Contemporaneous evolution of the Palaeoproterozoic–Mesoproterozoic sedimentary basins of the São Francisco–Congo Craton

A. J. PEDREIRA[1] & B. DE WAELE[2,3]

[1]*CPRM–Geological Survey of Brazil, Av. Ulysses Guimarães, 2862, 41213-000 Salvador, Brazil (e-mail: apedreira@sa.cprm.gov.br)*

[2]*Tectonics Special Research Centre, The University of Western Australia, 35 Stirling Highway, WA 6009 Crawley, Australia*

[3]*Present address: British Geological Survey, Keyworth, Nottingham NG12 5GG, UK*

Abstract: Deposition of Palaeo–Mesoproterozoic sedimentary rocks on the São Francisco–Congo craton started during Statherian taphrogenesis (1.8–1.75 Ga), as verified by ages of *c.* 1.7 Ga determined for volcanic rocks of the lower part of the Espinhaço Supergroup in the states of Minas Gerais and Bahia (Brazil). These basins contain volcanic rocks and conglomerates alternating with sandstones, argillites and dolomites, deposited in continental, transitional and marine environments. The rocks in the westernmost sector of the Congo Craton (Central Africa) compose the Chela Group, comprising sandstones, argillites and dolomites. In the easternmost region of the Congo Craton the Kibaran, Akanyaru, Kagera and Muva supergroups occur: the first three in the Kibaran Belt and the last in the Irumide Belt and on the Bangweulu Block. They consist predominantly of pelites and schists, sandstones and, in lesser proportion, conglomerates, deposited in shallow marine, fluvial and lacustrine environments. Their sedimentation ages are constrained through ages on felsic tuff layers as follows: Chela Group 1790 $\pm$ 17 Ma, Kagera Supergroup 1780 $\pm$ 9 Ma, and Muva Supergroup 1879 $\pm$ 13 Ma. These data show that broadly coeval and sedimentologically similar epi-continental sedimentary basins occurred on the São Francisco and Congo cratons, suggesting the possible existence of a long-lived wide epi-continental sea covering large areas of these cratons during Statherian times.

The São Francisco Craton of South America and the Congo Craton of Africa are stable Archaean blocks of a once coherent landmass (Fig. 1) that broke up during the opening of the Atlantic Ocean. These cratonic nuclei are considered to have become stabilized during the Palaeoproterozoic Trans-Amazonian (South America) and Eburnian (Africa) events, and underwent a succession of later events along their margin including the Mesoproterozoic Espinhaço cycle in South America (Brito Neves *et al.* 1980), the Kibaran and Irumide orogens in Africa, often associated with the formation of the Rodinia supercontinent, and the Neoproterozoic Pan-African/Brasiliano orogenic events during the agglutination of Gondwana. The Pan-African/Brasiliano orogenesis reworked the edges of both cratons, giving birth to the Brasília, Araçuaí, Sergipano, Rio Preto and Riacho do Pontal belts in Brazil and the West Congo, Kaoko, Damara, Lufilian, Oubanguides and Zambezi belts and the East African orogen in Africa (Fig. 2).

The initial coherence of the São Francisco and Congo cratons prior to Gondwana was based largely on the occurrence of comparable Precambrian epi-continental sequences on both sides of the Atlantic Ocean (Trompette 1994). In the São Francisco Craton, the Statherian taphrogenesis (1.8–1.75 Ga) opened a series of intra-continental rifts, some of which expanded into sag basins (Brito Neves 2002), into which volcanic and sedimentary rocks were deposited, collectively called the Espinhaço Supergroup. On the Congo Craton, the Palaeo-/Mesoproterozoic successions comprise the Chela Group on the Angola–Kasai Shield (Torquato & Fogaça 1981), the Kibaran and Akanyaru/Kagera supergroups in the central African Kibaran Belt (Royal Museum for Central Africa 1990; Theunissen *et al.* 1991) and the Muva Supergroup on the Bangweulu Block and within the Mesoproterozoic Irumide Belt (Daly & Unrug 1982; De Waele & Mapani 2002; De Waele 2005; Fig. 2).

In Brazil these successions have been studied in detail and have their stratigraphical nomenclature

From: PANKHURST, R. J., TROUW, R. A. J., BRITO NEVES, B. B. & DE WIT, M. J. (eds) *West Gondwana: Pre-Cenozoic Correlations Across the South Atlantic Region.* Geological Society, London, Special Publications, **294**, 33–48. DOI: 10.1144/SP294.3 0305-8719/08/$15.00

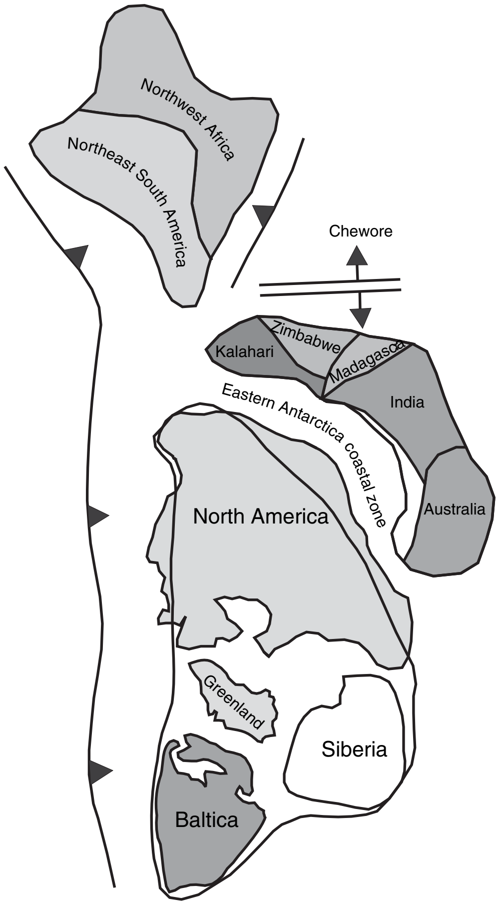

Fig. 1. The Columbia Supercontinent at the beginning of the Mesoproterozoic, according to the configuration of Rogers & Santosh (2002). Modified from Schobbenhaus & Brito Neves (2003).

formalized down to the formation hierarchy and their sedimentary environments described in detail; in Africa, however, most units have only recently been described in any detail, while in most cases stratigraphical nomenclature still needs to be formalized.

In this paper, we will present the known stratigraphy for the successions on the São Francisco Craton based on published papers, while for the African successions we use informal stratigraphies, either published in the literature, or in advanced stage of publication. We will use published age data, basin analysis and, where possible, sequence stratigraphy, to compare these successions. The stratigraphical columns of the sedimentary successions, both in Brazil and Africa, are shown in Figures 3 and 7–9.

Brazilian sedimentary basins: São Francisco Craton

The Palaeo–Mesoproterozoic sedimentary basins of Brazil, started as intra-continental rifts that opened during the Statherian taphrogenesis (1.8–1.75 Ga) and filled with aeolian sands, acid volcanic rocks and conglomerates. The abortion of the rifting process lead to the expansion of the basins into sags, that were filled with conglomerates, sandstones, fine-grained rocks and limestones, and were intruded by basic rocks, collectively named the Espinhaço Supergroup.

Espinhaço Supergroup

The Espinhaço Supergroup crops out in three different domains, all of them related to an orographic system named the Espinhaço Range, developed along a north–south trend between the 10°S and 20°S parallels in eastern Brazil: the southern Espinhaço Range, the northern Espinhaço Range and the Chapada Diamantina (Fig. 3).

In the southern Espinhaço Range, the Espinhaço Supergroup is divided into two groups (the lower Diamantina and the upper Conselheiro Mata), which comprise nine formations composed essentially of sandstones and fine-grained rocks (phyllites, siltstones, quartzites). Conglomerate beds and lenses occur at the base of the succession (Fig. 3a). The Espinhaço Supergroup in the northern Espinhaço Range, was divided by Schobbenhaus (1996) into the Oliveira dos Brejinhos and Santo Onofre groups. The lower, Oliveira dos Brejinhos Group, was deposited in a rift followed by a flexure in the interval comprising the Bom Retiro and Fazendinha formations (Fig. 3b). Recently Danderfer & Dardenne (2002) reviewed the succession from a tectonostratigraphical point of view, describing new formations and groups; the resulting interpretation confirms the one previously presented by Schobbenhaus (1996). In Chapada Diamantina, the Espinhaço Supergroup has been divided into three groups that comprise six formations (Fig. 3c). The succession of Chapada Diamantina and the one of the northern Espinhaço Range were considered to be sub-facies of the same succession (Schobbenhaus 1969).

