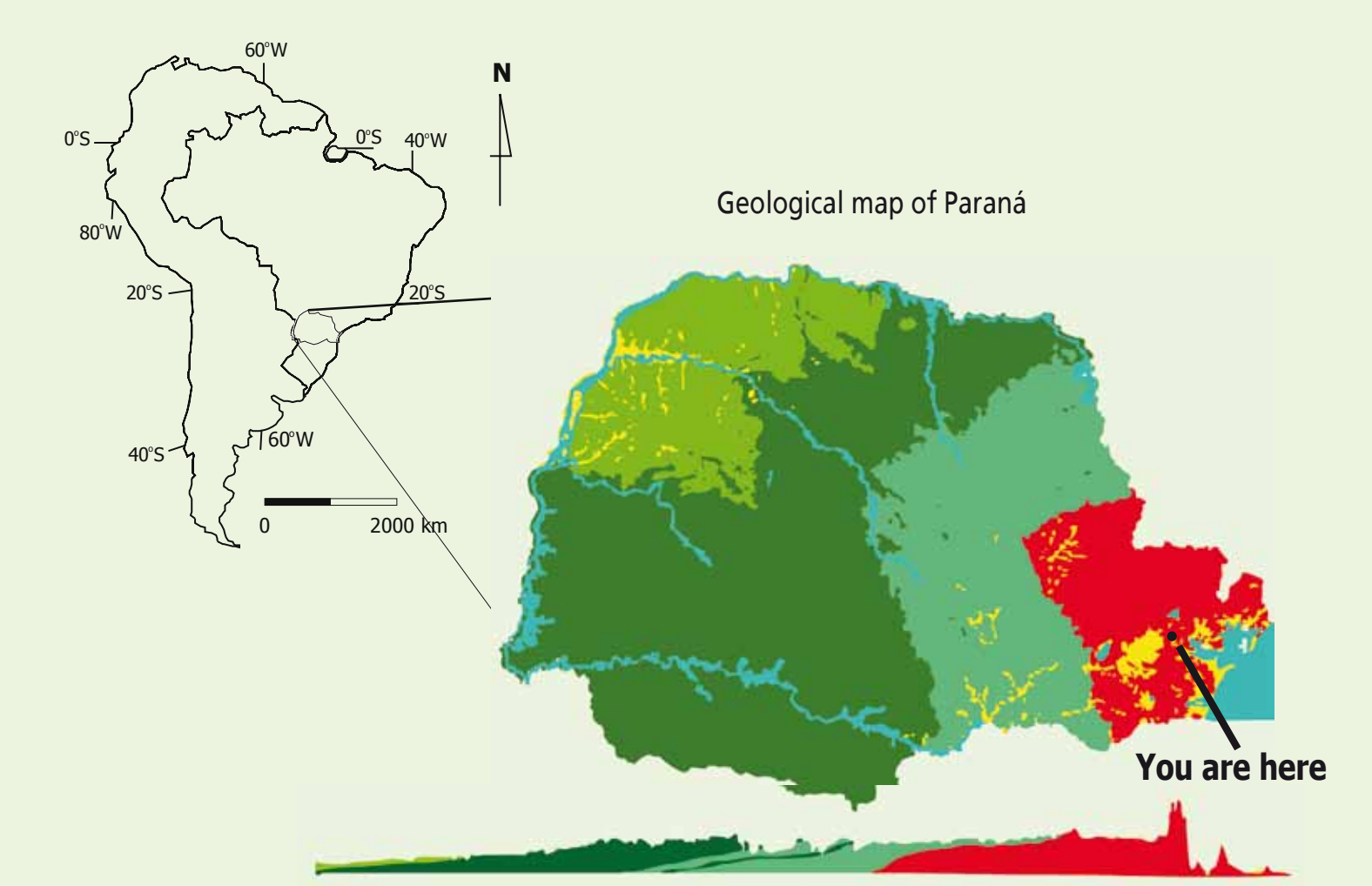


Geology of Paraná



| EON          | ERA       | PERIOD     | EPOCH         | Age<br>million years<br>Today | Features                                    | Geology         |
|--------------|-----------|------------|---------------|-------------------------------|---|-----------------|
| Phanerozoic  | Cenozoic  | Quaternary | Holocene      | 0.01                          | Marked<br>Northern Hemisphere<br>glaciation | Sediments       |
|              |           |            | Pleistocene   | 1.8                           |   |                 |
|              |           |            | Pliocene      | 5.3                           |   | Sediments       |
|              |           |            | Miocene       | 23                            |   |                 |
|              |           |            | Oligocene     | 34                            | Primates p. rolfateate                      |                 |
|              |           | Tertiary   | Eocene        | 55                            |   |                 |
|              |           |            | Paleocene     | 66                            | First horses appear                         |                 |
|              |           |            | Cretaceous    | 145                           | Dinosaurs appear;<br>flowers                |                 |
|              |           | Mesozoic   | Jurassic      | 200                           | First birds and<br>mammals appear           |                 |
|              |           |            | Triassic      | 248                           | First Dinosaurs appear                      |                 |
|              |           |            | Permian       | 252                           | Tribolites disappear                        |                 |
|              | Paleozoic |            | Carboniferous | 354                           | Fossils, common large<br>trees, reptiles    |                 |
|              |           |            | Devonian      | 463                           | Amphibians appear                           |                 |
|              |           |            | Silurian      | 417                           | Terrestrial plants appear                   |                 |
|              |           |            | Ordovician    | 443                           | First fishes                                |                 |
|              |           |            | Cambrian      | 541                           | First shells, trilobites prevail            | Paraná's shield |
