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Gondwana Research 10 (2006) 349 – 356
www.elsevier.com/locate/gr

GR Letter

Neoproterozoic India within East Gondwana: Constraints from recent geochronologic data from Himalaya☆

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Received 17 September 2005; accepted 7 April 2006
Available online 4 August 2006

Abstract

Recent geochronologic data of detrital zircons and neodymium isotopic signatures of the Himalaya, Arabian–Nubian Shield, and Western Australia–East Antarctica (the Pinjarra Orogen/Circum-East Antarctic Orogen) are assessed to estimate the location of Neoproterozoic basement of the Himalaya.

The protolith of the Higher Himalayan Gneisses is considered to have been derived from the Pinjarra Orogen/Circum-East Antarctic Orogen of Western Australia–East Antarctica, and not from the Indian Craton to the south. This conclusion strongly suggests the juxtaposition of the Indian Craton, which forms the basement of the Himalaya, with the Circum-East Antarctic Orogen during the Neoproterozoic when the protolith of the Higher Himalayan Gneisses deposited.

Keywords: Himalayan basement; Himalayan geochronology; Detrital zircons of Himalaya; East Gondwana assembly; Proterozoic East Gondwana

1. Introduction

India has been regarded to have belonged to East Gondwana and thus to have constituted a part of Rodinia during the Neoproterozoic time, juxtaposing with Antarctica to the southeast (Indian coordinate) and Western Australia to the east (e.g., Yoshida, 1995; Unrug, 1997). Based on this assembly, the Himalayan Orogen is considered to have formed at the northern margin of East Gondwana (Fig. 1), accepting the general understanding (e.g., Gansser, 1964) that the Himalayan basement is common to that of India.

However, recent Palaeomagnetic studies have thrown doubt on the above juxtaposition (e.g., Powell et al., 2001; Fitzsimons, 2003; Pisarevsky et al., 2003), negated the existence of East Gondwana during the Neoproterozoic, and suggested its assembly during the Pan-African period. Discussions on this topic are thus critical in understanding the assembly tectonics of Gondwana and Rodinia.

Recent geochronologic data from the Himalayan Orogen (e.g., Parrish and Hodges, 1996; Gehrels et al., 2003; Martin et al., 2005) have made us possible to examine the location where the source material of the Himalayan rocks came from, and thus to constrain the location where the Indian Craton that formed the basement of the Himalayan rocks was situated.

The present study discusses on the above subject, based on recent geochronologic and isotopic data from the Himalaya, along with those from adjoining East Gondwanan terranes.

2. Recent detrital zircon ages and neodymium isotopic data from the Himalayan rocks

The Himalaya is made up of four major tectonic zones, which successively piled up one over another along major tectonic boundaries all of which dip to the north (Fig. 2) (Upreti, 1997). They are from the north to the south, the Tibetan–Tethys Zone composed of the Palaeozoic to Palaeogene Tethys Sedimentary Series (TSS), the Higher Himalayan Zone composed of the Neoproterozoic (age of their source rocks)-Higher Himalayan Gneisses (HHG), the Lesser Himalayan Zone composed of the Proterozoic Lesser Himalayan Metasedimentary Sequence (LHM), and the foreland basin Siwalik Zone composed of the

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☆ This paper was presented at the 32nd IGC, Florence, 26th August 2004.

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doi:10.1016/j.gr.2006.04.011

