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Paleoproterozoic granitoids in the basement of Bangladesh: A piece of the Indian shield or an exotic fragment of the Gondwana jigsaw?

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Abstract

We present the first precise age for Precambrian basement rocks in Bangladesh. These lie within the Dinajpur block, located between the Indian Craton to the southwest and the Shillong Massif to the east. There are no surface outcrops and the rocks were intersected by drill holes. They consist of a suite of tonalitic and granodioritic rocks, variously deformed to granitic gneiss and intruded by younger monzogranite. A tonalite obtained at a depth of 227.48 m in drill hole BH-2 at Maddhapara, in northwestern Bangladesh, records a SHRIMP zircon $^{207}Pb/^{206}Pb$ magmatic age of 1722±6 Ma. Paleoproterozoic rocks with similar magmatic ages are unknown in the adjacent Indian blocks of the Chotanagpur Plateau (Indian Craton) or Shillong Massif. This lack of comparable ages may be due to the paucity of precise radiometric ages from the Indian terrains or, more likely, because there are real age differences, with the buried rocks at Maddhapara representing a separate and discrete microcontinental fragment (the Dinajpur block) that was trapped by the northward migration of India during Gondwana dispersal.

Keywords: Paleoproterozoic rocks; SHRIMP U–Pb dating; Dinajpur block; Bangladesh

1. Introduction

Bangladesh occupies a large part of the Bengal Basin, developed to the south of the Himalayas between the Indian platform to the west and the composite Indo-Burman Ranges and Arakan-Yoma Suture to the east (Fig. 1). The basin is one of the largest continental sedimentary depositories in the world, having been filled since the Miocene by detritus resulting from erosion of the Himalayas, and currently fed by the Ganges, Brahmaputra and Meghna river systems. These supply the world's largest delta, with an area of ~200,000 km^2 (Alam and Curry, 2003), that drains into the Bay of Bengal, south of Dhaka (Fig. 1).

Most of Bangladesh is covered by Tertiary and Quaternary sedimentary deposits which thicken to the south, where they locally exceed 20,000 m in thickness (Curray, 1991). The strata are deltaic to shallow marine in the north, but become progressively more marine to the south (Alam, 1989). Pre-Tertiary rocks are not exposed, although Cretaceous basaltic lavas of the Rajmahal Traps occur in the far west and Early Permian sandstones and shales with coal seams have been reported from drill holes in the Rangpur Saddle and Bogra Shelf areas (Fig. 1).

In 1960, drilling by the Standard Vacuum Oil Company led to the first discovery of crystalline basement rocks beneath the Bengal Basin, with the identification of granitic gneiss at a depth of 2150 m in the Bogra-X1 well (Khan, 1991) (Fig. 2). Subsequently, similar rocks were discovered in drill holes in the shelf area to the north, but at much shallower depths. At Maddhapara, the basement occurs at depths of 128–160 m and this prompted interest in the area as a source of aggregate. Drill holes were sunk into the basement and underground mining operations, via a series of tunnels, commenced in 1994. It is from one of the drill holes (BH-2) that we obtained samples to determine the age of the rocks.

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2. Geological setting

The study area at Maddhapara lies within the Rangpur Saddle (Bakhtine, 1966; Reimann, 1993; Khan, 2002), between the flood plains of the Ganges to the west and Brahmaputra to the east (Figs. 1 and 2). The Rangpur Saddle has been considered by some to represent the northeastern extension of the Indian Shield, possibly linking it to the Shillong Massif and Mikir Hills farther to the northeast (Reimann, 1993). To the north lies the Himalayan Foredeep, while to the south is the Bengal Foredeep, consisting of a series of troughs which extend offshore (Fig. 1); it is here that the deltaic sediments are thickest. Since at least the Eocene, the Calcutta–Mymensingh Hinge Zone (Alam et al., 1990) (Fig. 1) has marked the edge of the continental slope, subdividing the Bengal Basin into two main zones, with deep water sediments accumulating to the south and shelf sediments to the north.

In the Maddhapara area (Fig. 2), between latitudes 25°33′15″ and 25°34′15″ and longitudes 089°03′30″ and 089°04′53″, the basement has been intersected by boreholes, the shallowest of which are drill holes BH-2 and BH-18 at depths of 169.5 and 338.5 m, respectively, and samples from these have previously been subject to petrological and geochemical investigation (Ameen et al., 1998; Kabir et al., 2001).

3. Rock characteristics

The main rock type identified in the boreholes and tunnels at Maddhapara is tonalite (Ameen et al., 1998; Kabir et al., 2001), with lesser amounts of granodiorite and monzogranite. The tonalites are meso- to leucocratic, medium- to coarse-grained hypidiomorphic granular rocks, chiefly composed of plagioclase (22–51%), quartz (17–21%) and hornblende (13–31%), with lesser amounts of biotite (5–13%) and potash feldspar (5–11%) and trace amounts of clinopyroxene, titanite and iron oxides. Mineralogical variation mainly results from the amount of plagioclase relative to the mafic minerals. Biotite is commonly extensively altered to chlorite and plagioclase to sericite. Myrmekite is developed at plagioclase/potash feldspar contacts and biotite tends to be associated with hornblende (Kabir et al., 2001).

