: Cawood et al. 2007). Therefore, the ca 550 Ma populatic can not merely be correlated with the Pan-African even in the Higher Himalayan belt, but rather, possibly reflects contribution from CEAO in which strong Pan-African even of ca 500-600 Ma developed.

In the following, we try to examine the variations c zircon age populations in upper Proterozoic -lower Paleozo formations in the Himalayan orogen, regarding them to hav formed in nearly the same one basin extended along th northern margin of the Indian craton (Myrow et al. 200 2006; Torsvik et al. 2009).

To examine a possible polarity of zircon age populatior from east to west, data from Tistung 2 from the Kathmand Nappe (Gehrels et al. 2006a), lower Damgad Sandstor from the Dadeldhura Thrust Sheet (Gehrels et al. 2006b member E of the Tal Group from the Lesser Himalayan Zone of Uttaranchal (Myrow et al. 2003), and the Kunzam La Formation from the Tethys Himalayan Zone in Himachal Pradesh (Myrow et al. 2003) are together assembled in Fig. 6. The first two formations are regarded to be of the upper Proterozoic (Gehrels et al. 2006), while the latter two are referred to the uppermost Lower Cambrian or the Upper/ Middle Cambrian boundary (Myrow et al. 2003).

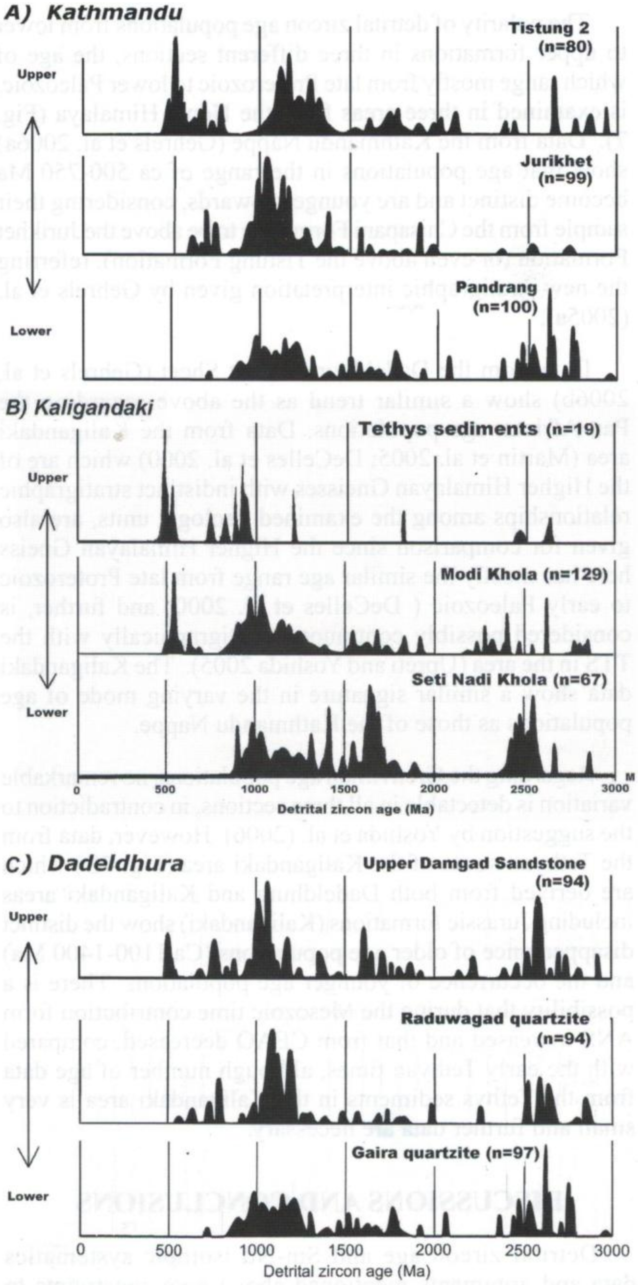

Fig. 7: Polarity of detrital zircon age populations from lower to upper Tethys Sediments in three different sections of the Himalaya (Compiled after DeCelles et al. 2000, Martin et al. 2005 and Gehrels et al. 2006a and b)

Although the depositional age of these formations are somewhat deviated, we can generally see a characteristic difference in zircon age populations between the eastern and the western Himalaya, referring also the data of late Proterozoic-Cambrian formations from Kathmandu, Kaligandaki and Dadeldhura areas (Fig. 7). Zircon age populations in the western Himalaya (Uttaranchal and Himachal Pradesh) have a tendency to increase ca 800-900 Ma and decrease ca 1100–1400 Ma populations compared with those of the eastern Himalaya (Kathmandu and Dadeldhura), thus appearing to suggest that the western areas of the Himalaya received more material from ANS and less material from CEAO compared to the eastern areas, referring characteristic age populations of the ANS and CEAO as shown in Fig. 3.