Deposition of the Espinhaço Supergroup began with a rift phase in all three domains. In the southern Espinhaço Range it encompassed mostly fluvial sandstones and alluvial fan conglomerates that predominate at the base of the Diamantina Group. In the northern Espinhaço Range, a first rift phase occurs during the initial deposition of the Oliveira dos Brejinhos Group, deposited in continental environments: alluvial fan, fluvial–aeolian,

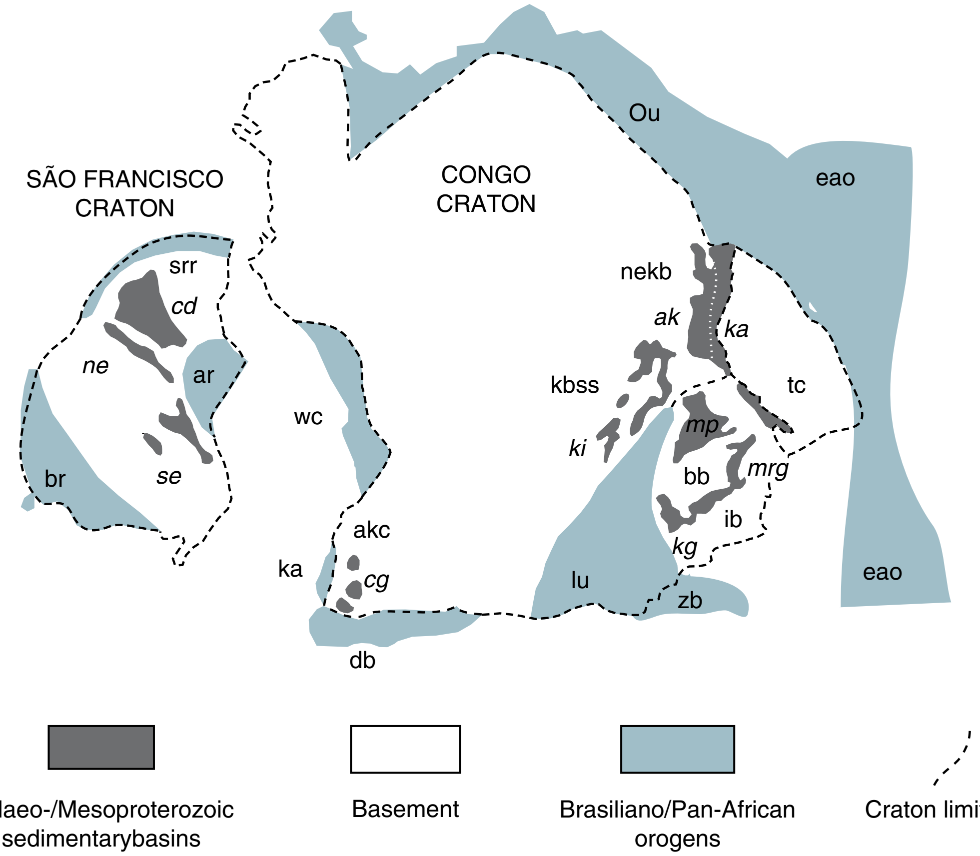

Fig. 2. Approximate Palaeo–Mesoproterozoic positions of the present São Francisco and Congo cratons and Palaeo Mesoproterozoic volcano-sedimentary cover. Key: br, Brasília Belt; srr, Sergipano/Riacho do Pontal/Rio Preto belts; ar, Araçuaí Belt; ka, Kaoko Belt; wc, West Congo Belt; akc, Angola-Kasai Block; db, Damara Belt; lu, Lufilian Belt; kbss, Kibaran Belt *sensu stricto*; ou, Oubanguides; nekb, Northeastern Kibaran Belt; bb, Bangweulu Block; ib, Irumide Belt; zb, Zambezi Belt; tc, Tanzania craton; eao, East African Orogen. Sedimentary successions discussed in the text are indicated in italics as follows: *ne*, northern Espinhaço Supergroup; *se*, southern Espinhaço Supergroup; *cd*, Chapada Diamantina; *cg*, Chela Group; *ki*, Kibaran Supergroup; *ak*, Akanyaru Supergroup; *ka*, Kagera Supergroup; *mp*, Mporokoso Group; *mrg*, Manshya River Group (including the Kasama Formation); and *kg*, Kanona Group. Modified from Brito Neves (2004).

deltaic and lacustrine. The Rio dos Remédios Group of the Chapada Diamantina is composed of acid volcanic rocks, aeolian sandstones and polymict conglomerates interpreted as alluvial fans; it was also deposited during the rift phase.

The rift phase of the Espinhaço Supergroup is followed in the three domains by a transitional phase well characterized in the southern Espinhaço Range (Martins-Neto 2000). This transitional phase is represented in the top of the Diamantina Group by the Galho do Miguel Formation, a thick sandstone formation deposited in aeolian and shallow-marine environments (Dossin *et al.* 1987). Danderfer & Dardenne (2002) correlated this formation with the Bom Retiro and Mangabeira formations respectively of the northern Espinhaço Range (Fig. 3b) and Chapada Diamantina (Fig. 3c).

The transitional phase is followed in the southern Espinhaço and Chapada Diamantina domains by the sag phase. In the southern Espinhaço Range, this sag phase is represented by the Conselheiro Mata Group, composed of interstratified sandstones and shales/argillites that represent shallow-marine deposits with occasional incursions of fluvial and aeolian sediments (Almeida Abreu & Renger 2002) and terminated with some scarce limestone intercalations. In the northern Espinhaço Range, the sag phase comprises only the Bom

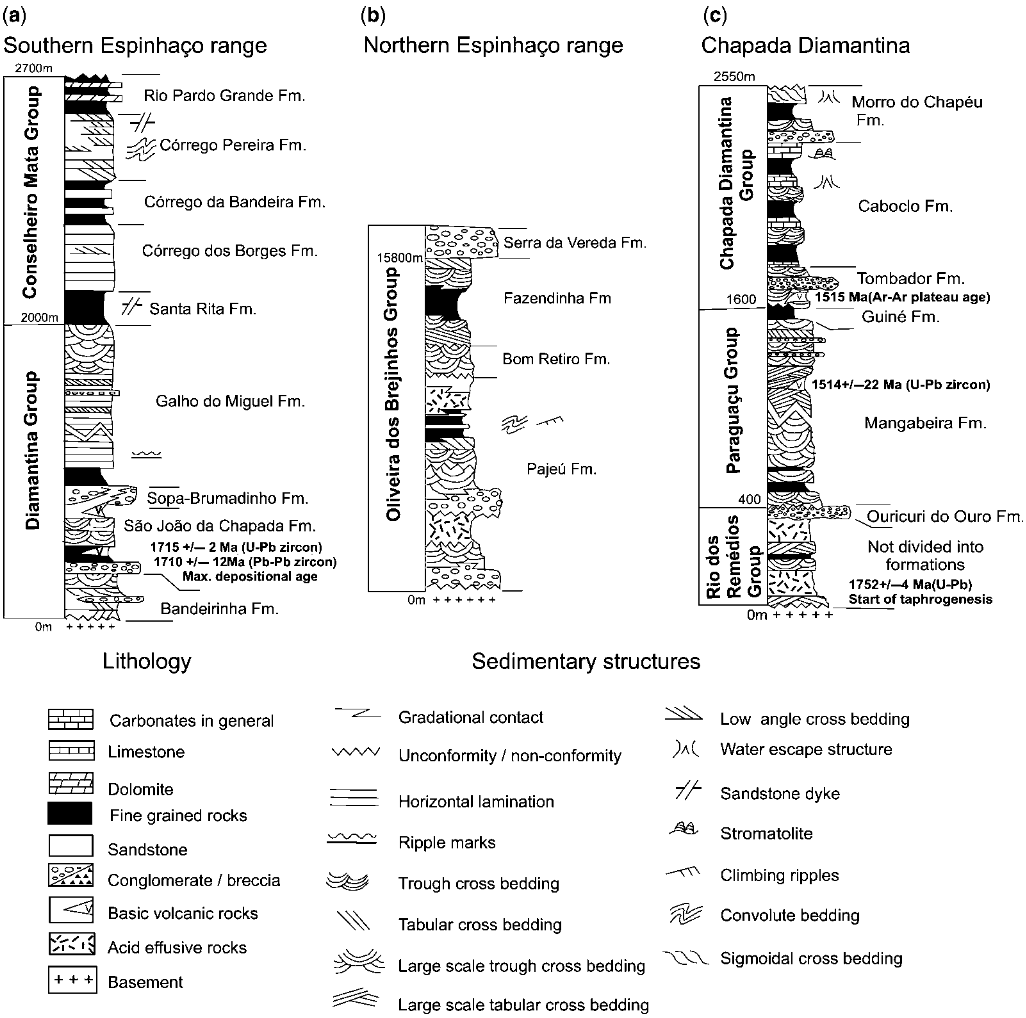

Fig. 3. Stratigraphical columns of the Espinhaço Supergroup: (**a**) Diamantina and Conselheiro Mata groups, after Martins-Neto (2000), Schöll & Fogaça (1979) and Silva 1999; (**b**) Oliveira dos Brejinhos and Santo Onofre groups, modified from Danderfer & Dardenne (2002) and Schobbenhaus (1993); (**c**) Rio dos Remédios, Paraguaçu and Chapada Diamantina groups, modified from Pedreira (1994) and Pedreira & Rocha (2004).

Retiro and Fazendinha formations, composed of interstratified sandstones and shales/argillites (Schobbenhaus 1996). The Chapada Diamantina Group represents the sag phase in the Chapada Diamantina. In this group the basal and upper formations were deposited both in continental and transitional/shallow-marine environments; the intermediate formation was entirely deposited in shallow-marine environment, containing at least four intercalations of stromatolitic carbonate.

In the southern Espinhaço Range, the supergroup crops out in a rift-sag type basin, whose stratigraphic evolution was controlled by its subsidence history (Martins-Neto 2000). The rift phase of the basin comprises four depositional sequences (Silva 1993): Olaria, Natureza, São João da Chapada and Sopa–Brumadinho. Each of these comprises one or more depositional systems and they are approximately correlated with lithostratigraphic units as shown in Figure 4, corresponding to one pre-rift and three rift stages.

