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# Burial and exhumation history of North-east Brazil
# Field work 2007

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

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Contribution to the project "Burial and exhumation history of NE Brazil focussing on the Camamu Basin: a multidisciplinary study based on thermal, sonic and stratigraphic data and landform analysis" funded by Statoil do Brasil

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G E U S

# 1. Summary

This report documents fieldwork in Brazil during four weeks in July and August 2007, in particular observations of the large scale landscapes in relation to geology and locations of rock samples taken primarily for apatite fission-track analysis (AFTA). The fieldwork was part of the research project 'Burial and exhumation history of NE Brazil focussing on the Camamu Basin: A multidisciplinary study based on thermal, sonic and stratigraphic data and landform analysis'. The project is carried out by GEUS in close cooperation with Geotrack for Statoil do Brasil as a multi-disciplinary research project aimed at understanding the regional burial and exhumation history of NE Brazil and the Camamu Basin.

The fieldwork was focussed on the Early Cretaceous rift systems near the Atlantic margin and on the interior highlands in the state of Bahia. The fieldwork was divided into three main trips, all starting in Salvador: A. Recôncavo and South Tucano basins (guided by Peter Cobbold), B. Chapada Diamantina, Planalto de Conquista (guided by Augusto Pedreira) and C. Canyon Rio São Francisco, Sergipe and Alagoas. Furthermore, a vertical transect to 2.3 km a.s.l. was sampled for AFTA in Serra do Mar, north-east of Rio de Janeiro.

A total of 116 rocks were sampled during the field work, of these 103 were intended for AFTA and 5 for VR whereas 8 were for possible dating. Out of the 103 outcrop AFTA samples, 77 have been selected for further analysis. The apatite yields for these samples have been determined and only 4 had insufficient apatite yields. Consequently, AFTA data will be available for 73 outcrop samples and the results and interpretations are expected over the first months of 2008. The sampling included profiles across the Recôncavo-Tucano basins where rocks from the prerift, synrift and postrift strata were sampled as well as outcrop samples near the location of deep wells included in the study. Samples were also taken along the exposed boundary fault of the Camamu Basin. The sampling included regional east-west transects from Salvador to Rio de Contas (c. 350 km) and from west of Vitória da Conquista to Ilhéus (c. 200 km). The sampling also included vertical sections along the margins of the highlands.

Preliminary results of the geomorphological analysis indicate that two major erosion surfaces of regional extent can be defined within the study area; a lower surface extending from the coast and far into the interior (up to 400 m above sea level; a.s.l.) and a higher surface that includes the plateaux (planaltos) of Chapada Diamantina (c. 1200 m a.s.l.) and Planalto de Conquista (c. 900 m a.s.l.). Both surfaces cut across rocks of different resistances and ages and must therefore be erosional surfaces that formed towards a common base level. The surfaces are under destruction and are thus not in accordance with the present tectonic and climatic regime.

The lower surface has developed along the main rivers in the area, Rio de Contas, Rio Paraguaçu and Rio São Francisco. Deep gorges have formed where the rivers cut into resistant bedrock, but behind such obstacles the lower surface is wide where less resistant rocks occur. The lower surface is in general slightly tilted towards the sea. The higher surface can be correlated from Chapada Diamantina to Planalto de Conquista at a slightly lower elevation to the south and is thus dipping towards the south in this area. The surface

is characterized by an undulating plain with shallow and wide valleys, and it is preserved on high grounds with resistant rocks. Only remnants of the higher surface are preserved, but it must have been developed originally across a larger area where the lower surface has developed at the expense of the higher surface. Escarpments separate the lower surface from the higher surface. The valley patterns and the incision of rivers in the Recôncavo and Tucano basins show that the lower surface is also rapidly being dissected due to a change in base level after the formation of the lower surface in areas with easily eroding rocks.

Near the western margin of the Tucano Basin, the sedimentary sequences, including the Neogene Barreiras Group, appear to have been folded to form three anticlines with gentle eastern limbs and steeper western limbs. Each anticline lies between relatively straight, incised river valleys, which follow transfer faults in the rift system. The inference is that the anticlines are due to late Neogene compressional reactivation of an eastward-dipping normal fault and of the rift transfer faults.

The lower surface cuts across post-rift strata inside the Rift and across basement outside the Rift. The formation of the surface thus post-dates the Aptian Marizal Formation. The age of the surface may however, further be constrained by the well-documented outlier of the early Miocene, marine Sabiá Fm within the Recôncavo Basin. This occurrence testifies to a marine transgression, and we suggest that the exhumation leading to the formation of the lower surface occurred after this transgression and thus that the lower surface is younger than early Miocene.

The areas where the higher surface is defined are characterized by Cenozoic laterites and fresh-water diatomites. Both the higher surface and the laterites are currently being destroyed by erosion along the escarpments that outline the plateaux. Consequently, the laterites must have formed at the end of the erosional process that shaped the higher surface near a former base level. Correspondingly, the diatomite-rich lakes may have formed at that time. Based on the age of the laterites we can deduce that the higher surface formed during the Cenozoic. This time interval can be further narrowed if we assume that the younger, lower surface was formed subsequent to the deposition of the Sabiá Fm. The age of the higher surface may thus tentatively be found to be Palaeogene which agrees with geochronological constraints on deep weathering on similar plateaux in Minas Gerais.

Based on this preliminary interpretation, we find that the higher surface developed as a low-relief erosion surface towards a common base level, probably during the Palaeogene after an initial uplift event. Similarly, the lower surface developed during the Neogene, probably in the interval between the deposition of the Sabiá Fm and the Barreiras Group, after an uplift event that raised the higher surface to its present elevation around 1 km a.s.l. The lower surface thus developed at the expense of the uplifted higher surface, resulting in the formation of pronounced escarpments. Even the lower surface is presently under destruction due to minor uplift and compression during the Plio-Pleistocene.

A better discrimination between the areas where the higher and the lower surface can be defined awaits more detailed mapping. The timing of the uplift events will be further studied in the project that also will estimate the amount of exhumation involved in the formation of the erosion surfaces.

# 2. Background

Fieldwork was carried out in Brazil during four weeks in July–August 2007 with focus on the continental rift system and on the interior highlands in the state of Bahia. The fieldwork was part of the research project 'Burial and exhumation history of NE Brazil focussing on the Camamu Basin: A multidisciplinary study based on thermal, sonic and stratigraphic data and landform analysis'. The project is carried out by GEUS in close cooperation with Geotrack International for Statoil do Brasil Ltda as a multi-disciplinary research project aimed at understanding the regional burial and exhumation history of NE Brazil and the Camamu Basin. Based on a regional survey of the onshore areas north and south of Salvador and of the offshore basins, the project selected several traverses linking the onshore and offshore areas for a more detailed study where the geological and topographic conditions are most favourable for deciphering the exhumation history of the region. The integrated study (cf. Japsen *et al.* 2006, 2007a) is based on apatite fission-track analysis (AFTA) and vitrinite reflectance (VR) data from outcrop and well samples (e.g. Green *et al*. 2002; Japsen *et al*. 2005), sonic velocity data (e.g. Japsen *et al*. 2007a, b) and on landform analysis (e.g. Bonow *et al*. 2006a, b). The project started in 2007 and will be finished in 2008.

The aim of the field work was to carry out a general reconnaissance of the study area and 1) to sample rocks at outcrop for apatite fission-track analysis, 2) to select samples for apatite fission-track analysis from onshore and offshore wells, and 3) to make geomorphological investigations.

# 3. Regional setting

The study area is located on the Brazilian Atlantic margin, mainly in the state of Bahia but also in adjacent areas in the states of Sergipe and Alagoas (between 9°-16°S and 35°-43°W). Major tectonic features are the Precambrian São Francisco craton and the intracontinental Recôncavo-Tucano-Jatobá Rift that developed in Early Cretaceous times during the opening of the South Atlantic (Figs 3-1, 3-2). The Camamu Basin which is part of the same rift system is located offshore, south of the Recôncavo Basin, but the western margin of the Camamu Basin is exposed along the coast.

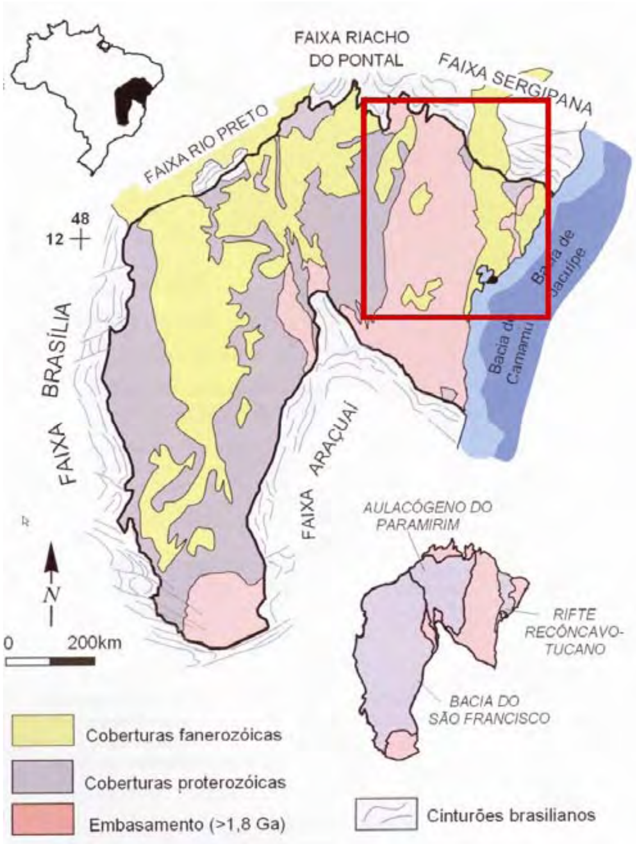


**Figure 3-1.** *Geological map of the São Francisco Craton. Red rectangle indicates the present study area. The pink colour in the map and the legend should be identical. Faixa= foldbelt. From Alkmin (2004).*

The coastal areas are dominated by lowland plains that have developed up to 200 km inland from the coast. Pronounced escarpments often border the lowland plains in the hinterland, and above the escarpment lay highland plains ('planaltos') (Fig. 3-3). The highlands and their escarpments are often referred to as 'chapadas', literally 'capping'. The highland plains are generally elevated to 1000–1400 m a.s.l., but above the plains some ridges have peaks that reach up to 2 km above sea level (a.s.l.).

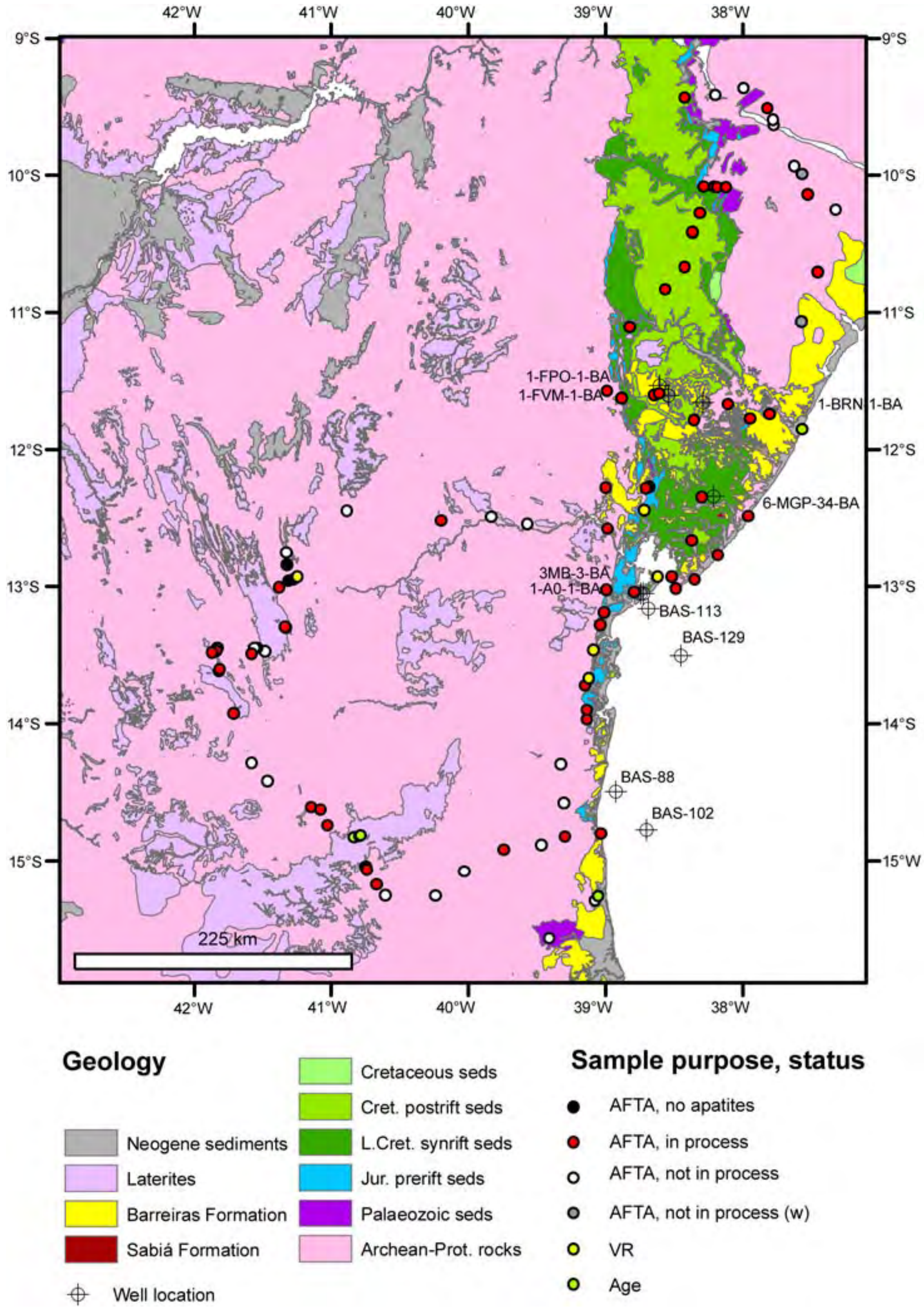


**Figure 3-2.** *Geological map of the study area, scale 1:6,000,000. Names of wells selected for further studies is shown on the map. Details of outcrop samples in Appendix (details of the map with sample numbers shown in Figs 6-1, 6-2). Sample symbols may be overlapping. Based on GIS maps of Brazil and of the state of Bahia (CPRM 2001, 2003).*

According to Sabaté *et al* (1995), the São Francisco Craton is generally surrounded by fold belts (e.g. the Sergipana foldbelt in the north-eastern part of the study area) where tectonic activity culminated during the Brasiliano cycle (c. 900–500 Ma) (Fig. 3-1). The continental crust within the Craton which is the thickest in Brazil, can be subdivided into three large Precambrian stratigraphic and tectonic units:

- a Late Proterozoic sedimentary cover related to the Brasiliano cycle,

- a Middle Proterozoic platform cover (Chapada Diamantina) and the correlated Espinhaço fold belt (1.6–1.0 Ga),
- an Archaean and Early Proterozoic basement (>1.6 Ga).

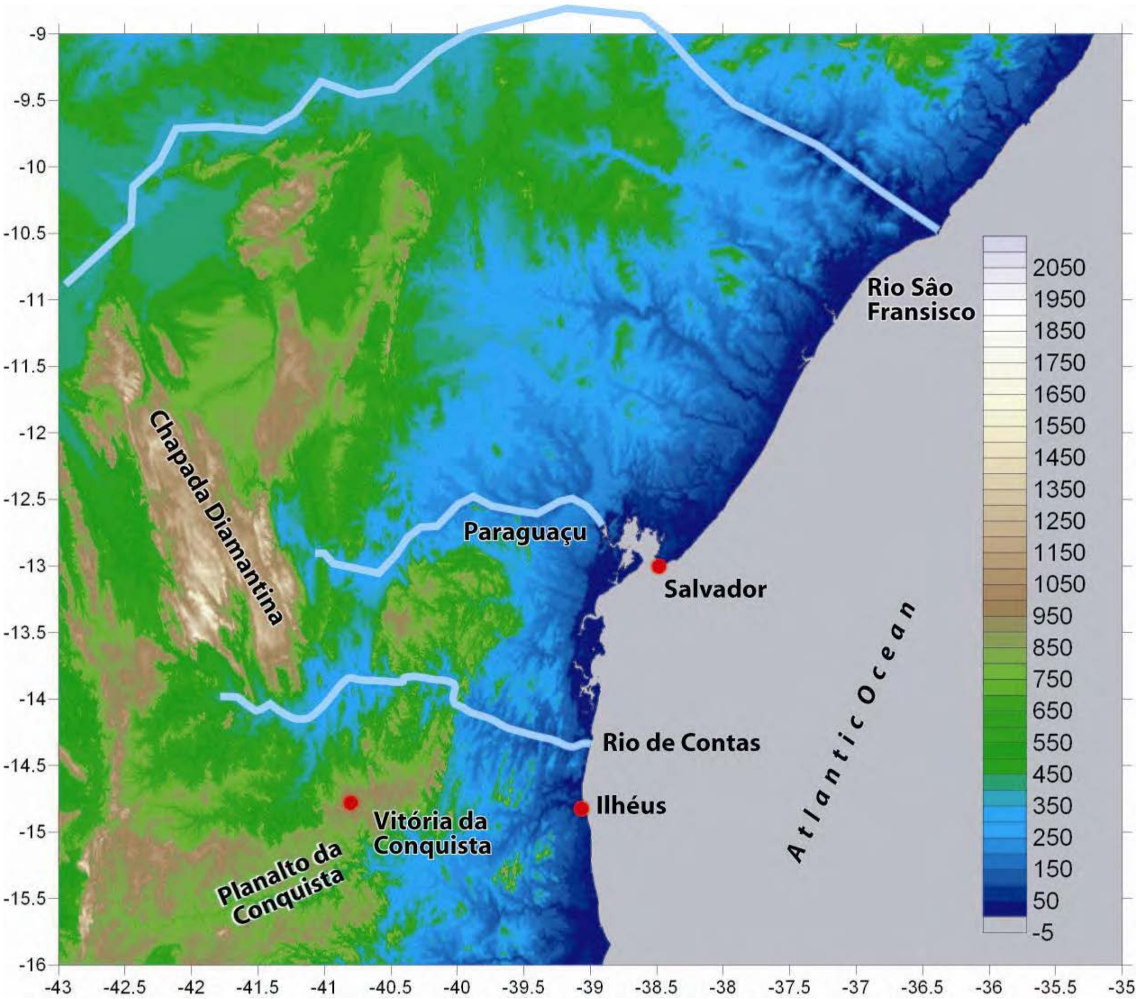


**Figure 3-3.** *Topography of the study area. Two topographical features dominate the landscape: The coastal plain and the high plains (‘planaltos’). Pronounced escarpments separate the two features. Colour scale in metres above sea level. Additional place names are shown on maps in Appendix.*

## 3.1 Chapada Diamantina

The plateau of Chapada Diamantina rises above the coastal plains c. 250 km from the Atlantic coast and has altitudes averaging around 1,000 m and peaks up to 1,700 m above sea level. The Chapada represents the divide between the São Francisco river valley to the west, and the terrain that extends eastwards towards the Atlantic coast. The central part of Chapada Diamantina comprises the Mesoproterozoic Chapada Diamantina Basin and Neoproterozoic Irecê, Ituaçu and Una-Utinga basins (Fig. 3-4). The Chapada Diamantina Basin that developed on continental crust is a quartzite-pelite-carbonate type cover sequence, represented by the Espinhaço Supergroup. Its low-grade strata are divided into the

Rio dos Remedios, Paraguayu and Chapada Diamantina Groups, unconformably overlain by the Neoproterozoic Una Group according to Pedreira & Bomfim (2000).

The Rio dos Remedios Group, a few hundred meters thick, comprises acid effusive rocks and strata that are related to crustal rifting. In places, the quartzites have sedimentary structures diagnostic of eolian facies, so that the Rio dos Remedios Group may be interpreted as a product of fissural volcanism in a desert environment. Its maximum age is 1718 ± l Ma.

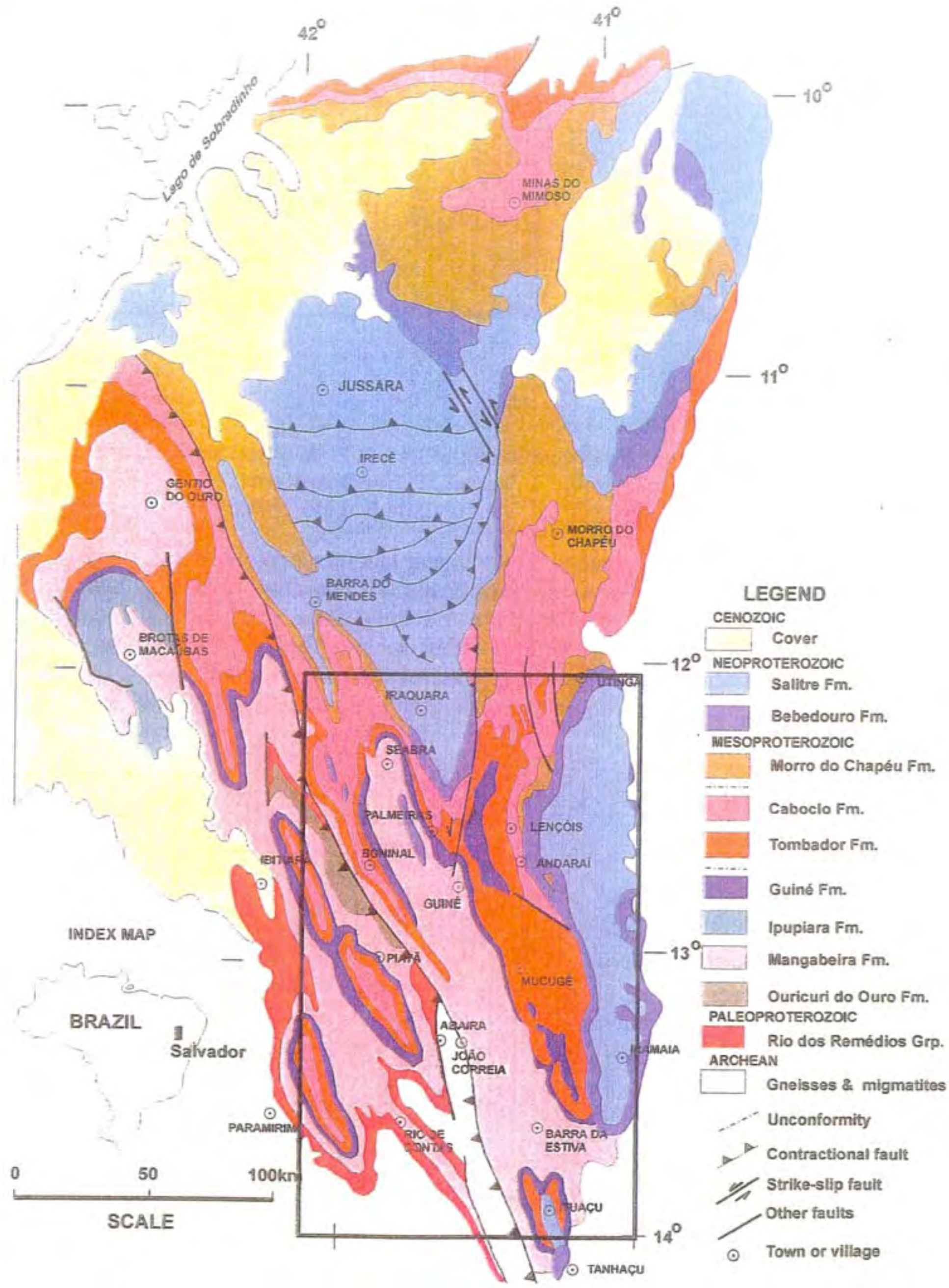


**Figure 3-4.** *Geological map of Chapada Diamantina. The rectangle corresponds to the detail shown in Fig. 9-3. From Pedreira & Bomfim (2000).*

The Paraguayu Group comprises the Ouricuri do Ouro, Mangabeira, Ipupiara and Guine formations. The Ouricuri do Ouro Formation (about 125 m thick) comprises conglomerates and subordinated sandstones. The sandstones are epiclastic with cross bedding and a few ripple marks that indicate their subaquous deposition. The Mangabeira Formation (>2000 m thick) is fine and coarse grained feldspathic sandstones that generally are cross bedded. The great thickness of this formation and the absence of major faults associated to it, suggest slow subsidence during its deposition. The Ipupiara Formation (up to 1500 m thick) consists of sandstones and shales, with ripple marks. In most of the Chapada Diamantina, the Mangabeira Formation is overlain by the Guine Formation. The basal part is characterised by shales and siltstones with a very weathered intercalation of conglomerate, followed by interbedded sandstones and siltstones. The upper part of the formation is characterized by fluvial channels cut into rippled sandstones. The depositional environment of the Guine Formation has therefore been interpreted as deltaic.

The Chapada Diamantina Group comprises the Tombador, Caboclo and Morro do Chapéu formations. The Tombador Formation (90-400 m thick) is essentially composed by sandstones and conglomerates. The sandstones range from fine to coarse grained, are cross or horizontally bedded. The conglomerates are of two types: The first type, with rounded pebbles whose diameter is up to 5 cm, is generally associated to fluvial sands; the second type is polymictic with some metric sized boulders are interpreted as alluvial fans. The Caboclo Formation (250 m thick) begins by calcarenites followed by pelites with sandstones and carbonate lenses in its type-area. The Morro do Chapéu Formation (250 m thick) is characterized by a basal fluvial conglomerates followed by estuarine and tidal flat sandstones and shales, and deltaic sandstones (Souza Cruz et al. 2006).

The Bebedouro and Salitre formations of the Una Group lie unconformably above the Chapada Diamantina Group. The Bebedouro Formation consists of diamictites, sandstones, siltstones and shales (200–350 m thick). The Salitre Formation comprises carbonates with very subordinate terrigenuous strata (100–240 m thick).