Texturally and mineralogically, the granodiorites are similar to the tonalites, but differ in their greater proportions of quartz (22–25%) and potash feldspar (12–19%), and lesser amounts of plagioclase (44–47%), hornblende (2–9%) and biotite (4%). Quartz commonly forms small aggregate clusters and as blebs around certain feldspar and clinopyroxene grains.

The monzogranites are dominated by quartz (24–31%) and feldspar, with the amount of potash feldspar (35% av.) commonly

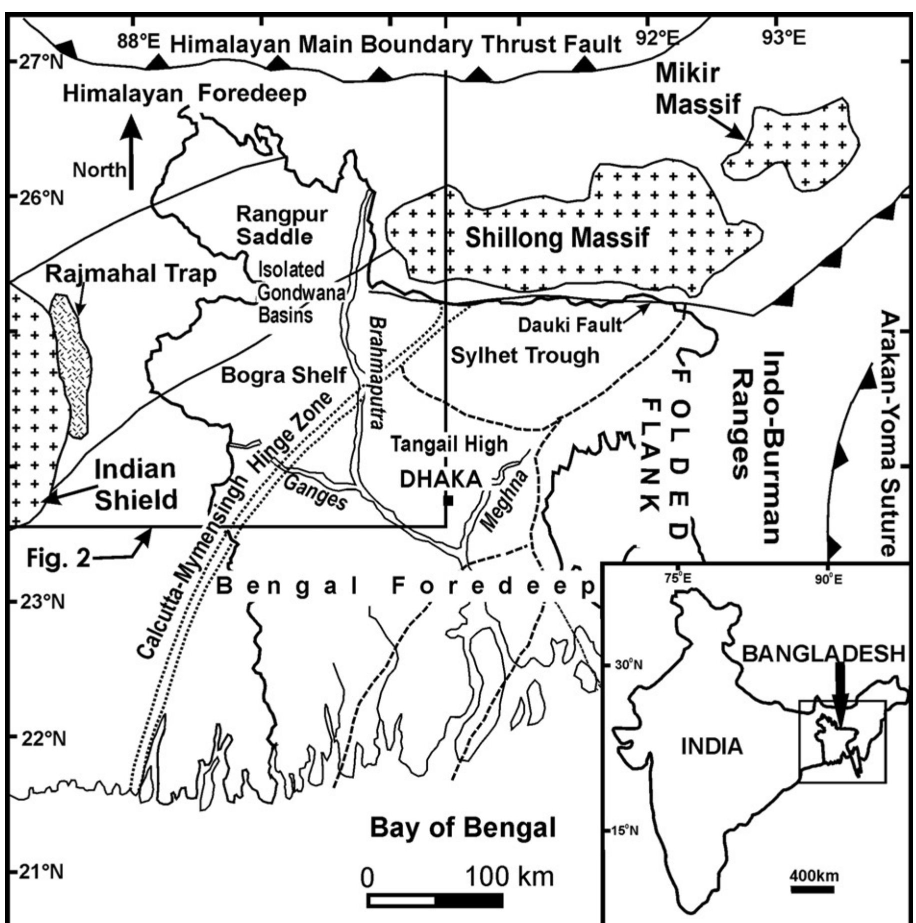

Fig. 1. Tectonic map of Bangladesh and adjoining areas (modified from Alam et al., 1990; Khan, 2002).