| Pre-cambrian |           |            | Proterozoic   | 2500                          | First multicellular organisms               |                 |
|              |           |            | Archean       | 4000                          | First unicellular organisms                 |                 |
|              |           |            | Hadean        | 4560                          | Earth forms                                 |                 |

Serra do Mar arises

Formation of granites bodies

The geological evolution of Paraná is followed when the state is crossed westward. The oldest rocks, formed more than three billion years ago, are found on the coastal plain. There, and all over Serra do Mar and the First Paraná Plateau, igneous and metamorphic rocks of Archean to early Paleozoic age outcrop in the region known as the PARANÁ SHIELD, whose strong relief reflects how resistant to weathering its rocks are.

From the Devonian scarp known as São Luiz do Purunã to the western border of the state, the PARANÁ SHIELD is overlain by the PARANÁ BASIN, a massive sequence of sedimentary and volcanic rocks of Silurian to Cretaceous age that sustains the state's Second and Third plateaus. In the early stages of the basin's evolution, South America and Africa were still unseparated parts of a supercontinent named Gondwana, and their geographic locations were very different from today's.

The PARANÁ BASIN evolved for more than 300 million years, in long transgression-regression cycles of an ancient sea that surrounded Gondwana. These cycles, immensely slow as compared to human lifetime, resulted in different marine, lacustrine, fluvial, and glacial rocks in Paleozoic times.

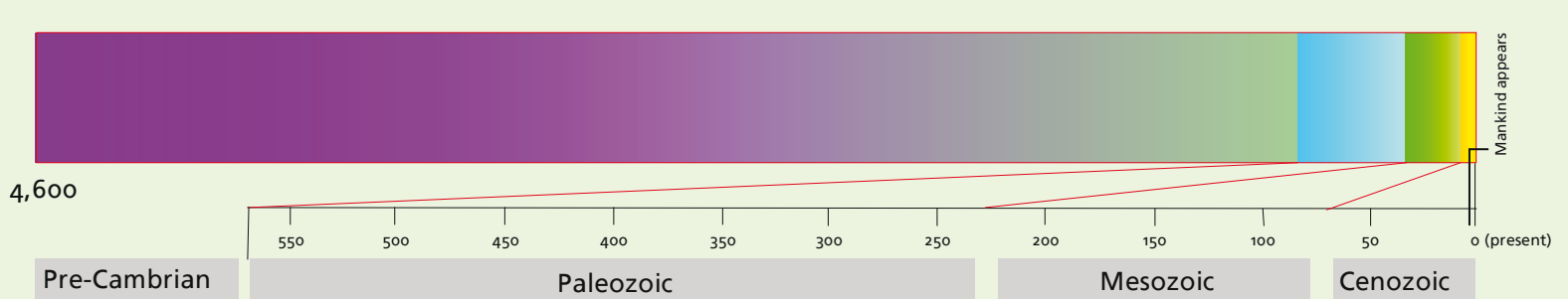
In Jurassic times, a desert named Botucatu, that spread for more than 1,500,000 km2, covered parts of southern Brazil, Paraguay, Uruguay, and Argentina.

The breakup of Gondwana, and the consequent separation of South America and Africa as the South Atlantic Ocean spread, took place in the Cretaceous. As part of the breakup process, extensive, up to 1,500 m of superposed basalt flows covered more than 1,200,000 km2 of the Paleozoic sedimentary rocks of the Paraná Basin. The remarkably fertile soil known as Terra Roxa derives from weathering of such basalt flows. By the end of the Cretaceous, desertic terrains (the Bauru Basin) spread over the basalt flows in northwestern Paraná as recorded by the Caiuá sandstone. Unlike the Terra Roxa, however, soils formed from these rocks are poorly fertile and highly susceptible to erosion.