The Brasiliano folding affected the entire Proterozoic sedimentary sequence in the Chapada Diamantina area, including the Salitre Formation.

## 3.2 The Recôncavo-Tucano-Jatobá Rift

The main rifting phase along the NE Brazilian margin occurred between 135 and 120 Ma, but the development of the Recôncavo-Tucano-Jatobá (RTJ) Rift failed following crustal separation between South America and Africa in the late Aptian (c. 120 Ma) (e.g. Milani & Davison 1988; Chang *et al.* 1992; Magnavita *et al.* 1994; Magnavita *et al.* 1998; Davison 1999). The rift contains Palaeozoic to Cenozoic strata and the post-Palaeozoic stratigraphy can be broken down into prerift, synrift and postrift phases (Figs 3-2, 3-5) (Magnavita *et al*. 1994). The Phanerozoic sequence in the RTJ Rift and the adjacent area contains several major unconformities (Table 3-1).

The prerift sequence consists of continental sandstones and lacustrine shales of Jurassic age (Sergi and Aliança formations, respectively) which progressively thin northward from a maximum thickness of 1200 m in the south Recôncavo Basin to less than 200 m in the Jatobá Basin.

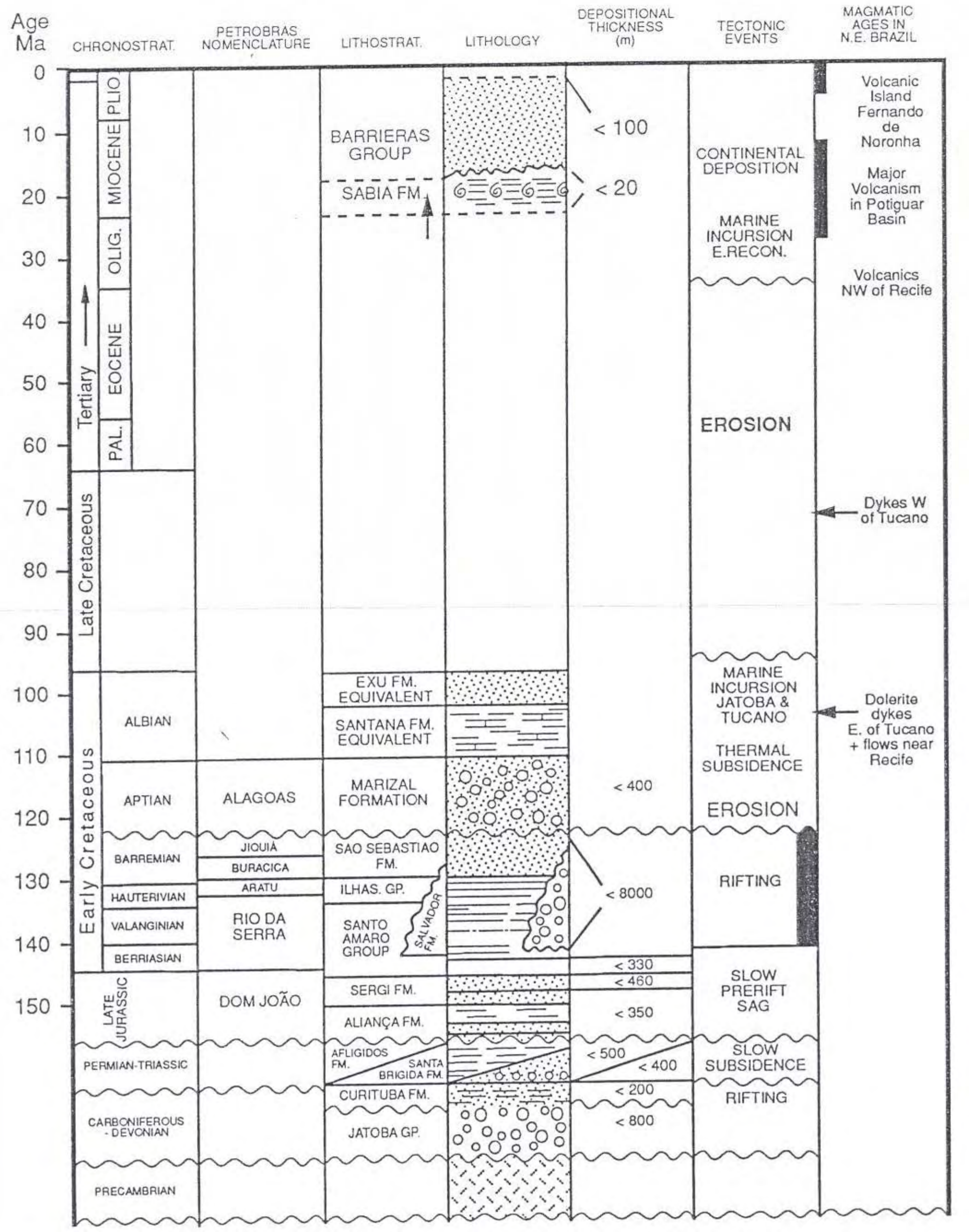


**Figure 3-5.** *Stratigraphic column and geological history of the Recôncavo-Tucano-Jatobá Rift. According to Caixeta et al. (1994) the deposits that are assigned a Permo-Triassic age in this Figure are exclusively of Permian age. From Magnavita et al. (1994).*

The rift phase was initiated during the Berresian to Valanginian (146–136 Ma), when the main extensional faulting occurred, and great thicknesses (locally up to 3 km) of coarse conglomerates were deposited next to major faults (Salvador Formation). In the centre of the basin a deep lake formed, which was filled by shales and turbiditic sandstones (Candeias Formation). Deltaic sandstones and shales (Ilhas Formation) and fluvial sandstones

(São Sebastião Formation) filled in the rift. Rifting stopped during the deposition of the latter formation in Barremian to early Aptian times (c. 130–120 Ma)

The basin was blanketed by postrift fluvial and alluvial conglomerates and sandstones with occasional thin lacustrine shales of Aptian age (Marizal Formation). The Marizal Formation was deposited on an undulating eroded surface underlain by tilted synrift strata. The Marizal Formation covers most of the Tucano and Jatobá basins, but have been largely eroded from the Recôncavo Basin (Fig. 3-2). The Marizal Formation reaches a maximum thickness of approximately 400 m in the Tucano Basin. According to Magnavita et al. (1994) evidence of Albian marine incursions is preserved in the Tucano and Jatobá basins (Santana and Exu formations).

## 3.3 Mesozoic cover outside the RTJ Rift

Vast areas of Brazil are covered by Mesozoic sediment. The Phanerozoic Sanfranciscana Basin is of special interest to this study because Cretaceous sediments here crop out over more than 100,000 km$^2$ in the western part of Bahia and further west (Campos & Dardenne 1997a). This eastern limit of this basin reaches 80 km west of the study area (as defined by Fig. 3-2). The Phanerozoic cover is composed mainly of sedimentary continental rocks and minor explosive volcanic rocks including rocks of Carboniferous to Permian, Early and Late Cretaceous as well as Quaternary age. The Upper Cretaceous is subdivided into the Mata da Corda and the Urucuia groups. The Cenomanian to Campanian Urucuia Group is composed of sandstones interpreted as dune deposits and braided stream deposits with transport from NEE to SWW, with sources in the north-east São Francisco Craton. It is present in the entire basin. The Mata da Corda Group is primarily of Maastrichtian age and is composed by volcanic rocks and by distal epiclastic sediments. It is present in the southern sector of the basin. The Cretaceous rocks are exposed over a planar surface at an elevation of c. 1 km a.s.l. Rivers are incised into the surface that cuts across the tilted Cretaceous strata (Campos & Dardenne 1997b). No conglomerates or faults are found along the present limits of the Cretaceous deposits that consequently appear to be defined by post-depositional exhumation; i.e. during the Cenozoic.

Upper Cretaceous rocks also crop out on Chapada do Araripe, c. 200 km north of the study area. These strata defines a plateau at an elevation of c. 1 km a.s.l., (e.g. Neto *et al.* 2006).

## 3.4 Cenozoic cover

Thin (<20 m) lower Miocene fossiliferous marine shales occur at one locality in the Recôncavo Basin (Sabiá Formation; see Figs 3-2, 6-1) (Viana *et al.* 1971).

The Barreiras Group of Miocene-Pliocene age was deposited as a fluvial sandstone cover (<100 m) along most of the Atlantic margin of Brazil (Pedreira 1971, and Bigarella 1975 as cited by Magnavita *et al*. 1994). The deposits even reach into the south-western part of the Tucano Basin and the basement areas south-west of the rift (CPRM 2003). There may however, be some degree of uncertainty in the discrimination between the Barreiras Group and lateritic covers as these names have been assigned to deposits of similar characteristics in terms of location and topography in southern Tucano and west of Recôncavo (Figs 6-1, 7-4). The sedimentological characteristics are indicative of deposition in a braided river system related to alluvial fans under an arid to semi-arid climate (Bôas *et al.* 2001). The basal portion of the Barreiras Group was deposited in a proximal fluvial system whereas the upper portion was deposited in a more distal zone according to Bôas *et al*. (2001) who found the deposits to be indicative of steep relief resulting from tectonic action. The age of the Barreiras Group has been a topic of debate, but Bezerra *et al*. (2001) argued that the top of the Barreiras Group near Natal could be taken to be Pliocene based on relative dating by palaeomagnetic and micropollen. According to Figueiredo *et al*. (1994) a Pliocene age of the Barreiras Group was confirmed by pollen analysis and the study of 38 species of *Dicotyledoneae*.

Arai (2006) argued that recent palaeontological and sedimentological studies have shown irrefutable marine influence on the Barreiras Group and that its basal part dates back to the early and middle Miocene. According to Arai (2006) palynological dating and coring of the Barreiras Group with coeval lithostratigraphic units in offshore basins of the Brazilian continental margin and elsewhere in the world have permitted new interpretation in the light of sequence stratigraphic concepts. This integrated studies permitted correlation of the origin of the Barreiras Group with the Miocene global eustatic rise, which reached its maximum from the Burdigalian to the Serravalian (20-12 Ma). Deposition of the Barreiras *senso lato* was interrupted in the Tortonian (early late Miocene), when a global eustatic fall exposed and eroded part of the Barreiras and led to the formation of prograding wedges in the offshore portion of the continental margin basins. Renewed eustatic rise in the Pliocene (Zanclean, 5-4 Ma) initiated a second depositional phase ('Barreiras Superior'). Erosion and reworking of the Barreiras Group during the Quaternary have contributed to the present configuration of the continental shelf. According to this interpretation of Arai (2006), the origin of the Barreiras Group is solely seen in the light of global eustacy whereas possible influence of tectonic movements is not discussed.

Vast areas in the interior highlands of the state of Bahia are mapped as Cenozoic or Neogene laterites ("Coberturas detrito-lateríticas", CPRM 2003). These thick (>100 m?) covers of heavily weathered basement rock (saprolites) are found on the planaltos and other elevated areas (Fig. 9-5). They probably represent remnants of more extensive saprolites that have been preserved in the uplifted areas where they have not yet been removed by fluvial erosion. Direct dating of weathering phenomena in Brazil has become possible by $^{40}Ar$ / $^{39}Ar$ and K-Ar analysis of supergene K-Mn oxides (e.g. Vasconcelos et al. 1994). Spier et al. (2006) investigated deep weathering profiles overlying iron ore deposits in Minas Gerais, south-west of the study area (c. 44ºW, 22ºS). Laser incremental-heating $^{40}Ar$ / $^{39}Ar$ results for grains of manganese oxides revealed ages ranging from c. 62 to 14 Ma, where older Mn-oxides occurred near the surface, while younger Mn-oxides occurred at depth. However, many samples collected at the weathering–bedrock interface yielded ages in the 51–41 Ma range, suggesting that the weathering profiles had reached their present depth in the Paleogene. The age versus depth distributions obtained showed that little advance of the weathering front had occurred in the lateritic profiles during the Neogene. Spier et al. (2006) found that the weathering was not controlled by the steady-state advance of weathering fronts through time, but reflected climatic and geomorphological conditions prevailing in a remote past. The geochronological results also confirmed that the ancient landsurfaces in the study area probably remained immune to erosion for tens of millions of years, and that the deep weathering mostly occurred in the Paleogene during hot and wet climatic conditions. Spier et al. (2006) also noted that deep weathering profiles are a characteristic of the plateau in the area studied and thus sets it apart from the dissected landscape that surrounds the plateau: The plateau hosts much deeper weathering profiles than the surrounding landscape; local relief within the plateau is less pronounced than in the surrounding plains; ages of weathering profiles on the plateau are much greater than ages for the surrounding plains.

Finally, there are several occurrences of fresh-water diatomite deposits in the highlands of e.g. Chapada Diamantina and Planalto da Conquista, and apparently none in the lowlands. These deposits are exploited in numerous small-scale mines, but the literature on this subject is very sparse.

**Table 3-1.** *Major unconformities and main sedimentary sequences in the Phanerozoic sequence in the RTJ Rift and adjacent areas. Primarily based on Magnavita et al. (1994), Caixeta et al. (1994) and updated according to the geological map of Bahia (CPRM 2003). Geological ages from Gradstein et al. (2004) (Fig. 3-5).*

*Deposits of Quaternary age (2–0 Ma).*

Late Neogene unconformity; hiatus possibly around 2 Ma (Plio-Pleistocene).

*Deposits of possibly Pliocene age (5–2 Ma) (Figueiredo et al. 1994); Barreiras Group*.

Early Neogene unconformity; hiatus possibly 15 to 5 Ma (mid to late Miocene).

*Deposits of early Miocene age (c. 23–16; possibly Aquitanian to Burdigalian); Sabiá Fm*.

Late Mesozoic to mid-Cenozoic unconformity; hiatus c. 100 to 25 Ma (Late Cretaceous to Oligocene).

*Deposits of late Aptian age and Albian age (115–100 Ma); Marizal Fm, Santana and Exu Fms (Tucano, Jatobá).*

Aptian (break-up) unconformity; hiatus c. 125 to 115 Ma (mid-Aptian).

*Deposits of Tithonian to earliest Aptian age (151–125 Ma); Brotas, Santo Amaro, Ilhas and Massacará Groups.*

Early Mesozoic unconformity; hiatus c. 250 to 150 Ma (Triassic to Middle Jurassic).

*Deposits of Permian age (299–251 Ma); Santa Brigida Fm (Tucano Norte, Jatobá), Aracaré Fm (Sergipe-Alagoas), Afligidos Fm (Recôncavo, Tucano Sul).*

Late Palaeozoic unconformity; hiatus c. 360 to 300 Ma (Carboniferous).

*Deposits of Silurian (444–416 Ma) and Devonian (416–359 Ma) age; Taracatu Fm of the Jatobá Group and Curituba Fm, respectively.*

Early Palaeozoic unconformity; hiatus c. 540–440 Ma (Cambrian to Ordovician).

*Precambrian basement of Neoproterozoic age (1000–542 Ma).*

## 3.5 Burial and exhumation history of NE Brazil

### 3.5.1 Amount and timing of exhumation of the RTJ Rift

Magnavita *et al*. (1994) discussed the burial and exhumation history of the Recôncavo and Tucano basins extensively and the following is a summary of their main points.

Figure 3-6 shows the depth to the top of the thermal maturity zone of organic matter in the synrift strata (vitrinite reflectance Ro = 0.6). The maturity depth is shallow in the Recôncavo Basin where source rocks are mature at a depth of 0.8 km along the borders of the rift and reaches a maximum depth of 1.6 km (below mean sea level) in the centre of the basin. The southern part of the Tucano Basin has a distinctly greater maturity depth, reaching a maximum of 3.2 km in the centre of the basin, although source rocks on the western border are mature to within 400 m of the surface.

Assuming a geothermal gradient of 30ºC/km, Ro values of 0.6 imply the source rocks should be mature around a depth of 3 km according to Magnavita *et al*. (1994). However, heat flow in the Recôncavo Basin may have been higher during the rifting and the subsequent opening of the South Atlantic. Magnavita *et al*. (1994) reported an amount of exhumation of at least 1750 m at the location of the Rio do Bu oilfield based on VR data (see Fig. 3-6 for location). Davison (1987) estimated a minimum of 1 km of exhumation from the surface porosity of synrift shales in the middle of the Recôncavo Basin.

The surface outcrops are also indicative of large-scale removal of postrift strata from the Recôncavo and South Tucano basins, as early synrift strata crop out throughout the basin, and only a limited cover of postrift strata is preserved; e.g. the Marizal Formation with a maximum thickness of 400 m (Fig. 3-2).

Magnavita *et al*. (1994) thus concluded that the Recôncavo Basin had been deeply exhumed, but found no clear explanation for the shallow maturity depth along the western margin of the Recôncavo Basin. Possible causes were suggested to be migration of hot fluids from the deepest part of the basin, or movements along a large fault with an easterly dip that may have been present along the western margin.

Magnavita *et al*. (1994) noted that very little basin sediment is preserved outside the faulted basin margins, whereas strata in the basin are preserved at altitudes well above the elevation of the surrounding highly resistant Proterozoic basement. The only Cretaceous strata which onlap over the basin boundary faults are the postrift Marizal Formation in the North Tucano and Jatobá basins. Rift strata lie up to 1000 m a.s.l. in isolated buttes in the Jatobá Basin and stand up to 400 m higher than the surrounding basement. The topography in the Recôncavo Basin is more subdued, with the highest outcrops of sedimentary rocks reaching 200 m a.s.l.. Magnavita *et al*. suggested that this difference in relief could be due to high tropical rainfall in the Recôncavo Basin compared to the Jatobá Basin, which is almost a desert. The drainage pattern in the Precambrian basement has a mature dense dendritic pattern, whereas the Marizal Formation forms high plateaus which are cut by widely spaced large gorges, so that erosion due to water runoff is much more localized. Furthermore, the tops of the high plateaus are covered with intensely silicified limestone and sandstones which make them highly resistant to erosion.


**Figure 3-6.** *Depth to the onset of maturity of organic matter defined by vitrinite reflectance of 0.6 in the Recôncavo and south Tucano rifts. RBU: Location of the Rio do Bu oilfield, where erosion of sediment of 1750 m is estimated from vitrinite reflectance data. From Magnavita et al. (1994).*

Thin sandstones of presumed Devonian age are preserved at many localities outside the basin margins. These are thought to be part of a widespread shallow basin which linked the RTJ Rift with the Paleozoic age Parnaíba Basin farther north. Magnavita *et al*. (1994) found this to suggest that a pre-Devonian basement peneplain had been re-exhumed.

Widespread erosion of the synrift strata in the RTJ Rift took place soon after rifting between approximately 124 and 120 Ma, indicated by a regional unconformity between the Aptian age Marizal Formation and the older strata. Localized footwall uplift and associated erosion occurred during and probably soon after rifting, evidenced by the large thicknesses of conglomerates deposited along the rift border faults. The rift was probably near sea level when Albian age carbonates were laid down. These strata have been correlated with Albian age limestones in the Araripe Basin which are definitely marine. These carbonates lie immediately above the Marizal Formation in the Jatobá Basin. Surface uplift of at least 600 m (evidenced by these uplifted carbonates) was followed by regional erosion of unknown age which occurred before deposition of the Miocene age Sabia Formation in the Recôncavo Basin. Magnavita *et al*. (1994) referred to geomorphological evidence of regional erosion during the Oligocene, but concluded that there were no close constraints on when this second period of erosion occurred.

### 3.5.2 Exhumation studies in NE Brazil

Harman *et al*. 1998 reported apatite fission-track (AFT) data from outcrops on the São Francisco Craton west of the RTJ Rift, within the rift and from the basement block east of the rift. The AFT ages in that area ranged from 83 to 244 Ma and the samples adjacent to the coast were found to have the youngest ages; three basement samples east of the Recôncavo and southern Tucano basins had ages of 83, 94 and 95 Ma, whereas one sample from within the Rift had an age of 167 Ma. Samples from the Craton had ages ranging from 130 to 244 Ma.

Quantitative thermal histories derived from the data indicated two discrete phases of cooling: the first one coeval with continental breakup in the Early Cretaceous (c. 130 Ma) and the second one broadly coeval with a change in relative plate motion in the Late Cretaceous (60 to 80 Ma) (Harman *et al.* 1998). According to the modelling the cooling on the Craton has amounted to 50 to 70ºC since 130 Ma, whereas the cooling along the coast has amounted to 70 to 100ºC since 80 Ma. According to these authors a cooling of 80ºC corresponds to 3 to 5 km of denudation for a geothermal gradient of 15-30ºC/km. Harman *et al*. (1994) found evidence for a post-rift phase of tectonic inversion within several South American and African intracontinental rift basins. For example, there is a notable absence of Turonian strata along most of the Brazilian margin, c. 90 Ma (Davison 1999).

The significant cooling since the Late Cretaceous of the rocks now at surface within the study area recorded by the AFT data published by Harman *et al*. (1998) corresponds to the deep erosional cut into the postrift sequence found today in the RTJ Rift where only 400 m of the Marizal Formation is preserved. However, the possibility of smaller amounts of denudation due to higher geothermal gradients was not considered by Harman *et al*. (1998), and the age of the removed sedimentary sequence and when it was removed were not discussed.

Peulvast et al. (in press) found evidence for low post-Cenomanian denudation depths across the Brazilian Northeast (north of 8ºS) and concluded that the landscape had formed during that period in the context of continuously falling base level overprinted by episodic fluctuations. The post-Cenomanian uplift caused an inversion of the Cretaceous basins and generated a landscape in which the most elevated landforms correspond either to resistant

Mesozoic sedimentary caprock, or to eroded stumps of syn-rift Cretaceous footwall uplands. Peulvast et al. (in press) argued for a stepped landform system dominated by two erosional levels: A low plain between 0 and 300 m a.s.l. and the discontinous remains of a high plain between 750 and 1100 m a.s.l. The authors found that subsidence in the Cretaceous Araripe Basin ended after the deposition of the Cenomanian Exu Fm that caps Chapada do Araripe. In support of this statement the authors refer to unpublished studies of organic matter in the Albian sediments that suggest that no significant overburden was ever removed by erosion from the exposed upper surface of the Exu caprock (this is however, in contrast with VR values of 0.6 for the Albian strata; P.F. Green pers. comm.). Peulvast et al. (in press) referred to the increase in denudation rate occurring at 80-60 Ma over much of their study area estimated from apatite fission-track data by Harman et al. (1998), but did not comment on the km-deep exhumation since 80 Ma deduced by Harman et al. (1998) from the same data. The Neogene Barreiras Formation along the coast was found to testify to the last peak of erosion in the hinterland at c. 13 Ma or earlier.

# 4. Geological map and digital terrain model

We have prepared a geological map at a scale of 1 : 2,250,000 of the study area, separated in two maps for the north-eastern and the south-western study areas primarily based on the GIS map of Bahia at a scale of 1 : 1,000,000 (Figs 6-1, 6-2) (CPRM 2003). The corners of the map that were not covered by the Bahia map, was covered with additional information from the geological map of Brazil at a scale of 1 : 5,000,000 (CPRM 2001) and additional information from the geological map of the state of Sergipe (CPRM 1997). Place names are shown on the road maps in Appendix A, whereas sample locations are shown on both the geological map and on the road maps.

The focus of the map is the Phanerozoic cover, in particular the strata related to the Cretaceous rifting and the remnants of Cenozoic rocks. An area with Neoproterozoic–Lower Palaeozoic rocks including the Salobro Fm of c. 600 Ma in the SE corner of the map (south of Ilhéus) is mapped as Palaeozoic rocks (sample GC990-102). The extent of Cenozoic laterites are based on the geological map of Bahia where these covers are either indicated as Neogene detrital laterites (‘Coberturas detrito-lateríticas’, NQdl) or as Cenozoic detrital laterites (‘Coberturas detrito-lateríticas com concreções ferruginosas’ – Detrital lateritic cover with ferruginous concretions). The category ‘Neogene sediments’ on the map includes Quaternary strata (Q1, Q2) and Neogene alluvial strata (NQc) other than the Barreiras Formation (ENb, classified as Cenozoic on the Bahia map). Finally, the only occurrence of the Sabiá Formation is indicated on the map (Fig. 6-1).

The terrain models were constructed from the *Shuttle Radar Topography Mission* (SRTM). The data set has a resolution of about 90 * 90 m in the study area. The large-scale landforms were described and analysed by aid of the digital terrain model.

# 5. Fieldwork program

The fieldwork took place in the Brazil between July 27 and August 23 2007. The fieldwork was divided into three main trips, all starting in Salvador (Table 5-1):

A. Recôncavo and South Tucano basins, guided by Peter Cobbold (July 28–August 1).
B. Chapada Diamantina, Planalto de Conquista and the exposed margin of the Camamu Basin, guided by Augusto Pedreira (August 13–18).
C. Canyon Rio São Francisco, Sergipe and Alagoas (August 19–21).

Furthermore, a vertical transect to 2.3 km a.s.l. was sampled for AFTA in Serra do Mar, near Teresopolis (RJ) (Aug. 9–11). The fieldwork was carried out by car covering a distance of more than 5000 km during the three trips.

A list of suggested well samples for AFTA and VR was produced during visits to Petrobras' core store in Salvador (August 3) and to the core store of Cenpes in Rio (August 7). The project was presented at Petrobras' office in Salvador (July 27) and discussions and presentations were made at Statoil's office in Rio (August 6–8).