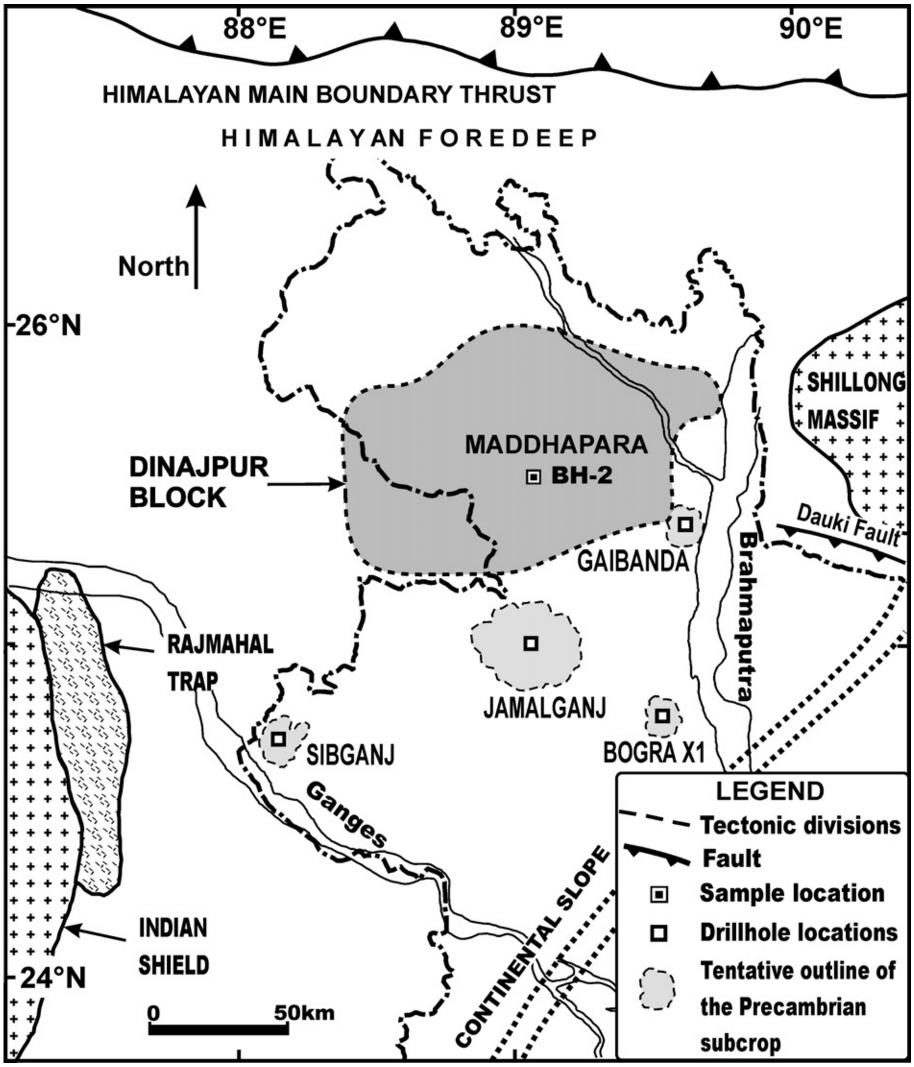

Fig. 2. Major tectonic elements of northwestern Bangladesh and surrounding areas (modified after Alam et al., 1990; Shamshuddin and Abdullah, 1997; Khan, 2002). The outline of the proposed Dinajpur Paleoproterozoic crustal block is taken from Mannan and Mirkhamidov (1981: unpublished report for Petrobangla). Other basement areas to the south are based on drill hole data (reported in Khan, 1991).

in excess of plagioclase (27% av.). Accessory minerals include biotite, hornblende and clinopyroxene, although they are less abundant than in the tonalites and granodiorites. The monzogranites occur mainly as veins and dykes, locally observed cutting the other two rock types (Kabir et al., 2001).

Representative samples were analysed for major element geochemistry by Ameen et al. (1998) and Kabir et al. (2001). In summary, the tonalites are characterised by low SiO_2 and high Al_2O_3, CaO, MgO and Fe_2O_3, reflected in the low quartz and high mafic mineral content, respectively. The K_2O content ranges from 1.48% to 2.16% and the average K_2O/Na_2O ratio of 0.54 confirms their tonalitic affinity. The granodiorites show slightly higher percentages of SiO_2 and lower Al_2O_3, CaO and MgO than the tonalites. The monzogranites are further enriched in SiO_2 and have higher alkali contents than the granodiorites, with K_2O/Na_2O ratios ranging from 1.09 to 1.50.

In the AFM diagram (Fig. 3a), all rocks show a calc-alkaline affinity. However, on most other major element plots (Fig. 3b, c and d), a clear distinction is evident between the tonalites/granodiorites and the monzogranites. The former conforms to a typical tonalite-trondhjemite-granodiorite (TTG) association (Fig. 3b), whereas the latter is calc-alkaline. The tonalites and granodiorites are metaluminous, whereas the monzogranites are peraluminous (Fig. 3c) and have normative corundum.

The geochemistry of the tonalites/granodiorites is consistent with an origin by partial melting of a mafic source (Barker, 1979). It is likely that the granodiorites are related by fractionation to the tonalites. However, the peraluminous nature of the monzogranites suggests that they represent a separate crustal source.

4. Geochronology

4.1. Techniques

Sample MP-1 is a tonalite collected from drill hole BH-2 (lat. 25°33′28″N; long. 89°04′07″E) at a depth of 227.48 m (745′ 10″). Approximately 260 g of rock was disaggregated in a hydraulic press, lightly ground in a tungsten carbide ring mill

Table 1
SHRIMP Th–U–Pb data obtained from sample MP-1 from Maddhapara, Bangladesh