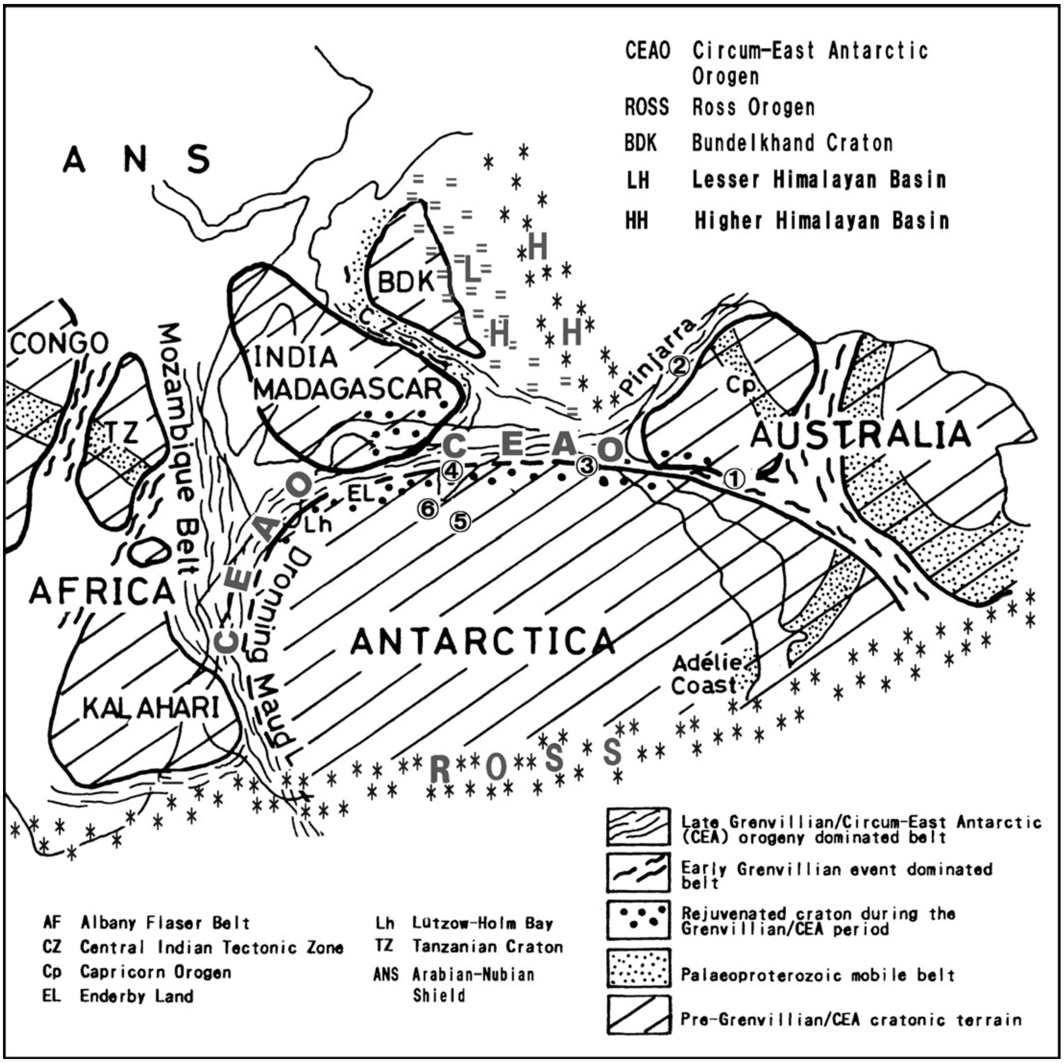

Fig. 1. Gondwana assembly and the Himalayan basins (modified from Yoshida et al., 2003) ①: Albany–Flaser Belt, ②: Northampton–Mullingarra–Leeuwin and Darling Zone, ③: Bunger Hills–Denmann Glacier area, ④: Prydz Bay, ⑤: Grove Mountains, ⑥: Southern Prince Charles Mountains (①–⑥ correspond to those in Fig. 4).

Caenozoic Siwalik Group. The Terai plain juxtaposes further to the south, forming the northern extension of the Indo-Gangetic Plain, filled with late Cenozoic to Recent sediments transposed from the Himalaya.