**Table 5-1.** *Fieldwork and other activities during the stay in Brazil.*

| Day | Week | Field work | Geo guide | Various | Air travel | Hotel |
|---|---|---|---|---|---|---|
| 26-Jul-07 | 30 | | | | Copenhagen | |
| Friday, 27 July 2007 | | | | Meeting Petrobras | -> Salvador | S |
| Saturday, 28 July 2007 | | Tour A | Cobbold | | | S |
| Sunday, 29 July 2007 | | | Cobbold | | | Tuc |
| Monday, 30 July 2007 | 31 | | Cobbold | | | Tuc |
| Tuesday, 31 July 2007 | | | Cobbold | | | S |
| Wednesday, 1 August 2007 | | | Cobbold | | | S |
| Thursday, 2 August 2007 | | | | Rock shipment | | S |
| Friday, 3 August 2007 | | | | Corestore, Salv. | | S |
| Saturday, 4 August 2007 | | | | | Salv->Rio | R |
| Sunday, 5 August 2007 | | | | (paper work) | | R |
| Monday, 6 August 2007 | 32 | | | Statoil's office | | R |
| Tuesday, 7 August 2007 | | | | Corestore, Rio | | R |
| Wednesday, 8 August 2007 | | | | Statoil's office | | R |
| Thursday, 9 August 2007 | | Teresop. | | | | Ter |
| Friday, 10 August 2007 | | Teresop. | | | | Ter |
| Saturday, 11 August 2007 | | | | | Rio->Salv | S |
| Sunday, 12 August 2007 | | | | (paper work) | | S |
| Monday, 13 August 2007 | 33 | Tour B | Pedreira | | | Muc |
| Tuesday, 14 August 2007 | | | Pedreira | | | RdC |
| Wednesd., 15 August 2007 | | | Pedreira | | | S |
| Thursday, 16 August 2007 | | | Pedreira | | | VdC |
| Friday, 17 August 2007 | | | Pedreira | | | Ilh |
| Saturday, 18 August 2007 | | | Pedreira | | | S |
| Sunday, 19 August 2007 | | Tour C | - | | | NSdG |
| Monday, 20 August 2007 | 34 | | - | | | Pir |
| Tuesday, 21 August 2007 | | | - | | | S |
| Wednesd., 22 August 2007 | | | | Rock shipment | | S |
| Thursday, 23 August 2007 | | | | | Salvador | |
| Friday, 24 August 2007 | | | | | -> Copenh. | |

Location of hotels:

Ilh – Ilheus (BA), Muc – Mucugê (BA), NSdG – Nossa Senhora da Glória (SE), Pir – Piranhas (AL), R – Rio de Janeiro (RJ), RdC – Rio de Contas (BA), S – Salvador (BA), Ter – Teresopolis (RJ), Tuc – Tucano, Caldas do Jorro (BA), VdC – Vitória da Conquista (BA).
AL: Alagoas, BA: Bahia, RJ: Rio de Janeiro, SE: Sergipe.

# 6. Rock sampling

A total of 116 rocks were sampled during the field work, of these 103 were intended for AFTA and 5 for VR whereas 8 were for possible dating. The AFTA / VR samples were shipped directly to Geotrack, Australia, whereas the remaining samples plus backups of most of the other samples were sent to GEUS, Denmark. Details about the samples are shown in Table A and road maps with location names and sample locations are also found in Appendix A. The area sampled in the state of Bahia covers 700 km north-south and 500 km east-west divided into two main areas, the Recôncavo-Tucano rift including the basement areas east of the rift (Tour A and C) and the interior highlands around Chapada Diamantina and Planalto de Conquista including the coast between Salvador and Ilhéus (Tour B). Furthermore a vertical transect to 2.3 km a.s.l. was sampled in Serra do Mar near Teresopolis (RJ).

Out of the 103 outcrop AFTA samples, 77 have been selected for further analysis. The apatite yields for these samples have been determined and only 4 had zero or insufficient apatite yields. Consequently, AFTA data will be available for 73 outcrop samples and the results and interpretations are expected to be available over the first months of 2008. Thus there remain 26 outcrop samples that may be included in the AFTA study at a later stage (Figs 6-1, 6-2).

## 6.1 Recôncavo, Tucano and Camamu Basins

Samples for AFTA and VR were collected across the rift along a couple of transects including basement rocks on either side of the Recôncavo and Tucano basins:

- Across the southernmost part of the Recôncavo Basin from Salvador city (sample GC990-14) across the island of Itaparica (where wells 3-MB-3-BA and 1-AO-1-BA are located) to Nazaré (GC990-46),
- across central Recôncavo Basin (where wells 1-FPO-1-BA, 1-FVM-1-BA and 1-BRN-1-BA are located) from Imbassai (GC990-16) at the coast to Feira de Santana (GC990-57),
- Across southern Tucano Basin (where well 6-MGP-34-BA is located) from a location west of Conde at the coast (GC990-41) to Serrinha (GC990-11),
- and a north-eastern profile from Serrinha that reaches basement at the transfer fault at Jeremoabo (GC990- 30–34) (cf. Destro *et al.* 2003).

The sampling within the rift includes prerift, synrift and postrift strata and thus covers the deep erosional cut into Palaeozoic rocks along the main western and eastern faults (GC990-21, GC990-32) as well as several samples of the postrift Marizal Formation. The basement exposed east of the rift was sampled from Salvador along the coast and into the states of Sergipe and Alagoas until Paulo Afonso (GC990-124). Samples of basement and Mesozoic strata were taken along the exposed boundary fault of the Camamu Basin (GC990- 108–116).

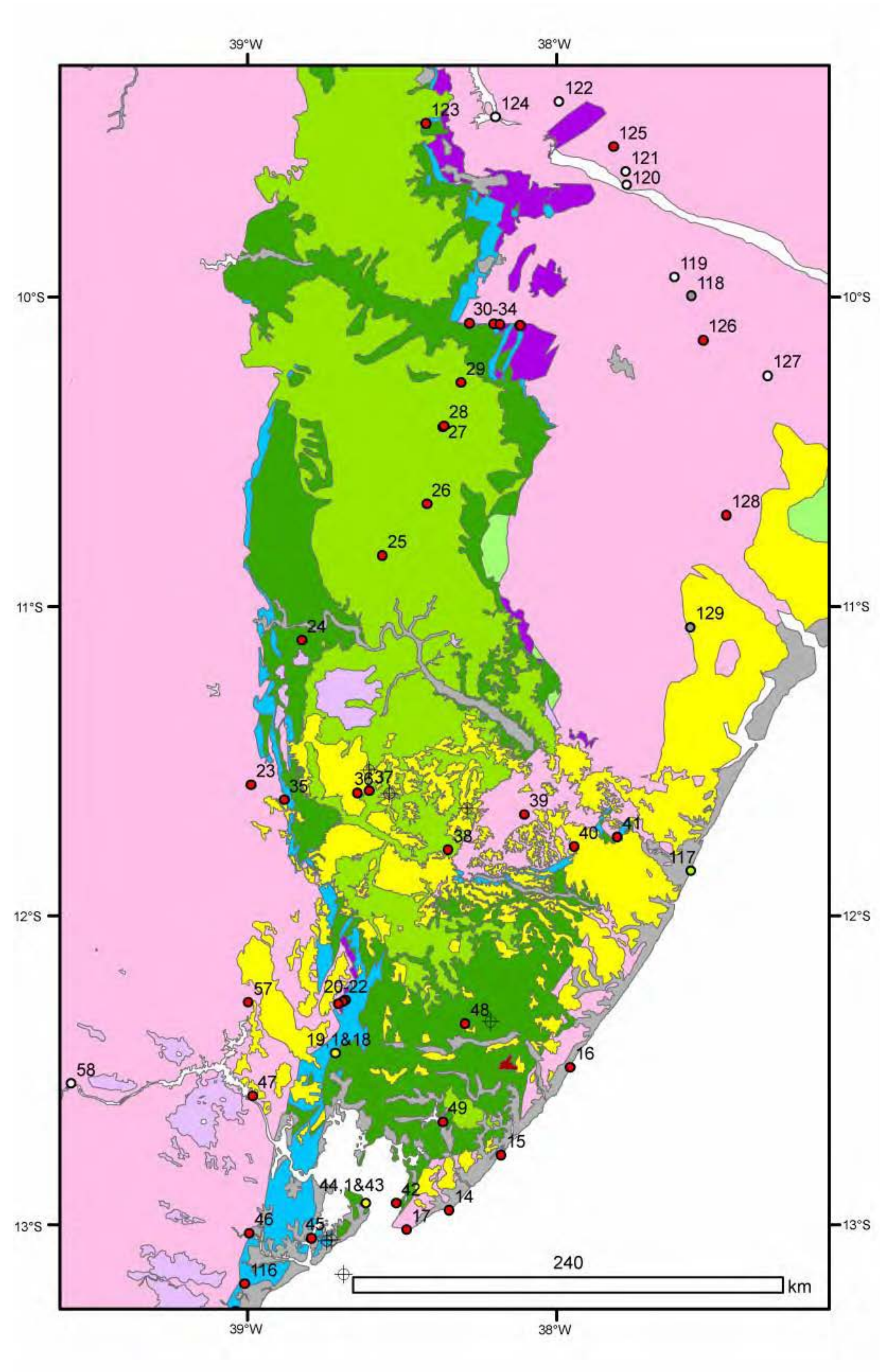


**Figure 6-1.** *Geological map of the north-eastern part of study area, scale 1:2,250,000. Detail of the map in Fig. 3-2 where the legend is shown. Sample numbers refer to Geotrack numbers (GC990; Table A). Note the location of the Sabiá Fm (dark red) between sample 48 and 16.*

Comments on special samples:

- The last rock sampled on the trip to Sergipe-Alagoas was close to the eastern margin of the Tucano Basin (GC990-123). The rock is a well-cemented sandstone and when the sample coordinates are plotted on the geological map of Bahia, the sample appears to be taken from Jurassic-Lower Cretaceous strata.
- The Barreiras Formation was sampled near Esplanada (GC990-40).
- An unknown, well-cemented sandstone with well-rounded grains was sampled at two locations along the coast at Arembepe and Sitio de Conde (GC990-15, -117). The sandstone is not indicated on the geological map of Bahia, but at Sitio do Conde, the sandstone was fossiliferous and containing oil shows, and was thought to be a prerift sandstone when investigated at location. Alternatively, it could a calcite-cemented beach deposit – see below.
- Very corse-grained fluvial sandstone of the Marizal Fm (or most likely of the Marizal Fm) was sampled in southern Tucano near Cicero Dantas (GC990- 25–29).

The tar-like material in sample GC990-117 has been investigated at GEUS. Preliminary geochemical data from analyses by gas chromatography (GC) and gas chromatography - tandem mass spectrometry (GC-MSMS) show the tar-like material to consist of biodegraded petroleum generated from a carbonate source rock (J. Bojesen-Kofoed 2008 pers.comm.). Biodegradation has resulted in complete elimination of normal alkanes and acyclic isoprenoids up to approximately nC30, whereas heavier n-alkanes, terpane and sterane biological markers have been preserved and concentrated, probably by a factor of nearly 100. The deposits on the beach probably represent the vestiges of an offshore petroleum spillage, probably from a ship or, less likely, from offshore production facilities. The well-cemented sandstone is thus most likely a recent beach deposit where quartz grains have been cemented by the calcite from the offshore reefs.

## 6.2 Chapada Diamantina and Planalto de Conquista

Numerous samples of Archaean basement and Proterozoic strata were taken for AFTA on Tour B from Salvador to Chapada Diamantina and Planalto de Conquista and back to the coast at Ilhéus and northwards to Salvador. The sampling thus included two regional east-west transects from Salvador to Rio de Contas (c. 350 km) and from west of Vitória da Conquista to Ilhéus (c. 200 km). The sampling was also aimed at covering vertical sections along the margins of the highlands; e.g.

- a profile from 330 to 1212 m a.s.l. along the eastern margin of Chapada Diamantina near Mucugê (GC990- 62–68),
- a profile from 529 to 1312 m a.s.l. along an interior escarpment in Chapada Diamantina near Jussiape (GC990- 73–76),
- a profile from 440 to 1575 m a.s.l. along the southern margin of Chapada Diamantina near Rio de Contas (GC990- 77–82), and
- a profile from 244 to 1055 m a.s.l. across Planalto de Conquista near Vitória da Conquista (GC990- 85–97).

Provided that the geothermal gradient is not too low, AFTA data from the samples that are deepest below the preserved planation surfaces may provide evidence for the timing when these samples were exhumed from below the planation surface when the surface had a wider extent; i.e. when the planation surface was uplifted to its present elevation.

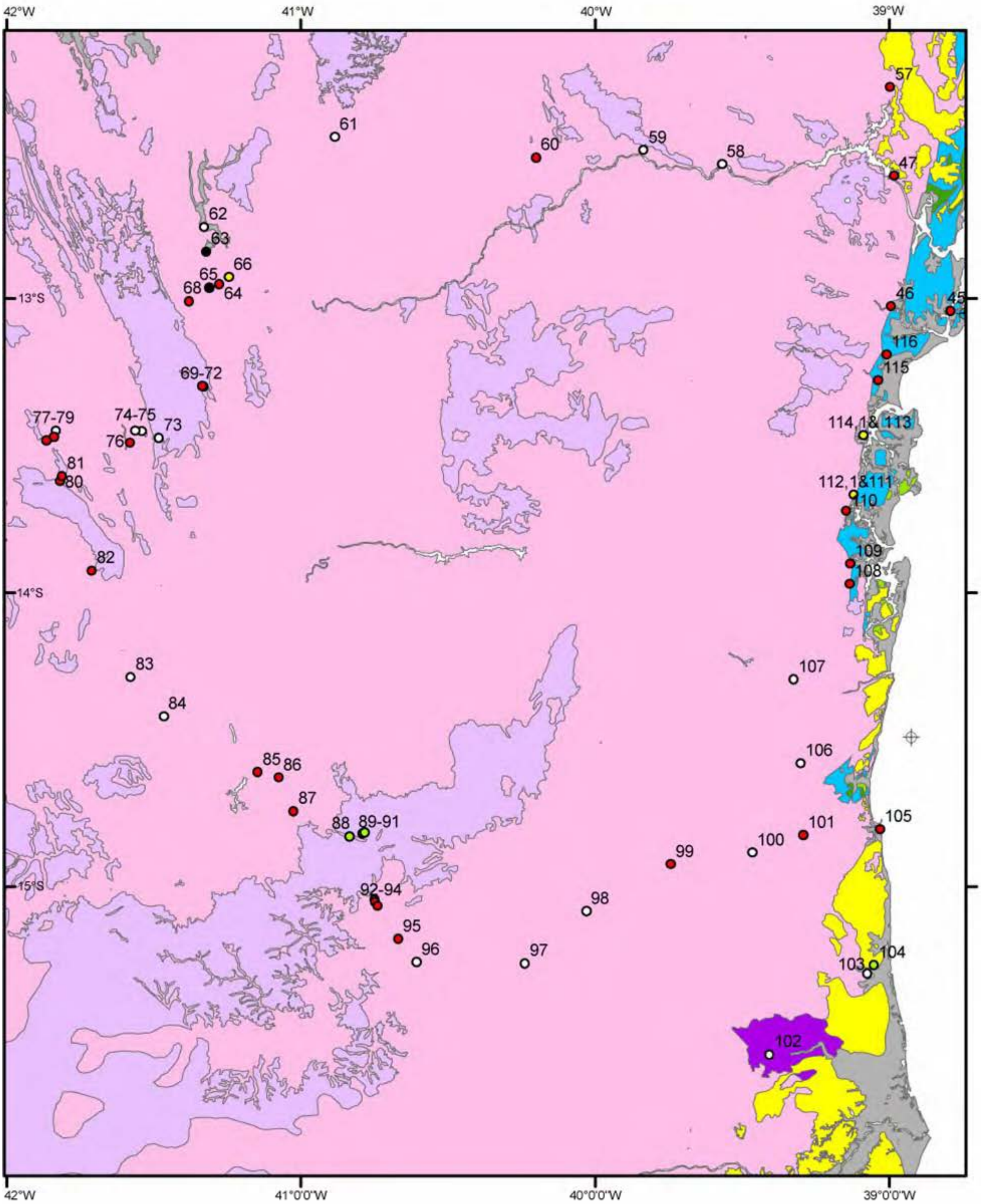


**Figure 6-2.** *Geological map of the south-western part of study area, scale 1:2,250,000. Detail of the map in Fig. 3-2 where the legend is shown. Sample numbers refer to Geotrack numbers (GC990; Table A).*

Fresh samples of diatomites were collected from an active production site on the planalto of Chapada Diamantina near Cascavel, SW of Mucugê (GC990- 69–71). At this location we observed well preserved leaves and trunks of wood in the diatomite deposits. Sun-dried samples were taken from an abandoned site near Vitória da Conquista and from a near-by production plant (GC990- 90–91). We were told that trunks of trees only occurred at the site we visited near Cascavel, and that the thickness of these deposits was about 10 m. Furthermore, we were told that diatomite deposits only occurred in the highland. Three samples of diatomites have been sent to Dr. Isabel Isarada Alcantar, Michoacna, Mexico, for possible dating.

## 6.3 Serra do Mar, state of Rio de Janeiro

The high relief outside Rio de Janeiro makes it is possible to collect samples along a vertical transect and thus to estimate palaeo-geothermal gradients from palaeo-temperature estimates vs. elevation and to get a narrow estimate of when cooling episodes began based on data from a restricted area. A vertical profile was sampled in Serra do Mar near Teresopolis from 500 to 2263 m a.s.l. (GC990- 50–56).

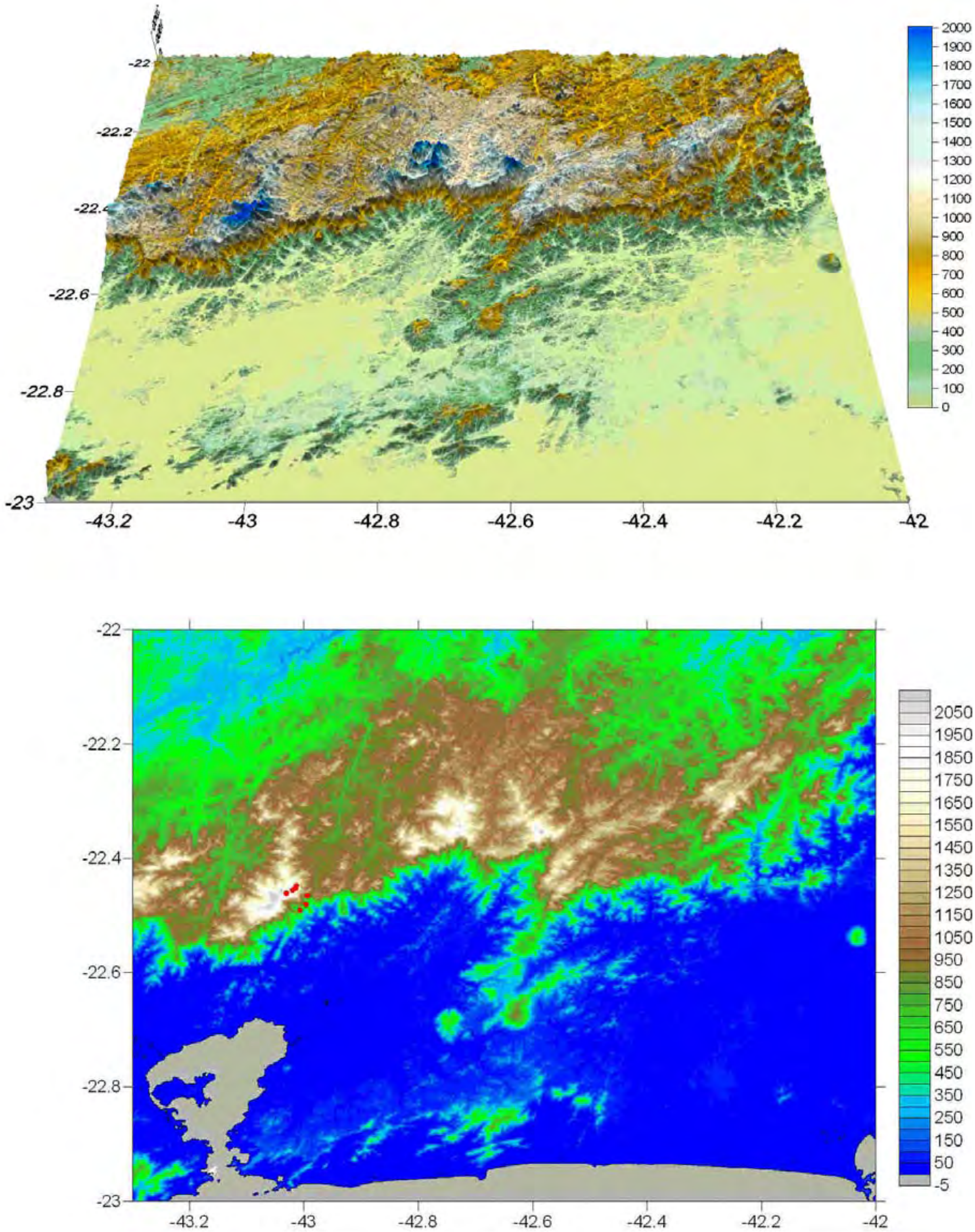


**Figure 6-3.** *Topographic maps of part of the state of Rio de Janeiro (the city is in the SW corner). Sample locations are indicated on the lower map.*

# 7. Geomorphological observations identifying two main surfaces

Two main surfaces have been identified within the study area, and possibly another highly dissected surface at high elevations (Fig. 7-1). There may or may not be one or more other surfaces in the area, but has not been investigated in detail yet. But for the surfaces, several escarpments and deeply incised valleys are common landscape features that also have been identified in the study area. The geomorphological part of this field report is however mainly based on the field observations and on field documentation (mainly photographs, but also the relationships between surfaces and geology). The interpretation of landforms is supported by maps that are constructed from the digital terrain model.

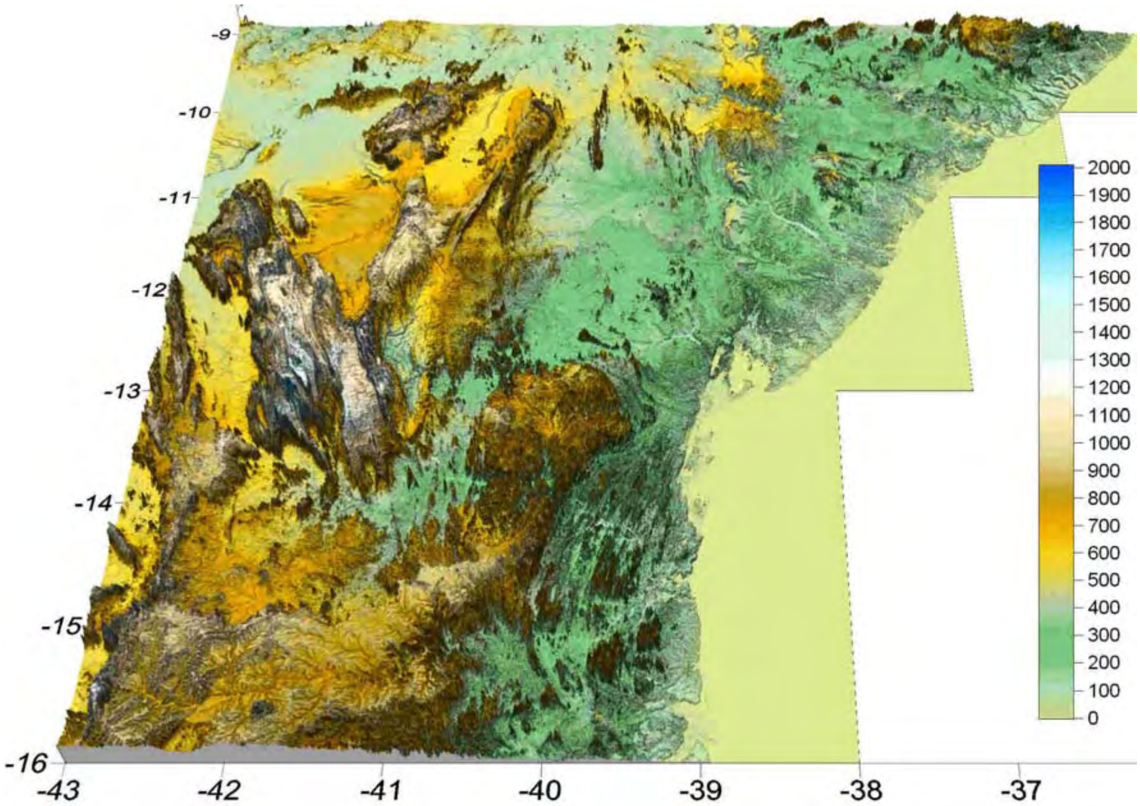


**Figure 7-1.** *The main topography of the study area. The lower surface is here coloured in light green while the higher surface is light yellow. 3D view based on digital elevation data.*

## 7.1 The lower surface

A surface of low relative relief with shallow valleys has developed over large areas in the study area (Figs 7-2, 7-3, 7-4). It is of widest extent in the northern part. It has been identified to about 400 m a.s.l, and it is at highest elevation in the west (Fig. 7-1). In a general perspective it is therefore slightly inclined, sloping towards the east and the sea. The surface cuts across rocks of different age and resistence (Archeaen basement and Mesozoic sediments) and this inidicates that the surface was formed by erosion towards a common base level.