The youngest geological units in Paraná are sediments of Quaternary age. Most representative examples are those generated under arid to semi-arid conditions over parts of Curitiba and Tijucas do Sul, those formed from weathering of crystalline rocks along the Serra do Mar range, marine sand deposits along the eastern coast, and also countless alluvial deposits along water streams in the state.

Geological time

If the 4.6 billion years of geological history were scaled to one single year, Mankind would have been on Earth since 8:14 p.m. December 31 i.e., within the last 3h ours and 46 minutes. Dinosaurs, that lived for 100 million years, would have lived no more than 8 days and 12 hours. Serra do Mar as it presents itself today would have arisen within the last 5 minutes of the year.o



Serra do Mar

What is Serra do Mar



Overlay LANSAT and SRTM imagery. Rodrigo Stella

Serra do Mar is the geomorphologic entity that takes shape from a more than 1,000 km long, 5 to 10 km wide fault escarpment that separates the Brazilian Highlands and the Atlantic coast. The range extends from Espirito Santo to Santa Catarina with mean altitude differences of 1,000 m, its highest point being the 1,969 m high Pico Paraná.

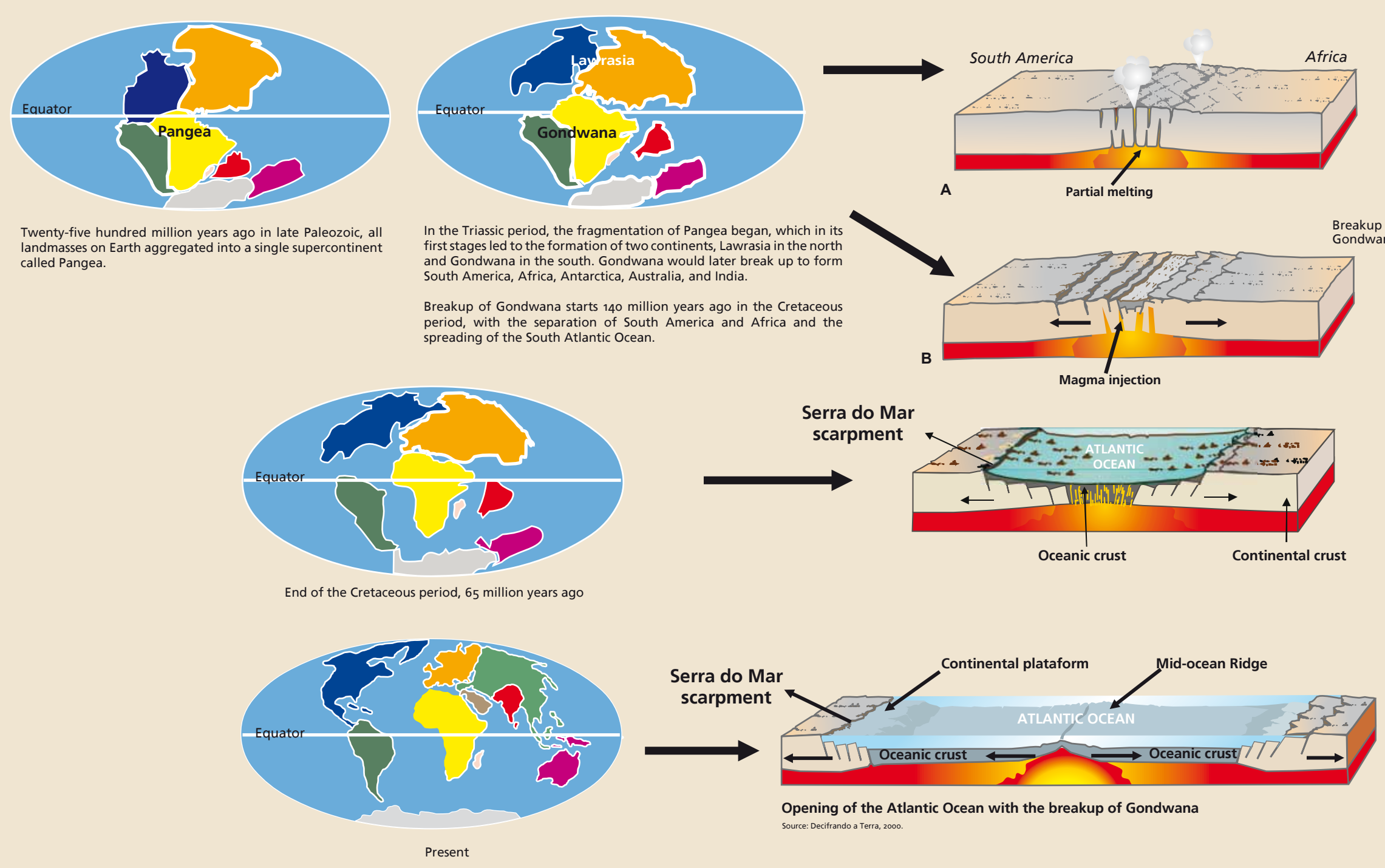


Serra do Mar view from the Marumbi.