Spot	U ppm	Th ppm	Th/U	Pb ppm	$^{204}Pb/^{206}Pb$	f206%	$^{208}Pb^{a}/^{232}Th$	+/−	$^{208}Pb^{a}/^{206}Pb^{a}$	+/−	$^{206}Pb^{a}/^{238}U$	+/−	$^{207}Pb^{a}/^{235}U$	+/−	$^{207}Pb^{a}/^{206}Pb^{a}$	+/−	%conc	$^{208}Pb^{a}/^{232}Th$ age	+/−	$^{206}Pb^{a}/^{238}U$ age	+/−	$^{207}Pb^{a}/^{235}U$ age	+/−	$^{207}Pb^{a}/^{206}Pb^{a}$ age	+/−
MP-1	467	283	0.60	160	0.00000	0.008	0.0892	0.0014	0.17369	0.00084	0.3105	0.0046	4.53	0.07	0.10570	0.00039	101	1726	26	1743	23	1736	13	1726	7
MP-2	268	162	0.60	92	0.00004	0.067	0.0887	0.0015	0.17185	0.00115	0.3119	0.0047	4.51	0.07	0.10487	0.00053	102	1718	28	1750	23	1733	14	1712	9
MP-3	354	235	0.67	120	0.00025	0.403	0.0872	0.0015	0.19359	0.00140	0.2999	0.0045	4.38	0.07	0.10586	0.00062	98	1690	27	1691	22	1708	14	1729	11
MP-4	180	106	0.59	63	0.00005	0.081	0.0903	0.0016	0.16761	0.00140	0.3182	0.0049	4.63	0.08	0.10546	0.00066	103	1748	30	1781	24	1754	14	1722	11
MP-5	349	205	0.59	120	0.00002	0.034	0.0898	0.0015	0.16803	0.00099	0.3139	0.0047	4.56	0.07	0.10524	0.00046	102	1738	27	1760	23	1741	13	1718	8
MP-6	214	184	0.86	77	0.00000	0.000	0.0888	0.0015	0.24689	0.00127	0.3099	0.0047	4.54	0.07	0.10623	0.00049	100	1719	27	1740	23	1738	14	1736	9
MP-7	183	116	0.63	62	0.00001	0.000	0.0890	0.0015	0.18366	0.00115	0.3071	0.0047	4.50	0.08	0.10623	0.00054	99	1722	28	1726	23	1731	14	1736	9
MP-8	198	124	0.62	69	0.00000	0.034	0.0898	0.0016	0.17915	0.00154	0.3130	0.0048	4.56	0.08	0.10557	0.00070	102	1739	30	1755	24	1741	15	1724	12
MP-9	256	209	0.82	91	0.00003	0.055	0.0894	0.0015	0.23724	0.00136	0.3077	0.0047	4.53	0.08	0.10673	0.00055	99	1731	28	1729	23	1736	14	1744	10
MP-10c	286	247	0.87	102	0.00001	0.024	0.0867	0.0014	0.24352	0.00119	0.3083	0.0047	4.52	0.07	0.10628	0.00048	100	1681	26	1732	23	1734	14	1737	8
MP-10r	211	133	0.63	72	0.00002	0.029	0.0884	0.0015	0.18215	0.00131	0.3067	0.0047	4.44	0.08	0.10508	0.00060	101	1711	28	1725	23	1721	14	1716	10
MP-11	316	293	0.93	119	0.00000	0.000	0.0916	0.0015	0.26511	0.00107	0.3208	0.0048	4.63	0.07	0.10463	0.00040	105	1771	27	1793	24	1754	13	1708	7
MP-12	337	213	0.63	116	0.00005	0.075	0.0892	0.0015	0.18150	0.00105	0.3100	0.0047	4.47	0.07	0.10468	0.00047	102	1727	27	1741	23	1726	13	1709	8
MP-13r	215	101	0.47	72	0.00005	0.074	0.0887	0.0016	0.13335	0.00122	0.3128	0.0048	4.52	0.08	0.10474	0.00061	103	1718	30	1754	23	1734	14	1710	11
MP-13c	269	232	0.86	99	0.00002	0.025	0.0905	0.0015	0.24763	0.00134	0.3148	0.0048	4.58	0.08	0.10558	0.00054	102	1750	27	1764	23	1746	14	1724	9
MP-14	786	1352	1.72	329	0.00000	0.001	0.0865	0.0013	0.48749	0.00102	0.3051	0.0045	4.42	0.07	0.10509	0.00026	100	1677	24	1717	22	1716	13	1716	5

c = core.
r = rim.
f206% is (common ^{206}Pb/total ^{206}Pb) × 100.
%conc = % concordance defined as [(^{206}Pb/^{238}U age)/(^{207}Pb/^{206}Pb age) × 100].
[a] Corrected using measured ^{204}Pb.

and sieved to pass through −100 mesh. Zircons were concentrated using conventional heavy liquid techniques and approximately 75 grains were handpicked onto double-sided adhesive tape and set in Epirez™ resin, along with several grains of the Curtin University Sri Lankan gem zircon standard (CZ3) which has a conventionally measured ^{206}Pb/^{238}U age of 564 Ma (Nelson, 1997). When dry, the mounted zircons were effectively halved during polishing and the mount was gold coated. SHRIMP analytical techniques were similar to those described by Nelson (1997) and Williams (1998), utilising seven-cycle runs through the mass stations.

4.2. Zircon morphology

The zircon grains are pink in colour and are mostly euhedral, with well-formed prism and pyramidal faces and an average length to width ratio of 3:1. Elongate, rod-like inclusions of apatite are common and some crystals also contain irregular inclusions of titanite. Cathodoluminescence (CL) imaging reveals strong internal oscillatory zoning of magmatic origin (Fig. 4). A few grains have central cores where the zoning is less strongly developed, but these cannot be directly correlated to differences in age (see following discussion).