**Figure 7-2.** *The lower of the two main erosion surfaces in the study area (the green surface in Fig. 3-3). Photo location west of Feira de Santana towards the east at 200 m a.s.l. (approximate location -12.5, -39.5 deg, Fig. 7-3) (photo 616).*

**Figure 7-3.** *The lower surface at its uppermost position in the western part of the study area. Photo location outside Livramento de Nossa Senhora, photo towards the southwest at 470 m a.s.l. (sample GC990-59, photo 407).*

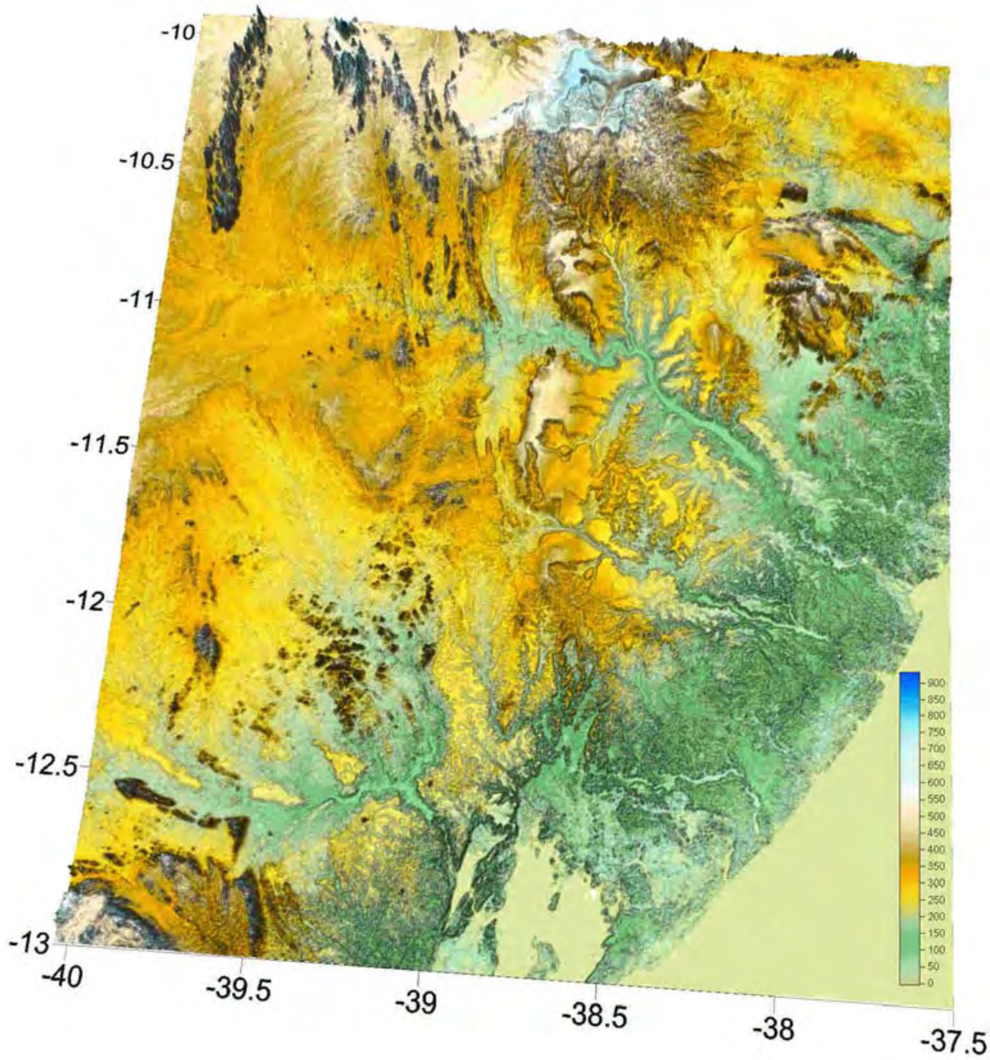


**Figure 7-4.** *Detail of the lower surface in the northern part of the study area between 200 to 400 m a.s.l. (gold-yellow). At present the surface is under destruction as witnessed by the incision of valleys (green areas) as a result of a lowered base level. Note the different colour coding from Fig. 7-1.*

## 7.2 The higher surface

The higher surface, at between 1200 to 900 m a.s.l., is dominating the regional landscape pattern in the western part of the study area (Fig. 7-1). In general it is more dissected than the lower surface. It is also inclined, but the general direction is different from that of the lower surface, as it is higher in the north and lowers towards the south. It is an erosion surface as it cuts across different rock types and escarpments often bound this surface. (Figs 7-5, 7-6, 7-7) In detail the surface is characterised by an undulating plain with shallow and wide valleys. At present the surface is being dissected.

**Figure 7-5.** *View from c. 1300 m a.s.l. overlooking the higher surface at 1200 m a.s.l. in the central part of Chapada Diamantina. Shallow valleys (to the left) has developed in the extensive surface. Note the escarpment in the background (sample GC990-73, photo 537)*.

**Figure 7-6.** *The higher surface ends abruptly at an escarpment in the Chapada Diamantina area. The surface is slightly dissected by wide and shallow valleys. The summits of the escarpment here may be remnants of a still higher surface (sample GC990-72, photo 530)*.

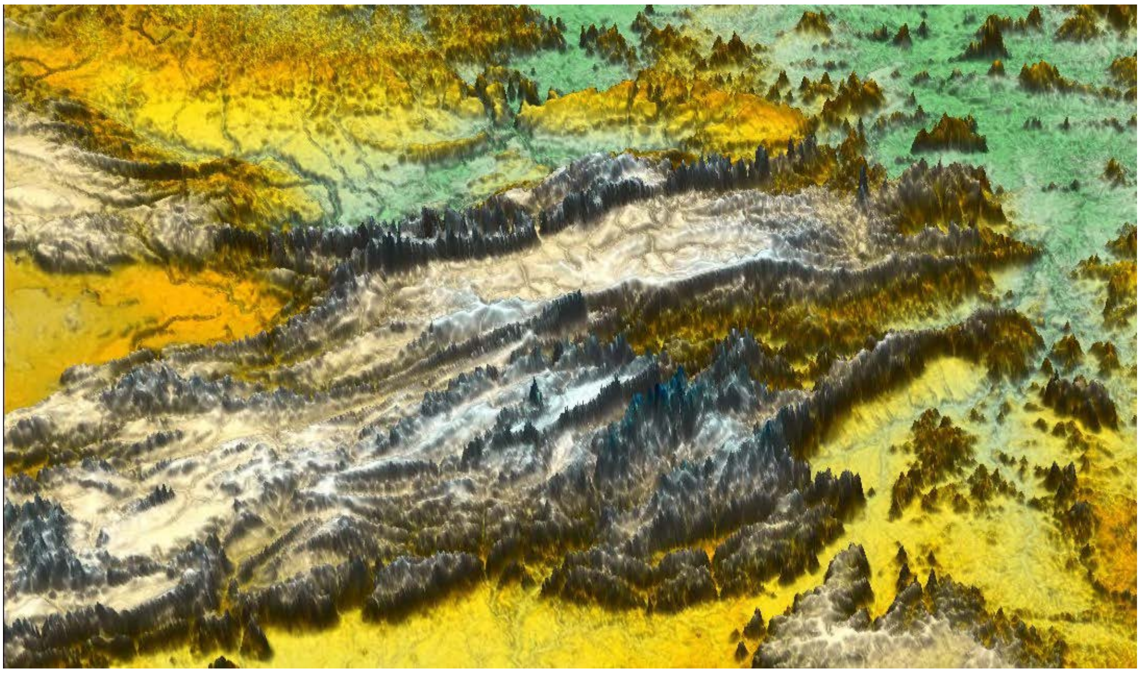

**Figure 7-7.** *Detailed 3D view of Chapada Diamantina. View is from the west towards the east with the higher surface (white-sand colour, c. 1200 m a.s.l.) in the central parts and the pronounced N-S running escarpments (up to 1700 m a.s.l.) bordering the surface. Note the shallow valleys incised in the higher surface (cf. Fig. 7-6).*

***Figure 7-8.*** *The higher surface is at c. 900 m a.s.l. in the area east of Vitória da Conquista (sample GC990-88, photo 669)*.

## 7.3 Incision of valleys: Relationships to base level, geology and escarpments

To illustrate the relationship between valley incision and surface development two examples will be used: The rivers Paraguaçu (Fig. 7-9, 7-10) and Rio de Contas (Fig. 7-11).

The Paraguaçu river has cut a deep gorge just before it enters the South Atlantic (Fig. 7-9). Upstream of the gorge, a surface at low elevation is rather well developed across several different rocks with differential resistance, which argues that the surface is an erosion surface developed towards a common base level. This is especially clear in the south-western corner (in fig. 7-9) because here the surface is widely developed in limestone (?pj), upstream an area with remnants of more resistant rocks (Fig. 7-10).

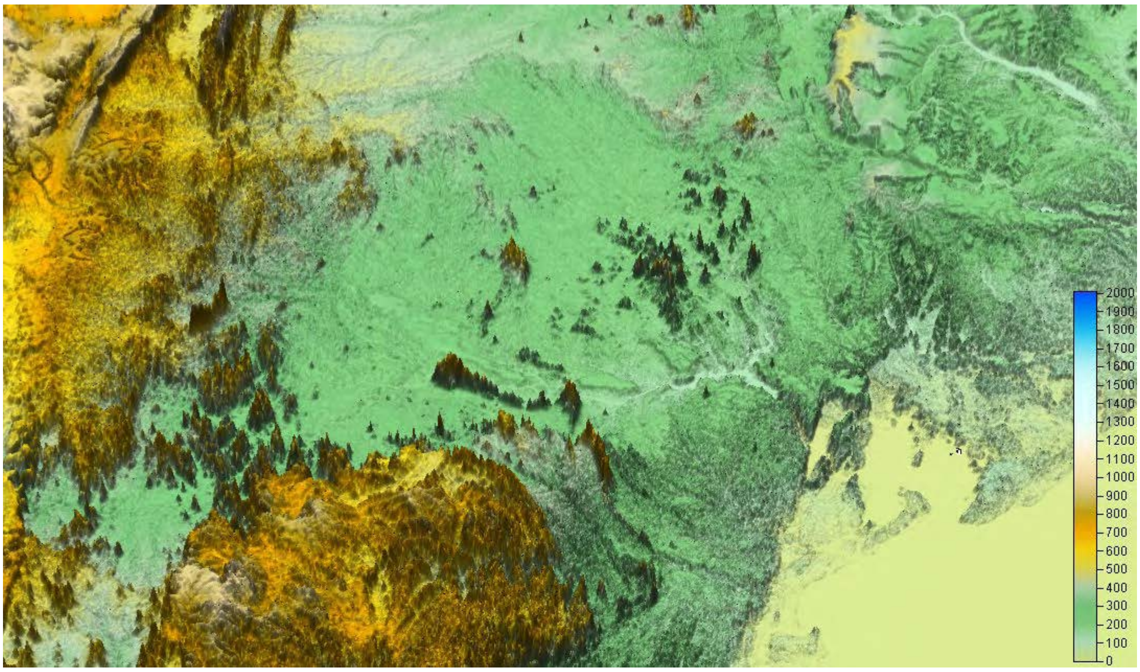


***Figure 7-9.*** *Part of the drainage area for the Paraguaçu river. The river is located in the right-centre, where it cuts a deep gorge across a high ridge of basement rocks, before it reaches the sea.*

The Rio de Contas (river) has cut a gorge through resistant rocks along a weakened geological structure. Here, similar to the Paraguaçu river, the rocks behind the gorge are less resistant, and therefore it has been possible for the surface to develop further here. However it is interesting that above the gorge, much younger rocks (Cenozoic laterites) are preserved on the plateaux that are the remnants of a more extensive erosion surface (the higher surface) (Fig. 7-9, 7-10). The higher surface – with its weathering mantle – is only preserved because the underlying rock is resistant against weathering (see Fig. 9-4). The escarpments are erosional escarpments and represent the boundary of erosion for the lower surface (Fig. 7-11).

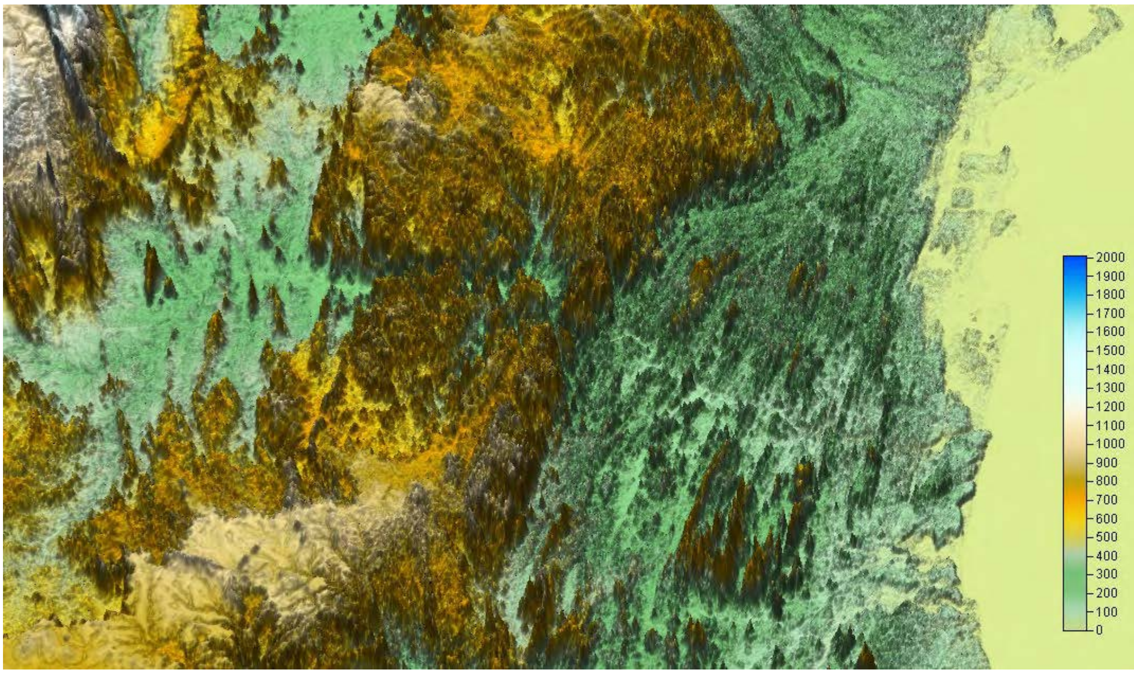


**Figure 7-10.** *Part of the drainage area for the Rio de Contas river. The river is located in the centre of the figure. The gorge here is developed within resistant basement. Upstream of the gorge the surface is extensive, as the rocks here are more easily eroded.*

**Figure 7-11.** *View of the winding escarpment north of Vitória da Conquista. The flat surface in the background (see Fig. 7-8) is cut across strata prone to erosion. They are preserved because they are on top of resistant metamorphic rock, here seen as the slopes of the escarpment (photo 645).*

The valley patterns and the incision of rivers in the Recôncavo and the Tucano Basin show that the lower surface is rapidly being dissected in areas where the Marizal Formation crop out (Fig 7-12). Steeply incised valleys cut through poorly consolidated, weathered Cretaceous strata (Fig. 7-13). This must be due to change of base level that has occurred after the formation of the lower surface.

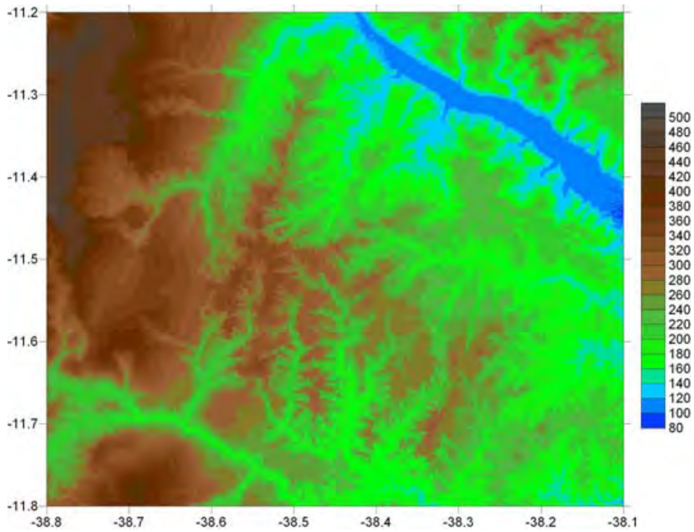


**Figure 7-12.** *Detail map of the valley incision patterns into the lower surface where the Marizal Formation outcrop (here mainly brown) at the eastern border of the Tucano Basin. This indicates a very late change of base level that probably corresponds to a late uplift event (few hundred metres).*

**Figure 7-13.** *Valley incision in the Marizal Formation. Front: Erosion is fast in the unconsolidated material. Background: The almost horizontal surface is being dissected by valleys (centre). Location west of Sátiro Dias (sample GC990-36, photo 148).*

## 7.4 Landforms as a result of weathering and the saprolites

Weathering of rocks and the formation of saprolites are significant for the changing of landscapes in the study area. Generally, in areas that are wet the rock is totally weathered and fresh rock can hardly be found, but in more dry areas the saprolites have been stripped leaving blocks of fresh, unweathered rock behind (corestones) and the fresh bedrock at the weathering front exposed. The weathering processes exploits zones of weakness and thus enhances structural and lithological differences.

**Figure 7-14.** *Corestones close to the summit of Pedra do Sino, Teresopolis. The saprolites have been stripped off (sample GC990-50, photo 280).*

**Figure 7-15.** *Basement quarry near Nazaré, southern Recôncavo: Sharp contrast between fresh rock and the overlying weathering mantle (the weathering front). The in situ weathered basement is confirmed by cross-cutting quartz veins (sample GC990-46, photo 202).*

# 8. Geological observations regarding the development of the lower surface

## 8.1 West of the RTJ Rift

Road BR116 from Feira de Santana northwards through Serrinha (road map 47 in the Appendix) follows the western margin of the Rift. From the road it was thus possible to observe the general alignment of the surface across basement (to the west) and across the Marizal Formation within the rift (to the east). The similar relief and elevation of the present surface, independent of the substratum, indicate that also the flat surface across the basement is a post-Marizal erosion surface (cf. Fig. 7-2 showing the landscape near Feira de Santana, south of Serrinha).

## 8.2 North-east of the RTJ Rift

Along the eastern side of the northern Tucano Basin a plain with low relative relief was observed until the northernmost location of the field work, at Paulo Afonso. Here the plain, which cuts across basement rocks is about 240 m a.s.l., is cut by the steep-sided Rio São Francisco Canyon (Fig. 8-1). Further towards south-east, the steep Canyon was observed at Canindé do São Francisco where the plain is around 225 m a.s.l. and the river bed around 60 m a.s.l. (samples GC990-120, 121).

**Figure 8-1.** *The Rio São Francisco Canyon at Paulo Alfonso (sample GC990-124, photo 870). Note the flat surface ('the lower surface') above the canyon.*

Residual hills of Silurian-Devonian sandstone were observed on the plain across Proterozoic basement between Canindé and Paulo Afonso (Fig. 8-2). The sandstone units are clearly tilted towards the south and this implies that the erosion surface is younger than the tilt; i.e. post-Silurian (sample GC990-69, photo 849). The tilt probably occurred during the late Palaeozoic tectonic event (Table 3-1) as the dip at right angles to the Rift indicates that it is not of Early Cretaceous age.

**Figure 8-2.** *Residual hills of Silurian-Devonian sandstone on the plain across Proterozoic basement between Canindé and Paulo Afonso. The sandstone units are clearly tilted towards the south. The flat-lying erosion surface of regional extent must be younger than the event that tilted the sandstones (sample GC990-124, photo 882).*

The low-relief plain east of the Tucano Basin extends into the Rift where it cuts across the Marizal Formation indicating that the plain is an erosion surface of post-Marizal age even in the basement areas. This conclusion is in agreement with the occurrence of a Jurassic outlier east of the Rift, south of Rio São Francisco at 38ºW.

## 8.3 Within the RTJ Rift

In the central part of the Tucano Basin a well-defined planation surface is found in areas with a resistant cover of the Marizal Formation. In several road cuts we observed outcrops of the Marizal Formation where sandstone was overlain by a well-cemented fluvial conglomerate (Fig. 8-3). The vegetation on top of these surfaces was very sparse.

The Marizal Formation is part of the postrift sequence and these deposits should therefore overstep the boundary faults of the rift. However, areas with Marizal cover within the rift lie immediately in contact with basement in the SE Tucano Basin (west of Esplanada). No conglomerates were observed within the Marizal Formation near the main fault and the deposition of the formation is thus – as expected – not related to fault movements (sample GC990-38, at Inhambupe). Consequently, the Marizal deposits must have been down-faulted relative to the basement block subsequent to their deposition. Furthermore, the erosion surface that cuts across Marizal Formation and basement rocks at about the same elevation, must have formed after the deposition of the Marizal Formation.

**Figure 8-3.** *Sandstone overlain by a well-cemented conglomerate of the Marizal Fm defines an intact planation surface in the central part of the Tucano Basin, here between Cicero Dantas and Jeremoabo (sample GC990-29, photo 118).*

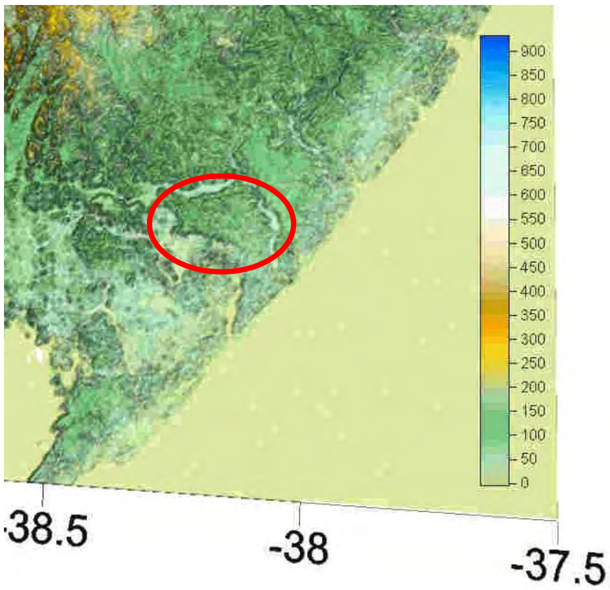


**Figure 8-4.** *Location of the Sabiá Formation (inside the red ellipse) within the Recôncavo Basin in an area where the lower surface is well preserved. Detail of Fig. 6-4. See also the geological map in Fig. 6-1.*

The lower surface is well-preserved in a part of the Recôncavo Basin where the outlier of the lower Miocene Sabiá Fm is found north-east of Salvador (Fig. 8-4).

## 8.4 Evidence for late Neogene compression within the RTJ Rift

By superimposing the main areas of outcropping Barreiras Fm on a Digital Topographic Model, it is possible to infer recent faulting and folding in the South Tucano basin (Fig. 8-5). Near the western margin of the basin, all of the sedimentary sequences, including Neocomian strata, the Marizal Fm, the overlying lower erosion surface, alluvial fans of the Barreiras Fm, and Neogene laterites, appear to have been folded together, to form three doubly-plunging anticlines (A1, A2 and A3). These have very gentle eastern limbs and steeper western limbs. Each anticline lies between relatively straight and incised river valleys, which follow transfer faults in the Neocomian rift system.

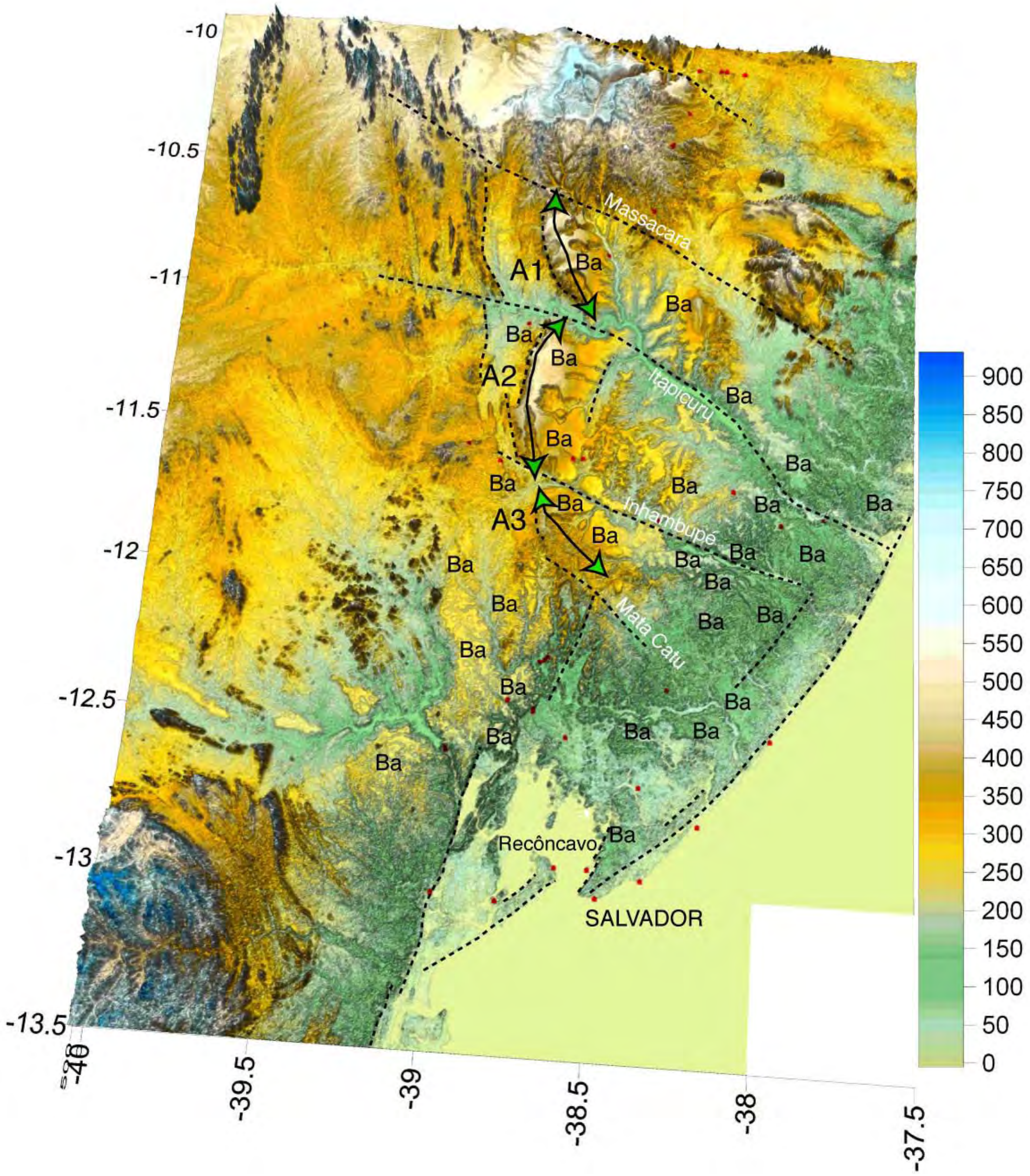


**Figure 8-5.** *Areas of outcropping Barreiras Fm (Ba), superimposed on a DTM of the Tucano and Recôncavo basins. Areas indicated by 'Ba' based on the geological map of Bahia (CPRM 2003), GoogleEarth images and the DTM. Dotted lines indicate traces of inferred faults (partly after Figueiredo et al. 1994), which may have been active today or in the Neogene. Full black traces, ending with green arrows, indicate doubly plunging anticlinal hinges (A1, A2 and A3). Small river valleys have incised the gently dipping eastern limbs of these folds. One valley has breached the hinge of a fold (the Biritinga Monocline, A2). Red dots indicate sample locations.*

The inference is that the anticlines are due to Neogene compression, acting in a generally E-W direction, and that their bounding faults are due to reactivation of the rift transfer faults. The Biritinga anticline (A2) has an eroded hinge line, which may overlie a reverse fault (Fig. 8-6). Such a reverse sense of slip may have resulted from compressional reactivation of an eastward-dipping normal fault of Neocomian age. These interpretations need checking in the field.