Until recently, the HHG were regarded to form the basement of the Himalayan Orogen comparable to the North Indian Craton (e.g., Gansser, 1964). However, the protolith of the HHG has now been recognized to be younger than that of the LHM (the Nawakot Group) based on detrital zircon ages as well as Nd isotopic signatures (e.g., Parrish and Hodges, 1996; DeCelles et al., 2000). Ages of detrital zircons from HHG range from ca. 500 Ma to 3400 Ma, with major clusters of ca. 900–1300 Ma and ca. 2500–2700 Ma (DeCelles et al., 2000; Gehrels et al., 2003; Martin et al., 2005; Gehrels et al., 2006, in press). Neodymium model ages (TDM) of HHG lie between 1.5–2.8 Ga and εNd (0) was shown to be slightly to moderately negative as +1 to −20) (Fig. 3) (Parrish and Hodges, 1996; Robinson et al., 2001; Argles et al., 2003). However, Martin et al. (2005) recently showed an average of εNd(0) to be −23 for the HHG rocks in his detailed analysis in the southern Annapurna region. In contrast, detrital zircons from the LHM are older than ca. 1.8 Ga, and Nd model ages range from 1.8 Ga to 2.6 Ga with εNd (0) values strongly negative as −16 to −30 with an average of −23 (Parrish and Hodges, 1996; Robinson et al., 2001; Argles et al., 2003; Martin et al., 2005).

DeCelles et al. (2000) suggested, from their zircon age data, that source material of the LHM might have been derived from the Northern Indian Craton, while that of the protolith of the HHG can be neither from the north India nor from the Lesser Himalayan Zone, but should be somewhere else. They pointed out a possibility of the northern part of the East African Orogen (Arabian–Nubian Shield) to the west of Himalaya (Indian coordinate, cf. Fig. 1) to be the source area for the sedimentation of the original rocks of the HHG. In contrast, Yoshida and Upreti (2004) and Upreti and Yoshida (2005) suggested that the recent geochronologic data from the Arabian–Nubian Shield do not support the idea of derivation of the source material of HHG from the Arabian Nubian Shield. Instead, they pointed out a good conformity of the geochronologic data of the late Mesoproterozoic terranes of Western Australia and East Antarctica (the

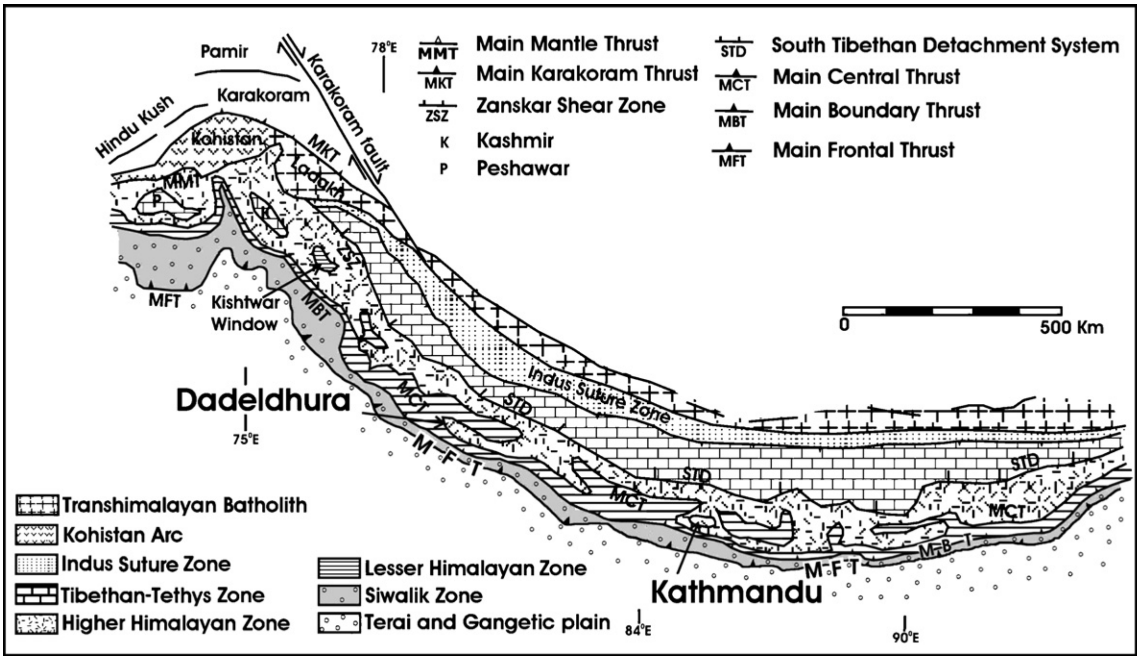

Fig. 2. Geological outline of the Himalayan Orogen (modified from Searle et al., 2003).