The polarity of detrital zircon age populations from lower to upper formations in three different sections, the age of which range mostly from late Proterozoic to lower Paleozoic, is examined in three areas from the Nepal Himalaya (Fig. 7). Data from the Kathmandu Nappe (Gehrels et al. 2006a) show that age populations in the range of ca 500-750 Ma become distinct and are younger upwards, considering their sample from the Chisapani Formation to be above the Jurikhet Formation (or even above the Tistung Formation), referring the new stratigraphic interpretation given by Gehrels et al. (2005a).

Data from the Dadeldhura Thrust Sheet (Gehrels et al. 2006b) show a similar trend as the above regarding the Pan-African age populations. Data from the Kaligandaki area (Martin et al. 2005; DeCelles et al. 2000) which are of the Higher Himalayan Gneisses with indistinct stratigraphic relationships among the examined geologic units, are also given for comparison since the Higher Himalayan Gneiss here has mostly the similar age range from late Proterozoic to early Paleozoic (DeCelles et al. 2000) and further, is considered possibly continuous stratigraphically with the TTS in the area (Upreti and Yoshida 2005). The Kaligandaki data show a similar signature in the varying mode of age populations as those of the Kathmandu Nappe.

Regarding the Grenvillian age populations, no remarkable variation is detectable in all three sections, in contradiction to the suggestion by Yoshida et al. (2006). However, data from the Tethyan strata of the Kaligandaki area (Fig. 7B) which are derived from both Dadeldhura and Kaligandaki areas including Jurassic formations (Kaligandaki) show the distinct disappearance of older age populations (Ca 1100-1400 Ma) and the occurrence of younger age populations. There is a possibility that during the Mesozoic time contribution form ANS increased and that from CEAO decreased, compared with the early Tethyan times, although number of age data from the Tethys sediments in the Kaligandaki area is very small and further data are necessary.

DISCUSSIONS AND CONCLUSIONS

Detrital zircon age and Sm-Nd isotopic systematics data and arguments mentioned above give constraints to the tectonics of East Gondwana during the Proterozoic to early Palaeozoic. These data suggest that the HHG should have received the material mostly from the CEAO including Western Australia and East Antarctica, and adjacent Archaean blocks as pointed out by Yoshida and Upreti (2006), but not from LHM in most part, which is regarded to have received material mostly from the North Indian craton as pointed out by DeCelles et al. (2000). The original material of the TTS is considered to have been mostly derived from the HHG and possibly, partly from the CEAO, and only very partly from the ANS in the western areas. The contribution of LHM to the TTS is very possible judging from geology, but is not well suggested from above geochronologic data. The dominance of slightly older Pan-African zircon age populations (ca 550 Ma) in TTS compared with prominent younger Pan-African ages (ca 450-500 Ma) of granite intrusions in the HHG appears to suggest that a considerable amount of zircons of the above age population were not derived from HHG but sourced from CEAO. However, there is a possibility that during the later times, the contribution of the ANS become large and that of the CEAO become small, judging from the pattern of age populations of the younger Tethys Sediments which include Mesozoic formations (Fig. 7B).

The provenances of rocks of the major three geologic units of the Himalayan orogen argued above do not support the idea that the Indian craton was an isolated block far apart from other crustal blocks during the Neoproterozoic as shown by some authors (Pisarevsky et al. 2003; Li et al. 2008). This is because the depositional age of original sediments of the HHG is generally estimated to be middle Neoproterozoic to early Palaeozoic. DeCelles et al (2000) gave this range of sedimentation to be ca 800-480Ma, and Yoshida and Upreti (2006) estimated it to be older than ca 550 Ma and the lower horizon (Formation I) might be early middle Neoproterozoic, younger than ca 800 Ma. According to the Cambrian assembly model of East Gondwana, the juxtaposition of the CEAO with the proto-Himalayan belt is estimated to be early Palaeozoic, the climax time of the Pan-African orogeny. With this model, it is impossible to derive material from CEAO to the Neoproterozoic HHG basin of the proto-Himalayan belt.