**Figure 8-6.** *The Biritinga Monocline, as seen obliquely by GoogleEarth, looking south.*

## 8.5 Salvador and the Salvador Horst

Seen from the distance, the Salvador skyline defines a remarkable constant level defined by the elevation of the Salvador Horst (c. 70 m a.s.l.) and (Fig. 8-7). Deposits of the Barreiras Group lie on top of the Salvador Horst north of centre of Salvador city (Fig. 8-5) (Magnavita *et al*. 1998). The upper part of the Barreiras Group was deposited in the distal part of a fluvial system (Bôas *et al.* 2001) and this level may thus be taken as a proxy for the sea level at that time. Consequently, the present elevation of the Barreiras Group in the Salvador area indicates the amount of post-Barreiras uplift of Salvador Horst. Assuming that the youngest part of the Barreiras Group was deposited at the end of the Pliocene, the amount of post-Barreiras uplift occurred since the Pliocene; i.e. over the last c. 2 million years.

**Figure 8-7.** *Salvador skyline seen from Mont Serrat. Note the constant elevation at about 70 m a.s.l. of the Salvador Horst (sample GC990-42, photo 175).*

## 8.6 The exhumed margin of the Camamu Basin

The road along the exhumed western limit of the Camamu Basin follows a clear escarpment defined by the rift fault with high-lying basement separated from the coastal plain developed across the Mesozoic sequence preserved within the rift (samples GC990-108 to 116). Additional sampling for AFTA and VR studies could be carried out if detailed maps of outcrops were available.

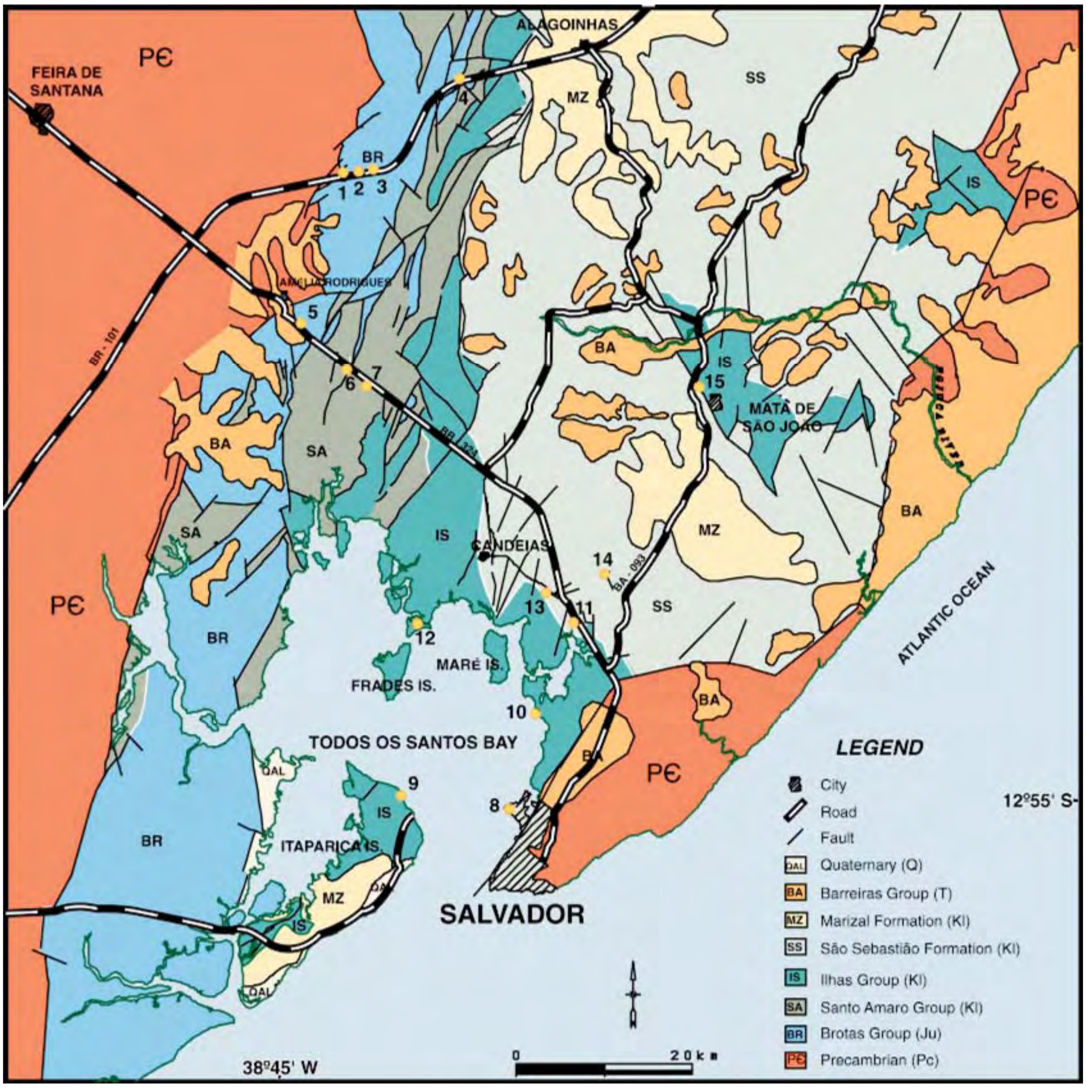


**Figure 8-5.** *Geological map of the southern Recôncavo Basin. Note that the Barreiras Group overlies basement on the Salvador Horst as well as on the western margin of the rift. From top to bottom the geological legend reads QAL Quaternary (Q), BA Barreiras Group (T), BZ Marizal Formation (Kl), SS São Sebastião Formation (Kl), IS Ilhas Group (Kl), SA Santa Amaro Group (Kl), BR Brotas Group (Ju), P€ Precambrian (Pc). From the guide book to the Recôncavo Basin by Magnavita et al. 1998. Numbers indicate stops on the field trip.*

# 9. Geological observations regarding the development of the higher surface

Two distinct areas of the highlands in south-western Bahia were visited during the fieldwork: Chapada Diamantina (Fig. 9-3) and Planalto de Conquista (Fig. 9-4). Both areas are dominated by the ‘higher surface’ at c. 1200 and 900 m a.s.l., respectively, but the geological development of these areas differs significantly. Whereas Planalto de Conquista lies within a basement area (although with a thick weathering mantle of laterites) (Fig. 3-1), Chapada Diamantina is characterized by a thick sequence Proterozoic strata that underwent folding during the Brasiliano cycle, c. 900 Ma (Fig. 3-4). The Planalto is thus part of the São Francisco Craton in the sense that it was not involved in the Brasiliano Cycle in contrast to Chapada Diamantina. This condition explains the marked morphological difference between the two areas where the Planalto is dominated by ‘higher surface’ (Fig. 7-8) whereas the Chapada is characterized by the ‘higher surface’ as well as escarpments above it (Fig. 7-6).

## 9.1 Chapada Diamantina

The sketch profile across Chapada Diamantina in Figure 9-1 shows that the ‘higher surface’ (Gerais de Mucugê) west of Mucugê is formed across the weathered feldspathic sandstones of the Mangabeira Formation. The escarpments along the plateau towards ENE and WSW are formed by the hard sandstone and conglomerates of the younger Tombador Formation. The eastern limp of the Chapada at Mucugê is thus the remnants of an anticlinal structure that has resisted destruction due to the resistant escarpments of the Tombador Formation. East of Mucugê, the softer limestones of the Salitre Formation have been graded to the level of the ‘lower surface’. The south-western limp of the Chapada, at Rio de Contas, is a synclinal structure where again the ‘higher surface’ has developed across the Mangabeira Formation whereas the escarpments (e.g. Pico das Almas) along the plateau are formed in the resistant sandstones and conglomerates of the underlying Rio dos Remedios Group. The low area at Jussiape where the Contas River lows, follows a major thrust between the two limbs of the Chapada.

The close relation between topography and geology in Chapada Diamantina is illustrated by Figure 9-2. The low areas (in green and blue colours) closely correspond to the areas where the limestones of the Salitre Formation (blue) and the Archaean basement (grey) are exposed. The plateau corresponding to the higher surface (light brown) primarily matches the outline of the Mangabeira Formation (light red). The escarpments above the higher surface (white) correspond to the Tombador Formation (orange) and the Rio dos Remedios Group (red).

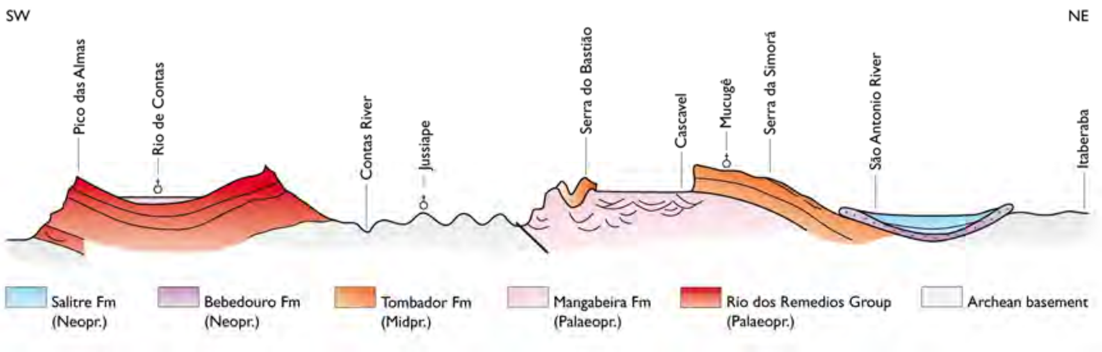


**Figure 9-1.** *Sketch profile across Chapada Diamantina (not to scale). The ‘higher surface’ cuts across the weathered feldspathic sandstones of the Mangabeira Formation at Rio de Contas and west of Mucugê. The escarpments along the plateaux have formed in the resistant sandstone and conglomerates in remnants of synclinal and anticlinal structures, respectively. The ‘lower surface’ cuts across limestone of the Salitre Formation and Archaean basement. Location on Fig. 9-3.*

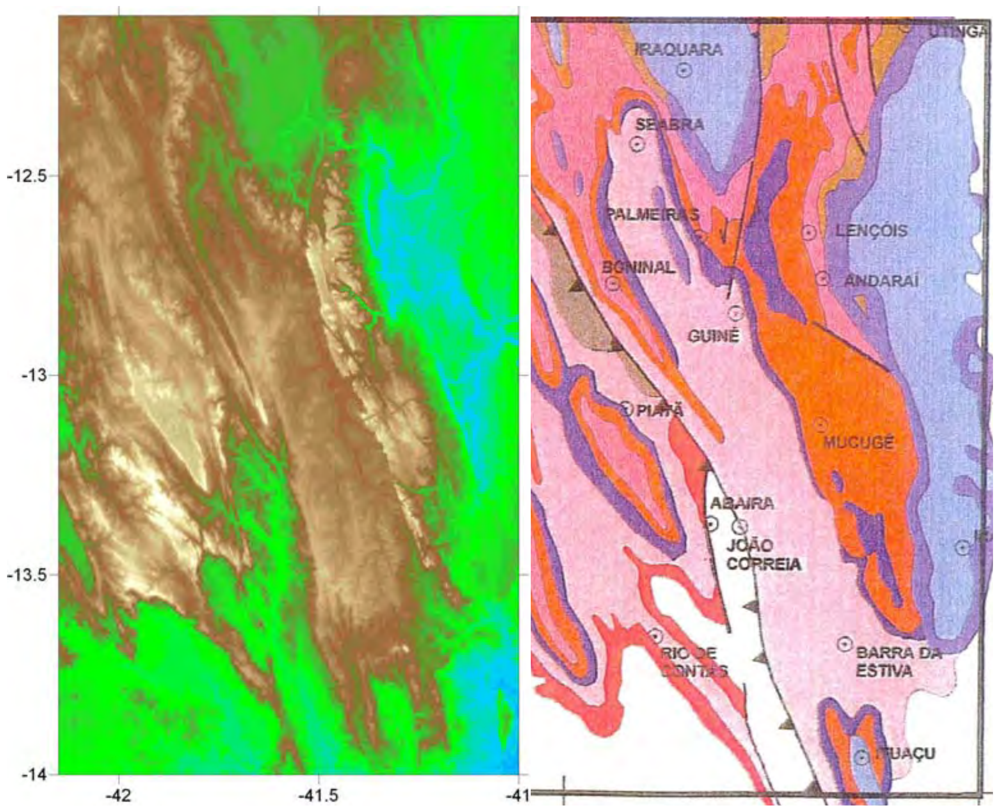


**Figure 9-3.** *Comparison of relief and lithology in Chapada Diamantina. Note the close correlation between e.g. low topography and the limestone (blue) as well as the ridges of resistant lithologies. Left: Topography; colour code in Fig. 3-3. Right: Detail of the geological map in Fig. 3-4 (rectangle); legend in Fig. 3-4.*

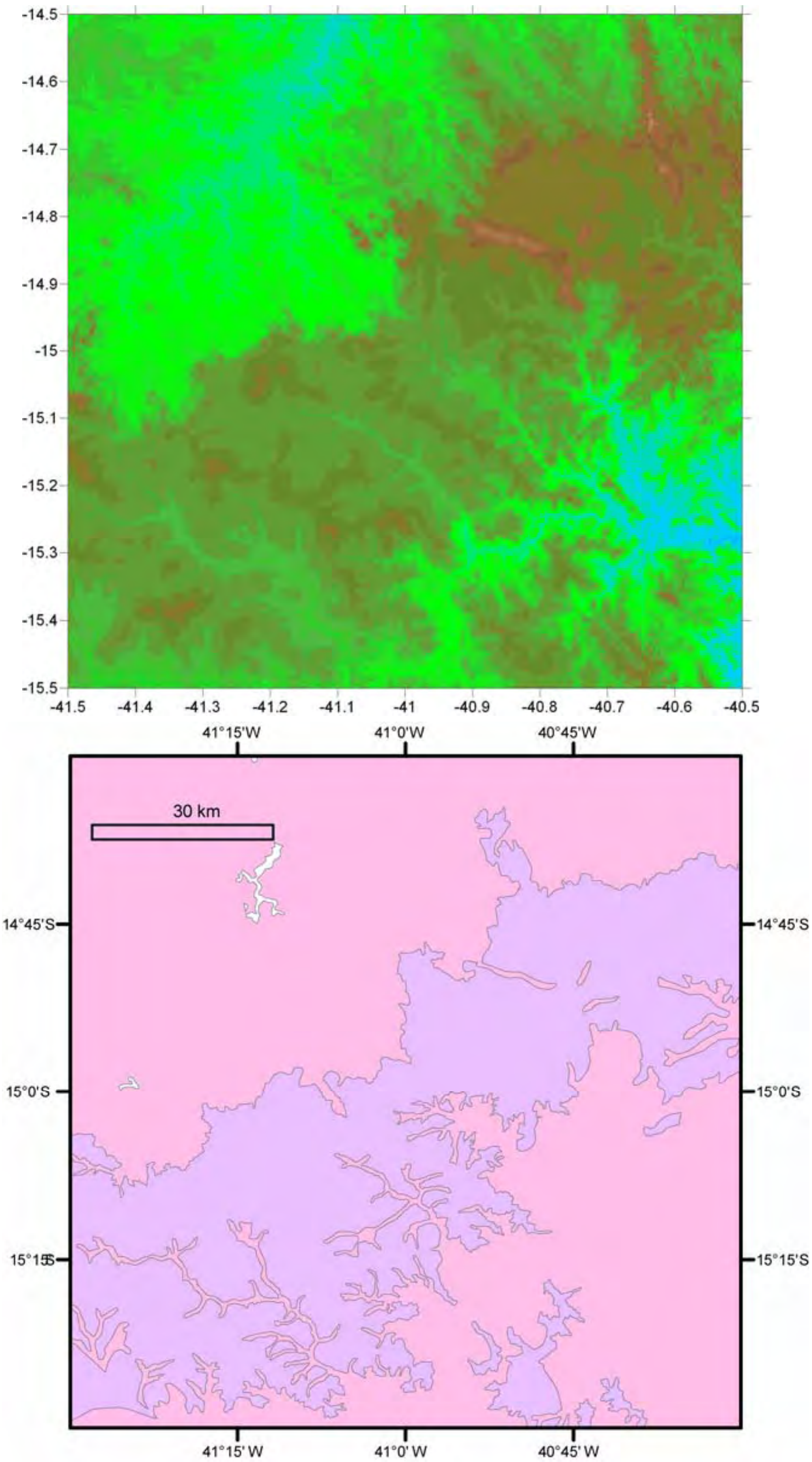


**Figure 9-4.** *Comparison of relief and geology (extent of Cenozoic laterites) on Planalto de Conquista. The extent of the preserved plateau is clearly delineated by the extent of the laterites. The plateau is being dissected by river incision that leads to the removal of the laterites. Topography (above) is a detail of Fig. 3-3 and geology (below) a detail of Fig. 3-2.*

## 9.2 Planalto de Conquista

Planalto de Conquista is located within the craton dominated by Archaean–Palaeoproterozoic basement, and correspondingly, the relief of the plateau is almost featureless (Fig. 9-4). The identical development of the higher surface across both the structurally controlled Chapada and featureless Planalto shows that the primary control on the surface development must have been a former base level rather than lithology.

## 9.3 Comparison of the two plateaux

A pronounced feature of the higher surface across both plateaux is that it is developed across the deeply weathered basement rocks (laterites) in contrast to the fresh rocks exposed in the surrounding lowlands. Figure 9-4 shows a comparison of relief and the extent of Cenozoic laterites on Planalto de Conquista. The extent of the preserved plateau is clearly delineated by the extent of the laterites. The plateau is being dissected by river incision that leads to the removal of the laterites. (Figs 9-5, 7-11).

**Figure 9-5.** *Thick saprolites at the south-eastern escarpment of the Planalto de Conquista (sample GC990-92, photo 684).*

Another characteristic of both plateaux is the occurrence of fresh-water diatomites that are exploited in numerous open pits. However, the diatomites in the highlands and their ages do not seem to have been much investigated. We visited an active diatomite mine in Lagoa Encantada located in a topographic low on the planation surface (Fig. 9-6). Many plant remains (leaves, tree trunks) and very fresh sediments may indicate young age; e.g. Quaternary. We saw an abandoned mine near Vitória da Conquista where such mines are frequent, and we visited a plant for processing diatomites (Ciemel) where the staff confirmed that the diatomites only occur in the highlands.

**Figure 9-6.** *Diatomite deposit on the in Chapada Diamantina on the plateau west of Mucugê (Lagoa Encantada, Cascavel; 1025 m a.s.l.). Note the trunks of tree that has been excavated from the diatomite (only occurring at this location) (sample GC990-, photo 507).*

Our hypothesis for explaining the concurrencies of both laterites and diatomites on the plateaux of Chapada Diamantina and Planalto de Conquista, is that this surface was graded to a former base level over a long period of exhumation and removal of cover rocks after which a thick weathering mantle developed across feldspathic sandstones and basement rocks. Similarly, diatomite was deposited in lakes across the flat and extensive surface. The surface was uplifted to its present elevation sometime during the Cenozoic (probably after the formation of the laterites; cf. Spier et al. 2006) and destruction of the surface started through incision of rivers. The oldest diatomites should thus post-date the first phase of regional exhumation and pre-date the uplift of the plateau to its present elevation.

# 10. Discussion and conclusions

## 10.1 Implications of the existence of two regional surfaces

An erosion surface that can be followed along a horizontal or inclined plain and that cut across rocks of different age and resistance can only have been formed towards a common base level. If the surface is of wide extent it must have formed during a significant time interval with stable tectonic conditions. A more elevated base level (e.g. due to subsidence) may cause burial, leading to preservation of older landscapes whereas a lowered base level (e.g. due to uplift) will be followed by valley incision and rejuvenation of the relief, ultimately leading to the development and formation of a new erosion surface. These basic conditions can be used to construct a relative tectonic event chronology which may not necessary include the whole landscape history. Therefore, the regional, low-relief surfaces in the study area are witnesses of two different periods when the landscapes were low in elevation.

Today only remnants of the higher surface are preserved, but the surface must have been developed across a much larger area. The higher surface was probably developed much farther towards the east than it is today and also covered the area between Chapada Diamantina and Planalto de Conquista. The lower surface probably developed at the expense of a higher surface, today seen as the flat-toped escarpments. The higher surface became dissected after a change of base level that probably was caused by an uplift event. The rivers started to incise and the relief adapted to the new base-level conditions. The lower surface was thus first developed along the main rivers (e.g. Rio de Contas and Paraguaçu) until only relatively low relief was left. Only the most resistant rocks and those areas farthest from the base level have not been dissected. Today these elevated areas are separated form the lower surface by significant escarpments. In less resistant rocks the lower surface is well developed, e.g. in the area between Chapada Diamantina and Planalto de Conquista in the upper reaches of Rio de Contas. The large area over which the lower surface has developed suggests a long time with stable base level and stable tectonic conditions. In West Greenland regional erosion surfaces have needed c. 20 Ma to develop, but more efficient weathering may decrease that time.

### 10.1.1 Evidence for late uplift and compression

The valley patterns and the incision of rivers in the Recôncavo and the Tucano basins show that the lower surface is rapidly being dissected in areas where the Marizal Formation crop out (Fig 7-12). This must be due to change of base level that has occurred after the formation of the lower surface. The fast incision suggests that this event must be young, because the easily dissected Marizal Formation still has rather large patches where the lower surface is coherent. Such a surface will only survive for long time in a low position or if other strata covered it. Based on the preliminary observations, it appears that the elevation of the lower surface increases in directions away from the coast and towards the north along the Tucano Basin. This indicates a very late change of base level that probably corresponds to a late uplift event of 200 to 400 m.

Near the western margin of the Tucano Basin, the sedimentary sequences, including the late Neogene Barreiras Group, appear to have been folded to form anticlines with gentle eastern limbs and steeper western limbs. Each anticline lies between relatively straight, incised river valleys, which follow transfer faults in the rift system. The inference is that the anticlines are due to late Neogene compressional reactivation of an eastward-dipping normal fault and of the rift transfer faults.

## 10.2 The age of the lower surface

It is clear from the observations of the geomorphological and geological relations around the RJT Rift that the lower surface cuts across basement in the extra-rift areas as well as post-rift strata within the Rift (Figs 3-2, 6-4). This means in very broad terms, that the formation of the surface post-dates the Aptian Marizal Formation within the study area and including the entire RTJ Rift, also the Albian Exu Formation (Magnavita et al. 1994).

It is furthermore clear that the flat basement areas are not re-exhumed Palaeozoic peneplains. This conclusion may be deduced from the above arguments alone, but the occurrence of residual hills of tilted layers of Devonian–Silurian sandstone east of the rift directly implies that the surface is not an early Palaeozoic peneplain (Fig. 8-2). The tilting of the sandstone probably occurred during the late Palaeozoic tectonic event that predated the Permian deposition (Table 3-1), and consequently, the formation of the lower surface across the basement occurred after that event.

The age of the lower surface may however, further be constrained by the well-documented outlier of the early Miocene, marine Sabiá Formation within the Recôncavo Basin (Fig. 7-1) (Viana et al. 1971). This occurrence testifies to a marine transgression that must have affected a continuous and larger area than that of the present-day outlier. As the outlier is found in an area where the lower surface generally is well-preserved (Fig. 8-4), the exhumation leading to the formation of the lower surface must have occurred after the early Miocene transgression and the surface must thus be of post-early Miocene age; i.e. c. post-20 Ma.

As an alternative to this interpretation, the Sabiá Formation could have been deposited on the lower surface, but that would imply that the surface was formed prior to the Miocene; i.e. pre-25 Ma. We do however, not consider that to be a geological possibility because of the rapid destruction which the lower surface is subject to in the study area where steeply incised valleys cut through poorly consolidated, weathered Cretaceous strata (Fig. 7-13). An equally unlikely alternative would be that the Miocene cover has preserved the lower surface and that it has recently been re-exhumed. This would imply that the Miocene cover rocks should be found at more locations (e.g. below the Barreiras Group) because the lower surface is so well preserved across large areas. However the Sabiá Formation has not been observed elsewhere.

The alluvial fans of the Barreiras Group along the Atlantic margin appear to be deposited on top of the lower surface. The formation of the lower surface thus pre-dates the Barreiras Group. The age of these strata is difficult to determine, and their basal part may be diachronouos across an area the size of Brazil, but within the Recôncavo Basin they have been dated to be of Pliocene age (Figueiredo et al. 1994), and we will take that to be representative for the study area. Consequently, it is likely that the lower surface formed during the middle and late Miocene; c. 20–5 Ma corresponding to the early Neogene unconformity in Table 3-1.

