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Géochimie (Géochronologie)

Palaeoproterozoic U–Pb SHRIMP zircon age from basement rocks in Bangladesh: A possible remnant of the Columbia supercontinent

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Abstract

We present new U–Pb SHRIMP zircon geochronological data for basement rocks in Bangladesh, and discuss the relationship with the formation of the Columbia supercontinent. Euhedral zircons from a diorite sample yield a concordia age of 1730 ± 11 Ma, which is interpreted as the crystallization age. The Palaeoproterozoic age of the examined basement rock and the common occurrences of similar ~1.7-Ga geologic units in the Central Indian Tectonic Zone and Meghalaya-Shillong Plateau in Indian Shield suggest their apparent continuation. This, together with the occurrence of similar ~1.7-Ga geologic units in the Albany-Fraser belt in Australia and East Antarctica, are used to suggest that the basement rocks in Bangladesh formed towards the final stages of the assembly of the Columbia supercontinent. ***To cite this article: I. Hossain et al., C. R. Geoscience 339 (2007).***

Résumé

Âge paléoprotérozoïque U–Pb (SHRIMP) sur zircon du socle du Bangladesh : un témoin possible du supercontinent Columbia. De nouvelles mesures d'âges U–Pb sur des zircons provenant d'un socle situé au Bangladesh, réalisées à l'aide de la microsonde ionique SHRIMP II (CAGS, Pékin, Chine), sont discutées, en relation avec la formation du supercontinent Columbia. Des zircons automorphes provenant d'une diorite donnent un âge concordia de 1730 ± 11 Ma, interprété comme âge de cristallisation. L'âge paléoprotérozoïque de ce socle, ainsi que la présence commune d'unités géologiques d'âges comparables (environ 1,7 Ga) dans la zone tectonique Centre-Indienne et le plateau Meghalaya-Shillong du bouclier Indien, suggèrent une apparente continuité de toutes ces unités. Ces données, ainsi que l'existence de domaines d'âges comparables dans la ceinture Albany-Fraser, en Australie, et dans l'Est de l'Antarctique, suggèrent que les roches du socle du Bangladesh se sont formées au cours des stades terminaux du supercontinent Columbia. ***Pour citer cet article : I. Hossain et al., C. R. Geoscience 339 (2007).***

Keywords: U–Pb SHRIMP age; Basement rock; Palaeoproterozoic; Bangladesh; Columbia supercontinent

Mots clés : Âge U–Pb SHRIMP ; Socle ; Paléoprotérozoïque ; Bangladesh ; Supercontinent Columbia

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1. Introduction

Supercontinents containing most of the earth's continental crust are considered to have existed at least twice in Proterozoic times. The younger one, Rodinia, formed ~1.0 Ga ago [17] by accretion and collision of fragments produced by break-up of the older supercontinent, Columbia, which was assembled by global-scale 2.0–1.8-Ga collisional events [30]. Based on the distribution of U–Pb zircon ages, coupled with Nd and Hf isotope data, Condie [7] recognized that there is a major peak in juvenile crustal production rate at ca. 1.9 Ga (Fig. 1). The ~2.1–1.7-Ga distribution in Fig. 1 probably corresponds to inboard manifestations of subduction/collision/post-collision-related magmatism, associated with the formation of the Columbia supercontinent. As with the case of any supercontinent, the exact configuration of the Columbia supercontinent awaits more and precise geochronological information from separated continental fragments, providing a means to establish former linkages.