Circum-East Antarctic Orogen: CEAO, Yoshida, 1995, the Pinjarra Orogen of Fitzsimons, 2003) with those of HHG, suggesting the source area of the HHG to be the CEAO.

3. Geochronologic data from the Circum East Antarctic Orogen (CEAO)

The late Mesoproterozoic Circum-East Antarctic Orogen (CEAO, Yoshida, 1995; Yoshida et al., 2003) runs around East Antarctica, eastern margin of India, and continues to western (Pinjarra Orogen) and southwestern (Albany–Flaser Orogen) margins of Australia (cf. Fig. 1), most part of this orogen representing extensive rejuvenation during the latest Neoproterozoic–early Palaeozoic times (the Pan-African Orogeny). The Pinjarra Orogen continuing from Western Australia to East Antarctica (Fitzsimons, 2003) forming a part of the CEAO is situated adjacent to the eastern fringe of the Himalaya (cf. Fig. 1). Age peaks of zircons from these areas are mostly composed of ca. 900 to 1300 Ma and ca. 500 to 600 Ma (Fig. 4) (e.g., Fitzsimons, 2003; Yoshida et al., 2003). These data, along with distinct 2.6–2.8 Ga ages of the Yilgarn Craton and surrounding areas (e.g., Myers, 1993) and 2.4–2.5 Ga of the East Antarctic Craton (e.g., Tingey, 1991) are quite consistent with the data from the HHG and in favour of considering the source material of these rocks almost totally to have derived from the CEAO.

4. Discussion

4.1. Different sources of the Lesser Himalayan metasedimentary sequence and the Higher Himalayan Gneisses

Age population of detrital zircon grains recently reported from the Himalaya, along with neodymium isotopic data, suggests that the LHM and the HHG obtained their source material from different areas. The material of the LHM are considered to have been derived from the North Indian Craton, while those of the HHG from some other area (s) (DeCelles et al., 2000; Gehrels et al., 2003).

Myrow et al. (2003) pointed out a strong similarity of the detrital zircon age populations of the younger (Cambrian) rocks (Tal Group) of the Lesser Himalayan Zone of the Uttranchal region in western Himalaya with those of the HHG as well as TSS. However, the initial juxtaposition of the HHG and the LHM is considered to have occurred during the early Palaeozoic (Cambrian and Ordovician) Pan-African Orogeny (e.g., DeCelles et al., 2000; Gehrels et al., 2003), and therefore, the Higher Himalayan Zone and the Lesser Himalayan Zone might have been juxtaposed, or very close each other during the early Cambrian, even though the plate motion at that time was extremely rapid. Therefore, it is natural that both the HHG and LHM have the similar characteristics in the zircon age populations. Further, the younger Lesser Himalayan rocks reported by Myrow et al. (2003) appear to be very similar to the Palaeozoic Phulchawki Group of the central Nepal Himalaya where these Palaeozoic strata are considered to have tectonically traveled from the Tibetan–Tethys Zone by the thrusting-nappe tectonics (Stöcklin, 1980). Although we can no more discuss on this possibility in the Uttranchal region due to the lack of detailed geologic data in Myrow et al.'s (2003) report, we may point out that the geochronologic data of Myrow et al. (2003) are quite conformable with data from Nepal Himalaya by regarding their young Lesser Himalayan rocks as the Tethys Sedimentary Series (or the Phulchawki Group).