The data are supportive to the classical idea of the juxtaposition of the Indian craton with the CEAO during the Neoproterozoic~Cretaceous. The juxtaposition of the Indian craton with the CEAO during the Neoproterozoic is in support of the assembly of East Gondwana during the late Mesoproterozoic Circum-East Antarctic Orogeny (Yoshida 1995; Yoshida et al. 2003), and thus is in contradiction to both the recent models of the Pan-African assembly of East Gondwana mentioned above (Fitzsimons 2000, 2003), and isolated India-Enderby Land crust on the globe during the Neoproterozoic as has been suggested from palaeomagnetic studies (Pisarevsky et al. 2003; Li et al. 2008).

ACKNOWLEDGEMENTS

We thank G. E. Gehrels and K. Arita who reviewed the early manuscript in 2007, and A. K. Sinha who reviewed the last version of the manuscript in 2011, both of them gave valuable suggestions to improve this paper.

REFERENCES

Acharyya, S. K., 2000, Breakup of Australia-India-Madagascar block, opening of the Indian Ocean and continental accretion in Southeast Asia with special reference to the characteristics of the peri-Indian collision zones. Gondwana Res., v. 3, pp. 425-443.

Argles, T. W., Foster, G. L., Whittington, A., Harris, N., and George, M., 2003. Isotope studies reveal a complete Himalayan section in the Nanga Parbat syntaxis. Geology, v. 31, pp. 1109-1112.

Belyatsky, B. V., Krylov, D. P., Levsky, L. K., and Grikurov, G. E., 1990, Zircon geochronology of the granulite complexes of Enderby Land, East Antarctica. Zbl. Geol. Palaont. Teil 1, H. 1/2, pp. 1-18.

Black, L. P., Harley, S. L., Sun, S. S., and McCulloch, M. T., 1987, The Rayner Complex of East Antarctica: complex isotopic systematics within a Proterozoic mobile belt. Jour. Metamorphic Geol., v. 5, pp. 1-26.

Black, L. B., Sheraton, J. W., Tingey, R. J., and McCulloch, M. T., 1992a, New U-Pb zircon ages from the Denman Glacier area, East Antarctica, and their significance for Gondwana reconstruction. Antarctic Science, v. 4, pp. 447-460.

Black, L. P., Harris, L.B., and Delore, C. P., 1992b, Reworking of Archaean and Early Proterozoic components during a progressive, Middle Proterozoic tectonothermal event in the Albany Mobile Belt, Western Australia. Precamb. Res., v. 59, pp. 95-123.

Boger, S. D., Wilson, C. J. L., and Fanning, C. M., 2001, Early Palaeozoic tectonism within the East Antarctica: the final suture between east and west Gondwana? Geology, v. 29, pp. 463-466.

Carson, C. J., Fanning, C. M., and Wilson, C. J. L., 1996, Timing of the Progress Granite, Larsemann Hills: evidence for Early Palaeozoic orogenesis within the east Antarctic Shield and implications for Gondwana assembly. Australian J. Earth Sci., v. 43, pp. 539-553.

Clark, D. J., Hensen, B. J., and Kinny, P. D., 2000, Geochronological constraints for a two-stage history of the Albany-Fraser Orogen, Western Australia. Precamb. Res., v. 102, pp. 155-183.

Clark, D. J., Sun, S. S., and White, R. W., 1995, Grenville-age belts and associated older terranes in Australia and Antarctica. AGSO J. Australian Geol. and Geophys., v. 16, pp. 25-39.

Clarke, D. J., Kinny, P. D., Post, N. J. and Hensen, B. J., 1999, Relationships between magmatism, metamorphism and deformation in the Fraser Complex, Western Australia: constraints from the new SHRIMP U-Pb zircon geochronology. Austral. Jour. of Earth Sci., v. 46, pp. 923-932.