Basement rocks from Bangladesh were never considered in the configuration of Columbia, partly due to the lack of exposed igneous or metamorphic rocks. The geology of Bangladesh is characterized by extensive Tertiary and Quaternary successions, forming part of one of the largest continental sedimentary depositories in the world [8]. Drill-hole geological investigations from the Maddhapara area (between 89°03′30″E to 89°04′53″E and 25°33′15″N to 25°34′15″N; Fig. 2), northwestern part of Bangladesh, reveal that basement rocks occur at a shallow depth (~128 m; e.g., [19]). Ameen et al. [2] recently reported a U–Pb SHRIMP age of 1722 ± 6 Ma from a tonalitic core sample from this area (obtained at a depth of 227.48 m in drill hole BH-2). They consider the buried rocks at Maddhapara to represent a separate and discrete microcontinental fragment that was trapped by the northward migration of India during Gondwana dispersal. Here we report a new U–Pb SHRIMP zircon age for a dioritic sample (obtained from tunnel, at a depth of 276 m), and based on a literature survey, we attempt to evaluate the significance of basement rocks from Bangladesh in a supercontinent framework. We suggest the possibility of basement rocks in Bangladesh forming the continuation of the Central Indian Tectonic Zone and Meghalaya-Shillong Plateau in the Indian Shield, based on available geochronological and palaeogeographical information.

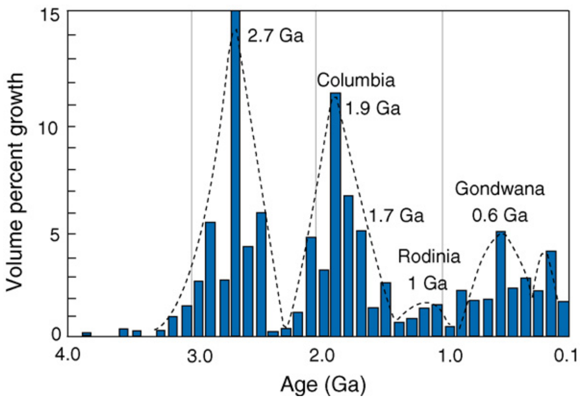

Fig. 1. Frequency distribution of juvenile crustal production with time. Juvenile crust ages are U–Pb zircon ages used in conjunction with Nd and Hf isotope data (modified after [15]).

Fig. 1. Distribution en fréquence du volume de croûte juvénile créée en fonction du temps. Les âges de la croûte juvénile sont des âges zircon U–Pb, comparés aux données des isotopes Nd et Hf et des associations lithologiques (d'après [15], modifié).

2. Geologic and petrographic information

The basement rocks in Bangladesh are dominantly dioritic rocks, with minor granitoids. Amphibole and biotite form the dominant mafic minerals in all the rock types. Although late hydrothermal alteration is observed in some of the collected samples, the diorite sample (SL1) from which zircons were extracted for geochronology is fresh and shows no evidence of alteration. The sample is medium to coarse-grained and composed dominantly of plagioclase, hornblende, biotite, and quartz (Fig. 3A). Light pink to colourless zircon crystals (size range: 120 to 440 μm; length/width ratios: 3:2 to 4:1) are commonly included in large euhedral hornblende and subhedral to euhedral biotite. They exhibit typical magmatic oscillatory zoning, as seen in cathodoluminescence (CL) images (Fig. 3B). Some coarse zircons have isolated cores mantled by concentric zoning (e.g., grain SL1-6 in Fig. 3B). However, they do not show obvious age differences, as illustrated below. This suggests that all parts of the zircon grains grew close and probably preserve the magmatic crystallization age.

3. Geochronology methods

For U–Pb SHRIMP zircon dating, zircons were separated from the diorite sample (SL1) using conventional techniques. The zircon crystals were mounted in an epoxy disc together with standard zircon, and then polished to expose their cores. The internal structure for analyzed zircons was observed using CL images (e.g., Fig. 3B). Using guidance from the CL images, zoned mantle parts of zircons were