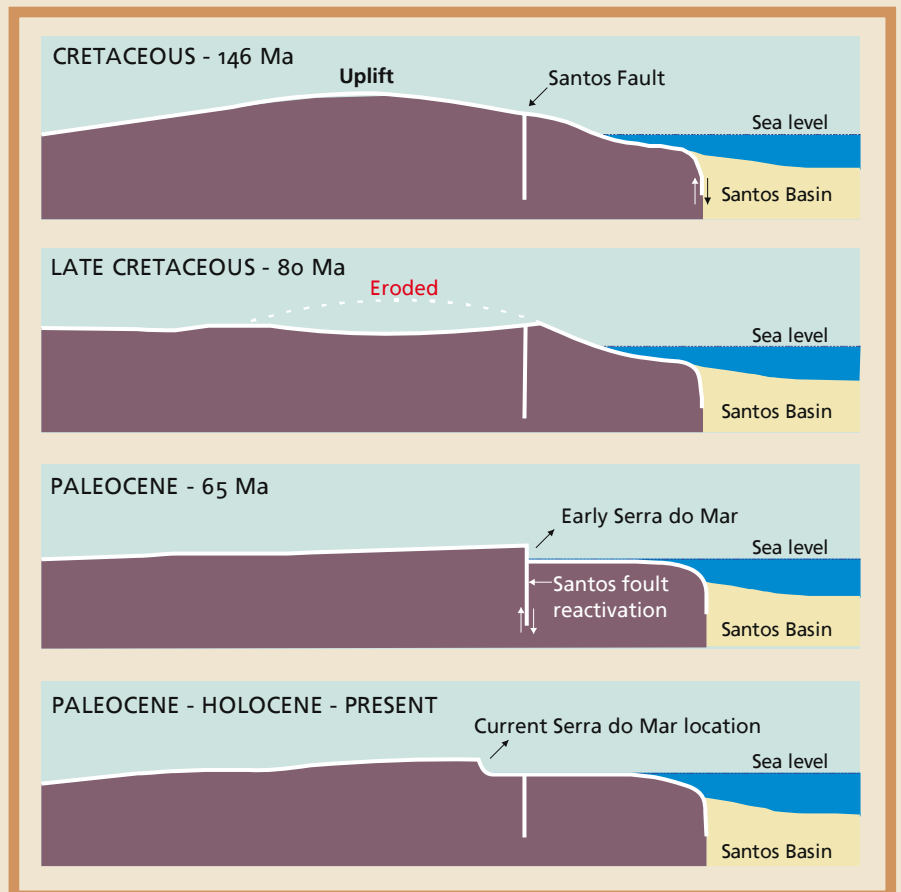
How and when did Serra do Mar arise

The rise of Serra do Mar is associated with the first stages of separation of Africa and South America and the consequent opening of the Atlantic Ocean 150 million years ago.

The continental separation process involved marked uplift of the entire southeastern coast of Brazil, during which large blocks were vertically displaced, some up, some down along geological faults. Serra do Mar corresponds to one of such uplifted areas to the east of the Santos fault. Its rise took place at approximately 65 million years ago, tens of kilometers east of the current coastline position. From then on, erosion has displaced the Serra do Mar scarp westward, the resulting sediments being washed to the sea to form marginal basins (e.g. Campos and Santos basins) from which oil is now exploited.



Evolution stages of Serra do Mar



Breakup of Gondwana triggers continental drift, with the separation of Africa and South America. The eastern margin of South America uplifts (southeastern Brazil).