The Olaria and Natureza depositional sequences correspond to the Bandeirinha Formation (Fig. 4). The first is bound at the base by a thrust fault and at the top by an erosional unconformity. The Natureza depositional sequence is composed of four depositional systems: alluvial fan, fluvial braided, aeolian and transitional, and is bound at the top by

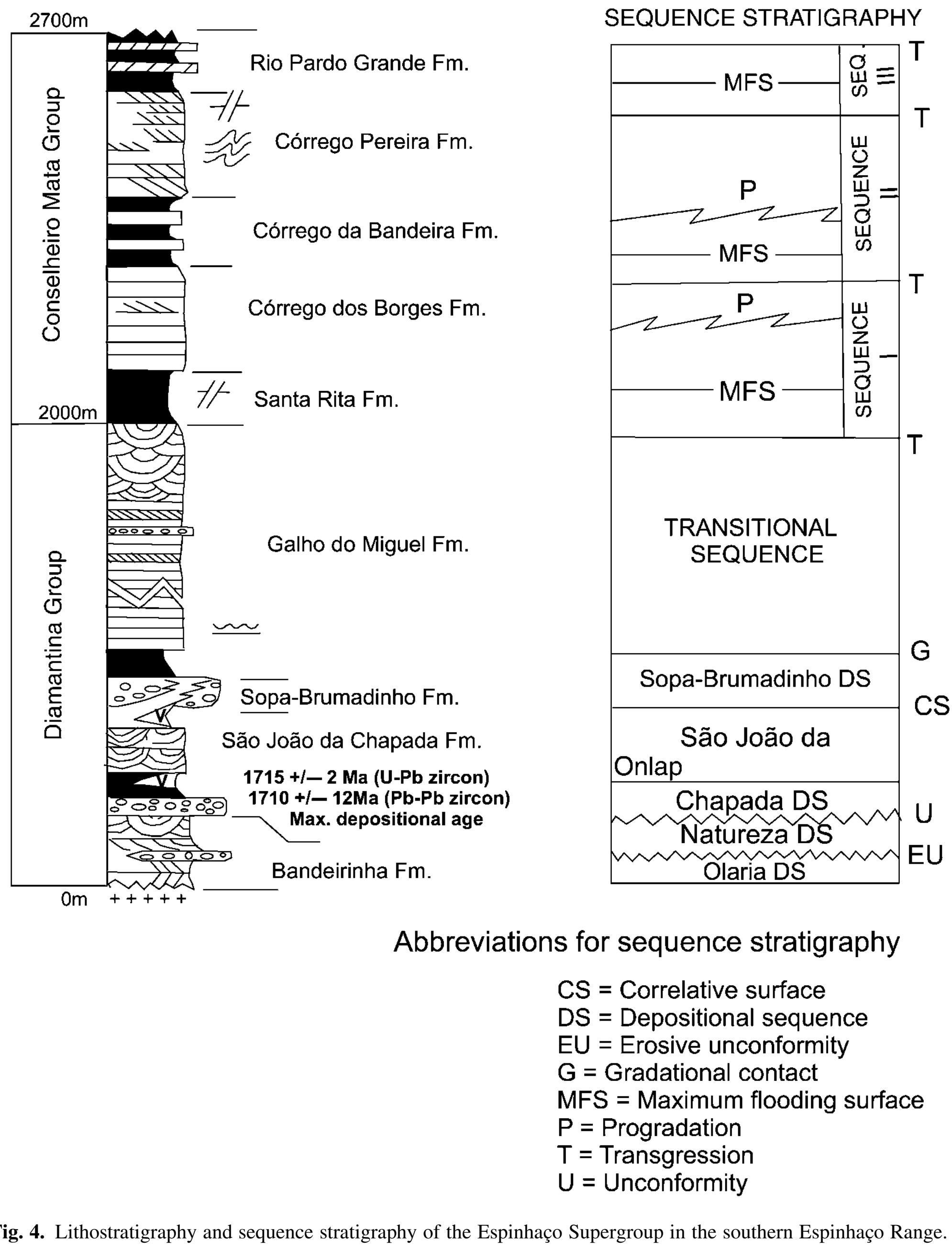

Fig. 4. Lithostratigraphy and sequence stratigraphy of the Espinhaço Supergroup in the southern Espinhaço Range. Lithology: see Figure 3a. Abbreviations: CS, correlative surface; DS, depositional sequence; EU, erosive unconformity; G, gradational contact; MFS, maximum flooding surface; P, progradation; T, transgression; U, unconformity. Modified from Martins-Neto (2000), Dupont (1995) and Silva (1993).

an angular unconformity. The São João da Chapada sequence begins with a talus deposit, with shallow-marine or lacustrine sedimentary rocks that onlap over it, indicating a transgression of the depositional base level. The Sopa-Brumadinho sequence is limited at the base by an angular unconformity, correlated with an erosional unconformity that crops out elsewhere. Lacustrine pelites cover the unconformity and grade vertically into polymict diamond-bearing conglomerates interpreted as a deltaic system. The top of the Sopa–Brumadinho depositional sequence consists of deltaic fans that grade into the aeolian sandstones of the Galho do Miguel Formation. In this formation, the subsidence rates are relatively low and balanced by basin fill. A marine transgression at the top of the formation is followed by higher subsidence rates and the beginning of the sag phase.

The formations that comprise the Conselheiro Mata Group (Fig. 3a) were grouped by Dupont (1995) into three sequences (Fig. 4). The lower one (Sequence I) comprises the Santa Rita and Córrego dos Borges formations; the intermediate (Sequence II) corresponds to the Córrego da Bandeira and Córrego Pereira formations; and the uppermost (Sequence III) coincides with the Rio Pardo Grande Formation. The first two begin with a transgression, reach the maximum flooding surface (MFS), and finish with progradation. The uppermost sequence (Sequence III) begins and ends with transgressions.

In the northern Espinhaço Range, Dominguez & Rocha (1993) divided the Espinhaço stratigraphic column into three depositional sequences (Fig. 5).

According to these authors, the lowermost unit, named Borda Leste, begins with banded

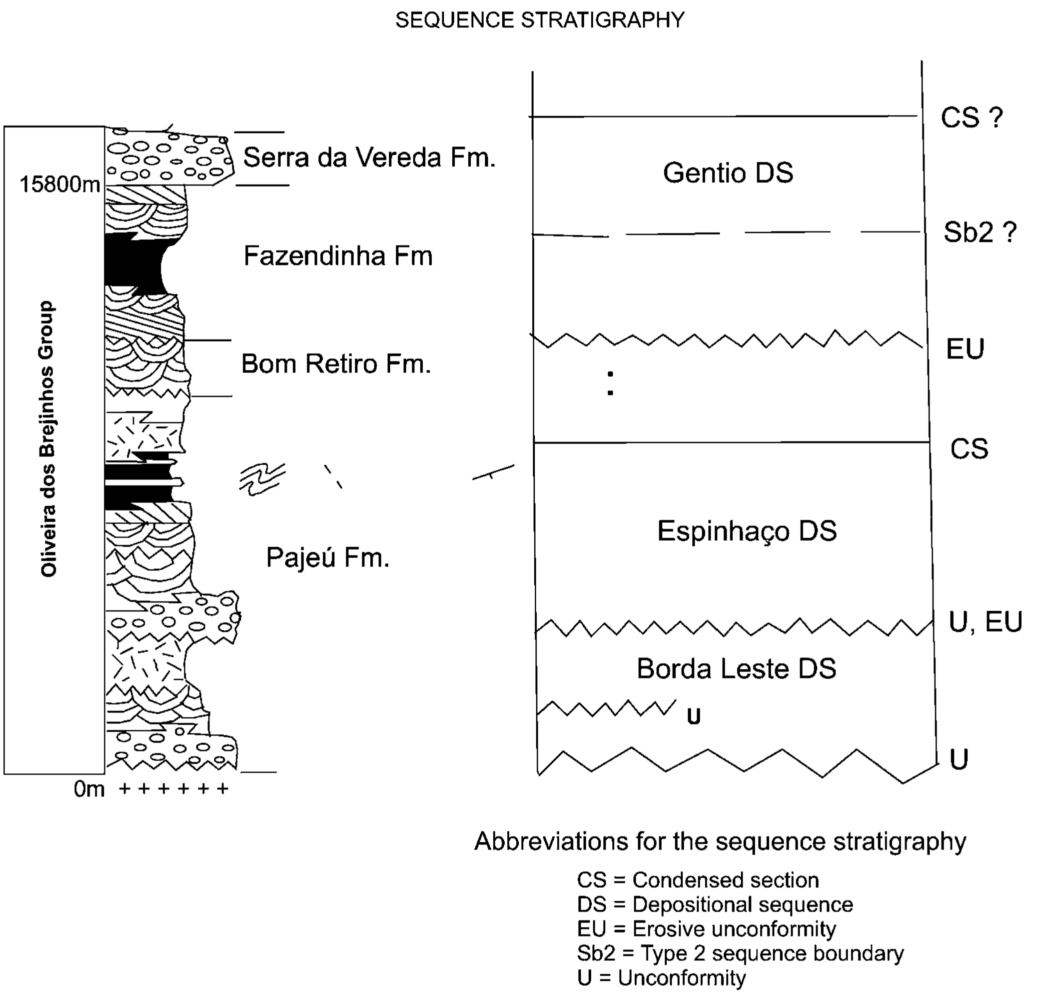

Fig. 5. Lithostratigraphy and sequence stratigraphy of the Espinhaço Supergroup in the northern Espinhaço Range. Lithology: see Figure 1b. Abbreviations: CS, condensed section; DS, depositional sequence; EU, erosive unconformity; SB1, type 1 sequence boundary; U, unconformity. Modified from Danderfer & Dardenne (2002) and Dominguez & Rocha (1993).