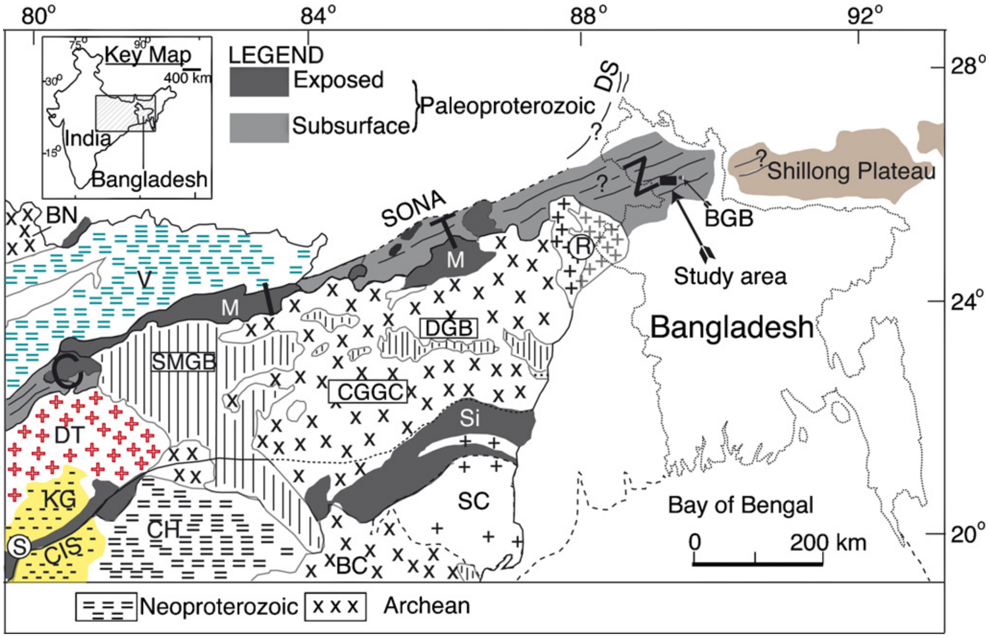

Fig. 2. Location map of the Maddhapara basement rocks in Bangladesh, showing tectonic elements and their relationship with CITZ (modified after [1,19,27]). Abbreviations: BC, Bastar Craton; BN, Bundhelkhand Craton; BGB, Barapukuria Gondwana Basin; CGGC, Chotanagpur Granite Gneiss Complex; CH, Chattisgarh; CIS, Central Indian Shear Zone; DGB, Damodar Gondwana Basins; DS, Darjeeling-Sikkim Himalaya; DT, Deccan Trap; KG, Karimnagar Granulite Belt; M, Mohakoshal and equivalents; R, Rajmahal Trap; S, Sausar; SC, Singhbhum Craton; Si, Singhbhum (Palaeoproterozoic); SMGB, Son Mahanadi Gondwana Basins; SONA, Son Narmada Lineament; V, Vindhyan.

Fig. 2. Carte de situation des roches du socle Maddhapara au Bangladesh, montrant les éléments tectoniques et leurs relations avec le CITZ (d'après [1,19,27], modifié). Abréviations : BC, craton de Bastar ; BN, craton de Bundhelkhand ; BGB, bassin gondwanien de Barapukuria ; CGGC, complexe granito-gneissique de Chotanagpur ; CH, Chattisgarh ; CIS, zone de cisaillement Centre-Indienne ; DGB, bassins gondwaniens de Damodar ; DS, Himalaya de Darjeeling-Sikkim ; DT, trap du Deccan ; KG, ceinture granulitique de Karimnagar ; M, Mohakoshal et ses équivalents ; R, trap de Rajmahal ; S, Sausar ; SC, craton de Singhbhum ; Si, Singhbhum (Paléoprotérozoïque) ; SMGB, bassins gondwaniens de Son Mahanadi ; SONA, linéament de Son Narmada ; V, Vindhyan.

analyzed for U–Pb isotopes and U, Th and Pb concentrations using a SHRIMP II ion microprobe at the Institute of Geology, Chinese Academy of Geological Sciences, Beijing. The analysis follows the methods of Compston et al. [6] and Williams and Claesson [38]. Measurements were corrected using reference zircon standard Temora (417 Ma; [4]). The common Pb was estimated from ^{204}Pb counts, and the data processing was carried out using Isoplot [20].