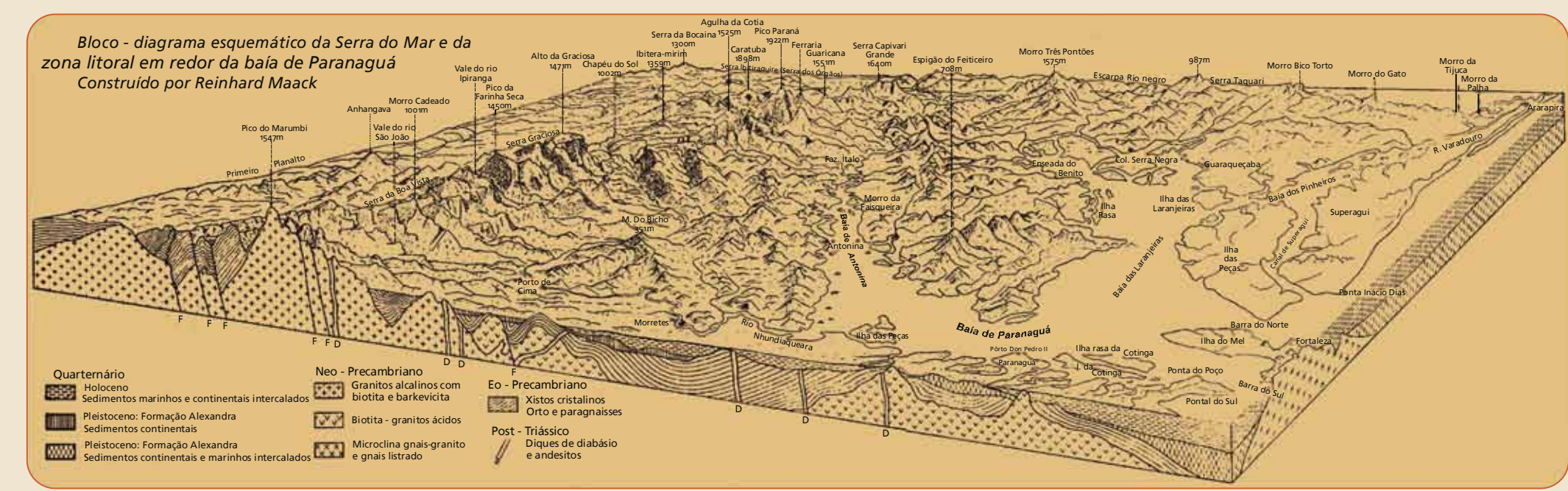
Erosion of the uplifted area to a large plain, rocks being washed away to form sedimentary basins like the petroleum-rich Santos Formation.

Marked tectonic uplift of terrains west of Santos Fault 65 million years ago, related to the continental separation process. The early Serra do Mar arises tens of kilometers east of the current coastline.

From Paleocene on, Serra do Mar scarp erodes to its current location.

Geology and the landscape

Geologically speaking, three groups of landscape elements outstand here: the rocky massives, the hills between the latter and the sea, and the coastal plain. The groups differ in age, each one showing its own, interesting history.