The derivation of source material of the HHG not from the Northern Indian Craton suggests that the basement of the protolith sediment of the HHG was juxtaposed with or situated

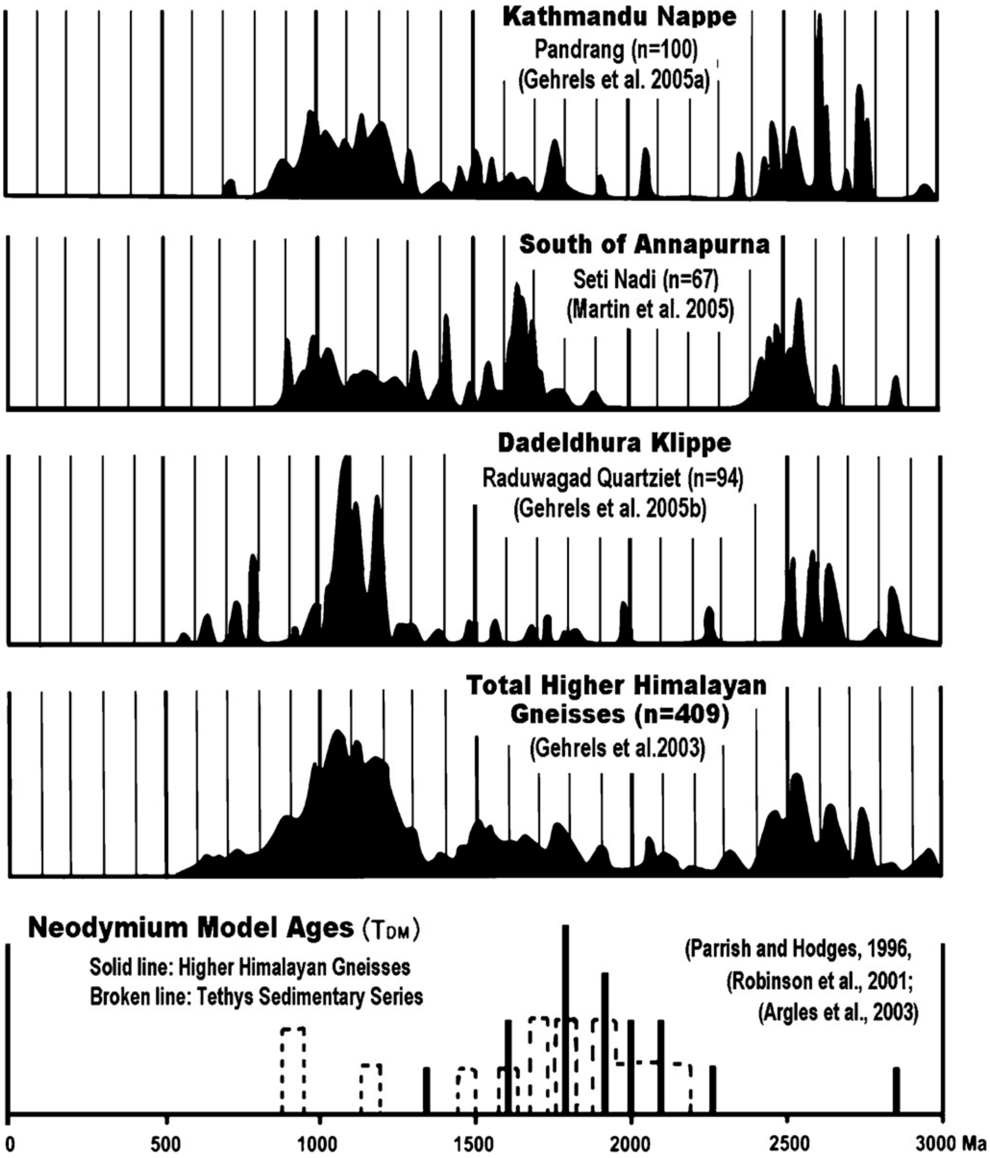

Fig. 3. Detrital zircon ages and TDM ages from the Higher Himalayan Gneisses. (Compiled from Parrish and Hodges, 1996; Robinson et al., 2001; Argles et al., 2003; Gehrels et al., 2003; Martin et al., 2005; Gehrels et al., 2006, in press).

very close to some landmass. This is in contradiction to recent palaeomagnetic studies showing that Indian Craton was isolated and far apart from other land masses (e.g., Pisarevsky et al., 2003; Li et al., 2004; Collins and Pisarevsky, 2005) during the Neoproterozoic.