4. Results

The analytical results of zircons in sample SL1 are listed in Table 1, and all analyzed zircons are shown in Fig. 3B. Ages are weighted means with 1σ errors. Eight individual analyses were carried out for seven zircon grains. The measurements have been done on large core or mantle parts of the grains. Although the analyzed spots have a wide range in concentrations of U (137–1159 ppm), Th (79–479 ppm), and ^{206}Pb (29.9–307 ppm), there is no systematic correlation between the estimated ^{207}Pb/^{206}Pb and U, Th and Pb contents, and Th/U ratio (Table 1). Seven spots of zircons have a consistent ^{206}Pb/^{238}U age between 1720 $\pm$ 45 to 1791 $\pm$ 44 Ma, yet spot SL1.6.1 yielded a younger ^{206}Pb/^{238}U age of 1440 $\pm$ 37 Ma (Table 1). This is due to recent Pb loss of the analyzed spot as shown in the concordia diagram (Fig. 4A). None of the zircon analyses showed any inheritance. All the analyzed zircons gave ^{207}Pb/^{206}Pb ages of 1678 $\pm$ 34 to 1737 $\pm$ 7 Ma. Seven concordant data yielded a concordia age of 1730 $\pm$ 11 Ma (95% confidence limit, MSWD = 0.6, probability of concordance = 0.24) (Fig. 4A). As the MSWD is indistinguishable from unity for this number of data points, it is not statistically significant to attempt any editing of the analyses. The concordia age is almost consistent with the weighted mean ^{207}Pb/^{206}Pb age of 1728 $\pm$ 11 Ma for all eight spots (95% confidence limit, MSWD = 0.78, probability of equivalence = 0.60) (Fig. 4B). Our U–Pb SHRIMP age is consistent with the available SHRIMP zircon age of 1722 $\pm$ 6 Ma for a tonalite from the same

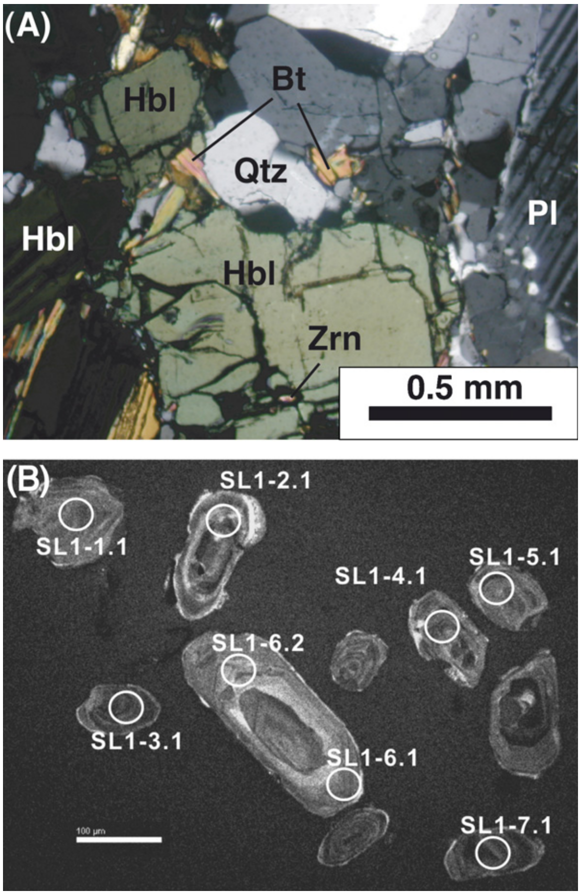

Fig. 3. Photomicrographs of zircons examined in this study. (**A**) Photomicrograph showing typical mineral assemblage of analyzed diorite (sample SL1). Crossed polars. Hbl: hornblende, Bt: biotite, Pl: plagioclase, Qtz: quartz, Zrn: zircon. (**B**) CL image of zircons in sample SL1 with analysed spots.