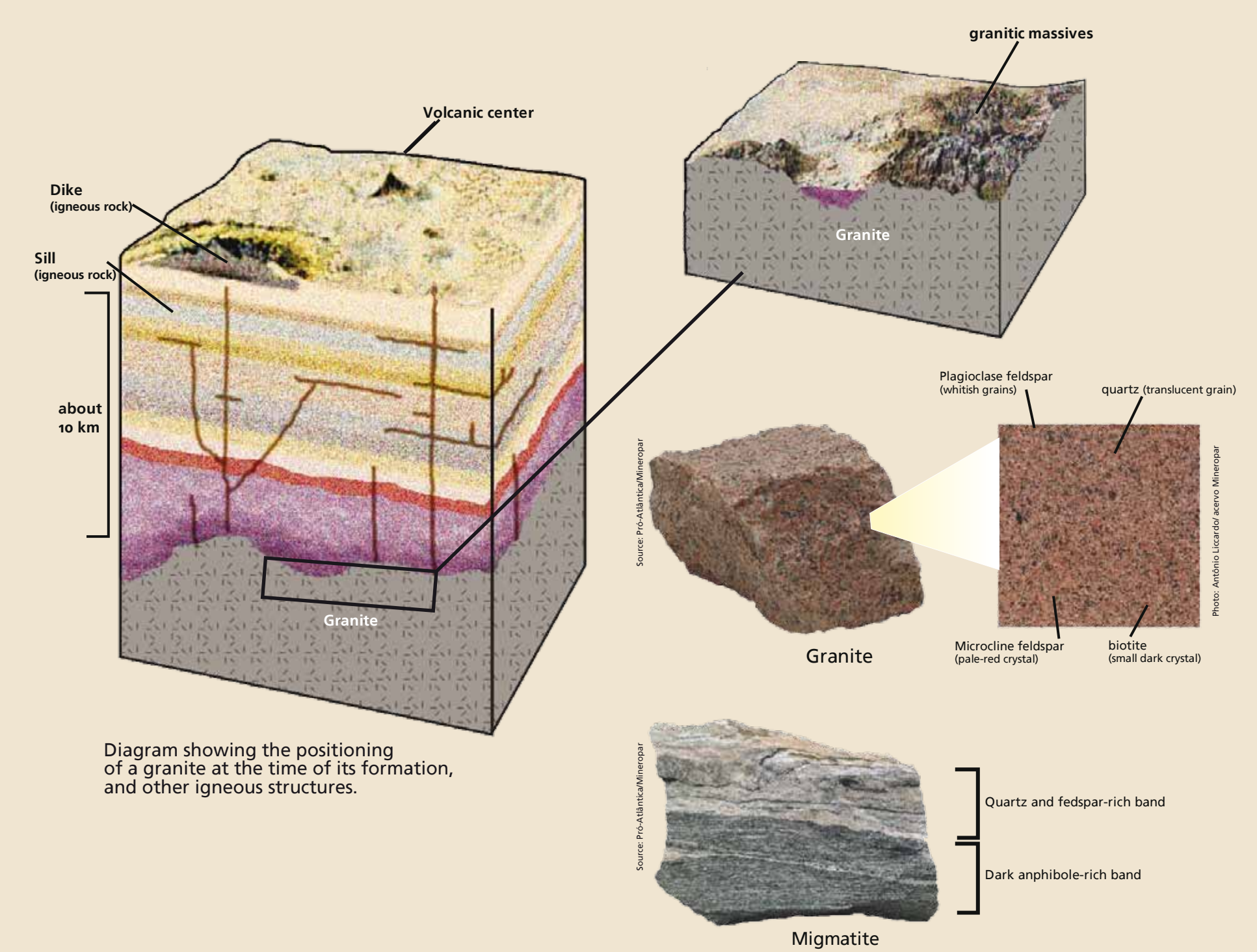


Geologist Reinhard Maack's original diagram (Geografia Física do Estado do Paraná, Curitiba 1968)

What is granite?

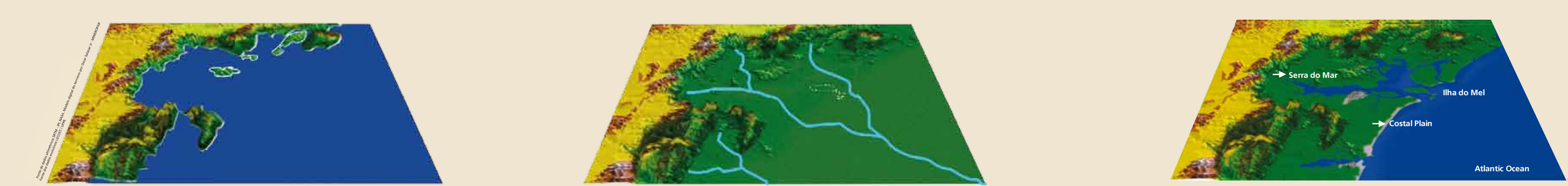
Granite is an igneous kind of rock that forms at depths most often lower than 10 km inside the Earth's crust from solidification of magma (lava-like melted rock). Its very slow solidification due to high temperature and pressure conditions allows mineral crystals to grow large enough to be seen without the aid of a microscope. Quartz and feldspar are always present in granite. Amphibole and biotite are dark mineral specimens often seen in such rocks. A large variety of mineral specimens, such as zircon, titanite, and apatite, among others, are also present, but in smaller quantities.

Gneiss and migmatite, however, are metamorphic types that result when pre-existing rocks are transformed under elevated temperature and pressure conditions. They are crystalline rocks like granite, but they show marked banding and orientation of mineral grains.



The Coastal Plain

Terrains in the coastal plains of Paraná have a maximum altitude of 20 m above the current sea level. They consist of sandy marine sediments younger than 120,000 years that deposited under large sea level variation conditions during glacial (cold) and interglacial (warm) stages over the last 1.8 million years of the Quaternary Period.