4.3. Results

A total of 16 analyses were made on 14 crystals of sample MP-1 and the results are presented in Table 1 and Fig. 5. During the analytical session, the zircons were run with 12 analyses of the standard, which recorded an uncertainty of 1.5%. Except for analysis 14, which has higher U, Th and Pb (Table 1), the remaining analytical sites show a range in U from 180–467 ppm and Th from 101–293 ppm, with an average Th/U ratio of 0.69. All grains are within 5% of concordance and the total data set define a weighted mean ^{207}Pb/^{206}Pb age of 1722±6 Ma. This has a chi-square value of 1.63, indicating some component of geological scatter. The two grains tested to determine if there was a difference between core and rim ages (MP-1–10 and MP-1–13 in Table 1 and Fig. 4a, b) indicate slightly lower U and Th contents and Th/U ratios for the rims and they also record slightly younger ^{207}Pb/^{206}Pb ages (Table 1). For grain 13, the difference in age is not significant within the uncertainties, but the ages do not overlap within error for grain 10. Although there is a clear difference in CL between the cores and rims of these two grains (Fig. 4a, b), the rims show oscillatory zoning that is identical to that in the cores of other grains (Fig. 4c). Furthermore, younger ^{207}Pb/^{206}Pb ages are also recorded from unzoned centers of some grains (Fig. 4e); there is therefore no direct link between position of analytical site within the grains and their age. We therefore consider that the weighted mean ^{207}Pb/^{206}Pb age of 1722±6 Ma is the best estimate of the crystallisation age of the tonalite.

5. Synthesis

The identification of Paleoproterozoic granitoids in the Maddhapara district of northwestern Bangladesh poses a number of intriguing questions with respect to the geological evolution