4.2. Possible source area for the Higher Himalayan Gneisses

DeCelles et al. (2000) suggested a possibility of the northern part of the East African Orogen to have provided source material for the Higher Himalayan Zone. Geochronologic data from the Arabian–Nubian shield forming the northern part of the East African Orogen were recently summarized by Johnson and Woldehaimanot (2003). U–Pb/Pb–Pb/Th–Pb detrital zircon and Rb–Sr whole-rock ages show considerable scatter from ca. 400 to 3000 Ma, but almost all of ages range from 550 to 850 Ma that form only one main peak of the age distribution. Nd isotopic data show that the shield is composed mostly of juvenile crust with TDM ages mostly younger than ca. 1400 Ma, with mostly positive εNd values. There are some older TDM ages and negative εNd values; they are however, obtained only from rocks occurring in restricted small older blocks, as shown on the map given by Johnson and Woldehaimanot (2003). It is difficult to consider that such older blocks were exposed extensively within the Arabian Nubian Shield during the late Proterozoic–early Palaeozoic time; but rather, it is quite probable that they should have been much smaller in extent or even did not expose on the surface of the shield.

It is obvious that the data from the Arabian Nubian Shield are inconsistent with the data from the Higher Himalayan rocks and obviously do not support the suggestion by DeCelles et al. (2000), although zircon populations from TSS appear to support some commitment of the Arabian–Nubian Shield to have provided material to TSS (cf. Upreti and Yoshida, 2005).