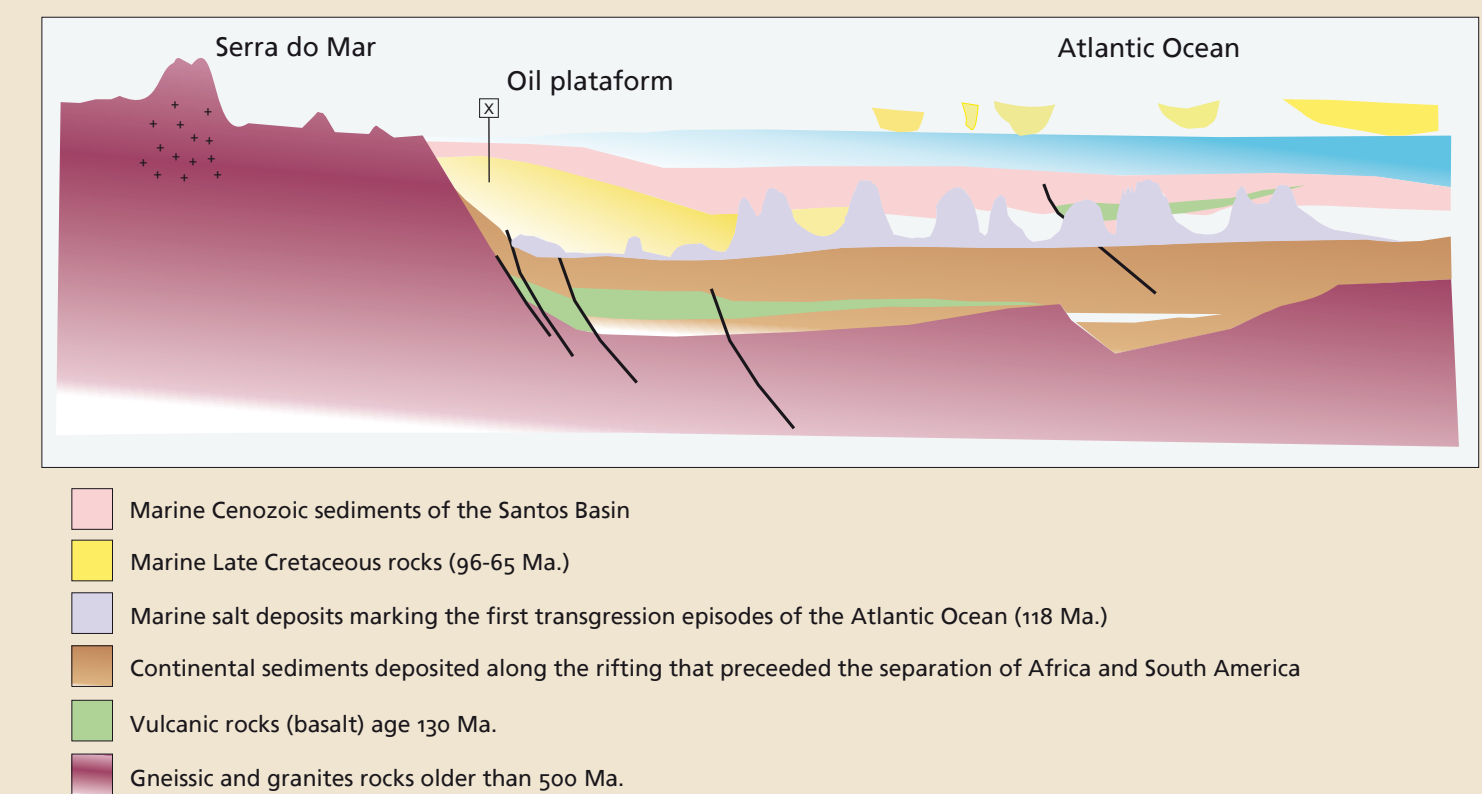
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At the climax of the last glacial period 18,000 years ago, the sea level was approximately 20 m below its current position, and extensive coastal plains cut by water streams were present. The coastline of Paraná was more than 100 km east of the current one. Use your imagination to visualize the transforming landscape. In the geological time, that would take no longer than a blink.

After the climax of the last glacial period 5,600 years ago, glaciers started to melt and the sea level rose rapidly to 3 m above its current position. The coastline was 2 to 5 km west of where it is now. Paranaçu and Guaratuba bays were much larger then, and the number and conformation of islands was quite different from today's. After 5,600 years, the sea level dropped to its current position, which led the younger parts of the coastal plains of Paraná to take shape..