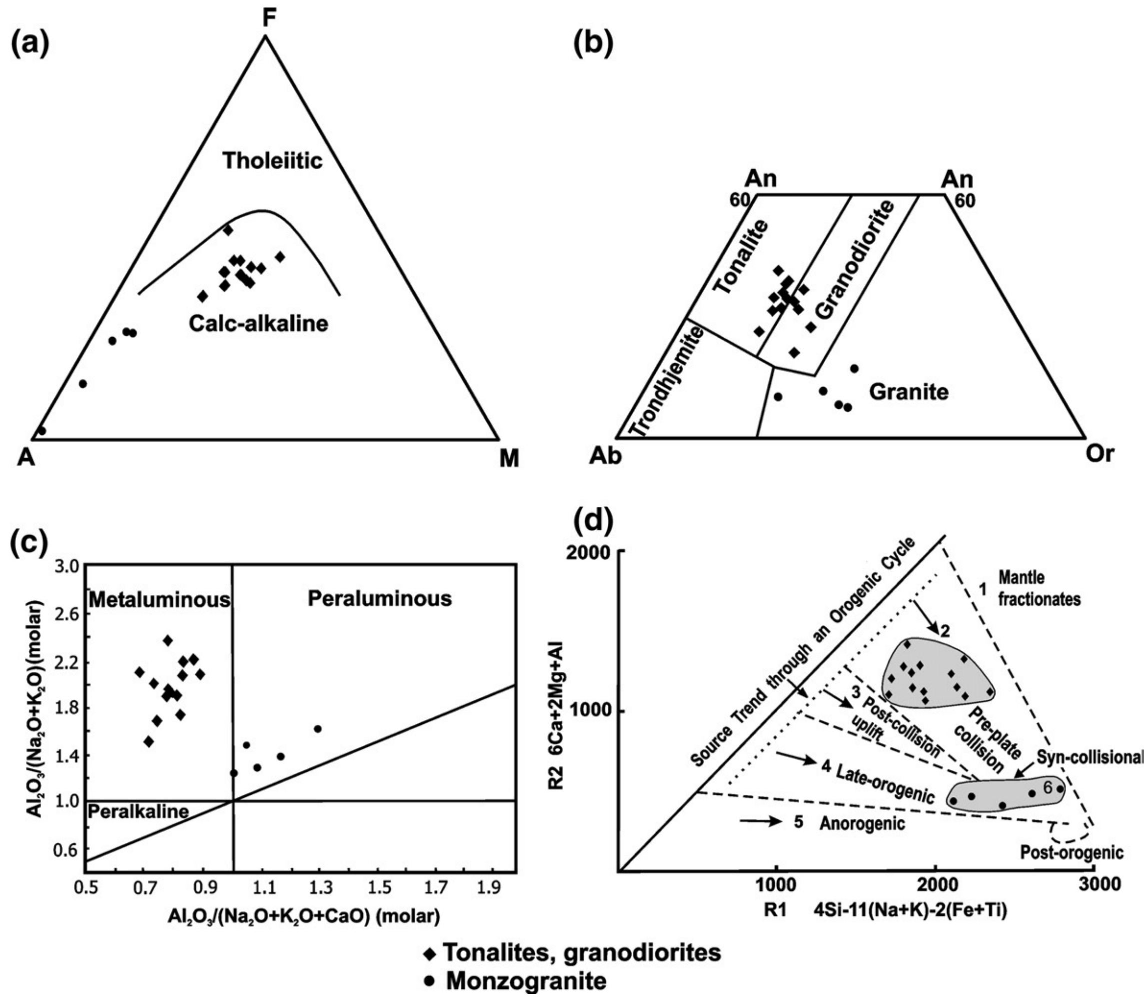

Fig. 3. Selected geochemical diagrams of granitoid samples from Maddhapara, Bangladesh (based on data presented in Ameen et al., 1998; Kabir et al., 2001). (a) AFM diagram (Irvine and Baragar, 1971), (b) Normative Ab–An–Or diagram (Barker, 1979), (c) Shand index diagram (after Maniar and Piccoli, 1989), (d) modified R1–R2 plot of de la Roche (after Batchelor and Bowden, 1985); group 1 — tholeiitic; group 2 — calc-alkaline and trondhjemitic; group 3 — high-potassic calc-alkaline; group 4 — sub-alkaline monzonitic, group 5 — alkaline and peralkaline, and group 6 — anatectic two-mica leucogranites. Grey area enclosing diamonds indicates field of Maddhapara tonalites-granodiorites; grey area enclosing circles indicates field of Maddhapara monzogranites.

and tectonic setting of the area and its relations to adjacent Precambrian blocks of the Indian shield (Fig. 6).

Our preliminary interpretation of the petrographic and limited geochemical data (Ameen et al., 1998; Kabir et al., 2001) is that the tonalites and granodiorites form part of a TTG suite. They plot in the 'pre-plate collisional' field (that includes typical trondhjemites) in the de la Roche diagram of Batchelor and Bowden (1985), and are quite distinct from the monzogranites, which plot in the 'syn-collision' field (Fig. 3d) and thus appear to represent a separate younger suite.

The question arises as to how these rocks may be related to adjacent Precambrian blocks in neighbouring India. If the rocks of the Dinajpur block are indeed the northeastern extension of the Indian shield (Reimann, 1993), then similarities would be expected between them and the rocks exposed here. In the Chotanagpur Plateau, which represents the northeasternmost tip of the shield (I on Fig. 6), the main components are the Chotanagpur granite and associated ortho- and paragneisses, which lie to the north of the Singhbhum Granite and its associated gneisses. Unfortunately, there is a paucity of reliable geochronological data from the area and it is difficult to make a meaningful comparison. The Singbhum Granite has a reported whole-rock Sm–Nd age of 3.12 ± 0.01 Ga (Ghosh et al., 1996), a whole-rock Pb–Pb age of 3163 ± 126 Ma (Sengupta et al., 1991), and a $^{207}Pb/^{206}Pb$ zircon age of 3380 ± 6 Ma (Sengupta et al., 1996). The granite is overlain by a supracrustal sequence which shows a range in whole-rock Sm–Nd and Pb–Pb ages from ~3.09 Ga to ~2.80 Ga (Misra and Johnson, 2005). Although reactivated at several periods during the Proterozoic – at ~2.2, 1.8, 1.6–1.5 and 1.0 Ga (Misra and Johnson, 2005) – no primary rocks with ages of ~1720 Ma are recorded from the area. Mallik et al. (1991) reported rather imprecise Rb–Sr ages of 1599 ± 33 Ma for charnockite, 1522 ± 71 Ma for associated granitic gneiss and 1580 ± 33 Ma for migmatite in the Chotanagpur gneiss complex, north of the Singbhum mobile belt, whilst Ray Barman et al. (1994) reported a Rb–Sr age of 1457 ± 63 Ma for syenite and 1331 ± 125 Ma for another charnockite in the gneiss complex. The closest analogue to the tonalite age of 1722 ± 6 presented here is the very imprecise Rb–Sr age of 1717 ± 102 Ma for gneissic rocks from the Chotanagpur gneiss complex obtained by Mallik et al. (1992).