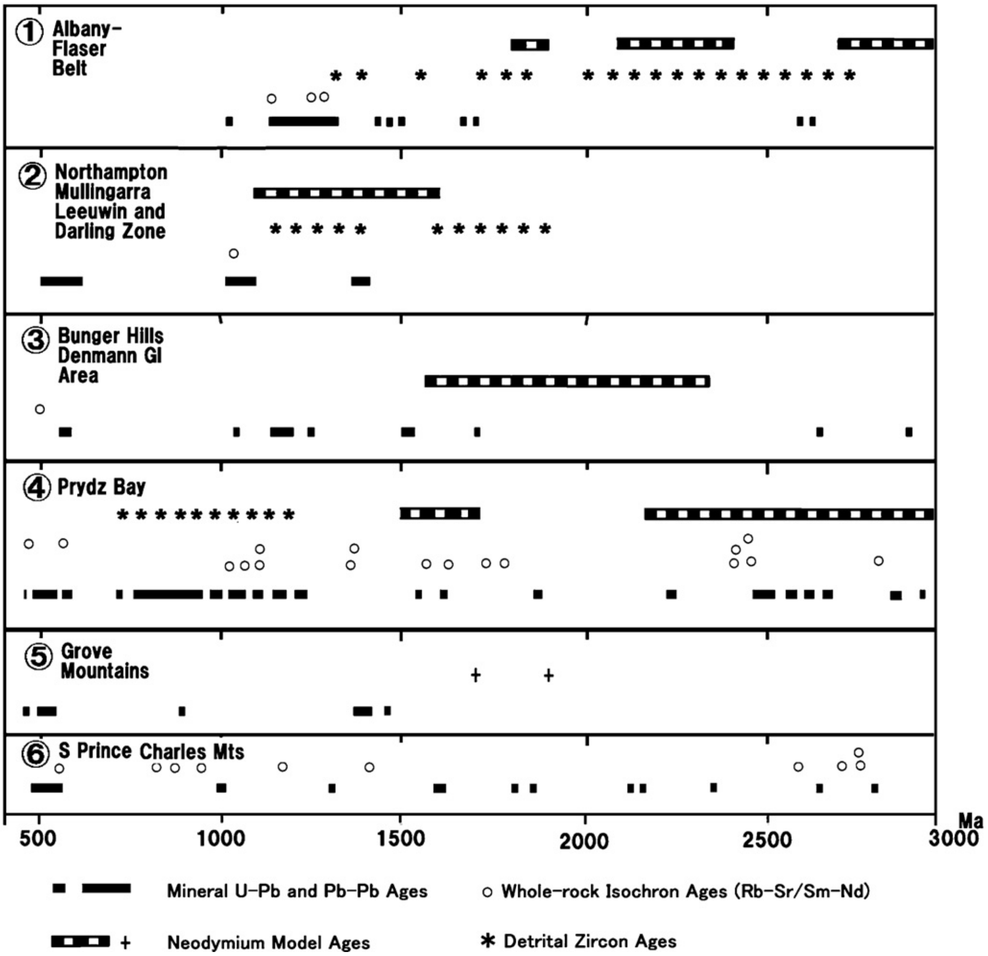

Fig. 4. Geochronologic data from the eastern Circum-East Antarctic Orogen (Pinjarra Orogen). Data are referred to the following literatures. Collerson and Sheraton, 1986; Tingey, 1991; Sheraton et al., 1992; Black et al., 1992a,b; Zhao et al., 1992, 1993; Kinny et al., 1993; Zhao et al., 1995; Hensen and Zhou, 1995; Nelson et al., 1995; Clark et al., 1995; Carson et al., 1996; Zhang et al., 1996; Snape et al., 1997; Clark et al., 1999, 2000; Zhao et al., 2000; Boger et al., 2001; Mikhalsky et al., 2001; Tong et al., 2002; Rasmussen et al., 2002; Fitzsimons, 2003; Zhao et al., 2003 and references therein.

In contrast, the geochronologic and neodymium isotopic data from the CEAO of East Gondwana are quite conformable with the data of HHG as pointed out above. This strongly suggests the derivation of source material of HHG from the CEAO. This argument results in the conclusion that India was not isolated, but was juxtaposed with or very close to the CEAO during the Neoproterozoic time.

4.3. Time of the sedimentation of protolith of the Higher Himalayan Gneisses

The Higher Himalayan Gneisses (HHG) were regarded for long to be the oldest rocks of the Himalayan Orogen and represent the tectonically intruded part of the basement rocks possibly referred to the North Indian Craton (e.g., Gansser, 1964). However, the age of the protolith of HHG has recently been regarded to be Neoproterozoic to early Palaeozoic, between ca. 480–800 Ma based on geochronological studies of detrital zircons (DeCelles et al., 2000). Martin et al. (2005) also reported detrital zircon ages from rocks in the HHG zone surrounding MCT from different sections (valleys) in west-central Nepal, and showed that the youngest ages of examined samples range from 499 to 900 Ma intermingled within a short section. Their results appear to suggest the superposition or close continuation in time of sedimentation of the protolith of HHG with that of Tibetan–Tethys Sedimentary Series (TSS), since the oldest part of the latter is dated back as old as the Ordovician (Nepal Himalaya, e.g., Stöcklin, 1980) or even the Eocambrian (northwest Indian Himalaya, e.g., Bhargava and Bessi, 1999). The above data appear to support the idea that the HHG are stratigraphically continuous with the TSS, including the lower part of and the lower horizon of the TSS (e.g., Gansser, 1964; Le Fort, 1975; Yoshida et al., 2004). The TSS shows strong isoclinal folding structures throughout, with both northward and southward vergencies, having formed in different generation and timing (Hagen, 1969; Steck, 2003; Yoshida et al., 2004). It is considered possible that strong folding structure, and further later tectonic disturbance related to MCT thrusting movement, might have made the HHG rocks to have been complexly intermingled within their younger and older strata.