DeCelles, P. G., Gehrels, G. E., Quade, J., LaReau, B., and Spurlin, M., 2000, Tectonic implications of U-Pb zircon ages of the Himalayan Orogenic Belt in Nepal. Science, v. 288, pp. 497-499.

DePaulo, D. J., Manton, W. I., Grew, E. S., and Halpern, M., 1982, Sm-Nd, Rb-Sr and U-Th-Pb systematics of granulite facies rocks from Fyfe Hills, Enderby Land, Antarctica. Nature, v. 298, pp. 614-618.

Fitzsimons, I. C. W., 2000, Grenville age basement provinces in East Antarctica: evidence for three separate collisional orogens. Geology, v. 28, pp. 879-882.

Fitzsimons, I. C. W., 2003, Proterozoic basement provinces of southern and southwestern Australia, and their correlation with Antarctica. In: Yoshida, M., Windley, B.F. and Dasgupta, S. (Eds.), Proterozoic East Gondwana: Supercontinent Assembly and Breakup. Geol. Society, London, Special Pub. No. 206, pp. 93-130.

Gehrels, G. E. DeCelles, P. G., Martin, A., Ojha, T. P., and Pinhassi, G., 2003, Initiation of the Himalayan Orogen as an early Paleozoic thin-skinned thrust belt. GSA Today v. 13 (9), pp. 4-9.

Gehrels, G. E., DeCelles, P. G., Ojha, T. P., and Upreti, B. N., 2006a, Geologic and U-Th-Pb geochronologic evidence from early Paleozoic tectonism in the Kathmandu thrust sheet, central Nepal Himalaya. GSA Bull., v. 118, pp. 185-198.

Gehrels, G. E., DeCelles, P. G., Ojha, T. P., and Upreti, B. N., 2006b, Geologic and U–Pb geochronologic evidence for early Paleozoic tectonism in the Dadeldhura thrust sheet, far-west Nepal Himalaya. Jour. Asian Earth Sci., v. 28, Issues 4-6, pp. 385-408.

Grew, E. S., Manton, W. I., and James, P. R., 1988, U-Pb data on granulites facies rocks from Fold Island, Kemp Coast, East Antarctica. Precamb. Res., v. 42, pp. 63-75.

Hensen, B. J. and Zhou, B., 1995, A Pan-African granulite facies metamorphic episode in Prydz Bay, Antarctica: evidence from Sm-Nd garnet dating. Australian Jour. Earth Sci., v. 42, pp. 249-258.

Johnson, P. R. and Woldehaimanot, B., 2003, Development of the Arabian-Nubian Shield: perspectives on accretion and deformation in the northern East African Orogen and the assembly of Gondwana. In: M. Yoshida, B.F. Windley and S. Dasgupta (eds.), Proterozoic East Gondwana: Supercontinent Assembly and Breakup, Geol. Soc. Special Pub. No. 206, Geol. Soc., London, pp. 289-325.

Kinny, P. D., Black, L. P., and Sheraton, J. W., 1997, Zircon U-Pb ages and the distribution of Archaean and Proterozoic rocks in the Rauer Islands. Antarctic Science, v. 5, pp. 193-206.

Li Z. X., Bogdanova, S. V., Collins, A. S., Davidson, A., De Waele, B. Ernst, R. E., Fitzsimons, I. C. W., Fuck, R. A., Gladkochub, D. P., Jacobs, J., Karlstrom, K. E., Lul, S., Natapovm, L. M., Pease, V., Pisarevsky, S. A., Thrane, K., and Vernikovsky, V., 2008, The Geodynamic map of Rodinia: assembly, configuration, and braek-up history of Rodinia: a synthesis. Precamb. Res., v. 160, pp. 179-210.

McCulloch, M. T. and Black, L. P., 1984, Sm-Nd isotopic systematics of Enderby Land granulites and evidence for the redistribution of Sm and Nd during metamorphism. Earth and Planet. Sci. Lett., v. 71, pp. 46-58.

Martin, A. J., DeCelles, P. G., Hehrels, G. E., Patchett, P. J., and Isachsen, C., 2005, Isotopic and structural constraints on the location of the Main Central thrust in the Annapurna Range, central Nepal Himalaya. GSA Bull. v. 117, pp. 926-944.