Fe–Mg formations overlain by conglomerates and fluvial sediments, whose deposition was followed by an episode of uplift and then a major episode of subsidence. The unconformity that separates the two episodes may be comparable to the break-up unconformity that characterizes the evolution of rift basins. The subsidence episode allowed sedimentation of the Espinhaço depositional sequence. This sequence consists of fluvial sediments that were rapidly covered by aeolian sands and then by coarse-grained shallow-water arenaceous sediments; these were deposited under the influence of waves and currents and were followed by fine-grained graphitic sediments.

A major drop in the sea level led to incision of the Espinhaço depositional sequence by rivers and deposition of a third depositional sequence, the Gentio depositional sequence, composed of coarse grained turbiditic sediments, possibly deposited on a sequence boundary without sub-aerial exposure (Fig. 5). These relationships led Dominguez & Rocha (1993) to interpret the Espinhaço Supergroup in the northern Espinhaço Range as a rift-sag basin.

The Espinhaço succession in the Chapada Diamantina consists of four depositional sequences (Pedreira 1994; Fig. 6): the basal Rio dos Remédios sequence is composed of aeolian sands, effusive rocks and polymict conglomerates, the later named Ouricuri do Ouro Formation.

The succession that follows, the Paraguaçu depositional sequence, begins with a transgression of the coast line (Souza 1986) followed by deposition of fluvial and thick aeolian sands of the Mangabeira Formation. At the top of the formation, closely-spaced argillaceous levels herald a new sea-level elevation (see Shaney & McCabe 1994; Pedreira 2003), an event that began with deposition of the Guiné Formation and closed with deltaic deposits that characterize a regression (Pedreira 1995). The Tombador–Caboclo depositional sequence that overlies it has a lower section (Tombador Formation) that comprises both continental and transitional deposits (Castro 2003); the upper section (Caboclo Formation) is essentially marine. Along its stratigraphic column there are two drops in sea level, represented by incised valleys (Pedreira & Rocha 2004), first filled with fluvial sediments and then by marine deposits representing transgressions of the coast line. A last drop in sea level started the deposition of the Morro do Chapéu Formation, whose base consists of fluvial diamond-bearing conglomerates. After the deposition of the fluvial conglomerates, a new elevation of the sea level deposited a sandy tidal flat followed by regressive deltaic sediments. The top of the Morro do Chapéu depositional sequence is truncated by the unconformity below the glacial Neoproterozoic deposits.

The depositional age of the Espinhaço basins has been determined by dating zircons from volcanic units in the lower parts of the Espinhaço Supergroup in the southern Espinhaço Range and Chapada Diamantina only (Fig. 3a and c). In the former area they comprise *c*. 1711 Ma (zircon U–Pb, Schobbenhaus 1993), 1710 ± 12 Ma (Pb–Pb on carbonate, Dussin & Dussin 1995), and 1715 ± 12 Ma (zircon U–Pb, Machado *et al.* 1989). Similar ages were found in rhyolites, rhyodacites and dacites of the Rio dos Remédios Group at the base of the Chapada Diamantina (Fig. 3c): 1752 ± 4 Ma (zircon U–Pb, Schobbenhaus *et al.* 1994). Higher up in the stratigraphical column, at the base of the Chapada Diamantina Group, intrusive dykes have been dated as *c*. 1515 Ma (Ar/Ar plateau ages, Battilani *et al.* 2005). In the northern Espinhaço Range there are no age data for any acid volcanic rocks of similar stratigraphical position to the Rio dos Remédios Group.

African sedimentary basins: Congo Craton

Several sedimentary successions occur on the Congo Craton (Fig. 2), from west to east, the Chela Group in Angola, the Kibaran Supergroup in the Mesoproterozoic Kibaran Belt of the CDR, the Akanyaru and Kagera supergroups of the CDR, Rwanda and Burundi (formerly known as the Rwanda or Burundi supergroups), and the Muva Supergroup on the Bangweulu Block and in the Mesoproterozoic Irumide Belt of Zambia and southeast CDR. Of those, only the Chela Group and parts of the Kagera and Muva supergroups are relatively undeformed, allowing reconstruction of a stratigraphic column, while for the more deformed and metamorphosed successions of the Kibaran and Irumide belts only a synthetic stratigraphic column can be presented. Basin analysis and sequence stratigraphy is only attempted on the undeformed Mporokoso Group.

Chela Group

The Chela Group crops out in the neighbourhood of the town of Sá da Bandeira on the Umpata Plateau, Angola. It is the westernmost succession on the Congo Craton (Fig. 2) and comprises five formations (Torquato & Fogaça 1981; Fig. 7). From the base to top these are the Tundavala Formation (begins with a basal conglomerate followed by sandstones with pyroclastic intercalations), the Humpata Formation (acid volcaniclastic rocks, products of explosive volcanism, with sandstone

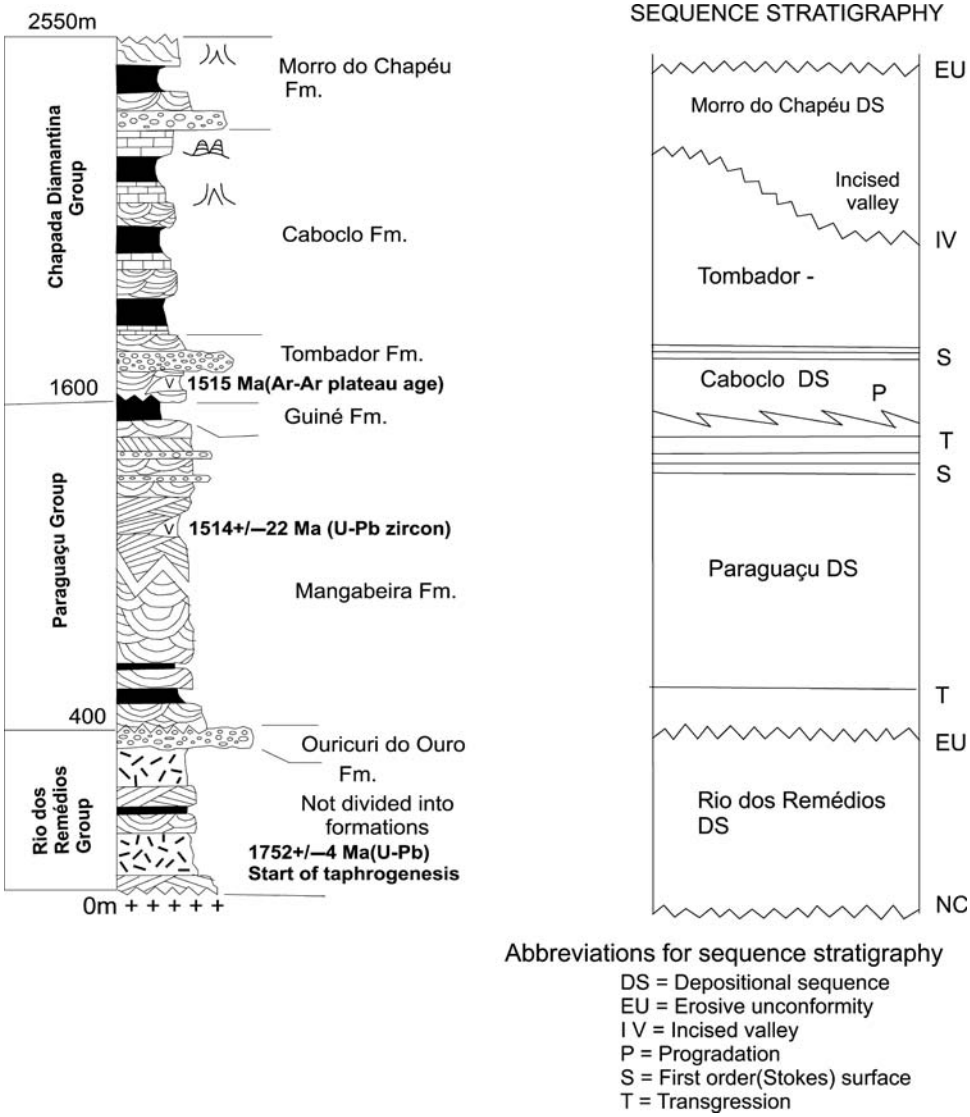

Fig. 6. Lithostratigraphy and sequence stratigraphy of the Espinhaço Supergroup in Chapada Diamantina. Lithology: see Figure 3c. Abbreviations: DS, depositional sequence; EU, erosive unconformity; I, incised valley; P, progradation; S, first-order (Stokes) surface; T, transgression. Modified from Pedreira (1994, 1995, 2003).

intercalations), the Bruco Formation (basal volcanogenic conglomerate followed by interbedded sandstones and siltstones with volcanic and conglomeratic levels), the Cangalongue Formation interbeds (argillite, limestone and arkosic sandstone), and the Leba Formation (cherts, argillite and stromatolitic dolomites). With the exception of the Bruco Formation, partially deposited in a fluvial environment, and the Cangalongue Formation, interpreted as continental red beds, the Chela Group was deposited in shallow-marine environments.

The depositional age of the Chela Group was determined at 1790 ± 17 Ma by the U–Pb SHRIMP method on magmatic zircons from an ignimbrite of the Humpata Formation (McCourt *et al.* 2004), similar to the Rio dos Remédios effusive rocks in the São Francisco Craton.