## 10.3 The age of higher surface

Based on the available observations, the age of the higher surface cannot be as tightly constrained as that of the lower surface. Within the study area, the surface is only identified in areas where the primary rocks are of Archaean and Proterozoic age. However, the higher surface corresponds to vast areas covered by Cenozoic laterites as indicated by the geological map of Bahia (CPRM 2003) (cf. Fig. 9-4). The broad timing of the laterites to be of Cenozoic age does however, seem to be reasonable because it implies that the higher surface is of post-Cretaceous age. This result is in agreement with the geological constraints on the age of the flat surfaces that cuts across the Sanfranciscana Basin and defines Chapada do Araripe, c. 80 west and 200 km north of the study area, respectively. These surfaces cut across Maastrichtian and older strata at elevations around c. 1 km a.s.l., but correlation with the higher surface in the study area needs more detailed mapping (e.g. Campos & Dardenne 1997a; Neto *et al.* 2006).

Based on the age of the laterites in the highlands we can deduce that the higher surface formed during the Cenozoic. This time interval can be further narrowed if we include the above argumentation that the younger, lower surface was formed subsequent to the deposition of the lower Miocene Sabiá Formation. The age of higher surface may thus tentatively be taken to be Palaeogene which in broad terms is in agreement with the geochronological constraints on deep weathering on similar plateaux in Minas Gerais (Spier et al. 2006).

## 10.4 Tentative event chronology

The higher surface developed as a low-relief erosion surface towards a common base level probably during the Palaeogene after an initial uplift event. Similarly, the lower surface developed during the Neogene, probably in the interval between the deposition of the Sabiá Formation and the Barreiras Group after an uplift event that lifted the higher surface to its present elevation around 1 km a.s.l., e.g. at Planalto de Conquista. The lower surface thus developed at the expense of the uplifted higher surface, and consequently a pronounced escarpment form the limit between the higher and the lower surface. Even the lower surface is presently under destruction due to uplift during the Plio-Pleistocene. The lower surface has been lifted by varying amounts; e.g. by 200-400 m in the Tucano Basin.

A better discrimination between the areas where the higher and the lower surface can be defined awaits more detailed mapping. The timing and magnitude of the uplift events will be further studied in the project that also will estimate the amount of exhumation involved in the formation of the erosion surfaces. A better definition of the burial and exhumation history onshore will depend on a better understanding of the relation between exhumation and development of laterites across the planaltos as well as the age and depositional pattern of the Sabiá Fm and the Barreiras Group.

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# 12. Appendix. List of rocks sampled and location maps

**Table A. Rocks sampled**

Code for sample purpose and status:

0 AFTA, no or insufficient apatites, processing of sample stopped
1 AFTA, sufficient apatite yield, processing of sample ongoing
2 AFTA, sample available, but not being processed
3 AFTA, sample available, but not being processed. Strongly weathered rock (w)
4 VR
5 Possible age determination

Formation. Lithology symbols from geological maps of Bahia and Sergipe (CPRM 1999, 2003).

SDt Silurian-Devonian sandstone (Tucaratu Fm)
ENdl Cenozoic laterite
J3b Jurassic (Sergi-Aliança Fms undifferentiated)
MNm1 Proterozoic (Macururé Group)

Altitudes in metres above sea level estimated by GPS

Formation ages in the Recôncavo and Tucano Basins (see Fig. <strat<)
Based on Caixeta et al. (1994), Magnavita et al. (1994), Bezerra et al. (2001)

| **Formation** | **Stratigraphic age** | **Age (Ma)** | |
|---|---|---|---|
| Barreiras Group | Latest Miocene-Pliocene | 5 - 2 | |
| Marizal Fm | Upper Aptian | 115 - 112 | |
| Massacará Fm | Hautr. - Barremian | 120 - 132 | Tucano |
| Ilhas Group | Valang - Hautr. | 136 - 127 | Tucano |
| Maracangalha Fm | Valanginian - Early Apt. | 140 - 120 | Recôncavo |
| Salvador Fm | Barriasian - Barremian | 145 - 125 | |
| Sergi Fm | Tithonian (upper) | 150 - 144 | |
| Aliança Fm | Tithonian (lower) | 150 - 144 | |
| Afligidos Fm | Permian | 290 - 250 | |
| Basement | Precambrian | > 500 | |

## Road maps with locations of sampled rocks

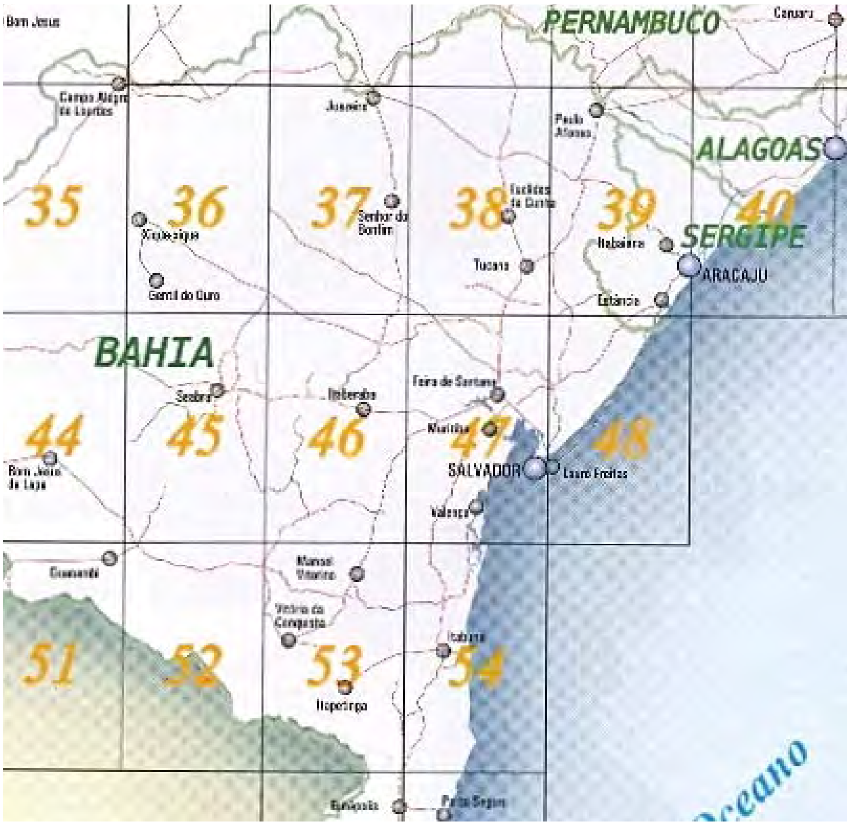



**Figure A.** *Index map for the road maps in the Appendix with location of the sampled rocks; Road maps 38, 39, 45 – 48, 53, 54 with indication of both GEUS and Geotack number (cf. Table A). Scale of road maps ca. 1 : 675,000.*

| Geotrack sample no. | GEUS no. | Map | Purpose | Purpose, status | Locality | Region | Elevation (m a.s.l.) | lat | long | New Photo DSC_0xxx | Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GC990-14 | 514401 | 48 | AFTA | 1 | Itapuá | Salvador | 0 | -12.9530 | -38.3475 | 42-43 | 28-07-2007 |
| GC990-15 | 514402 | 48 | AFTA | 1 | Arembepe | Salvador | 0 | -12.7747 | -38.1790 | 44-46 | 28-07-2007 |
| GC990-16 | 514403 | 48 | AFTA | 1 | Imbassai | Bahia, NE | 0 | -12.4910 | -37.9568 | 53-54 | 28-07-2007 |
| GC990-17 | 514404 | 47 | AFTA | 1 | Hotel Pestana | Salvador | 0 | -13.0158 | -38.4850 | 57 | 29-07-2007 |
| GC990-18 | 514405 | 47 | AFTA | 1 | Amélia Rodrigues, BR324, km 550 | Recôncavo | 96 | -12.4457 | -38.7162 | 59-60 | 29-07-2007 |
| GC990-19.1 | 514406 | 47 | VR | 4 | Amélia Rodrigues, BR324, km 550 | Recôncavo | 96 | -12.4457 | -38.7162 | 61-62 | 29-07-2007 |
| GC990-20 | 514408 | 47 | AFTA | 1 | Teodoro Sampaio, BR101, km 146 | Recôncavo | 159 | -12.2743 | -38.6828 | 63-64 | 29-07-2007 |
| GC990-21 | 514409 | 47 | AFTA | 1 | Teodoro Sampaio, BR101, km 147 | Recôncavo | 137 | -12.2787 | -38.6909 | 65-67 | 29-07-2007 |
| GC990-22 | 514410 | 47 | AFTA | 1 | Teodoro Sampaio, BR101, km 148 | Recôncavo | 136 | -12.2863 | -38.7052 | 69 | 29-07-2007 |
| GC990-23 | 514411 | 47 | AFTA | 1 | Serrinha | Tucano | 377 | -11.5772 | -38.9873 | 91-93 | 29-07-2007 |
| GC990-24 | 514412 | 38 | AFTA | 1 | Tracupá | Tucano | 175 | -11.1102 | -38.8232 | 94 | 29-07-2007 |
| GC990-25 | 514413 | 39 | AFTA | 1 | Ribeiral do Pombal, BR410, km 4 | Tucano | 220 | -10.8362 | -38.5637 | 98-100 | 30-07-2007 |
| GC990-26 | 514414 | 39 | AFTA | 1 | Cicero Dantas, S | Tucano | 340 | -10.6697 | -38.4198 | 101-104 | 30-07-2007 |
| GC990-27 | 514415 | 39 | AFTA | 1 | Cicero Dantas | Tucano | 440 | -10.4210 | -38.3675 | 108-109 | 30-07-2007 |
| GC990-28 | 514416 | 39 | AFTA | 1 | Cicero Dantas, N | Tucano | 439 | -10.4170 | -38.3640 | 110 | 30-07-2007 |
| GC990-29 | 514417 | 39 | AFTA | 1 | Jeromoabo, S | Tucano | 363 | -10.2778 | -38.3092 | 117-118 | 30-07-2007 |
| GC990-30 | 514418 | 39 | AFTA | 1 | Jeremoabo | Tucano | 273 | -10.0847 | -38.2818 | 119-120 | 30-07-2007 |
| GC990-31 | 514419 | 39 | AFTA | 1 | Jeremoabo | Tucano | 303 | -10.0875 | -38.2032 | 123-124 | 30-07-2007 |
| GC990-32 | 514420 | 39 | AFTA | 1 | Jeremoabo | Tucano | 294 | -10.0885 | -38.1828 | 125-126 | 30-07-2007 |
| GC990-33 | 514421 | 39 | AFTA | 1 | Jeremoabo | Tucano | 302 | -10.0913 | -38.1185 | 127 | 30-07-2007 |
| GC990-34 | 514422 | 39 | AFTA | 1 | Jeremoabo | Tucano | 265 | -10.0915 | -38.1173 | 129-131 | 30-07-2007 |
| GC990-35 | 514423 | 47 | AFTA | 1 | Biritinga, W | Tucano | 324 | -11.6257 | -38.8808 | 134-135 | 31-07-2007 |
| GC990-36 | 514424 | 47 | AFTA | 1 | Sátiro Dias, W | Tucano | 304 | -11.6032 | -38.6430 | 147 | 31-07-2007 |
| GC990-37 | 514425 | 47 | AFTA | 1 | Sátiro Dias | Tucano | 251 | -11.5968 | -38.6065 | (149-151) | 31-07-2007 |
| GC990-38 | 514426 | 48 | AFTA | 1 | Inhambupe | Tucano | 188 | -11.7870 | -38.3502 | 158 | 31-07-2007 |
| GC990-39 | 514427 | 48 | AFTA | 1 | Aporá | Bahia, NE | 204 | -11.6732 | -38.1045 | 159-161 | 31-07-2007 |
| GC990-40 | 514428 | 48 | Strat age? | 1 | Esplanada | Bahia, NE | 160 | -11.7767 | -37.9433 | 162-163 | 31-07-2007 |
| GC990-41 | 514429 | 48 | AFTA | 1 | Altamira | Bahia, NE | 35 | -11.7463 | -37.8043 | 170 | 31-07-2007 |
| GC990-42 | 514430 | 47 | AFTA | 1 | Mont Serrat | Salvador | 0 | -12.9300 | -38.5180 | 180-181 | 01-08-2007 |
| GC990-43 | 514431 | 47 | AFTA | 1 | Bom Despacho | Itaparica Isl. | 0 | -12.9302 | -38.6158 | 190-196 | 01-08-2007 |
| GC990-44.1 | 514432 | 47 | VR | 4 | Bom Despacho | Itaparica Isl. | 0 | -12.9302 | -38.6158 | 190-196 | 01-08-2007 |
| GC990-45 | 514434 | 47 | AFTA | 1 | Jiribatuba | Recôncavo | 0 | -13.0425 | -38.7920 | (197-198) | 01-08-2007 |
| GC990-46 | 514436 | 47 | AFTA | 1 | Nazaré | Recôncavo | 27 | -13.0273 | -38.9935 | 199-205 | 01-08-2007 |

| Geotrack sample no. | GEUS no. | Map | Purpose | Purpose, status | Locality | Region | Elevation (m a.s.l.) | lat | long | New Photo DSC_0xxx | Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GC990-47 | 514437 | 47 | AFTA | 1 | Muritiba | Recôncavo | 100? | -12.5833 | -38.9833 | 207 | 01-08-2007 |
| GC990-48 | 514438 | 48 | AFTA | 1 | Pojuca, Miranga | Recôncavo | 50 | -12.3500 | -38.2957 | 215-219 | 03-08-2007 |
| GC990-49 | 514439 | 47 | AFTA | 1 | Simões Filho | Recôncavo | 42 | -12.6677 | -38.3682 | 224-225 | 03-08-2007 |
| GC990-50 | 514440 | | AFTA | 1 | Teresopolis 2263 m | Rio de Janeiro | 2263 | -22.4617 | -43.0305 | 297 | 10-08-2007 |
| GC990-51 | 514441 | | AFTA | 1 | Teresopolis 2000 m | Rio de Janeiro | 2000 | -22.4560 | -43.0200 | 321 | 10-08-2007 |
| GC990-52 | 514442 | | AFTA | 1 | Teresopolis 1688 m | Rio de Janeiro | 1688 | -22.4522 | -43.0147 | 326 | 10-08-2007 |
| GC990-53 | 514443 | | AFTA | 1 | Teresopolis 1510 m | Rio de Janeiro | 1510 | -22.4478 | -43.0130 | 333 | 10-08-2007 |
| GC990-54 | 514444 | | AFTA | 1 | Teresopolis 920 m | Rio de Janeiro | 920 | -22.4652 | -42.9938 | 342-343 | 11-08-2007 |
| GC990-55 | 514445 | | AFTA | 1 | Teresopolis 725 m | Rio de Janeiro | 725 | -22.4805 | -42.9967 | 344, 346 | 11-08-2007 |
| GC990-56 | 514446 | | AFTA | 1 | Teresopolis 500 m | Rio de Janeiro | 500 | -22.4905 | -43.0067 | 352-353 | 11-08-2007 |
| GC990-57 | 514447 | 47 | AFTA | 1 | Feira de Santana | Recôncavo | 288 | -12.2810 | -38.9960 | 391 | 13-08-2007 |
| GC990-58 | 514448 | 47 | AFTA | 2 | Argoim | Itaberaba | 167 | -12.5433 | -39.5683 | 403-404 | 13-08-2007 |
| GC990-59 | 514449 | 47 | AFTA | 2 | Capivari | Itaberaba | 201 | -12.4955 | -39.8348 | 409-411 | 13-08-2007 |
| GC990-60 | 514450 | 46 | AFTA | 1 | Itaberaba, E | Itaberaba | 250 | -12.5205 | -40.2002 | - | 13-08-2007 |
| GC990-61 | 514451 | 46 | AFTA | 2 | Lajedinho | Itaberaba | 600 | -12.4515 | -40.8838 | 427 | 13-08-2007 |
| GC990-62 | 514452 | 45 | AFTA | 2 | Andarai | Chapada Diamantina | 330 | -12.7572 | -41.3285 | 451-452 | 13-08-2007 |
| GC990-63 | 514453 | 45 | AFTA | 0 | Andarai, N | Chapada Diamantina | 337 | -12.8408 | -41.3215 | 453-456 | 13-08-2007 |
| GC990-64 | 514454 | 45 | AFTA | 1 | Mucugê | Chapada Diamantina | 800 | -12.9505 | -41.2765 | 457-459 | 13-08-2007 |
| GC990-65 | 514455 | 45 | AFTA | 0 | Mucugê | Chapada Diamantina | 1086 | -12.9627 | -41.3115 | 460-461 | 13-08-2007 |
| GC990-66 | 514456 | 46 | AFTA | 2 | Igatu | Chapada Diamantina | 498 | -12.9273 | -41.2440 | 469-470 | 14-08-2007 |
| GC990-67.1 | 514457 | 46 | VR | 4 | Igatu | Chapada Diamantina | 498 | -12.9273 | -41.2440 | 469-470 | 14-08-2007 |
| GC990-68 | 514458 | 45 | AFTA | 1 | Mucugê | Chapada Diamantina | 1212 | -13.0087 | -41.3795 | 475-485 | 14-08-2007 |
| GC990-69 | 514459 | 45 | Age | 5 | Lagoa Encantada, Cascavel | Chapada Diamantina | 1023 | -13.2985 | -41.3300 | 506-520 | 14-08-2007 |
| GC990-70 | 514460 | 45 | Age | 5 | Lagoa Encantada, Cascavel | Chapada Diamantina | 1023 | -13.2985 | -41.3300 | 506-520 | 14-08-2007 |
| GC990-71 | 514461 | 45 | Age | 5 | Lagoa Encantada, Cascavel | Chapada Diamantina | 1023 | -13.2985 | -41.3300 | 521-524 | 14-08-2007 |
| GC990-72 | 514466 | 45 | AFTA | 1 | Lagoa Encantada, Cascavel | Chapada Diamantina | 1033 | -13.2973 | -41.3350 | 526-527 | 14-08-2007 |
| GC990-73 | 514467 | 45 | AFTA | 2 | Capão da Volta | Chapada Diamantina | 1312 | -13.4742 | -41.4828 | 533 | 14-08-2007 |
| GC990-74 | 514468 | 45 | AFTA | 2 | Jussiape, N | Chapada Diamantina | 1025 | -13.4510 | -41.5407 | 546, 547 | 14-08-2007 |
| GC990-75 | 514469 | 45 | AFTA | 2 | Jussiape, N | Chapada Diamantina | 741 | -13.4505 | -41.5622 | 548-550 | 14-08-2007 |
| GC990-76 | 514470 | 45 | AFTA | 1 | Jussiape | Chapada Diamantina | 529 | -13.4918 | -41.5803 | 551-554 | 14-08-2007 |
| GC990-77 | 514471 | 45 | AFTA | 2 | Bittencourt | Rio de Contas | 1575 | -13.4495 | -41.8313 | 566-567 | 15-08-2007 |
| GC990-78 | 514472 | 45 | AFTA | 1 | Mato Grosso | Rio de Contas | 1309 | -13.4705 | -41.8397 | 570-571 | 15-08-2007 |
| GC990-79 | 514473 | 45 | AFTA | 1 | Rio de Contas | Rio de Contas | 1040 | -13.4820 | -41.8647 | 572 | 15-08-2007 |

| Geotrack sample no. | GEUS no. | Map | Purpose | Purpose, status | Locality | Region | Elevation (m a.s.l.) | lat | long | New Photo DSC_0xxx | Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GC990-80 | 514474 | 45 | AFTA | 1 | Livramento | Rio de Contas | 543 | -13.6210 | -41.8187 | 575 | 15-08-2007 |
| GC990-81 | 514475 | 45 | AFTA | 1 | Rio de Contas, S | Rio de Contas | 891 | -13.6040 | -41.8110 | 580-581 | 15-08-2007 |
| GC990-82 | 514476 | 45 | AFTA | 1 | Brumado, N | Brumado | 404 | -13.9258 | -41.7100 | 622 | 16-08-2007 |
| GC990-83 | 514477 | 52 | AFTA | 2 | Brumado, S | Brumado | 488 | -14.2878 | -41.5777 | 629 | 16-08-2007 |
| GC990-84 | 514478 | 52 | AFTA | 2 | Aracatu | Brumado | 744 | -14.4212 | -41.4660 | 634-635 | 16-08-2007 |
| GC990-85 | 514479 | 52 | AFTA | 1 | Anagé | Vitoria da Conquista | 377 | -14.6103 | -41.1458 | 654-655 | 16-08-2007 |
| GC990-86 | 514480 | 53 | AFTA | 1 | Anagé, S | Vitoria da Conquista | 594 | -14.6302 | -41.075 | 660-661 | 16-08-2007 |
| GC990-87 | 514481 | 53 | AFTA | 1 | Anagé, further S | Vitoria da Conquista | 806 | -14.7433 | -41.0247 | 662-663 | 16-08-2007 |
| GC990-88 | 514482 | 53 | AFTA | 1 | Hill, east of city | Vitoria da Conquista | 1055 | -14.8293 | -40.8348 | 675-678 | 16-08-2007 |
| GC990-89 | 514483 | 53 | age | 5 | Hill, east of city | Vitoria da Conquista | 1055 | -14.8293 | -40.8348 | - | 16-08-2007 |
| GC990-90 | 514484 | 53 | age | 5 | Lagoa João Gomez | Vitoria da Conquista | 903 | -14.8202 | -40.7905 | 679 | 16-08-2007 |
| GC990-91 | 514485 | 53 | age | 5 | Near Lagoa João Gomez | Vitoria da Conquista | - | -14.8167 | -40.7833 | - | 16-08-2007 |
| GC990-92 | 514486 | 53 | (AFTA) | 3 | Serra do Marçal | Vitoria da Conquista | 813 | -15.0442 | -40.7487 | 684-685 | 17-08-2007 |
| GC990-93 | 514487 | 53 | AFTA | 1 | Serra do Marçal | Vitoria da Conquista | 737 | -15.0525 | -40.7472 | 688-690 | 17-08-2007 |
| GC990-94 | 514488 | 53 | AFTA | 1 | Serra do Marçal | Vitoria da Conquista | 500 | -15.0667 | -40.7378 | 696 | 17-08-2007 |
| GC990-95 | 514489 | 53 | AFTA | 1 | Serra do Marçal | Vitoria da Conquista | 349 | -15.1787 | -40.6688 | 697 | 17-08-2007 |
| GC990-96 | 514490 | 53 | AFTA | 2 | Itambé | Vitoria da Conquista | 323 | -15.2570 | -40.6065 | 699 | 17-08-2007 |
| GC990-97 | 514491 | 53 | AFTA | 2 | Rio Catolés, Itapetinga | Vitoria da Conquista | 244 | -15.2612 | -40.2378 | 702 | 17-08-2007 |
| GC990-98 | 514492 | 53 | AFTA | 2 | Itororó, W | Itabuna | 262 | -15.0843 | -40.0295 | 704-705 | 17-08-2007 |
| GC990-99 | 514493 | 53 | AFTA | 1 | Floresta Azul, W | Itabuna | 222 | -14.9245 | -39.7422 | 706 | 17-08-2007 |
| GC990-100 | 514494 | 54 | AFTA | 2 | Itapé, W | Itabuna | 109 | -14.8852 | -39.4652 | 709-710 | 17-08-2007 |
| GC990-101 | 514495 | 54 | AFTA | 1 | BR101, Itabuna | Itabuna | 109 | -14.8245 | -39.2913 | 711-712 | 17-08-2007 |
| GC990-102 | 514496 | 54 | AFTA | 2 | BR101, Rio Pardo | Itabuna | 95 | -15.5715 | -39.4060 | 721-722 | 17-08-2007 |
| GC990-103 | 514497 | 54 | AFTA | 2 | Una, river | Itabuna | 9 | -15.2953 | -39.0743 | 740-741 | 17-08-2007 |
| GC990-104 | 514498 | 54 | Age | 5 | Una, N | Itabuna | 62 | -15.2670 | -39.0520 | 742 | 17-08-2007 |
| GC990-105 | 514499 | 54 | AFTA | 1 | Praia do Christo, Ilhéus | Itabuna | 0 | -14.8053 | -39.0318 | 758-760 | 18-08-2007 |
| GC990-106 | 514550 | 54 | AFTA | 2 | Uruçuca | Itabuna | 109 | -14.5807 | -39.3003 | 766 | 18-08-2007 |
| GC990-107 | 514551 | 54 | AFTA | 2 | BR101, Ubaitaba, N | Itabuna | 82 | -14.2952 | -39.3245 | 768 | 18-08-2007 |
| GC990-108 | 514552 | 54 | AFTA | 1 | Camamu town, SW | Camamu | 19 | -13.9717 | -39.1338 | 769-774 | 18-08-2007 |
| GC990-109 | 514553 | 54 | AFTA | 1 | Camamu town, N | Camamu | 18 | -13.9032 | -39.1327 | 780-781 | 18-08-2007 |
| GC990-110 | 514554 | 47 | AFTA | 1 | Itaberá | Camamu | 10 | -13.7232 | -39.1457 | 785-786 | 18-08-2007 |
| GC990-111 | 514555 | 47 | AFTA | 1 | Tabora, N | Camamu | 26 | -13.6680 | -39.1207 | 787-788 | 18-08-2007 |
| GC990-112.1 | 514556 | 47 | VR | 4 | Tabora, N | Camamu | 26 | -13.6680 | -39.1207 | 787-788 | 18-08-2007 |