Martin, A. J., Burgy, K. D., Kaufman, A. J., and Gehrels, G. E., 2011, Stratigraphic and tectonic implications of field and isotopic constraints on depositional ages of Proterozoic Lesser Himalayan rocks in central Nepal. Precamb. Res., v. 185, pp. 1-17.

Mikhalsky, E.V., Sheraton, J.W., and Beliatsky, B.V., 2001, Preliminary U-Pb dating of Grove Mountains rocks: implications for the Proterozoic to Early Palaeozoic tectonic evolution of the Lambert Glacier-Prydz Bay area (East Antarctica). Terra Antarctica, v. 8, pp. 3-10.

Myers, J.S., 1993, Precambrian history of the West Australian Craton and adjacent orogens. Annu. Rev. Earth Planet. Sci., v. 21, pp. 453-485.

Myrow, P. M., Hughes, N. C., Paulsen, T. S., Williams, I. S., Parcha, S. K., Thompson, K. R., Bowring, S. A., Peng, S.-C., and Ahluwalia, A. D., 2003, Integrated tectonostratigraphic analysis of the Himalaya and implications for its tectonics reconstruction. EPSL, v. 212, pp. 433-441.

Myrow, P. M., Thompson, K. R., Hughes, N. C., Paulsen, T. S., Sell, B. K. and Parcha, S. K., 2006, Cambrian stratigraphy and depositional history of the northern Indian Himalaya, Spiti Valley, north-central India. GSA Bull., v. 118, pp. 491-510.

Nelson, D. R., Myers, J. S., Nutman, A. P., 1995, Chronology and evolution of the middle Proterozoic Albany-Fraser Orogen, Western Australia. Austral. rJo. Earth Sci., v. 42, pp. 481-495.

Parrish, R. R. and Hodges, K. V., 1996, Isotopic constraints on the age and provenance of the Lesser and Greater Himalayan sequences, Nepalese Himalaya. Geol. Soc. Amer. Bull. v. 108, pp. 904-911.

Pisarevsky, S. A., Wingate, M. T. D., Powell, C. McA, Johnson, S., Evans, D. D., 2003, Models of Rodinia assembly and fragmentation. In: M. Yoshida, B.F. Windley and S. Dasgupta (eds.), Proterozoic East Gondwana: Supercontinent Assembly and Breakup, Geol. Soc. Special Pub. No. 206, Geol. Soc., London, pp. 35-55.

Rasmussen, B., Bengtson, S., Fletcher, I. R., and McNaughton, N. J., 2002, Discoidal impressions and trace-like fossils more than 1200 million years old. Science v. 296, pp. 1112-1115.

Robinson, D. M., DeCelles, P. G., Patchett, P. J., and Garzione, C.N., 2001, The kinematic evolution of the Nepalese Himalaya interpreted from Nd isotopes. Earth and Planet. Sci. Lett. v. 192, pp. 507-521.

Searle, M. P., Simpson, R. L., Law, R. D., Parish, R. R., and Waters, D. J., 2003, The structural geometry, metamorphic and magmatic evolution of the Everest massif, High Himalaya of Nepal-South Tibet. Jour. Geol. Soc., London v. 160, p. 345-366.

Sheraton, J. W., Black, L. P. and Tindle, A. G., 1992, Petrogenesis of plutonic rocks in a Proterozoic granulite-facies terrane-the Bunger Hills, East Antarctica. Chemical Geology, v. 97, pp. 163-198.

Shiraishi, K., Ellis, D. J., Fanning, C. M., Hiroi, Y., Kagami, H., and Motoyoshi, Y., 1997, Re-examination of the metamorphic and protolith ages of the Rayner Complex, Antarctica: evidence for the Cambrian (Pan-African) regional metamorphic event. In: C.A. Ricci (Ed.), The Antarctic Region: Geological Evolution and Processes, Terra Antarctica Pub., Siena, pp. 79-88.

Snape, I., Black, L. P., and Harley, S. L., 1997, Refinement of the timing of magmatism, high-grade metamorphism and deformation in the Vestfold Hills, East Antarctica from new SHRIMP U-Pb zircon geochronology. In: Ricci, C.A. (Ed.), The Antarctic Region: Geological Evolution and Processes. Terra Antarctica Publication, Siena, pp. 139-148.