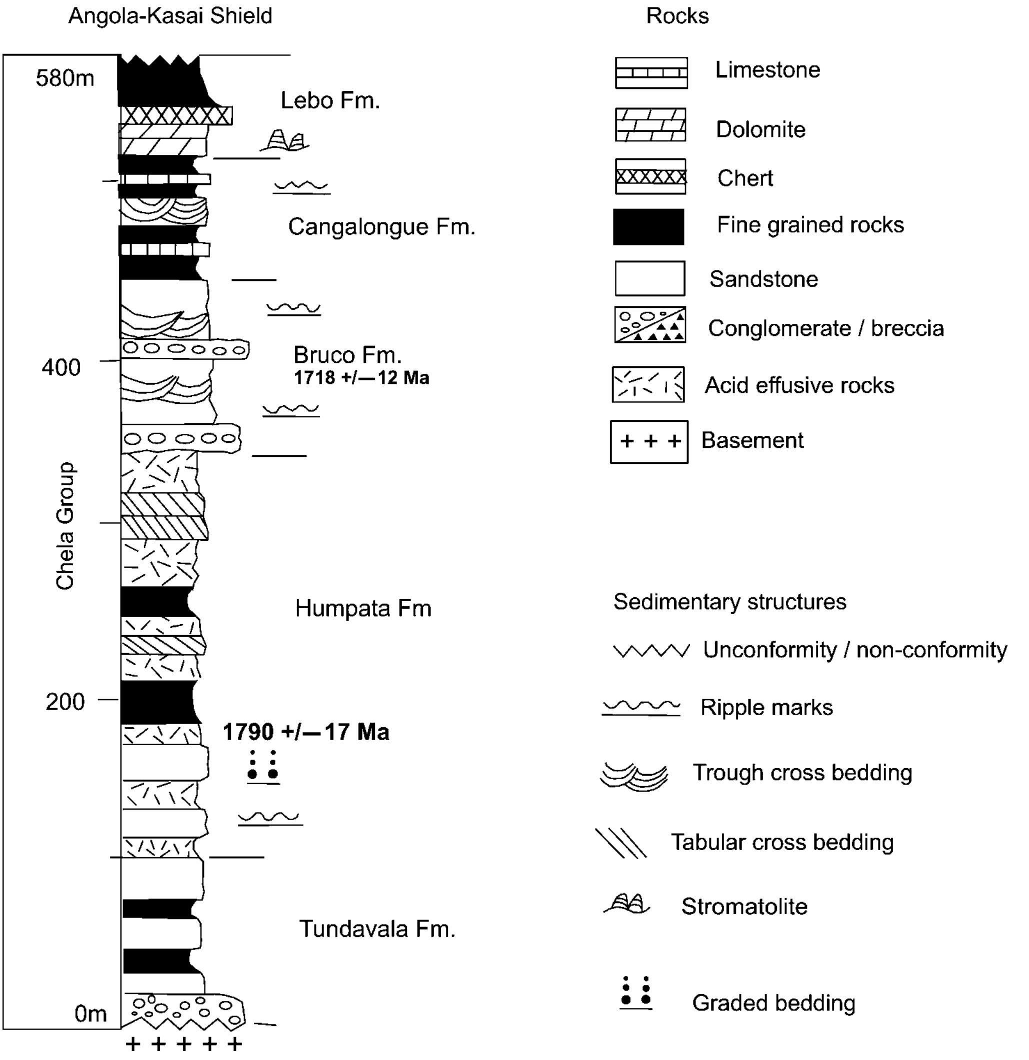

Fig. 7. Stratigraphical column of the Chela Group in the region of the Humpata Plateau, Angola (modified from Torquato & Fogaça 1981 and McCourt *et al.* 2004).

Kibaran and Akanyaru/Kagera supergroups

The Kibaran and Akanyaru/Kagera supergroups occur in the central eastern sector of the Congo Craton, in the Kibaran Belt. Their outcrops are distributed in two belts: the Kibaran Belt *sensu stricto* and the Northeastern Kibaran Belt (Tack *et al.* 1994) (Fig. 8). The Northeastern Kibaran Belt can be further divided into a Western Internal Domain and an Eastern External Domain, separated by a basement rise of Palaeoproterozoic gneisses and schists referred to as the Rusizian Rise (Lavreau 1985; Tack *et al.* 1994).

Burundi Group and Rwanda Group were the names of the succession in Burundi and Rwanda respectively (Royal Museum for Central Africa 1990; Theunissen *et al.* 1991), but similar successions extend into northern Tanzania, southern Uganda and eastern Congo, where they were sometimes referred to under the same name, but more often than not, were attributed local and informal stratigraphical names. The successions of the Northeastern Kibaran Belt have recently been redefined into the Akanyaru Supergroup, which occurs in the Western Internal Domain, and the Kagera Supergroup, occurring in the Eastern

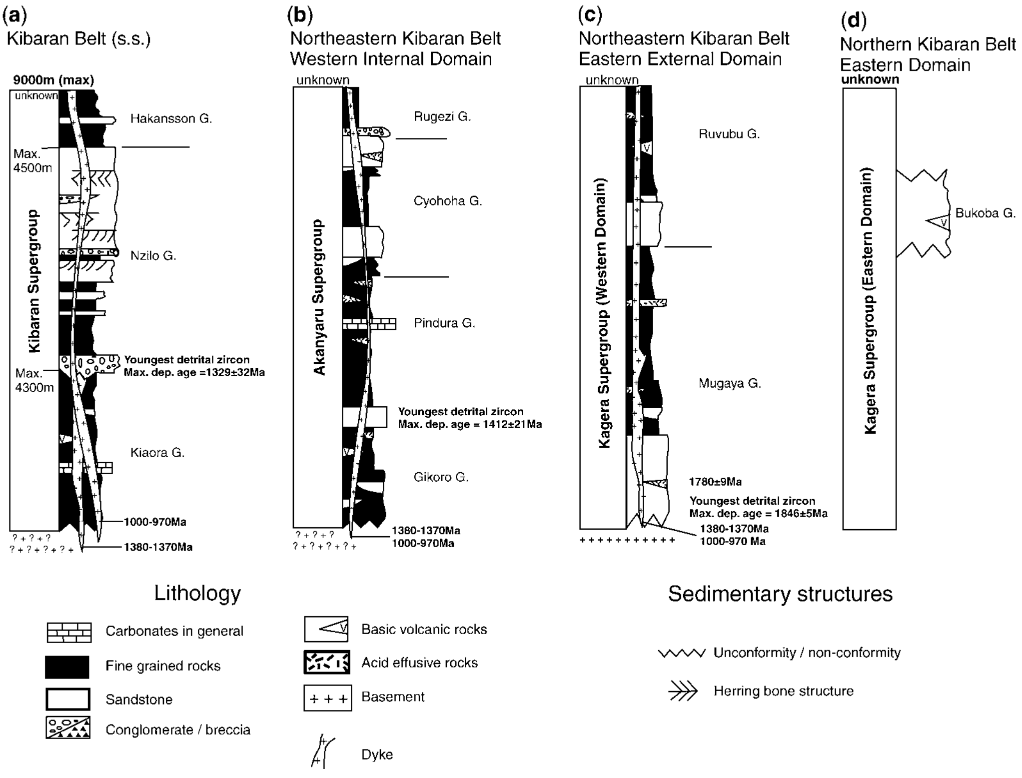

Fig. 8. Stratigraphical columns of (**a**) Kibaran, (**b**) Akanyaru and (**c**, **d**) Kagera supergroups (see Fig. 2 for location within the Kibaran Belt).

External Domain. The sedimentary succession in the Kibaran Belt *s.s.* was formalized as the Kibaran Supergroup, comprising the Kiaora, Nzilo and Hakansson groups (Kokonyangi *et al.* 2001, 2006).

In the Kibaran Belt *s.s.*, the Kibaran Supergroup consists of three groups: the basal Kiaora Group dominated by pelites/schists, the middle Nzilo Group dominated by quartzites, and the upper Hakansson Group, dominated by pelitic units (Fig. 8; Kokonyangi *et al.* 2001, 2006). The two lower successions are separated by the regionally defined Kataba Conglomerate. The only age data available for these units are from the Nzilo Group, which unconformably overlies 1.38 Ga granitoids, and is intruded by *c.* 1.00 Ga Sn-bearing granitoids, providing its maximum and minimum ages, respectively (Kokonyangi *et al.* 2006). The older Kiaora Group is intruded by the 1.38 Ga granitoids (i.e., its minimum age is 1.38 Ga), while no age constraints are available for the Hakansson Group.

In the Western Internal Domain of the Northeastern Kibaran Belt, the Akanyaru Supergroup comprises four groups (Fig. 8), which include pelites/schists and sandstones/quartzites and at least one marble bed. In the basal Gikoro and Pindura groups schisto-arkosic successions with volcanic rocks and basic intrusions are reported. In the westernmost part of the Eastern External Domain, the Kagera Supergroup is subdivided into the Mugaya and Ruvubu groups, whereas in the eastern part only one, the Bukoba Group, is recognized. In the eastern domain the Kagera Supergroup unconformably overlies the Archaean Tanzania Craton, but for the western domain of the Northeastern Kibaran Belt and the Kibaran Belt *s.s.* the presence of the basement is unproved.