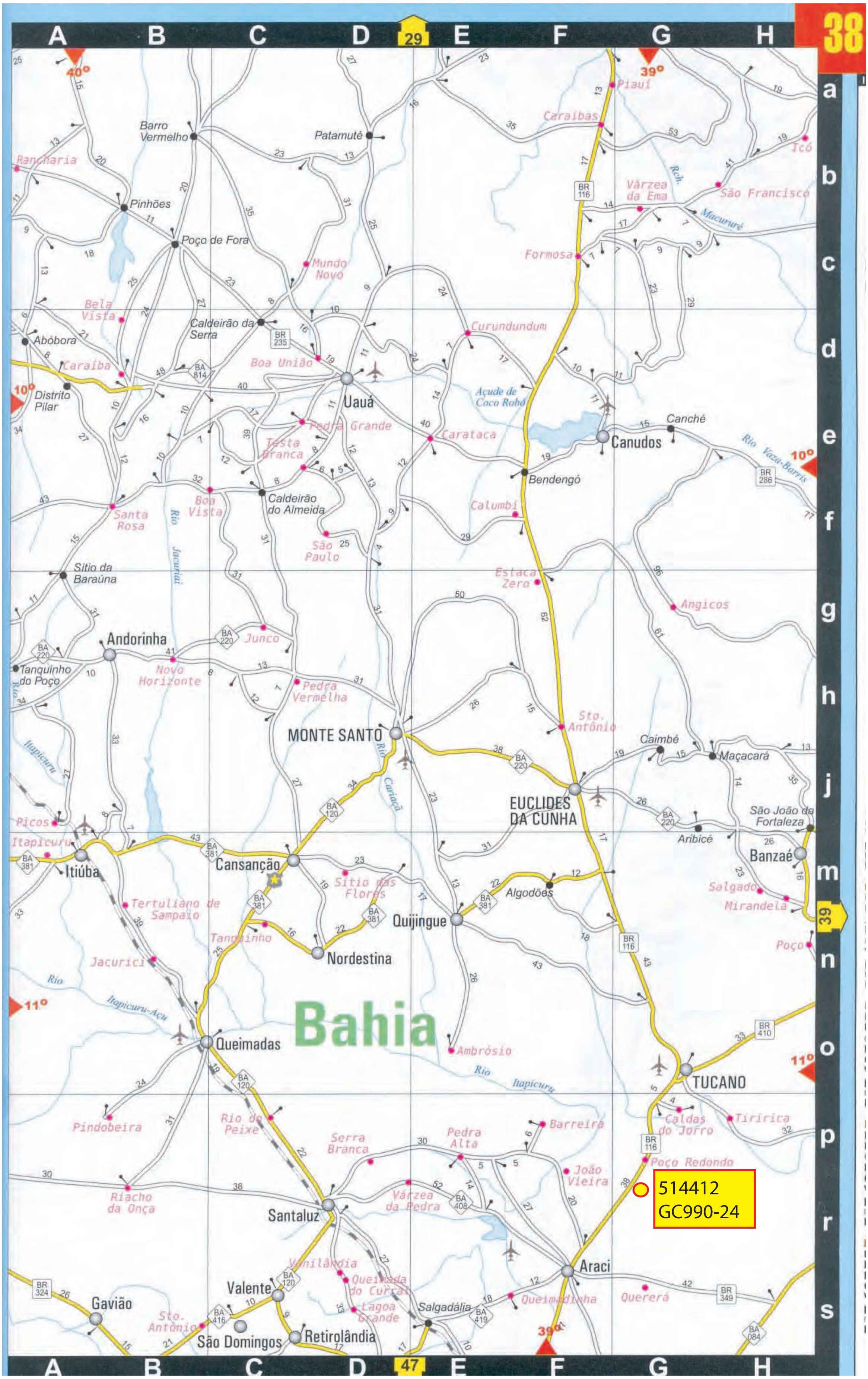
| Geotrack sample no. | GEUS no. | Map | Purpose | Purpose, status | Locality | Region | Elevation (m a.s.l.) | lat | long | New Photo DSC_0xxx | Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GC990-113 | 514557 | 47 | AFTA | 1 | Maricuabo | Camamu | 17 | -13.4658 | -39.0875 | 789-793 | 18-08-2007 |
| GC990-114.1 | 514558 | 47 | VR | 4 | Maricuabo | Camamu | 17 | -13.4658 | -39.0875 | 789-793 | 18-08-2007 |
| GC990-115 | 514559 | 38 | AFTA | 1 | Valença, N | Camamu | 22 | -13.2792 | -39.0377 | 796-797 | 18-08-2007 |
| GC990-116 | 514560 | 47 | AFTA | 1 | Valença, N | Camamu | 16 | -13.1910 | -39.0093 | 798 | 18-08-2007 |
| GC990-117 | 514561 | 48 | AFTA | 0 | Sitio de Conde, beach | Bahia, NE | 0 | -11.8562 | -37.5653 | 815-830 | 19-08-2007 |
| - | 514562 | 48 | age | 5 | Sitio de Conde, beach | Bahia, NE | 0 | -11.8562 | -37.5653 | 815-830 | 19-08-2007 |
| GC990-118 | 514563 | 39 | (AFTA) | 3 | Monte Alegre do Sergipe | Sergipe, N | 278 | -9.9960 | -37.5632 | 839-840 | 20-08-2007 |
| GC990-119 | 514564 | 39 | AFTA | 2 | Poço Redondo | Sergipe, N | 316 | -9.9363 | -37.6185 | 842 | 20-08-2007 |
| GC990-120 | 514565 | 39 | AFTA | 2 | Rio SF, river, Canindé | Sergipe, N | 57 | -9.6387 | -37.7727 | 859 | 20-08-2007 |
| GC990-121 | 514566 | 39 | AFTA | 2 | Rio SF, plateau, Piranhas | Alagoas | 225 | -9.5948 | -37.7765 | 860 | 20-08-2007 |
| GC990-122 | 514567 | 39 | AFTA | 2 | Delmiro Gouveia | Alagoas | 253 | -9.3685 | -37.9917 | 867-868 | 20-08-2007 |
| GC990-123 | 514568 | 39 | AFTA | 1 | Juá | Tucano, Bahia | 359 | -9.4393 | -38.4222 | 873,874,876 | 20-08-2007 |
| GC990-124 | 514569 | 39 | AFTA | 2 | Rio SF, Paulo Afonso, E | Alagoas | 225 | -9.4185 | -38.1972 | 881 | 20-08-2007 |
| GC990-125 | 514570 | 39 | AFTA | 1 | Piranhas, W | Alagoas | 282 | -9.5142 | -37.8163 | 886-887 | 20-08-2007 |
| GC990-126 | 514571 | 39 | AFTA | 1 | São Clemente | Sergipe, N | 204 | -10.1397 | -37.5262 | 891 | 21-08-2007 |
| GC990-127 | 514572 | 39 | AFTA | 2 | Feira Nova | Sergipe, N | 231 | -10.2540 | -37.3168 | 892 | 21-08-2007 |
| GC990-128 | 514573 | 39 | AFTA | 1 | Itabaiana | Sergipe, S | 162 | -10.7062 | -37.4507 | 898 | 21-08-2007 |
| GC990-129 | 514574 | 39 | (AFTA) | 3 | Salgado, S | Sergipe, S | 141 | -11.0683 | -37.5680 | 905 | 21-08-2007 |

| Geotrack sample no. | GEUS no. | Rock type | Formation | Stratigraphic age | Age (Ma) | Comment |
|---|---|---|---|---|---|---|
| GC990-14 | 514401 | - | Basement | Archean | > 2600 | |
| GC990-15 | 514402 | Sandstone | ? | ?Recent beach deposit | ? | Cemented, not indicated on map |
| GC990-16 | 514403 | - | Basement | Archean | > 2600 | |
| GC990-17 | 514404 | - | Basement | Archean | > 2600 | Near intrusion |
| GC990-18 | 514405 | Sandstone | Sergi Fm | Tithonian (upper) | 150 - 144 | Weathered |
| GC990-19.1 | 514406 | Shale | Sergi Fm | Tithonian (upper) | 150 - 144 | |
| GC990-20 | 514408 | Sandstone | Aliança Fm | Tithonian (lower) | 150 - 144 | Red bed |
| GC990-21 | 514409 | Sandstone | Afligidos Fm | Permian | 290 - 250 | Red bed |
| GC990-22 | 514410 | - | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-23 | 514411 | - | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-24 | 514412 | Sandstone | Ilhas Group | Valang - Hautr. | 136 - 127 | Cemented |
| GC990-25 | 514413 | Sandstone | Marizal Fm | Upper Aptian | 115 - 112 | |
| GC990-26 | 514414 | Sandstone | Marizal Fm? | Upper Aptian | 115 - 112 | |
| GC990-27 | 514415 | Sandstone | Marizal Fm? | Upper Aptian | 115 - 112 | Fluvial, coarse |
| GC990-28 | 514416 | Sandstone | Marizal Fm | Upper Aptian | 115 - 112 | Congl. in upper part |
| GC990-29 | 514417 | Sandstone | Marizal Fm | Upper Aptian | 115 - 112 | Congl. in upper part |
| GC990-30 | 514418 | Sandstone | Sergi Fm | Tithonian (upper) | 150 - 144 | Fault zone, strike slip |
| GC990-31 | 514419 | Sandstone | Alianca Fm? | Tithonian (lower) | 150 - 144 | Congl., pebles |
| GC990-32 | 514420 | Sandstone | - | Palaeozoic | > 250 | Fault zone, compl. mineral. |
| GC990-33 | 514421 | Conglomerate | - | Palaeozoic or older | > 250 | North of fault /basement |
| GC990-34 | 514422 | - | Basement | Neoproterozoic | > 500 | Reactivated fault |
| GC990-35 | 514423 | Sandstone | Sergi Fm | Tithonian (upper) | 150 - 144 | Weathered, loose sand |
| GC990-36 | 514424 | Sandstone | Marizal Fm | Upper Aptian | 115 - 112 | Weathered, red |
| GC990-37 | 514425 | Sandstone | Marizal Fm? | Upper Aptian | 115 - 112 | Fresh and hard rock. Near location of well 1-FVM-1-BA |
| GC990-38 | 514426 | Sandstone | Marizal Fm | Upper Aptian | 115 - 112 | Near N-S boundary fault, sand fraction |
| GC990-39 | 514427 | - | Basement | Archean | > 2600 | Fresh, East of Tucano fault |
| GC990-40 | 514428 | Sandstone | Barreiras Group | Latest Miocene-Pliocene | 5 - 2 | |
| GC990-41 | 514429 | - | Basement | Archean | > 2600 | Weathered, by river |
| GC990-42 | 514430 | Conglomerate | Salvador Fm | Barriasian - Barremian | 145 - 125 | Very coarse |
| GC990-43 | 514431 | Sandstone | Maracangalha Fm | Valanginian - Early Apt. | 140 - 120 | Lacustrine turbidite |
| GC990-44.1 | 514432 | Black shale/silt | Maracangalha Fm | Valanginian - Early Apt. | 140 - 120 | Lacustrine turbidite |
| GC990-45 | 514434 | Sandstone | Sergi Fm | Tithonian (upper) | 150 - 144 | |
| GC990-46 | 514436 | - | Basement | Archean - Palaeoprot. | > 1600 | Overlain by U.Jur., sharp flat contact - NO! by weathered basement |

| Geotrack sample no. | GEUS no. | Rock type | Formation | Stratigraphic age | Age (Ma) | Comment |
|---|---|---|---|---|---|---|
| GC990-47 | 514437 | - | Basement | Archean - Palaeoprot. | > 1600 | Fresh rock |
| GC990-48 | 514438 | Sandstone | Massacará Fm | Hautr. - Barremian | 120 - 132 | Below Marizal? surface. 'Kbh' on map |
| GC990-49 | 514439 | Sandstone | Massacará Fm | Hautr. - Barremian | 120 - 132 | Weathered, firm sand. 'Kbh' on map |
| GC990-50 | 514440 | - | Basement | Archean | > 2600 | Summit |
| GC990-51 | 514441 | - | Basement | Archean | > 2600 | |
| GC990-52 | 514442 | - | Basement | Archean | > 2600 | Waterfall |
| GC990-53 | 514443 | - | Basement | Archean | > 2600 | Pool |
| GC990-54 | 514444 | - | Basement | Archean | > 2600 | Road cut |
| GC990-55 | 514445 | - | Basement | Archean | > 2600 | Road cut |
| GC990-56 | 514446 | - | Basement | Archean | > 2600 | Road cut |
| GC990-57 | 514447 | Gneiss | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-58 | 514448 | Granite | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-59 | 514449 | Granite/Quartzite | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-60 | 514450 | Granite/gneiss | Basement | Archean - Palaeoprot. | > 1600 | weathered |
| GC990-61 | 514451 | Amphibolite? | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-62 | 514452 | Conglomerate | Bebedouro Fm | Neoproterozoic | 1000 - 540 | Conglomerate |
| GC990-63 | 514453 | Sandstone | Tombador Fm | Midproterozoic | 1600 - 1000 | |
| GC990-64 | 514454 | Sandstone | Tombador Fm | Midproterozoic | 1600 - 1000 | |
| GC990-65 | 514455 | Sandstone | Tombador Fm | Midproterozoic | 1600 - 1000 | |
| GC990-66 | 514456 | Siltstone | Caboclo Fm | Midproterozoic | 1600 - 1000 | |
| GC990-67.1 | 514457 | Claystone | Caboclo Fm | Midproterozoic | 1600 - 1000 | |
| GC990-68 | 514458 | Sandstone | Tombador Fm | Midproterozoic | 1600 - 1000 | |
| GC990-69 | 514459 | Diatomite | - | Cenozoic | < 65 | One big piece, cut from deepest part of the pit |
| GC990-70 | 514460 | Diatomite | - | Cenozoic | < 65 | One piece + selected pieces with fragments of leaves etc |
| GC990-71 | 514461 | Wood | - | Cenozoic | < 65 | Wood from diatomite section |
| GC990-72 | 514466 | Sandstone | Mangabeira Fm | Midproterozoic | 1600 - 1000 | Rift sequence, sample at plantation surface |
| GC990-73 | 514467 | Sandstone | Mangabeira Fm | Midproterozoic | 1600 - 1000 | Rift sequence, N81 |
| GC990-74 | 514468 | Sandstone | Mangabeira Fm | Midproterozoic | 1600 - 1000 | Escarpment below planalto |
| GC990-75 | 514469 | - | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-76 | 514470 | - | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-77 | 514471 | Sandstone | Ouricuri do Ouro | Midproterozoic | 1600 - 1000 | Mirante |
| GC990-78 | 514472 | Sandstone | Ouricuri do Ouro | Midproterozoic | 1600 - 1000 | sst/conglomerate |
| GC990-79 | 514473 | Sandstone | Ouricuri do Ouro | Midproterozoic | 1600 - 1000 | Bridge, small river |

| Geotrack sample no. | GEUS no. | Rock type | Formation | Stratigraphic age | Age (Ma) | Comment |
|---|---|---|---|---|---|---|
| GC990-80 | 514474 | Sandstone | Rio dos Remédios Group | Paleoproterozoic | 1800 - 1600 | Below O.doO. Fm,, aeolian |
| GC990-81 | 514475 | Sandstone | Ouricuri do Ouro | Midproterozoic | 1600 - 1000 | |
| GC990-82 | 514476 | Gneiss | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-83 | 514477 | Granitic basement | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-84 | 514478 | Granitic basement | Basement | Archean - Palaeoprot. | > 1600 | White, alkaline felspar, quartzite |
| GC990-85 | 514479 | Gneiss | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-86 | 514480 | Gneiss | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-87 | 514481 | Gneiss | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-88 | 514482 | Quartzite | Basement | Archean - Palaeoprot. | > 1600 | Apatites?? sample at plantation surface |
| GC990-89 | 514483 | Conglomerate | - | Cenozoic | < 65 | Conglomerate with iron cement |
| GC990-90 | 514484 | Diatomite | - | Cenozoic | < 65 | abandonned mine, burned diatomite |
| GC990-91 | 514485 | Diatomite | - | Cenozoic | < 65 | from ciemel factory, sun dried |
| GC990-92 | 514486 | Saprolite | Cenozoic laterite (ENdl) | Cenozoic | < 65 | Apatites?? |
| GC990-93 | 514487 | - | Basement | Archean - Palaeoprot. | > 1600 | Hard rock |
| GC990-94 | 514488 | Granulite | | Archean - Palaeoprot. | > 1600 | |
| GC990-95 | 514489 | Granulite / Amph | | Archean - Palaeoprot. | > 1600 | Weathered |
| GC990-96 | 514490 | - | Basement | Archean - Palaeoprot. | > 1600 | Quartzite |
| GC990-97 | 514491 | Granulite | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-98 | 514492 | Granulite | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-99 | 514493 | - | Basement | Archean - Palaeoprot. | > 1600 | Slightly weathered |
| GC990-100 | 514494 | Granulite | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-101 | 514495 | Granulite | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-102 | 514496 | Sandstone | Salobro Fm | Neoprot. - Lower Pz | 600 | |
| GC990-103 | 514497 | Granulite | Basement | Paleoproterozoic | > 1600 | |
| GC990-104 | 514498 | Sand | Above Barreiras Group | Late Cenozoic | < 5 | White sand from upper part - beach deposit: Dinofl?? |
| GC990-105 | 514499 | Granulite | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-106 | 514550 | Granulite | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-107 | 514551 | Granulite | Basement | Archean - Palaeoprot. | > 1600 | |
| GC990-108 | 514552 | Sandstone + Congl. | Sergi-Aliança undiff, "J3b" | Upper Jurassic | 154 - 135 | Aeolian + river sand |
| GC990-109 | 514553 | Granulite | Basement | Archean - Palaeoprot. | > 1600 | Camamu escarpment |
| GC990-110 | 514554 | Granulite | Basement | Archean - Palaeoprot. | > 1600 | Waterfall, escarpment |
| GC990-111 | 514555 | Sandstone | Sergi-Aliança undiff, "J3b" | Upper Jurassic | 154 - 135 | Just above basement! |
| GC990-112.1 | 514556 | Organic matter | Sergi-Aliança undiff, "J3b" | Upper Jurassic | 154 - 135 | Copy from #555 |

| Geotrack sample no. | GEUS no. | Rock type | Formation | Stratigraphic age | Age (Ma) | Comment |
|---|---|---|---|---|---|---|
| GC990-113 | 514557 | Sandstone | Sergi-Aliança undiff, "J3b" | Upper Jurassic | 154 - 135 | Basement contact! (weathered basement below) |
| GC990-114.1 | 514558 | Organic matter | Sergi-Aliança undiff, "J3b" | Upper Jurassic | 154 - 135 | Copy from #557 |
| GC990-115 | 514559 | Granulite | Basement | Archean - Palaeoprot. | > 1600 | Fresh rock, below weathering mantle |
| GC990-116 | 514560 | Sandstone | Sergi-Aliança undiff, "J3b" | Upper Jurassic | 154 - 135 | Aeolian, near last basement outcrop |
| GC990-117 | 514561 | Sandstone | ? | ?Recent beach deposit | ? | Coastal, beach congl. with shels and oil seep (?) |
| - | 514562 | Sandstone | ? | ? | ? | Copy from above |
| GC990-118 | 514563 | Schist + quartz | Basement | Precambrian | > 570 | No apatites? (cobra snake) |
| GC990-119 | 514564 | Granite | Basement | Precambrian | > 570 | |
| GC990-120 | 514565 | ? | Basement | Precambrian | > 570 | Bridge to Piranhas |
| GC990-121 | 514566 | Granite | Basement | Precambrian | > 570 | |
| GC990-122 | 514567 | Granite | Basement | Precambrian | > 570 | |
| GC990-123 | 514568 | Sandstone | ? | Jurassic-Early Cretaceous | 150-120 | Well-cemented |
| GC990-124 | 514569 | - | Basement | Precambrian | > 570 | Weathered |
| GC990-125 | 514570 | Sandstone | *SDt" | Silurian-Devonian | 435 - 345 | Tilted fault block above present land surface |
| GC990-126 | 514571 | Granite | Basement | Precambrian | > 570 | Small quarry (2 bulls) |
| GC990-127 | 514572 | Metamorphic | Basement, "MNm1" | Precambrian | > 570 | |
| GC990-128 | 514573 | Gness (?) | Basement | Precambrian | > 570 | |
| GC990-129 | 514574 | ? | Basement or Barreiras Group | ? | ? | Weathered or cemented ! |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Formosa
Mundo Novo
Bela Vista
Caldeirão da Serra
Abóbora
Caraíba
Distrito Pilar
Boa União
Uauá
Curundundum
Açude de Cocorobó
Pedra Grande
Testa Branca
Carataca
Canudos
Canché
Rio Vaza-Barris
Bendengó
Boa Vista
Caldeirão do Almeida
Santa Rosa
Calumbi
São Paulo
Estaca Zero
Sítio da Baraúna
Angicos
Junco
Andorinha
Tanquinho do Poço
Novo Horizonte
Pedra Vermelha
Sto. Antônio
MONTE SANTO
Caimbé
Maçacará
EUCLIDES DA CUNHA
São João da Fortaleza
Aribicé
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Cansanção
Sítio das Flores
Algodões
Banzaê
Salgado
Mirandela
Tertuliano de Sampaio
Quijingue
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Nordestina
Jacurici
Poço
Bahia
Queimadas
Ambrósio
Rio Itapicuru
TUCANO
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Caldas do Jorro
Pindobeira
Rio do Peixe
Serra Branca
Pedra Alta
Barreira
Poço Redondo
João Vieira
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Araci
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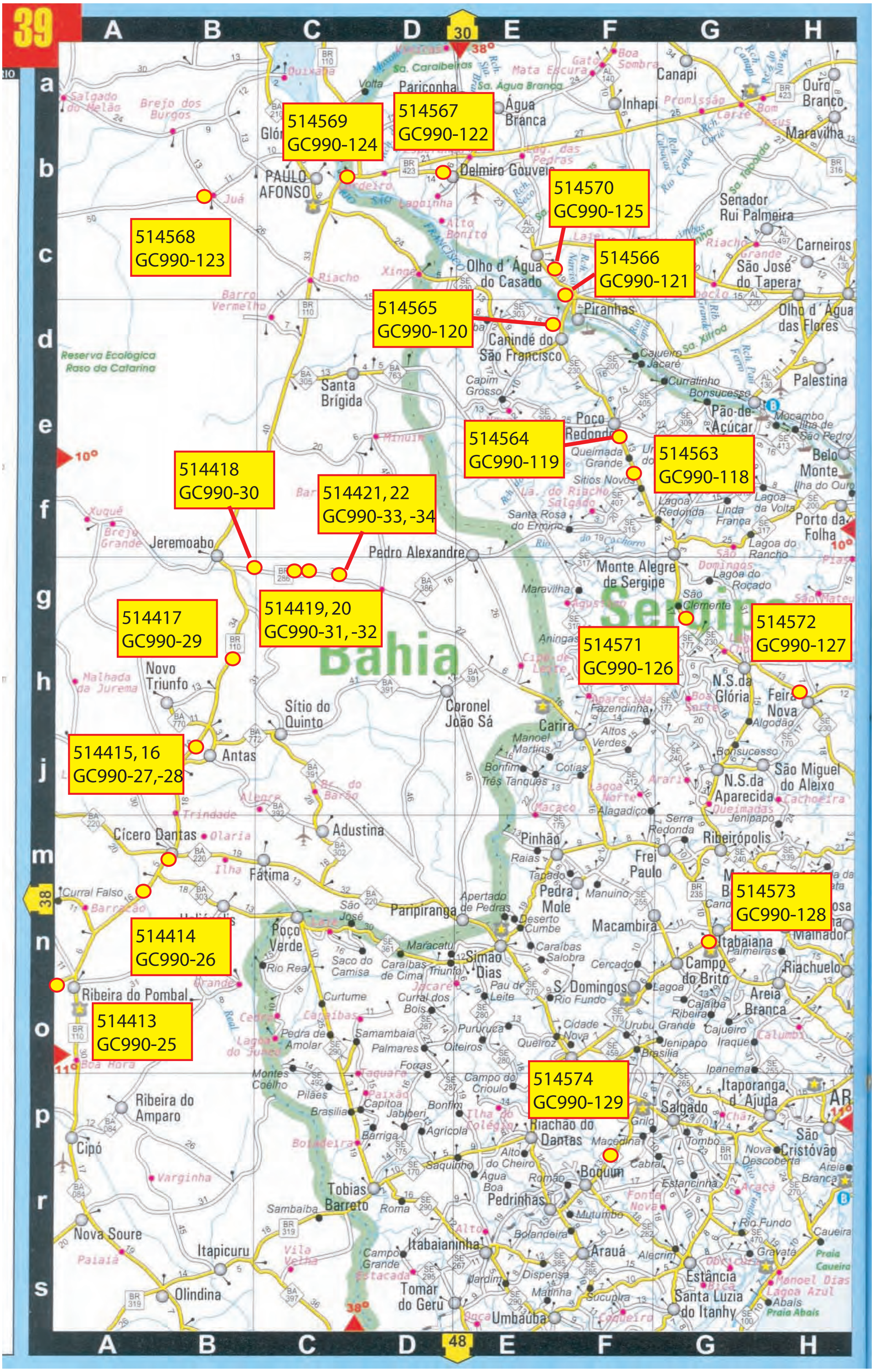