Tingey, R. J., 1991, The regional geology of Archaean and Proterozoic rocks in Antarctica. In: Tingey, R. J.'(Ed.), The Geology of Antarctica. Oxford University Press, Oxford, pp. 1-73.

Tong, L., Wilson, C. J. L., and Liu, X., 2002, A high-grade event of ~1100 Ma preserved within the ~500 Ma mobile belt of the Larsemann Hills, East Antarctica: further evidence from ^{40}Ar-^{39}Ar dating. Terra Antarctica, v. 9, pp. 73-86.

Torsvik, T. H., Paulsen, T. S., Hughes, N. C., Myrow, P. M., and Ganerød, M., 2009, The Tethyan Himalaya: palaeogeographical and tectonic constraints from Ordovician palaeomagnetic data. Jou. Geol. Soc., v. 166, pp. 679-687.

Yoshida, M., 1995, Assembly of East Gondwana during the Grenvillian and its rejuvenation during the Pan-African period. Geol. Soc. India, Mem. 34, pp. 25-45.

Yoshida, M. and Upreti, B. N., 2006, Neoproterozoic India within East Gondwana: Constraints from recent geochronologic data from Himalaya. Gondwana Research, v. 10, pp. 349-356.

Yoshida, M., Santosh, M., and Rajesh, H. M., 2003, Role of Pan-African events in the Circum-East Antarctic Orogen of East Gondwana: a critical overview. In: M. Yoshida, B.F. Windley and S. Dasgupta (eds), Proterozoic East Gondwana: Supercontinent Assembly and Breakup, Geol. Soc. Special Pub. No. 206, Geol. Soc., London, pp. 57-75.

Yoshida, M., Upreti, B. N., DeCelles, P G., Gherels, G. E., and Ojha, T. P., 2006, Basement history and provenance of the Tethys sediments of the Himalaya: An appraisal based on recent geochronologic and tectonic data. Bull. Tethys Geol. Soc., v. 1, pp. 1-6.

Young, D. N., Zhao, J-X, Ellis, D. J., and McCulloch, M. T., 1997, Geochemical and Sr-Nd isotopic mapping of source provinces for the Mawson charnockites, east Antarctica: implications for Proterozoic tectonics and Gondwana reconstruction. Precamb. Res., v. 86, pp. 1-19.

Zhang, L, Tong, L., Liu, X., and Scharer, U., 1996, Conventional U-Pb ages of the high-grade metamorphic rocks in the Larsemann Hills, East Antarctica. In: Pang, Z., Zhang, J. and Sun, J. (Eds.), Advances in Solid Earth Sciences, Science Press, Beijing, pp. 27-35.

Zhao, Y., Song, B., Wang, Y., Ren, L., Li, J., and Chen, T., 1992, Geochronology of the late granite in the Larsemann Hills, East Antarctica. In: Yoshida, Y., Kaminuma, K. and Shiraishi, K. (Eds), Recent Progress in Antarctic Earth Science, Terra Scientific Publishing, Tokyo, pp. 155-161.

Zhao, Y., Liu, X., Song, B., Zhang, Z., Li, J., Yuoa, Y., and Wang, Y., 1995, Constraints on the stratigraphic age of the Larsemann Hills, East Antarctica: possible implications for Neo-Proterozoic tectonics. Precamb. Res., v. 75, pp. 175-188

Zhao, Y., Fanning, C. M., Liu, X-C., and Lin, X-H., 2000, The Grove Mountains, a segment of a Pan-African Orogenic Belt in East Antarctica. Abstracts, 31st IGC, San Paulo.

Zhao, Y. Song, B., Zhang, Z., Fu, Y., Chen, T., Wang, Y., Ren, L., Yao, Y., Li, J., and Liu, X., 1993, An early Palaeozoic (Pan-African) thermal event in the Larsemann Hills and its neighbours, Prydz Bay, East Antarctica. Science in China (Ser. B), v. 23, pp. 1001-100.

Zhao, Y., Liu, X. H., Liu, X. C.,and Song, B., 2003, Pan-African events in Prydz Bay, East Antarctica, and their implications for East Gondwana tectonics. In: Yoshida, M., Windley, B.F. and Dasgupta, S. (Eds.), Proterozoic East Gondwana: Supercontinent Assembly and Breakup. Geol. Society, London, Special Publications No. 206, pp. 231-245.