The depositional environment of the Kibaran and Akanyaru/Kagera supergroups is interpreted as shallow-marine, but in the Northeastern Kibaran Belt a turbiditic facies has been reported (Baudet *et al.* 1988), attesting to the presence of deeper environments. The depositional age of the Kagera Supergroup was determined by a zircon U–Pb crystallisation age of 1780 $\pm$ 9 Ma in the Murore Tuff at the base of the Mugaya Group (Cutten *et al.* 2004). The age of the Akanyaru Supergroup is constrained by the youngest detrital

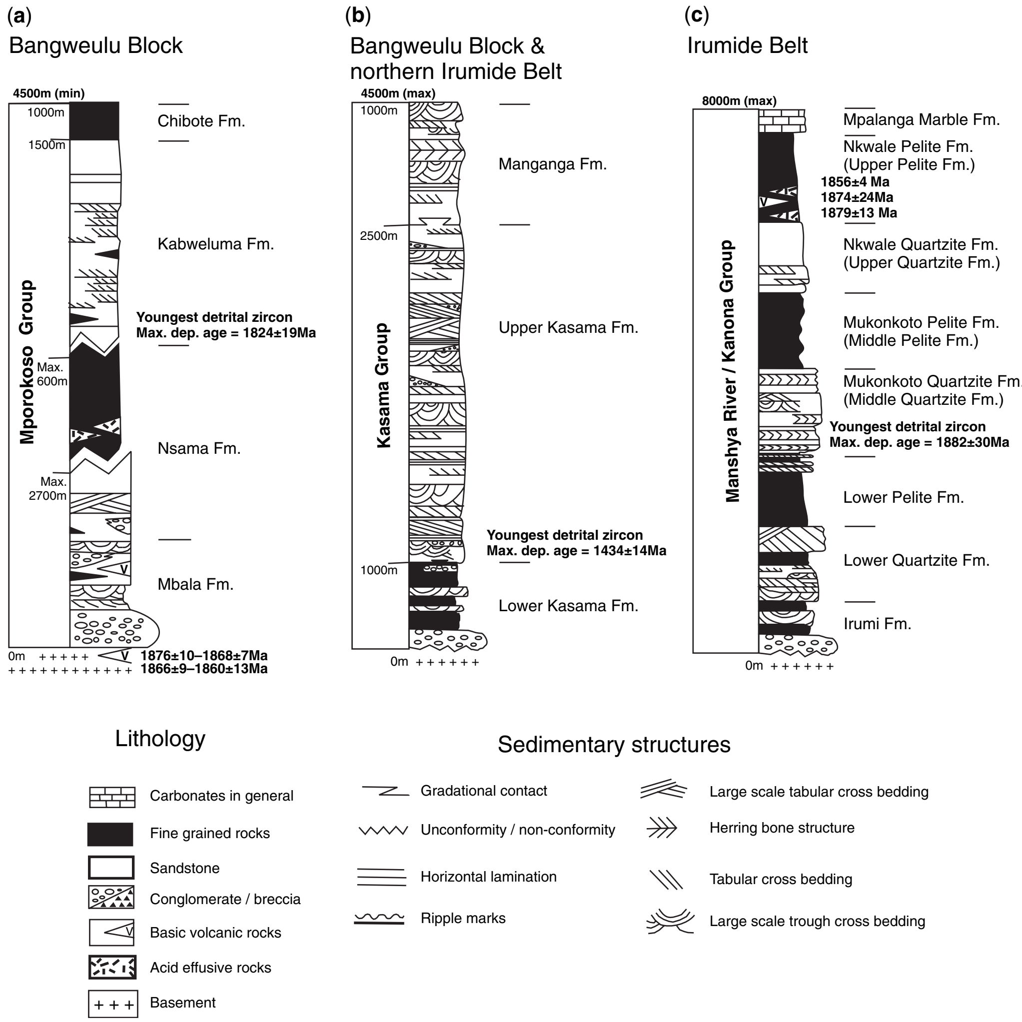

Fig. 9. Stratigraphical columns of the (**a**) Mporokoso, (**b**) Kasama and (**c**) Manshya River/Kanona groups in the Bangweulu Block and Irumide Belt. Formation names in brackets refer to equivalent formations in the southern part of the Irumide Belt (Kanona Group of De Waele & Mapani 2002). Modified from Daly & Unrug (1982) and De Waele & Mapani (2002).

zircon identified in the Gikoro Group at 1412 $\pm$ 21 Ma, indicating its maximum age of deposition, and granitoid intrusions intruding the sequence dated at *c.* 1.38 Ga (Tack *et al.* 2002; Kokonyangi *et al.* 2004).

Muva Supergroup

The Muva Supergroup comprises two groups that occur in the Bangweulu Block and within the Irumide Belt, with the names of Mporokoso Group (Andersen & Unrug 1984) and Manshya River Group (De Waele & Mapani 2002; De Waele *et al.* 2006), respectively (Fig. 9). According to Andrews-Speed (1989), the Mporokoso Group consists of both immature and mature sandstones, conglomerates, ordered or not, cherts, tuffs, and volcanic rocks. It was deposited in both fluvial and shallow-marine environments: the former is represented by the immature sandstones and the conglomerates, the latter by the mature sandstones. The Manshya River Group was involved in the folding of the Irumide Belt and consists of meta-siltstones, phyllites, slates and quartzites, with sporadic calc-silicate rock and marble at the top (Daly & Unrug 1982; De Waele & Mapani 2002;

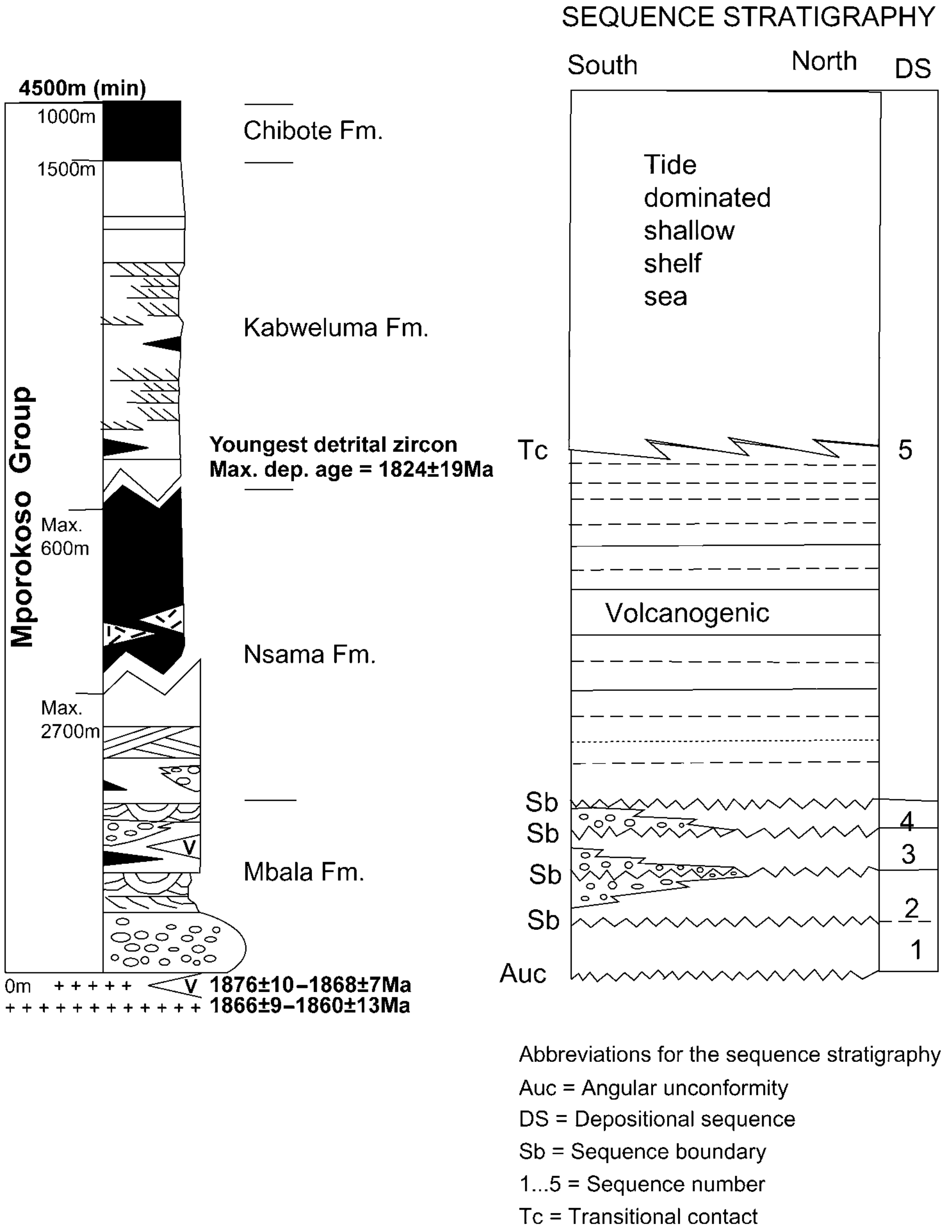

Fig. 10. Lithostratigraphy and sequence stratigraphy of the Mporokoso Group in the Bangweulu Block. Lithology: see Figure 9a. Abbreviations: AU, angular unconformity; DS, depositional sequence; SB, sequence boundary; TC, transitional contact. Modified from Andrews-Speed (1989).

De Waele *et al.* 2006). Its depositional environment is interpreted as shallow-marine (Daly & Unrug 1982; De Waele & Mapani 2002), although fluvial units have been recognized in the northeastern Irumide Belt (Daly & Unrug 1982).

The Mporokoso Group was classified by Andrews-Speed (1989) as a megasequence bound at the base by a regional angular unconformity and at the top by the present erosional surface; no angular unconformities were recognized within the group (Fig. 10). It is divided into five depositional sequences: the lower four correspond to the Mbala Formation, the upper one comprises the Nsama and Kabweluma formations (Fig. 10).