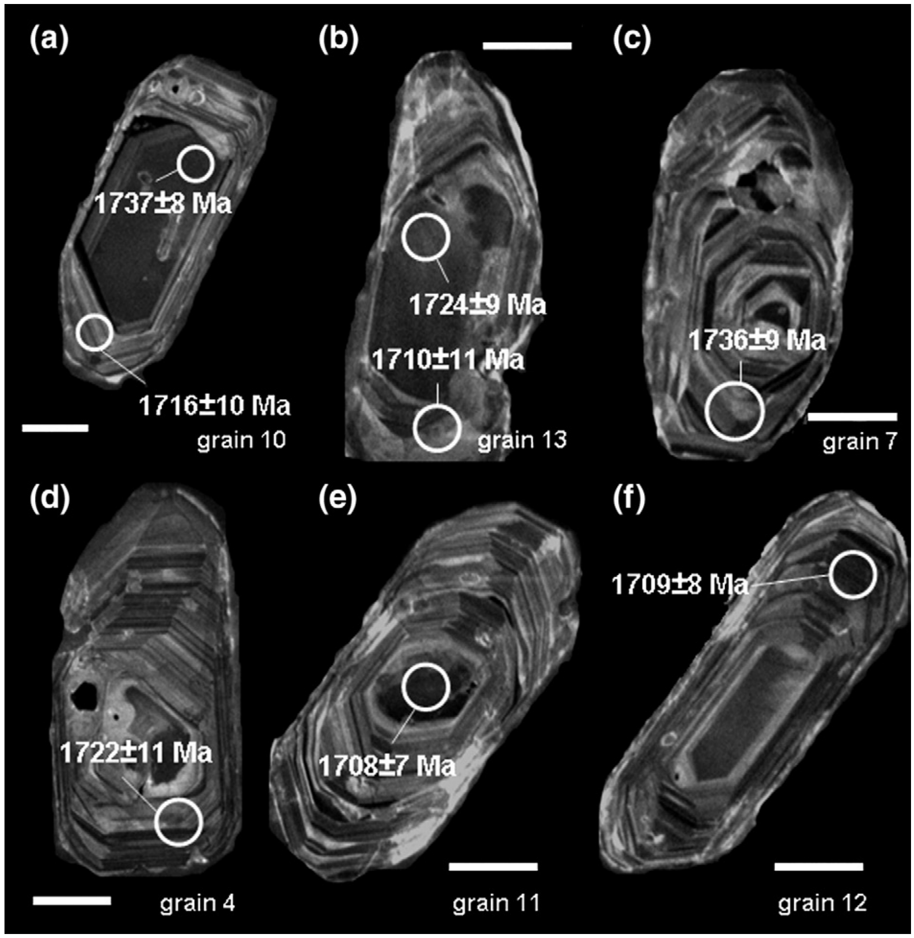

Fig. 4. Cathodoluminescence (CL) images of selected zircons from Bangladesh sample MP-1: (a) grain 10, (b) grain 13; (c) grain 7, (d) grain 4, (e) grain 11, (f) grain 12. The grain numbers are as listed in Table 1. The white circles show the sites of the SHRIMP spots, with age in Ma. The scale bar is 50 μm long in each image.

However, since multi-phase reactivation of rocks in this region has taken place, it appears highly unlikely that this Rb–Sr age reflects a primary magmatic event. Ghose et al. (1973) presented K–Ar data for several Chotanagpur rocks, which included the timing of amphibolite facies metamorphism of basic sills within the metasedimentary rocks between 1086–893 Ma and the subsequent

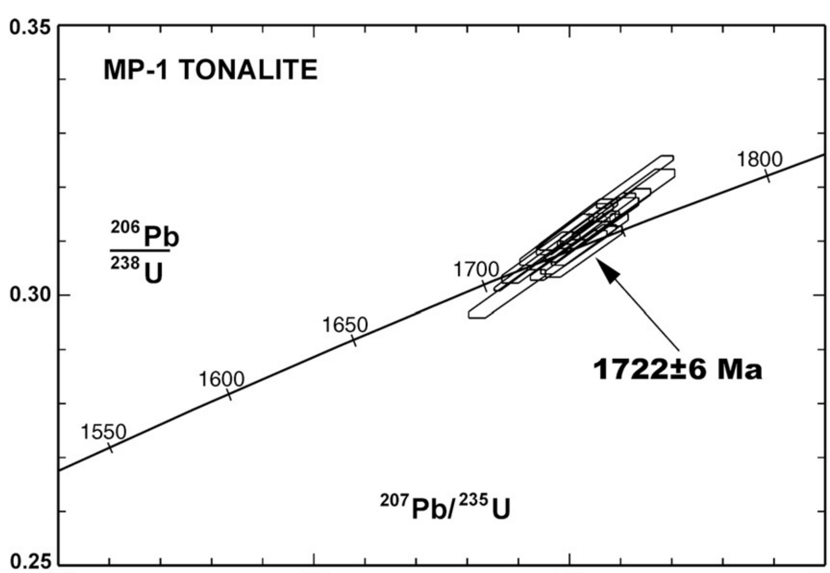

Fig. 5. Concordia diagram of SHRIMP U–Pb data for Sample MP-1 from Bangladesh.

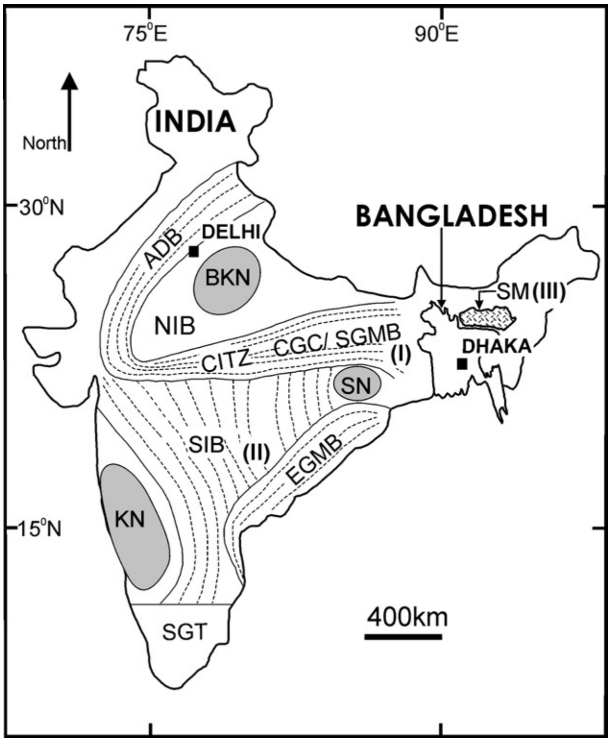

Fig. 6. Simplified tectonic map of India showing Archean cratonic areas and Proterozoic mobile belts (modified from Bhowmik, 2006). EGMB — Eastern Ghats Belt, CGC — Chotanagpur Gneissic Complex, SGMB — Singhbhum Mobile Belt, CITZ — Central Indian Tectonic Zone, ADB — Aravalli–Delhi Belt, SIB — South Indian Block, NIB — North Indian Block, KN — Karnataka Craton, SN — Sataun, BKN — Bundelkhand Gneiss, SGT — South Indian Granulite Terrane, SM — Shillong Massif. I identifies the Chottanagpur area, II the Karimnagar granulite belt and III the Shillong Massif, as discussed in the text.