Fig. 3. Microphotographies des zircons examinés dans le cadre de cette étude. (**A**) Assemblage minéralogique typique de la diorite analysée (échantillon SL1). Hbl : hornblende, Bt : biotite, Pl : plagioclase, Qtz : quartz, Zrn : zircon. (**B**) Image (CL) de zircons analysés dans l'échantillon SL1.

area [2]. Therefore, it can be concluded that the magmatic crystallization of the basement rocks in Bangladesh took place at ca. 1.7 Ga.

5. Discussion

Interpretations of configuration of Proterozoic supercontinents are controversial because of the inherent difficulties and uncertainties in matching continental fragments that were dispersed prior to the assembly and subsequent break-up and dispersal. The case of the Columbia supercontinent is no different. The recognition of the 2.1- to 1.8-Ga collision/accretionary

Table 1
Summary of zircon U-Th-Pb analyses in sample SL1 from Maddhapara

Tableau 1
Résumé des analyses U-Th-Pb sur zircon dans l'échantillon SL1 (Maddhapara)

Spots	U (ppm)	Th (ppm)	$^{206}Pb^{*}$ (ppm)	$^{206}Pb_c$ (%)	$^{232}Th/^{238}U$	Age (Ma)**			Isotope ratios (±%)**			
						$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb^{*}$	$^{208}Pb/^{232}Th$	$^{238}U/^{206}Pb$	$^{207}Pb^{*}/^{206}Pb^{*}$	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$
SL 1.6.1	137	79	29.9	1.22	0.59	1.440 ± 37	1.723 ± 48	1.455 ± 74	4.000 ± 2.9	0.1055 ± 2.6	3.64 ± 3.9	0.2502 ± 2.9
SL1.6.2	208	130	57.9	0.88	0.65	1.791 ± 44	1.678 ± 34	1.799 ± 65	3.122 ± 2.8	0.1030 ± 1.9	4.55 ± 3.4	0.3203 ± 2.8
SL1.5.1	318	238	86.0	0.35	0.77	1.759 ± 42	1.708 ± 21	1.753 ± 53	3.188 ± 2.7	0.1046 ± 1.1	4.52 ± 3.0	0.3137 ± 2.7
SL 1.4.1	1159	479	307.0	0.10	0.43	1.729 ± 41	1.737 ± 07	1.677 ± 51	3.250 ± 2.7	0.1063 ± 0.4	4.51 ± 2.7	0.3077 ± 2.7
SL1-3.1	258	192	69.8	0.70	0.77	1.754 ± 44	1.722 ± 25	1.786 ± 66	3.198 ± 2.9	0.1054 ± 1.4	4.55 ± 3.2	0.3127 ± 2.9
SL 1-2.1	295	202	77.9	0.59	0.71	1.720 ± 45	1.719 ± 22	1.668 ± 56	3.271 ± 3.0	0.1053 ± 1.2	4.44 ± 3.2	0.3057 ± 3.0
SL1-1.1	414	325	111.0	0.39	0.81	1.751 ± 42	1.714 ± 18	1.736 ± 50	3.204 ± 2.7	0.1050 ± 1.0	4.52 ± 2.9	0.3121 ± 2.7
SL1-7.1	271	153	73.2	0.32	0.58	1.757 ± 44	1.724 ± 20	1.804 ± 58	3.192 ± 2.9	0.1056 ± 1.1	4.56 ± 3.1	0.3133 ± 2.9

Errors are 1 sigma; Pb_t and Pb^{*} indicate the common and radiogenic portions, respectively.
Error in standard calibration was 0.74% (not included in above errors, but required when comparing data from different mounts).
Spots SL1.1.1 and SL1.7.1 correspond to core, while other analyses have been done on zoned mantle parts of zircons.
** Common Pb corrected using measured ^{204}Pb.