The first and lowermost sequence consists of planar cross-bedded fluvial sandstones interpreted as braided-river deposits. Sequence 2 (Fig. 10) contains a coarsening-upward succession of immature trough cross-bedded sandstone interpreted as the deposits of sandy to pebbly sheet-braided rivers, capped by conglomerates deposited in wide shallow channels. The base of Sequence 3 is formed by an influx of debris flow or grain flows; the coarse, poorly sorted conglomerates include intra-basin pebbles of reworked sandstone. These conglomerates are overlain by a fining-up sequence of fluvial sandstones followed by marine ones, which represent a transgressive sequence. A final flux of fluvial sandstones marks the start of Sequence 4 of the Mbala Formation. These fluvial sediments pass upwards into shallow-marine sandstones. Sequence 5 comprises both the Nsama and Kabweluma formations. The former is essentially composed by mudstone tuff and chert with minor cross-bedded sandstones; the latter comprises essentially cross-bedded and rippled sandstones.

The Mporokoso Group of the Bangweulu Block unconformably overlies a plutono-volcanic basement dated using zircon U–Pb at 1.87–1.86 Ga (De Waele *et al.* 2004; De Waele 2005). Tuff layers, associated with this basement occur within the basal parts of the Mporokoso Group, strongly suggesting a depositional age of *c.* 1.86 Ga. Similar tuffs and lavas also occur within the Manshya River succession of the Irumide Belt, and yielded zircon U–Pb ages of 1879 ± 13, 1871 ± 24 and 1856 ± 4 Ma, directly constraining ages of deposition for that group to be broadly coeval with deposition of the Mporokoso Group (De Waele 2005).

Discussion

A correlation between the Espinhaço Supergroup in the Brazilian states of Minas Gerais and Bahia (Fig. 3a, c) and the Chela Group (Fig. 7) was made by Torquato & Fogaça (1981) on a bed-to-bed basis. These authors extended this correlation to the Neoproterozoic Nosib and Khoabendus formations of Namibia, but because of the 1.78 Ga age of a felsic tuff in the Chela Group, this latter correlation is unsustainable (McCourt *et al.* 2004). As correlation from one continental landmass to another is not advisable, we will limit the discussion to a comparison of the Palaeo–Mesoproterozoic basins of the São Francisco and Congo cratons.

Comparisons between the Espinhaço Supergroup in the southern Espinhaço Range and the Chapada Diamantina can be made on several counts. There were similar depositional environments: continental in the Diamantina and Rio dos Remédios, and most of the Paraguaçu groups, and shallow-marine with continental incursions in the Conselheiro Mata and Chapada Diamantina groups. Tectonic settings are also similar: extensional in the Diamantina and Rio dos Remédios/Paraguaçu groups and flexural/thermal in Conselheiro Mata and Chapada Diamantina groups. Moreover, as indicated by the geochronological determinations already mentioned (Schobbenhaus 1993; Dussin & Dussin 1995; Schobbenhaus *et al.* 1994), these successions were deposited simultaneously at *c.* 1.75 Ga.

For the northern domain of the Espinhaço Supergroup, the Pajeú Formation was also deposited in an intra-continental rift and the Bom Retiro Formation is transitional; the Fazendinha Formation was deposited in the sag phase. Geochronological dating of felsic tuffs in the successions of the northern Espinhaço Range would determine whether deposition was coeval with that in the southern Espinhaço Range and Chapada Diamantina.

The Espinhaço Supergroup and the Chela Group have different depositional ages: 1790 ± 17 Ma for the Chela Group and 1710 ± 12 Ma for the Diamantina Group. On a lithological basis, the Humpata Formation of the Chela Group and the Rio dos Remédios Group of the Chapada Diamantina, both composed of acid effusive rocks (Figs 7 and 3c), are comparable, but the age determinations clearly indicate that volcanism was strongly diachronous. Within the Congo Craton, the Chela Group and the Kibaran, Ankanyaru/Kagera groups appear to be coeval with depositional ages of 1790 ± 17 Ma for the Chela Group and 1780 ± 9 Ma for the Akanyaru Supergroup. Additionally, both successions were deposited in similar shallow-marine environments, making a direct correlation between these sequences plausible. It must, however, be noted that geochronological data for the Kibaran successions are very sparse at present, and that multiple sedimentation cycles may be present in these successions, spanning the Palaeoproterozoic through to the end of the Mesoproterozoic.

Finally, comparison of the Kibaran, Akanyaru and Kagera supergroups with the Muva Supergroup is somewhat problematic, because the latter is about 100 Ma older (*c.* 1.86 Ga) and one of its components (the Mporokoso Group on the Bangweulu Block) was deposited in a continental rather than shallow-marine environment. However, the depositional age of the Manshya River Group (*c.* 1.8 Ga, De Waele & Mapani 2002; De Waele 2005), which does represent a shallow-marine succession, places its deposition in the Palaeoproterozoic and makes it coeval with the Mporokoso Group.

The intracratonic basins (Espinhaço and Mporokoso) may be compared in terms of sequence stratigraphy, especially in the southern Espinhaço Range. The lower parts of both were divided into several depositional sequences with conglomerates, probably characterizing the retreat of escarpments. The uppermost depositional sequences also appear to be similar (sequences I, II and III of Fig. 4 and the tide-dominated shallow-marine sections of Fig. 10). To a lesser degree, similar features may be seen in the Chapada Diamantina. Thus it is suggested that in the São Francisco–Congo craton, the rift shoulders at the base of the Espinhaço Supergroup and the Bangweulu Block represented topographic highs, dominated by alluvial fans, lacustrine, aeolian and fluvial environments, while the Conselheiro Mata and Chapada Diamantina groups, and the Kibaran and Irumide belts, were the loci of shallow seas within or at the margin of the Congo Craton.

Conclusions

The sedimentological, stratigraphic, tectonic and geochronological data presented here show that broad coeval epi-continental sedimentary basins were forming on the São Francisco–Congo craton during the Palaeo–Mesoproterozoic and over a relatively long period of time (1880–1700 Ma, at least). The tectonic regime that governed the deposition of these basins (mostly rift-sag) was similar over the entire São Francisco–Congo continent, as were the sedimentary environments. This suggests the possible existence of a wide shallow-water epi-continental sea covering large extents of the São Francisco–Congo craton during Statherian times.

The senior author (AJP) thanks B.B. de Brito Neves and his fellow editors for the invitation to present this paper at the Gondwana 12 Conference, and CPRM–Geological Survey of Brazil for logistical support. The authors also thank Alexandre Uhlein, B.B. de Brito Neves and an anonymous reviewer for suggestions that considerably improved an earlier version of this paper. This is TSRC publication 380.

References

Almeida Abreu, P. & Renger, F. E. 2002. Serra do Espinhaço meridional: um orógeno de colisão do Mesoproterozóico. *Revista Brasileira de Geociências*, **32**, 1–14.

Andersen, L. S. & Unrug, R. 1984. Geodynamic evolution of the Bangweulu block, northern Zambia. *Precambrian Research*, **25**, 187–212.

Andrews-Speed, C. P. 1989. The Mid-Proterozoic Mporokoso Basin, Northern Zambia: Sequence Stratigraphy, Tectonic Setting and Potential for Gold and Uranium Mineralisation. *Precambrian Research*, **44**, 1–17.

Battilani, G. B., Vasconcelos, P. M., Gomes, N. S. & Guerra, W. J. 2005. Geochronological data of dykes and sills intruding Proterozoic sequences of the Tombador Formation, Bahia-Brazil. *In*: Rosa, M. L. et al. (eds) *Anais do 3° Simpósio sobre o Craton do São Francisco, CBPM/UFBA/SBG, Salvador*, 139–142.

Baudet, D., Hanon, M., Lemonne, E. & Theunissen, K. 1988. Lithostratigraphie du domaine sédimentaire de la chaine Kibarienne au Rwanda. *Annales de la Société Géologique Belge*, **112**, 225–246.

Brito Neves, B. B. 2002. Main Stages of the development of the sedimentary basins of South America with the tectonics of supercontinents. *Gondwana Research*, **5**, 175–196.

Brito Neves, B. B. 2004. A História dos Continentes–Trajetórias e tramas tectônicas. *In*: Mantesso-Neto, V., Bartorelli, A ., Carneiro, C. D. R. & Brito Neves, B. B. (eds) *Geologia do Continente Sul-Americano; Evolução da Obra de Fernando Flávio Marques de Almeida*. Beca, São Paulo, 123–149.

Brito Neves, B. B., Cordani, U. G. & Torquato, J. R. 1980. Evolução geológica do Precambriano no estado da Bahia. *In*: Inda, H. V. & Duarte, J. B. (eds) *Geologia e Recursos Minerais do Estado da Bahia*, **3**, 1–101.

Castro, M. R. 2003. *Estratigrafia de Seqüências na Formação Tombador, Grupo Chapada Diamantina, Bahia*. PhD Thesis, Instituto de Geociências, Universidade de São Paulo.

Cutten, H., de Waele, B., Fernandez-Alonso, M. & Tack, L. 2004. Age constraints for basin evolution and sedimentation in the 'Northeastern Kibaran Belt.' *In*: *20th Colloquium of African Geology, Orléans, France*, **123**.

Daly, M. C. & Unrug, R. 1982. The Muva Supergroup, northern Zambia. *Transactions of the Geological Society of South Africa*, **85**, 155–165.

Danderfer, A. & Dardenne, M. A. 2002. Tectonoestratigrafia da bacia Espinhaço na porção norte do Craton do São Francisco: registro de uma evolução poliistórica descontínua. *Revista Brasileira de Geociências*, **32**, 449–460.

De Waele, B. 2005. *The Proterozoic geological history of the Irumide Belt, Zambia.*, PhD Thesis, Curtin University of Technology, Australia.

De Waele, B. & Mapani, B. 2002. Geology and correlation of the central Irumide Belt. *Journal of African Earth Sciences*, **35**, 385–397.