emplacement and metamorphism of the Chotanagpur granite at 878–800 Ma. They also quoted younger Neoproterozoic and Phanerozoic K–Ar ages from the area. None of these match the age we have obtained from Bangladesh.

Further south in the Indian Shield, Santosh et al. (2004) have reported Electron Probe Micro Analyzer (EPMA) data on zircon, monazite and uraninite from two granulite areas (the Karimnagar and Bhopalpatnam belts) developed either side of the Pranhita–Godarvi rift basin (II on Fig. 6). Zircons from the Bhopalpatnam granulite belt contain 1.9 Ga cores mantled by 1.7 Ga rims and there are also zircons with core ages of 1.7–1.6 Ga, indicating extensive new growth at this time. Santosh et al. (2004) conclude that the Bhopalpatnam granulite belt represents a ∼1.6 Ga collision between the Bastar and Dharwar cratons, whereas the Karimnagar granulite belt, on the southwest side of the Pranhita–Godarvi rift, is part of the Dharwar Craton, since it shows no sign of Proterozoic reactivation. However, the ages reflect the high-grade metamorphic event and there is no evidence of magmatic rocks of this age in the region.

Another possible correlation of the Dinajpur block is with the Shillong Massif and Mikir Hills to the east (Fig. 1 and III on Fig. 6). The Shillong Massif is composed of a variety of east–west trending gneisses, schists and granitoids and has a broadly similar trend to the Central Indian Tectonic Zone (CITZ) further to the west (Acharyya, 2003; Bhowmik, 2006). Some of the schists are aluminous, with sillimanite, corundum and cordierite, suggesting high-temperature/low-pressure metamorphism (Krishnan, 1982). This gneissic complex is reported to be overlain by the Shillong 'series' (Krishnan, 1982), composed of conglomerates, quartzites, iron formations and micaceous schists. More recent work on the Shillong Massif (Awati et al., 1995) supports this interpretation, with the lower sequence (Tyrsad Formation) being Paleoproterozoic in age and the unconformably-overlying, weakly metamorphosed Shillong Formation being somewhat younger. Both formations were intruded by mafic dykes (Khasi 'greenstones') and then by a series of discordant granite plutons (Mylliem granite) during the Neoproterozoic (cf. Awati et al., 1995; Ghosh et al., 2005). Rb–Sr whole-rock age data by Ghosh et al. (1991) from the Patharhkang area in the Shillong Massif (Fig. 6) include a 1714±44 Ma date for a granitic gneiss forming part of the basement complex. Although similar to our SHRIMP U–Pb age for tonalite from the Dinajpur block, it should be noted that the Shillong date was obtained using the Rb–Sr technique and is thus likely to reflect a cooling age following metamorphism and not the emplacement age of the gneissic protolith. More recently, Chatterjee et al. (2007) have obtained EPMA monazite dates from the Garo–Goalpara Hills region in the western part of the Shillong Massif. However, the oldest metamorphic age was 1596±15 Ma, considerably younger than the magmatic age we have obtained from the Dinajpur block in Bangladesh.

An important point to make is the lack of identification, in either the Chotanagpur region of the NE Indian Shield or the Shillong Massif, of any tonalitic granitoids such as those present in the Dinajpur block. Furthermore, as reviewed above, no Paleoproterozoic magmatic ages have been recorded in the literature from these areas either. Although the geochronological data for India are sparse, it is unlikely that such rock types would go undetected. This may, therefore, be an indication that the rocks in Bangladesh constitute a unique and separate entity and are not part of either the Indian shield or the Shillong Massif. Certainly, differences between the Dinajpur block and the Shillong Massif are not unexpected, as its original disposition with respect to the latter is unclear. The Shillong Massif has been affected by major thrusting and strike-slip movement associated with the Himalayan uplift and this distinction is emphasised when the epicentres of recent earthquakes are plotted (Gupta, 1995), the general absence of earthquakes in the Maddhapara area being in marked contrast to the intense activity recorded in and around the Shillong Massif and areas to the east.

Whatever the relationship to adjacent terrains, our new precise SHRIMP U–Pb zircon age of 1722±6 Ma from tonalite in the Dinajpur block at Maddhapara, Bangladesh, provides an important time-line that can be used when correlating future work in adjacent portions of the Indian shield, and in areas wider afield in Gondwana during the reconstruction and tracing of the break-up of that supercontinent.

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