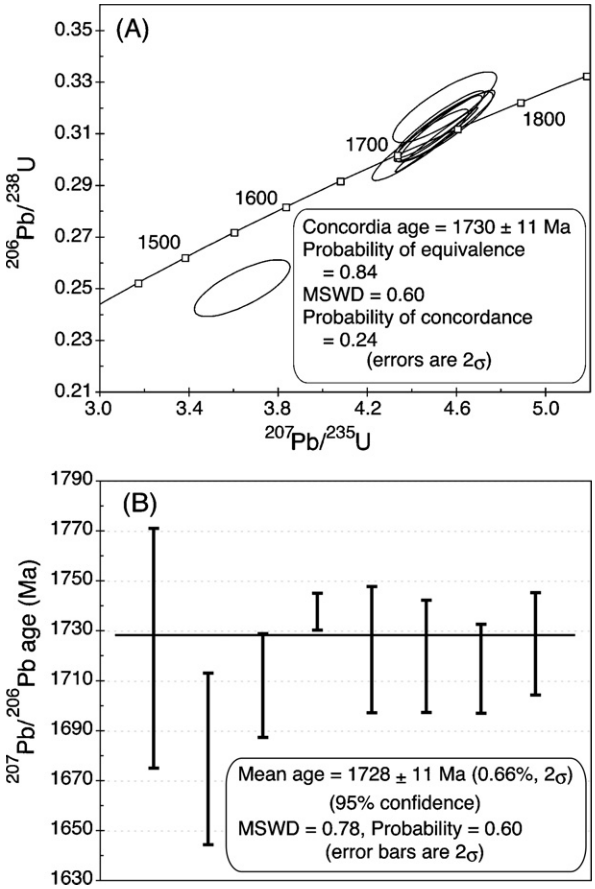

Fig. 4. (**A**) Concordia diagram showing SHRIMP analyses of zircons in sample SL1. (**B**) Diagram showing the weighted mean age for zircons in sample SL1 from Maddhapara.

Fig. 4. (**A**) Diagramme concordia montrant les analyses SHRIMP des zircons de l'échantillon SL1. (**B**) Diagramme donnant les âges moyens pondérés des zircons de l'échantillon SL1 provenant de Maddhapara.

events on nearly every continent, including the Transamazonian of South America, the Birimian of West Africa, the Trans-Hudson and its age-equivalent of North America, the Svecofennian and Kola-Karelia of northern Europe, the Akitan and Central Aldan of Siberia, the Capricorn of Western Australia, the Transantarctic Mountains of Antarctica, the Trans-North China in North China, the Central Indian Tectonic Zone in India, etc., led geologists to consider that they represent the fragments of a pre-Rodinia supercontinent that formed in response to global-scale collision at this time (e.g., [7,30,41,43]).

The two possible configurations of Columbia, proposed by Rogers and Santosh [30] and Zhao et al. [41], differ mainly in the position of the North China Craton (NCC), with the former considering that NCC was adjacent to the Baltic and Amazonian cratons, and the latter placing the eastern margin of NCC against the western margin of the Indian Shield. Recent studies reported the occurrence of ∼1.8-Ga to ∼1.65-Ga mafic-felsic intrusions, including anorthosite–mangereite–charnockite–granite (AMCG) suites and rapakivi granites, in NCC (e.g., [40,42]). Similar Palaeoproterozoic AMCG and rapakivi magmatism is widespread along the margin of Amazonia and Baltica [11]. No such magmatism is reported from the western margin of the Indian shield during the concerned time frame. Hence, we follow the configuration of the Columbia supercontinent given in Rogers and Santosh [31] (Fig. 5), where NCC is placed adjacent to Baltica. If Bangladesh was part of this configuration, it is most likely to be placed between eastern India, East Antarctica, and southwestern Australia. To evaluate this, we review the Palaeoproterozoic rock record from these continental fragments.