Serra do Mar and our oil reserves

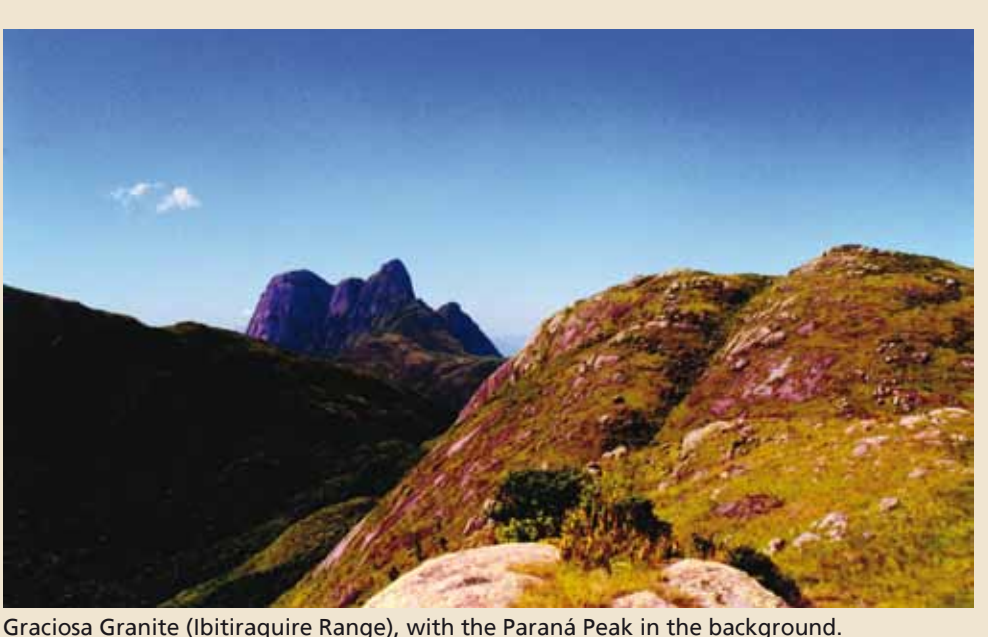
Oil production in Brazil is more intense over continental margin basins (Campos and Santos ones). The development of these sedimentary basins followed the separation of Africa and South America, when higher erosion rates due to the uplift of Serra do Mar allowed an increased amount of sediments to deposit. Such rocks now host our main oil reservoirs. Approximately three kilometers of sediments are estimated to have eroded from the continental border over the last 80 million years.



Realization:

Partners:

Idetalization



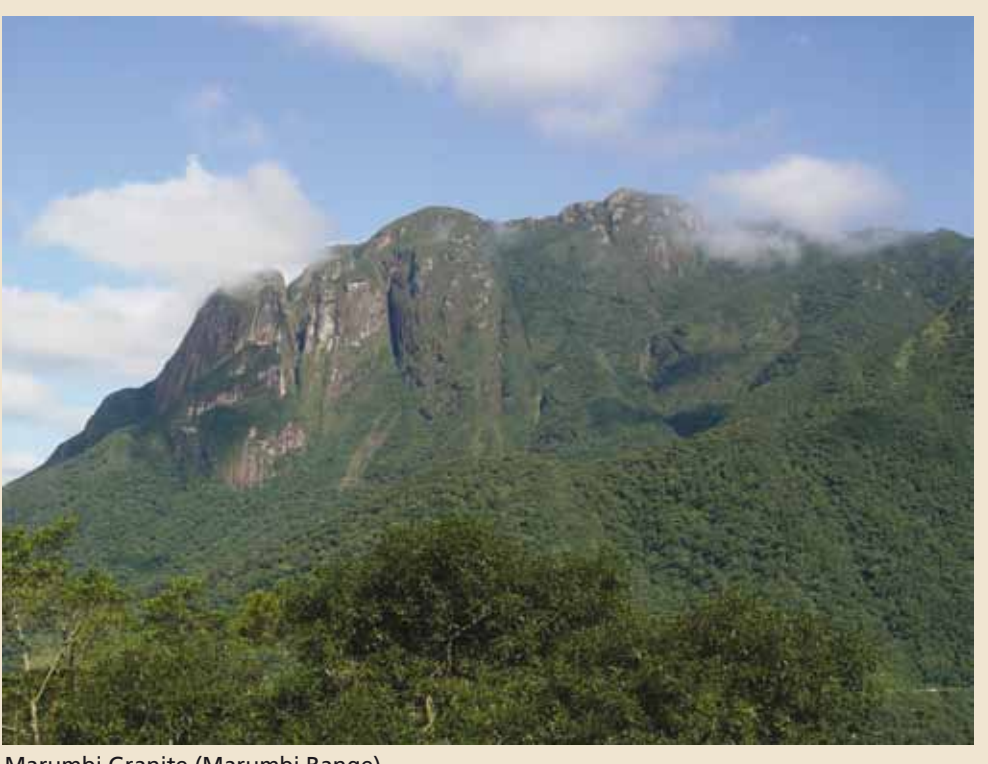
Graciosa Granite (Ibitiraque Range), with the Paraná Peak in the background



Graciosa Granite (Ibitiraque Range).



Graciosa Granite (Ibitiraque Range) featuring Cricica Peak.



Marumbi Granite (Marumbi Range)