A possibility can be pointed out that the younger ages (ca. 450–550 Ma) of detrital zircon so far obtained from rocks of the HHG are the result of rejuvenation by the Pan-African and later events, since the rejuvenation of several tens of million years cannot be detected by the U–Pb and Pb–Pb datings. Thus the oldest age of the Pan-African events is considered to be estimated by the oldest ages of the younger age population dated as ca. 534 Ma (Sm–Nd garnet, Argles et al., 2003) from northwestern Himalaya or 548 Ma (Th–Pb monazite, Catlos et al., 2001) from eastern Nepal Himalaya. If this idea is taken into account, the sedimentation of HHG can be older than ca. 550 Ma, and a time gap is considered to have existed between the sedimentation of HHG and TSS as suggested by Gehrels et al. (2003). However, geological evidence supports a gradational relationship between the TSS and HHG as mentioned above.

To conclude, it is considered possible that the protolith of the HHG are mostly older than ca. 550 Ma and that younger ages so far detected for detrital zircons from HHG are affected by lead loss during the Pan-African and later times. It is found that most HHG rocks from the Formation I from the Annapurna region show no detrital zircons younger than ca. 800 Ma (Martin et al., 2005). This may point to a possibility that the protolith of the lower part (Formation I) of the HHG formed early or middle Neoproterozoic, just after ca. 800 Ma. The rare occurrence of rocks with distinctly different ages of youngest detrital zircons in the rocks surrounding MCT (Martin et al., 2005) should be due to the folding and shearing disturbance of the original stratigraphic sequence of HHG as mentioned above. The evidence that the Ordovician to Devonian TSS carry zircons younger than ca. 500 Ma (Gehrels et al., 2003) is also a support to the above consideration. From the above data and discussions, the age of sedimentation of the protolith of HHS is considered to range from early or middle Neoproterozoic to early Palaeozoic.

4.4. East Gondwana during the Neoproterozoic

The palaeomagnetic studies mentioned above that have proposed the Pan-African assembly of East Gondwana have principally been supported by the work of Fitzsimons (2000, 2003) who proposed a hypothesis of the assembly of East Antarctica during the Pan-African period, based mostly on geochronologic constraints. He stressed that pre-Pan-African terranes of East Antarctica should be the aggregate of three different blocks of different origin and were separated each other by Pan-African orogens. He considered that these blocks do not constitute one late Mesoproterozoic orogen (such as the Circum-East Antarctic Orogen of Yoshida, 1995), and that they assembled through the Pan-African Orogeny during the latest Neoproterozoic to earliest Palaeozoic time. The assembly of East Antarctica during the Pan-African period naturally eliminated the existence of East Gondwana during the Neoproterozoic.

The idea of assembly of East Gondwana during the Pan-African period was criticized by Yoshida et al. (2003), based on existing geochronologic and geologic data mostly from East Antarctica. The palaeomagnetic arguments proposing the exclusion of India from East Gondwana during the Neoproterozoic (e.g., Torsvik et al., 2001; Powell et al., 2001; Pisarevsky et al., 2003) have also been criticized by Yoshida et al. (2002), who pointed out that data used to support the location of India to be far apart from Australia during the Neoproterozoic (ca. 750 Ma) may have some problems in their reliability because of the lack of critical discussions on the time of magnetization, since the key areas for the study were reported to have been affected by a Pan-African event.

Our arguments on the location of Indian Craton during the Neoproterozoic are considered to provide a critical constraint to the above discussions. It is strongly pointed out that the detrital zircon data from the Himalaya do not support the isolated India from other crustal blocks, but strongly suggest that some landmass with the Pan-African and Grenvillian ages should have been juxtaposed with. The CEAO is considered to be the best candidate from a variety of evidences so far discussed. Since if the source material of the Higher Himalayan Gneisses were derived from CEAO, the Indian Craton should have been near by or juxtaposed with the CEAO. This is a strong support to the inclusion of India into the East Gondwana and the importance of the CEAO for the formation of East Gondwana as well.

Acknowledgement

The present work was possible during the 2-year study of the first author in Nepal under the Senior Volunteer program of the Japan International Cooperation Agency (JICA). We acknowledge four reviewers, J. Ali, J.J. Veevers, K. Arita and L. Paudel whose comments and corrections were useful in improving the manuscript.

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