Although the geology of the ice-covered interior of the East Antarctic shield is poorly known, recent geological studies in the exposed basement of the Transantarctic Mountains and Wilkes Land margin suggest a correlation with Palaeoproterozoic granitoid rocks and Mesoproterozoic mafic igneous rocks from the Gawler and Curnamona cratons of Australia [14,23,25,26]. Subduction-related batholiths between approximately 1.7 and 1.6 Ga in the Albany-Fraser belt in Australia [22] have similar counterparts in the Windmill islands and Bunger Hills in Antarctica, suggesting attachments in pre-drift configuration [16].

In eastern India, zircons with core ages of 1.7–1.6 Ga from granulites (e.g., [33]) occurring along the flanks of Palaeoproterozoic rift basins suggest new growth at this time. These rift basins, which had matching rifts in the Columbia region of western North America, were instrumental in the configuration of Columbia proposed by Roger and Santosh [30]. One of the prominent features from the Indian shield, which figures in the Columbia supercontinent configuration, is the Central Indian Tectonic Zone (CITZ), considered as the collision zone along which the North and South Indian Blocks amalgamated during the Palaeoproterozoic (Fig. 2) [18,21,39]. Although recent works showed Mesoproterozoic (∼1.5-Ga) reworking of some of the Palaeoproterozoic lithologies from CITZ [3], the available geochronological data [9,35] suggest that the collision in central India progressed between 2100 and 1700 Ma. This is supported by the 2040–2090-Ma age of the ultra-high temperature metamorphic event [3], and a number of granitoid magmatic events, bracketed between 2.0–1.7 Ga, from the CITZ [1,28,29,32,34].