De Waele, B., Fitzsimons, I. C. W., Wingate, M. T. D., Mapani, B. & Tembo, F. 2004. A U–Pb SHRIMP geochronological database for the Irumide Belt of Zambia: from Palaeoproterozoic sedimentation to late Mesoproterozoic magmatism. *In*: *32nd International Geological Congress, Florence, Italy*, 870–871.

De Waele, B., Kampunzu, A. B., Mapani, B. S. E. & Tembo, F. 2006. The Irumide Belt of Zambia. *Journal of African Earth Sciences*, **46**, 36–70.

Dominguez, J. M. L & Rocha, G. M. F. 1993. Middle Proterozoic paleogeography of the São

Francisco Craton in the state of Bahia. *In*: *Anais do II Simpósio do Cráton do São Francisco, Salvador*, 158–159.

DOSSIN, I. A., GARCIA, A. J. V., UHLEIN, A., DARDENNE, M. A. & DOSSIN, T. M. 1987. Fácies Eólico na Formação Galho do Miguel, Supergrupo Espinhaço (MG). *In*: *Sociedade Brasileira de Geologia, Núcleo de Minas Gerais, Boletim*, **6**, 85–96.

DUPONT, H. 1995. O Grupo Conselheiro Mata no seu quadro paleogeográfico e estratigráfico. *Sociedade Brasileira de Geologia, Núcleo de Minas Gerais, Boletim* **13**, 9–10.

DUSSIN, I. A. & DUSSIN, T. M. 1995. Supergrupo Espinhaço: Modelo de evolução geodinâmica. *Geonomos*, **III**, 19–26.

KOKONYANGI, J., OKUDIAIRA, T., KAMPUNZU, A. B. & YOSHIDA, M. 2001. Geological evolution of the Kibarides Belt, Mitwaba, Democratic Republic of Congo, central Africa. *Gondwana Research*, **4**, 663–664.

KOKONYANGI, J., ARMSTRONG, R. A., KAMPUNZU, A. B., YOSHIDA, M. & OKUDAIRA, T. 2004. U–Pb zircon geochronology and petrology of granitoids from Mitwaba (Katanga, Congo): implications for the evolution of the Mesoproterozoic Kibaran belt. *Precambrian Research*, **132**, 79–106.

KOKONYANGI, J., KAMPUNZU, A. B., ARMSTRONG, R., YOSHIDA, M., OKUDAIRA, T. & ARIMA, M. 2007. The Mesoproterozoic Kibaride belt (Katanga, SE D. R. Congo). *Journal of African Earth Sciences*, **46**, 1–35.

LAVREAU, J. 1985. Le Groupe de la Rusizi (Rusizien du Zaïre, Rwanda et Burundi) à la lumière des connaissances actuelles. *Annual Report 1983–84, Department of Geology and Mining, Royal Museum for Central Africa, Tervueren, Belgium*, 111–119.

MACHADO, N., SCHRANK, A., ABREU, F. R., KNAUER, L. G. & ALMEIDA ABREU, P. 1989. Resultados preliminares da geocronologia U/Pb na Serra do Espinhaço Meridional. *Sociedade Brasileira de Geologia, Núcleo Minas Gerais, Boletim*, **10**, 171–174.

MARTINS-NETO, M. A. 2000. Tectonics and sedimentation in a Paleo/Mesozoic rift-sag basin (Espinhaço basin, southeastern Brasil). *Precambrian Research*, **103**, 147–173.

MCCOURT, S., ARMSTRONG, R. A., KAMPUNZU, A. B., MAPEO, R. B. M. & MORAIS, E. 2004. New U-Pb SHRIMP ages for zircons from the Lubango region, SW Angola: insights into the Proterozoic evolution of South-Western Africa. *In*: *Geoscience Africa 2004*. Geological Society of South Africa, 438–439.

PEDREIRA, A. J. 1994. *O Supergrupo Espinhaço na Chapada Diamantina Centro-oriental, Bahia: Sedimentologia, Estratigrafia e Tectônica*. PhD Thesis, Instituto de Geociências, Universidade de São Paulo.

PEDREIRA, A. J. 1995. Estratigrafia de seqüências e modelo deposicional da Formação Guiné (Mesoproterozoico) na Chapada Diamantina, Bahia. *Sociedade Brasileira de Geologia, Núcleo de Minas Gerais, Boletim*, **13**, 28–29.

PEDREIRA, A. J. 2003. Characterization of marine flooding surfaces in Proterozoic strata of the Chapada Diamantina, Brazil. *In*: ROSSETTI, D. F., GÓES, A. M. & TRUCKENBRODT, W. (eds) *3rd Latinamerican Congress of Sedimentology, Abstracts, Belém, Session 14*, 232–234.

PEDREIRA, A. J. & ROCHA, A. J. D. 2004. Revisão estratigráfica do Grupo Chapada Diamantina, Bahia. *In*: *Congresso Brasileiro de Geologia 42, Araxá, Anais*. Sociedade Brasileira de Geologia. (CD-ROM).

ROYAL MUSEUM FOR CENTRAL AFRICA 1990. *Carte Géologique du Burund*, 1 : 1,000,000 scale. Tervueren, Royal Museum for Central Africa.

ROGERS, J. J. W. & SANTOSH, M. 2002. Configuration of Columbia, a Mesoproterozoic supercontinent. *Gondwana Research*, **5**, 5–22.

SCHOBBENHAUS, C. 1969. Mapa geológico preliminar da região setentrional da serra do Espinhaço. *In*: *Congresso Brasileiro de Geologia 23, Salvador, Anais*. Sociedade Brasileira de Geologia. 74–86.

SCHOBBENHAUS, C. 1993. *Das Mittlere Proterozoikum Brasiliens mit besonderer Berücksichtung des zentralen Osten: Eine Revision*. PhD Thesis, Albert-Ludwiges Universität, Freiburg im Bresgau, Germany.

SCHOBBENHAUS, C. 1996. As tafrogêneses superpostas Espinhaço e Santo Onofre, Estado da Bahia: Revisão e novas propostas. *Revista Brasileira de Geociências*, **26**, 265–276.

SCHOBBENHAUS, C. & BRITO NEVES, B. B. 2003. A geologia do Brasil no contexto da Plataforma Sul-Americana. *In*: BIZZI, L. A., SCHOBBENHAUS, C., VIDOTTI, R. M. & GONÇALVES, J. H. (eds) *Geologia, Tectônica e Recursos Minerais do Brasil*. Companhia de Pesquisa de Recursos Minerais – Geological Survey of Brazil, Brasília, 5–54 (Explanatory text for the Geological Map of Brazil, 1:2,500,000 scale).

SCHOBBENHAUS, C., HOPPE, A., BAUMANN, A. & LORK, A. 1994. Idade U/Pb do Vulcanismo Rio dos Remédios Chapada Diamantina, Bahia. *In*: *Congresso Brasileiro de Geologia, Balneário Camboriú 38, Resumos Expandidos*. Sociedade Brasileira de Geologia, **2**, 397–398.

SCHÖLL, W. U. & FOGAÇA, A. C. 1979. Estratigrafia da serra do Espinhaço na região de Diamantina (M. G.). *Sociedade Brasileira de Geologia, Núcleo de Minas Gerais, Boletim*, **1**, 55–73.

SHANEY, K. W. & MCCABE, P. J. 1994. Perspectives on sequence stratigraphy of continental strata. *American Association of Petroleum Geologists, Bulletin*, **78**, 544–568.

SILVA, R. R. 1999. Evolução tectônica durante o Proterozóico das bacias do Espinhaço e São Francisco em Minas Gerais. Anais do VII Simpósio Nacional de Estudos Tectônicos/Simpósio Internacional de Tectônica da SBG. Lençóis, Brazil, Session 2, 12–14.

SOUZA, W. S. 1986. Contribuição aos estudos de revisão estratigráfica do Pré-Cambriano Brasileiro a partir da utilização do conceito de unidade deposicional. *In*: *Congresso Brasileiro de Geologia 34, Goiânia, Anais*, Sociedade Brasileira de Geologia, **1**, 391–401.

TACK, L., LIÉGEOIS, J. P., DEBLOND, A. & DUCHESNE, J. C. 1994. Kibaran A-type granitoids and mafic rocks generated by two mantle sources in a late orogenic setting (Burundi). *Precambrian Research*, **68**, 323–356.

TACK, L., FERNANDEZ-ALONSO, M., TAHON, M., WINGATE, M. T. D. & BARRITT, S. 2002. The 'northeastern Kibaran belt' (NKB) and its mineralisations reconsidered: new constraints from a revised lithostratigraphy, a GIS-compilation of existing geological maps and a review of recently published as well as unpublished igneous emplacement ages in Burundi. *In*: *11th IAGOD Quadrennial Symposium and Geocongress.* Geological Survey of Namibia, Windhoek, Namibia, 6.

THEUNISSEN, K., HANON, M. & FERNANDEZ-ALONSO, M. 1991. *Carte Géologique du Rwand*, 1:1,000,000 scale. Royal Museum for Central Africa, Tervueren.

TORQUATO, J. R. & FOGAÇA, A. C. 1981. Correlação entre o Supergrupo Espinhaço no Brasil, o Grupo Chela em Angola e as formações Nosib e Khoabendus da Namíbia. *In*: *Anais do Simpósio sobre o Craton do São Francisco e suas Faixas Marginais*, Sociedade Brasileira de Geologia/Coordenação da Produção Mineral, Salvador, 87–98.

TROMPETTE, R. 1994. *Geology of western Gondwana (2000-500 Ma). Pan-African-Brasiliano aggregation of South America and Africa.* A. A. Balkema, Rotterdam.