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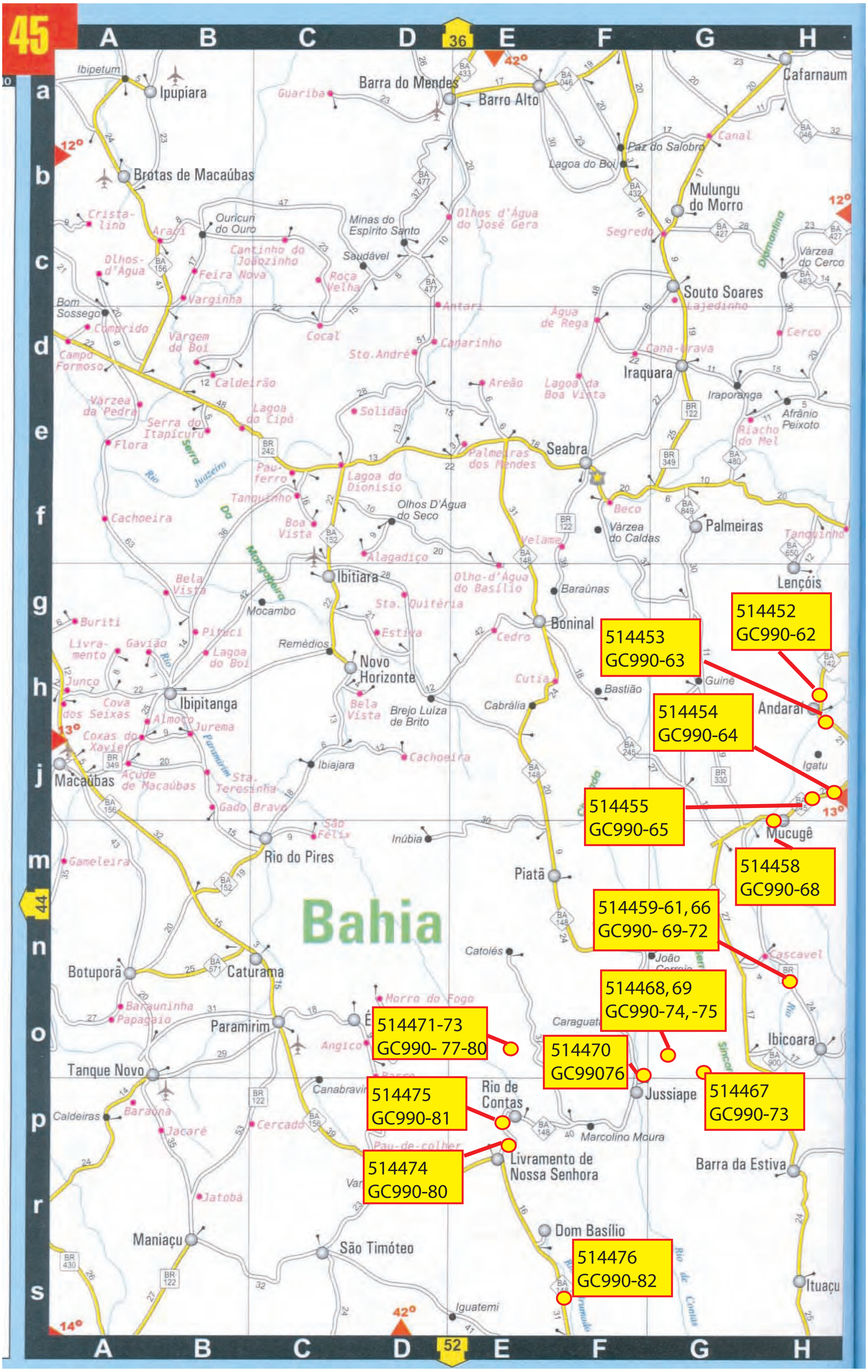
Sergipe
PAULO AFONSO
Jeremoabo
Pedro Alexandre
Canindé do São Francisco
Piranhas
Delmiro Gouveia
Coronel João Sá
Ribeira do Pombal
Cícero Dantas
Paripiranga
Simão Dias
Itabaiana
Tobias Barreto
Estância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Barro Alto
Cafarnaum
Mulungu do Morro
Souto Soares
Iraquara
Seabra
Palmeiras
Lençóis
Ibitiara
Boninal
Novo Horizonte
Ibipitanga
Andaraí
Mucugê
Macaúbas
Rio do Pires
Piatã
Botuporã
Caturama
Paramirim
Tanque Novo
Rio de Contas
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São Timóteo
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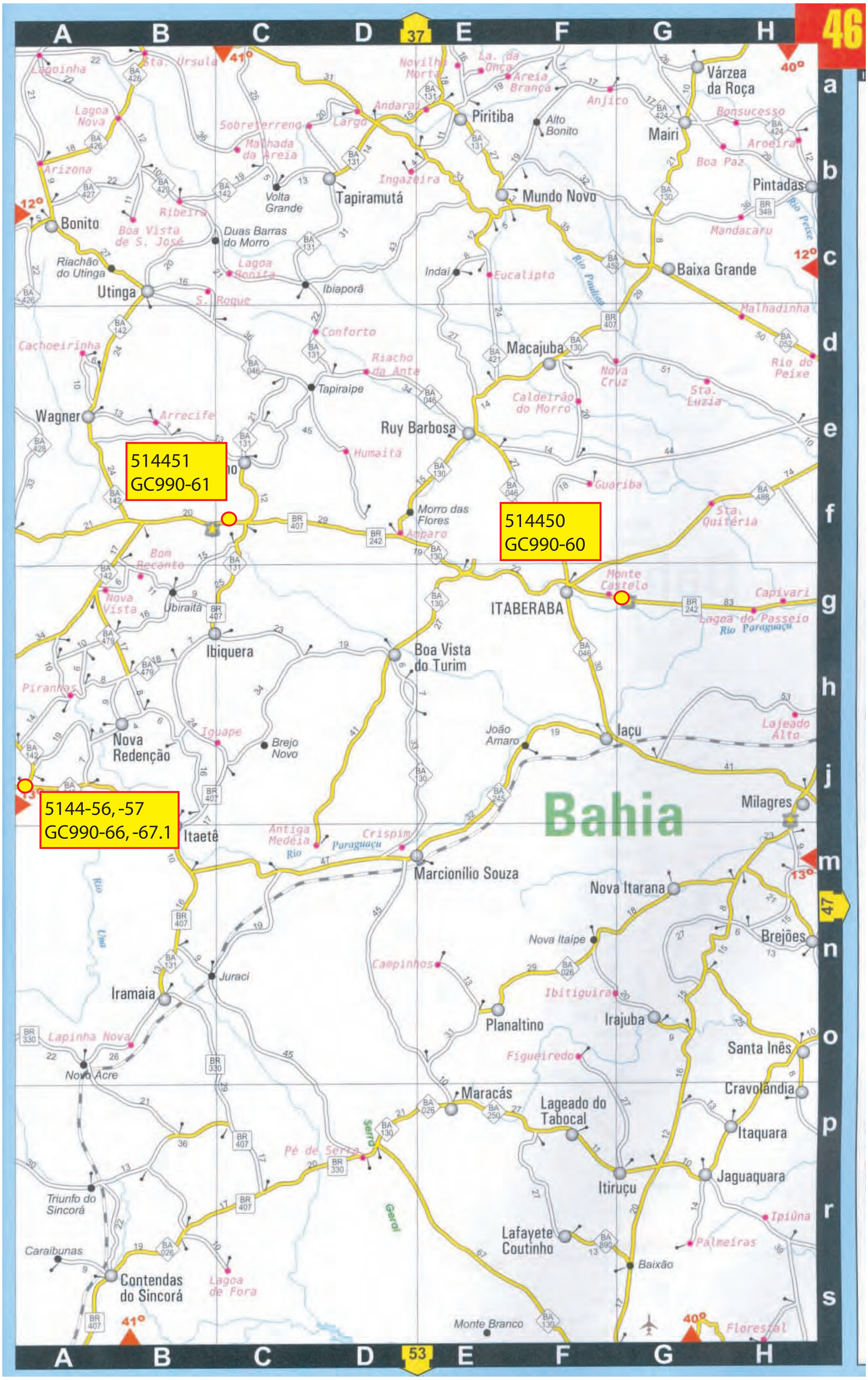
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Piritiba
Alto Bonito
Mairi
Mundo Novo
Tapiramutá
Volta Grande
Pintadas
Baixa Grande
Bonito
Riachão do Utinga
Utinga
Duas Barras do Morro
Ibiaporã
Indaí
Macajuba
Tapiraípe
Ruy Barbosa
Wagner
Morro das Flores
ITABERABA
Ubiraíta
Ibiquera
Boa Vista do Turim
Nova Redenção
Brejo Novo
João Amaro
Iaçu
Milagres
Itaetê
Marcionílio Souza
Nova Itarana
Nova Itaipe
Brejões
Juraci
Iramaia
Planaltino
Irajuba
Santa Inês
Novo Acre
Maracás
Lageado do Tabocal
Cravolândia
Itaquara
Jaguaquara
Itiruçu
Triunfo do Sincorá
Caraibunas
Contendas do Sincorá
Lafayete Coutinho
Baixão
Monte Branco
Lagoinha
Sta. Úrsula
Lagoa Nova
Arizona
Ribeira
Boa Vista de S. José
Sobreterreno
Malhada da Areia
Largo
Andaraí
Novilha Morta
La. da Onça
Areia Branca
Anjico
Bonsucesso
Aroeira
Boa Paz
Ingazeira
Mandacaru
Lagoa Bonita
S. Roque
Eucalipto
Malhadinha
Conforto
Cachoeirinha
Riacho da Anta
Rio do Peixe
Nova Cruz
Sta. Luzia
Caldeirão do Morro
Arrecife
Humaitá
Guariba
Sta. Quitéria
Amparo
Bom Recanto
Nova Vista
Monte Castelo
Capivari
Lagoa do Passeio
Rio Paraguaçu
Piranhas
Iguape
Lajeado Alto
Antiga Medéia
Crispim
Campinhos
Ibitiguira
Lapinha Nova
Figueiredo
Pé de Serra
Lagoa de Fora
Ipiúna
Palmeiras
Florestal
Serra Geral
Rio Una
Rio Paulista
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Barrocas
Biritinga
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Ichu
Riachão do Jacuípe
Pé de Serra
Candeal
Lamarão
Água Fria
Santa Bárbara
Tanquinho
Santanópolis
Irará
Ouriçangas
Ipirá
Serra Preta
Anguera
Aramari
FEIRA DE SANTANA
Coração de Maria
Teodoro Sampaio
Conceição do Jacuípe
Rafael Jambeiro
Antônio Cardoso
Santo Estevão
Amélia Rodrigues
São Gonçalo dos Campos
Conceição da Feira
São Sebastião do Passe
STO. AMARO
Itatim
Cachoeira
São Félix
MURITIBA
CRUZ DAS ALMAS
São Francisco do Conde
CANDEIAS
Santa Terezinha
Castro Alves
Sapeaçu
Conceição do Almeida
Saubara
São Felipe
Maragogipe
Simões Filho
Salinas da Margarida
Elísio Medrado
Dom Macedo Costa
Itaparica
Varzedo
Santo Antônio de Jesus
Amargosa
São Miguel das Matas
Nazaré
Vera Cruz
SALVADOR
Aratuípe
Laje
Ubaíra
Mutuípe
Jequiriçá
VALENÇA
Presidente Tancredo Neves
Cairu
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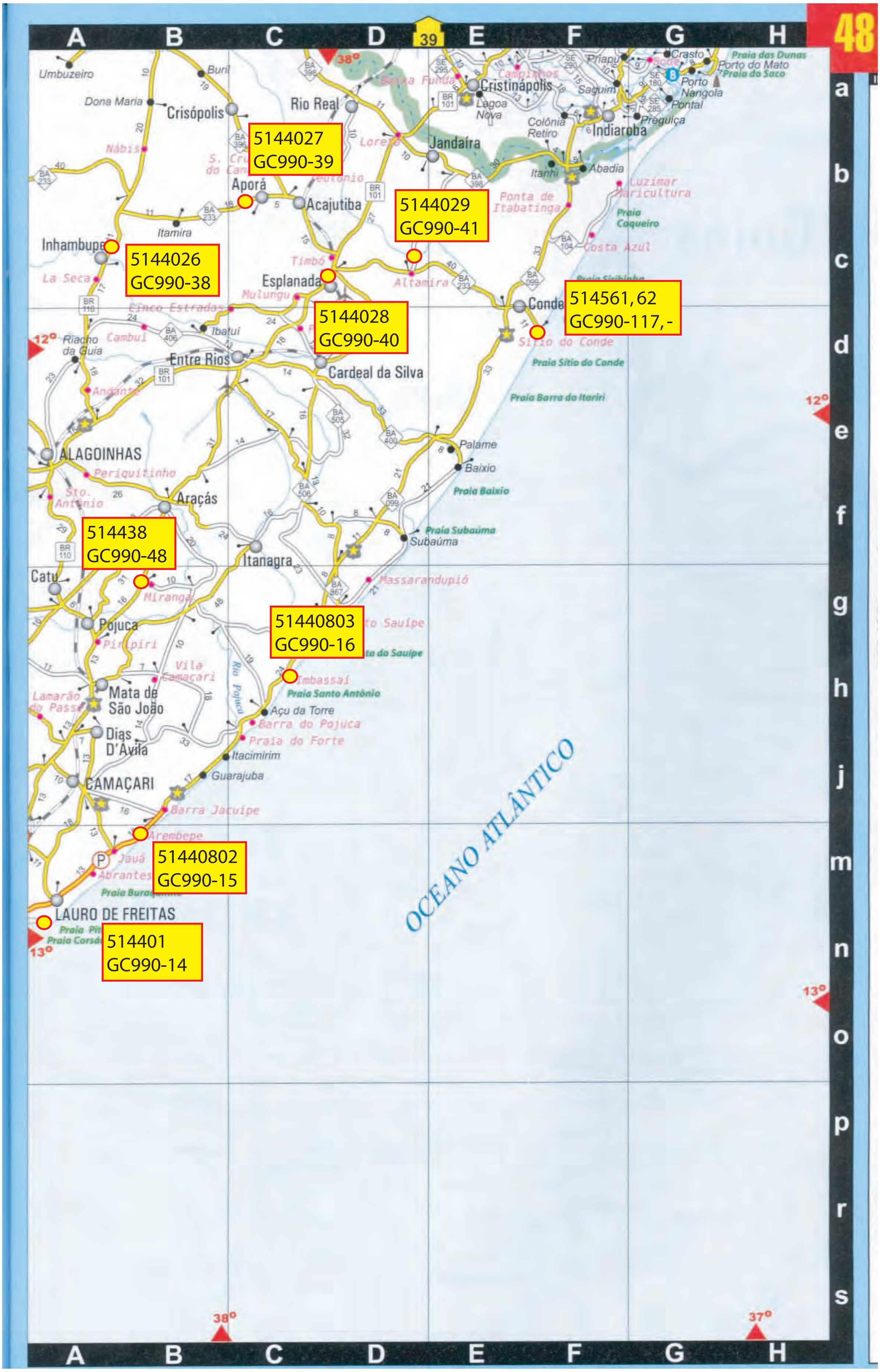
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Indiaroba
Itanhi
Abadia
Preguiça
Pontal
Crasto
Porto do Mato
Praia das Dunas
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Aporá
Acajutiba
Ponta de Itabatinga
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La Seca
Timbó
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Mulungu
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Sítio do Conde
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Praia Barra do Itariri
Cinco Estradas
Ibatuí
Riacho da Guia
Cambuí
Entre Rios
Cardeal da Silva
ALAGOINHAS
Periquitinho
Sto. Antônio
Araçás
Palame
Baixio
Praia Baixio
Praia Subaúma
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Massarandupió
Catu
Miranga
Pojuca
Pirpiri
Vila Camaçari
Imbassaí
Praia Santo Antônio
Mata de São João
Lamarão do Passé
Açu da Torre
Barra do Pojuca
Praia do Forte
Dias D'Ávila
Itacimirim
Guarajuba
CAMAÇARI
Barra Jacuípe
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Jauá
Abrantes
LAURO DE FREITAS
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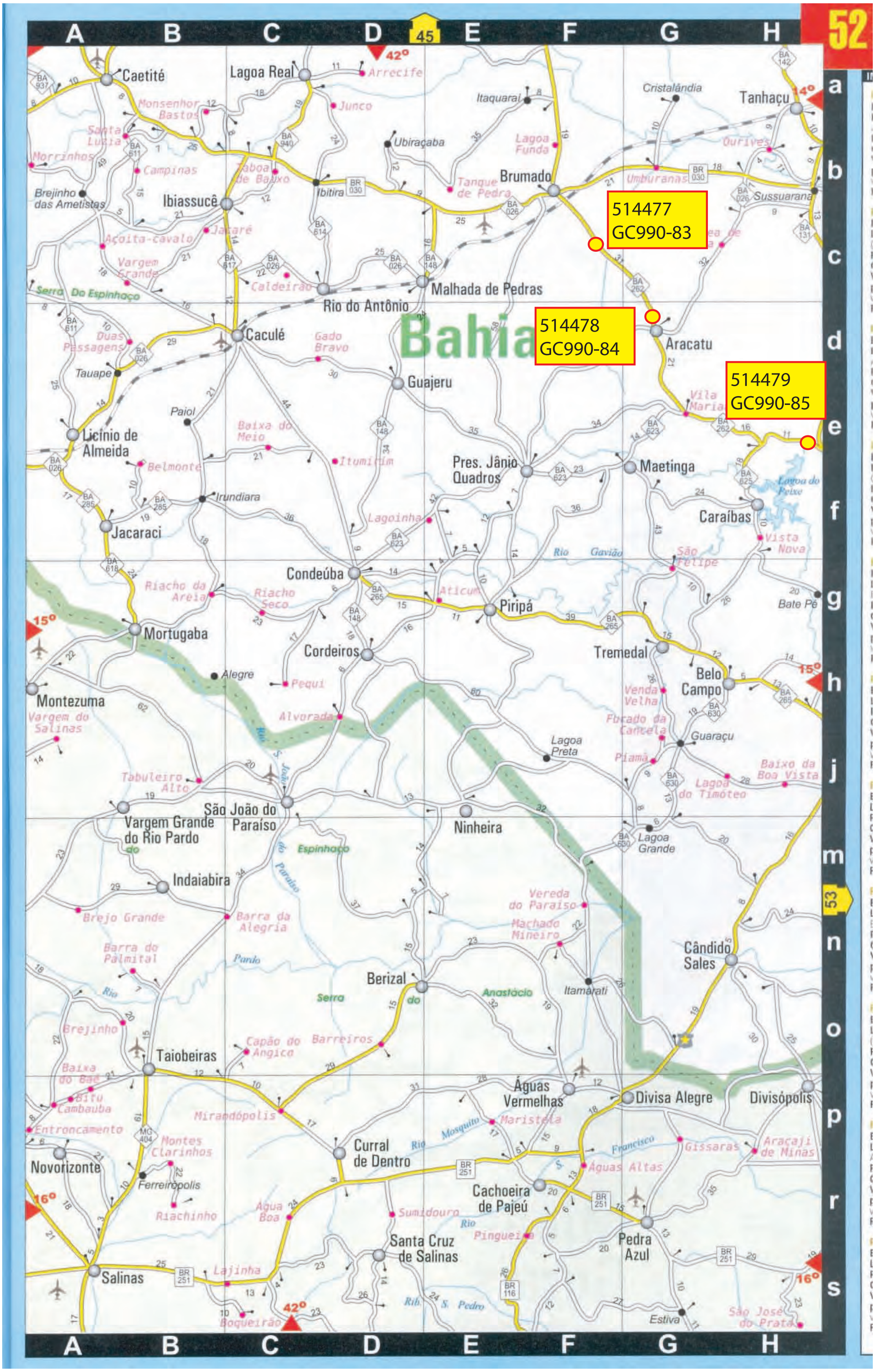
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Tabua de Baixo
Ibitira
Ubiraçaba
Itaquaraí
Lagoa Funda
Tanque de Pedra
Brumado
Cristalândia
Tanhaçu
Ourives
Umburanas
Sussuarana
Jataré
Açoita-cavalo
Vargem Grande
Serra do Espinhaço
Caldeirão
Rio do Antônio
Malhada de Pedras
Aracatu
Caculé
Gado Bravo
Duas Passagens
Tauape
Guajeru
Vila Maria
Paiol
Licínio de Almeida
Baixa do Meio
Belmonte
Itumirim
Pres. Jânio Quadros
Maetinga
Lagoa do Peixe
Caraíbas
Irundiara
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Jacaraci
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Rio Gavião
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Condeúba
Riacho da Areia
Riacho Seco
Aticum
Piripá
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Mortugaba
Cordeiros
Tremedal
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Vargem do Salinas
Venda Velha
Furado da Cancela
Alvorada
Lagoa Preta
Guaraçu
Piamã
Baixo da Boa Vista
Lagoa do Timóteo
Tabuleiro Alto
São João do Paraíso
Vargem Grande do Rio Pardo
Ninheira
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Brejo Grande
Barra da Alegria
Machado Mineiro
Barra do Palmital
Cândido Sales
Berizal
Serra
Anastácio
Itamarati
Brejinho
Capão do Angico
Barreiros
Taiobeiras
Águas Vermelhas
Divisa Alegre
Divisópolis
Baixa do Baé
Bitu Cambaúba
Mirandópolis
Maristela
Entroncamento
Montes Clarinhos
Curral de Dentro
Gissaras
Araçaji de Minas
Novorizonte
Ferreirópolis
Águas Altas
Cachoeira de Pajeú
Riachinho
Água Boa
Sumidouro
Pinguei
Pedra Azul
Santa Cruz de Salinas
Salinas
Lajinha
Boqueirão
Estiva
São José do Prata
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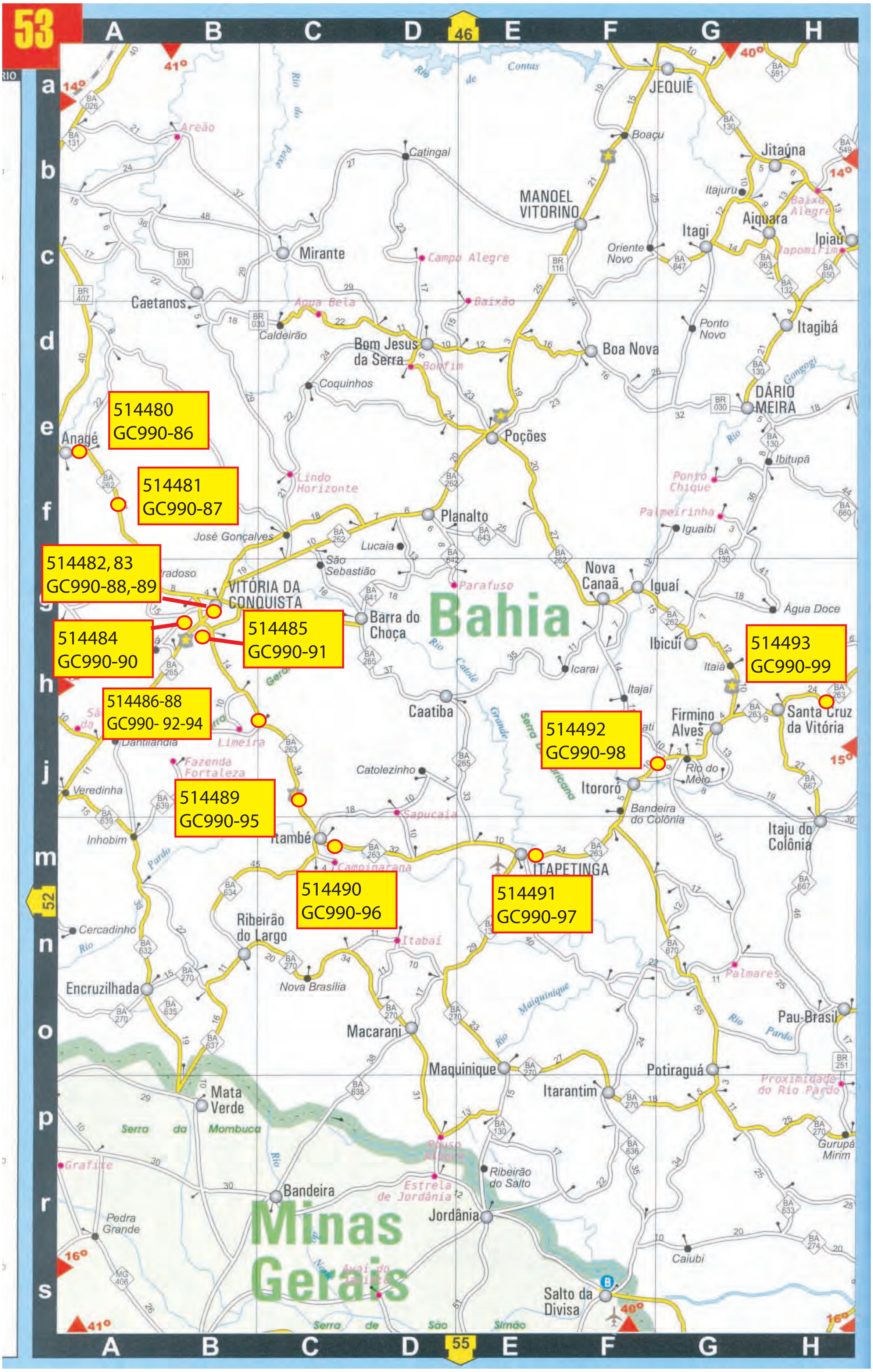
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Poções
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Mirante
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Algodão
Ibirataia
Barra do Rocha
Ibirapitanga
Ubatã
Tapirama
Poço Central
Gonboji
Ubaitaba
Aurelino Leal
Itapitanga
Laje do Banco
Banco Central
Taboquinhas
Igrapiúna
Camamu
Tapuia
Maraú
Ibiaçu
Itacaré
Coaraci
Uruçuca
Almadina
Itajuípe
Bandeira do Almada
São Roque
Rio do Braço
Castelo Novo
Sambaituba
Aritaguá
Mutuns
Barro Preto
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ILHÉUS
Floresta Azul
Ibicaraí
Itapé
Buerarema
São José da Vitória
Olivença
Areia Branca
Palmira
Jussari
Itatingui
Arataca
Anuri
Vila Brasil
Res. Bio. do Una
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Una
Camacã
Santa Luzia
Pimenta
Betânia
Puxim do Sul
Mascote
Jacarandá
Barreiras
Canavieiras
Teixeira do Progresso
Ouriçana
Santa Maria Eterna
Boca do Córrego
Belmonte
Itapebi
Praia Boca da Lagoa
Praia Barra do Serinhaém
Praia Ponta do Mutá
Barra Grande
Campinho
Praia Taipus Fora
Praia Cassange
Praia Algodões
Ponta Grande
Praia Piracanga
Praia da Concha
Praia Siriaco
Praia Havaizinho
Praia Itacarézinho (Camboinha)
Serra Grande
Praia Mamoã
Praia do Norte
Praia do Sul
Ponta Itapuã
Praia Jairi
Praia Ilha de Comandatuba
Praia Puxim
Praia Barra do Albino
Praia da Costa
Praia Atalaia
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