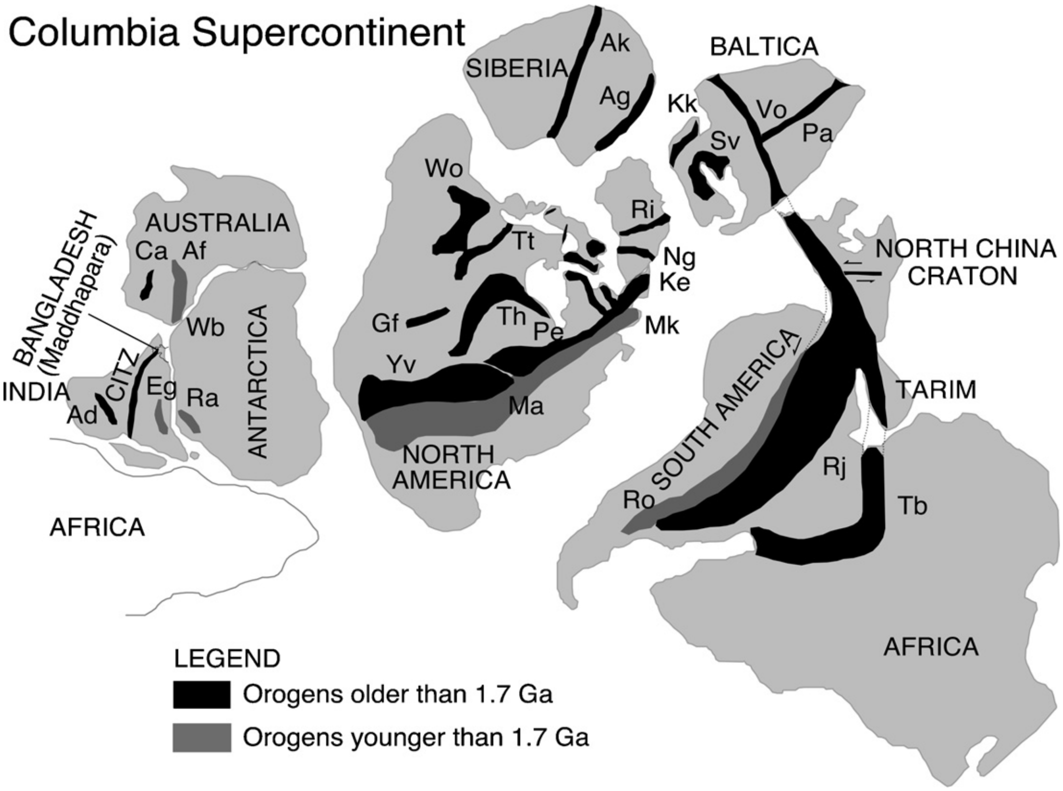

Fig. 5. Schematic map showing the Columbia supercontinent with its remnant in Bangladesh, as a continuation of the CITZ (modified after [31]). Abbreviations of orogens: Af, Albany-Fraser; Ad, Aravalli-Delhi; Ag, Angara; Ak, Akitkan; Ca, Capricorn; CITZ, Central Indian Tectonic Zone; Eg, Eastern Ghats; Gf, Great Falls; Ke, Ketilidian; Kk, Kola-Karelia; Ma, Mazatzal; Mk, Makkovikian; Ng, Nagssugtoqidian; Pa, Pachemel; Pe, Penokian; Ra, Rayner; Ri, Rinkian; Rj, Rio Negro-Juruena; Ro, Rondonian; Sv, Sveckofennian; Tb, Transamazonian–Birimian; Th, Trans-Hudson; Tt, Thalston-Thelon; Vo, Volhyn; Wb, Windmill Islands–Bunger Hills; Wo, Wopmay; Yv, Yavapai.

Fig. 5. Carte schématique du supercontinent Columbia, indiquant ses reliques au Bangladesh, en tant que continuation de la CITZ (modifiée d'après [24]). Abréviations des orogènes : Af, Albany-Fraser ; Ad, Aravelli-Delhi ; Ag, Angara ; Ak, Akitkan ; Ca, Capricorne ; CITZ, zone tectonique Centre-Indienne ; Eg, Ghats orientaux ; Gf, Grerat Falls ; Ke, Ketilidian ; Kk, Kola-Karélie ; Ma, Mazatzal ; Mk, Makkovikian ; Ng, Nagssugtoqidian ; Pa, Pachemel ; Pe, Penokien ; Ra, Rayner ; Ri, Rinkien ; Rj, rio Negro-Juruena ; Ro, Rondonien ; Sv, Svekofennien ; Te, Transamazonien–Éburnéen ; Th, Trans-Hudson ; Tt, Thalston-Thelon ; Vo, Volhyn ; Wb, Windmill Islands–Bunger Hills ; Wo, Wopmay ; Yv, Yavapai.

Further north, extensive occurrence of ∼1.9-Ga-old porphyritic granites is observed in the lesser Himalayas [36,37]. DeCelles et al. [10] reported detrital zircon ages of ∼2.0-to 1.8-Ga range from the Lesser Himalaya of Nepal. Granitic gneiss dated at ∼1.7 Ga occurs in the Darjeeling-Sikkhim Himalaya [24]. Towards the northeast, Ghosh et al. [12,13] reported ages as old as 1.7 Ga for basement granitic gneisses from the Meghalaya plateau, while Chatterjee et al. [5] reported ages of 1.5 Ga from gneissic rocks within the Shillong Plateau.

The above summary of geochronological information gives ample justification to the consideration of basement rocks in Bangladesh as being the apparent continuation of the Central Indian Tectonic Zone with further extension into the Meghalaya-Shillong Plateau. This differs from the suggestion of Ameen et al. [2] that the basement rocks in Bangladesh constitute a unique and separate entity, with no meaningful comparison with the CITZ and/or Meghalaya-Shillong Plateau. Finally, the common occurrence of ∼1.7-Ga geologic units on nearly every continent (e.g., [7,30,41,43]) warrants the consideration of basement rocks of Bangladesh in the Columbia supercontinent framework. Thus, U–Pb SHRIMP zircon ages of diorite (1730 ± 11 Ma; this study) and tonalite (1722 ± 6 Ma; [2]) indicate that the basement rocks in Bangladesh formed towards the final stages of the assembly of the Columbia supercontinent (∼1.9–1.7 Ga).

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