Brazilian Experience in the Development of Non Living Resources of the South and Equatorial Atlantic Ocean

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RESUMO

São discutidos aspectos relativos aos recursos minerais presentes no Mar Territorial, Zona Econômica Exclusiva e Plataforma Continental Brasileira. Um mapa indicando as áreas de interesse para mineração é incluído e os recursos minerais são categorizados segundo a urgência, importância, valor e prioridade. Ao final deste são sugeridas várias atividades a serem desenvolvidas no período de 2009 a 2028.

ABSTRACT

Aspects related with the Brazilian Territorial Sea, Exclusive Economic Zone and Continental Shelf resources are discussed. A map showing areas of relevant mining interest is included and a mineral resources ranking according urgency, importance, economic value and priority is also indicated. Several activities to carry out progressively from 2009 to 2028 are suggested.

Key-Words: Exclusive Economic Zone, Continental Shelf, Territorial Sea, Non-Living Resources.
INTRODUCTION

The Brazilian Territorial Sea, Exclusive Economic Zone and Continental Shelf together have a surface of approximately 4.5 million square kilometers (Fig. 1).
Activities related to the development of mineral resources in these regions and adjacent oceanic areas are guided by the National Policy for the Resources of the Sea and Sectorial Plan for the Resources of the Sea. These legal instruments aim to promote the sustainable use of living and non-living marine resources with regard to the economic and social development of the country.

Figure 1: Brazilian maritime areas, from CPRM (2008).
It is up to the Inter-Ministry Commission for the Resources of the Sea to coordinate the activities and propose to the President of Brazil priorities for the programs, projects and activities related to these legal instruments. The implementation of projects and activities occurs in a decentralized manner through several ministries, research institutions, the scientific community and public companies, in accordance with their respective skills.

Among the various programs of the Inter-Ministry Commission for the Resources of the Sea is the Program for the Assessment of Mineral Resources of the Brazilian Continental Shelf (REPLAC). The National Plan of Work of REPLAC was designed for a four-year period (2007 to 2010) with the aim to research and increase knowledge of the seabed and subsoil, as well as to collect the necessary information to allow integrated management of this area. This plan was developed with the participation of various segments of government agencies, research institutions and public enterprises.

THE RESOURCES BASE

Marine scientific research and other activities from the National Plan of Work of REPLAC are carried out individually by or in partnership between the Geological Survey of Brazil, national research institutions from several Brazilian universities and the Directorate of Hydrography and Navigation from the Brazilian Navy.

Among the various research projects undertaken by Brazil in the last three years are: geology of the Brazilian continental shelf and adjacent ocean areas, organized in geological information system; digital bathymetric charts of the inner continental shelf at 1:100,000 scale; systematic research for sands, gravels and carbonates; other projects for placers, phosphorites and coal.

The project “Geology of the Brazilian Continental Shelf and Adjacent Ocean Areas” carried out by the Geological Survey of Brazil, represents the state-of-the-art in geological knowledge of this area integrated with and correlated to a wide variety of geological information, tectonics and mineral resources in a single geo-referred environment. The collection of data and research institutions and governmental agencies in different levels of knowledge and formats, which were submitted to procedures to generalize and conduct digital filtering and merges with adjustments in the representation of 1:2,500,000 scale. This product has been used as a basis for Project planning on larger scales (CPRM, 2008).

MINERAL RESOURCES

Sand and Gravel (Aggregates)

As is shown on the map Figure 2 considerable quantities of commercial-grade sand and gravel have been found in the inner Brazilian continental shelf. From Torres (north state limit of Rio Grande do Sul) to Chuí (south state limit of Rio Grande do Sul) the concentration of quartzose sand, similar to the material currently present along the modern beach, was estimated and totalized an amount of $9.6 \times 10^9$ m$^3$ (Martins & Toldo, 2006). These resources will be used mainly for civil construction industry and as a source for reconstruction of eroded areas along Brazilian coast (beach nourishment).

Studies developed in Santa Catarina along southern Brazil outer continental shelf reveal also an amount of sand along two areas of the inner continental shelf that was calculated in 5.2 billions of cubic meters (Laguna to Mampituba) and 7.2 billions of cubic meters (São Francisco to Itajaí), (Martins et al., 2005).

Taken into consideration that mining marine deposits of sand and gravels are usually developed near the line coast Brazil intend to develop mining activity carefully and in a restricted fashion in order to minimize harmful results to coastal ecosystem once that it can create a plume of sediments and can disrupt fauna and flora.

In addition, although the high socio-economic interest of this commodity, it has not yet been exhibited at large scale on the Brazilian Continental Shelf.
Bioclastics Aggregates

Calcarenous shells, lithotamium and other bioclastic mineral resources were also located and evaluated for calcium carbonate. The main use for them is agriculture, water filters, cosmetics industry, dietary supplements, bone implants, animal nutrition and water treatment in lakes.

The occurrence is mainly concentrated along the continental shelf between Para river and Cabo Frio, as one of the most extensive area of...
bioclastic carbonate. The carbonate sediments that occur in the inner and middle shelf are represented by sand and gravels formed by solid and branched coralline algae, concretions, molluscs, bryozoans and benthonic foraminifera.

The estimated amount in a reserve in the continental shelf of Pernambuco is 1.96 x 10 ton, considering the bathymetry between 20 and 30 m, admitting the average thickness is of 1.5 m (Montalverne & Coutinho, 1992).

It is believed that the content of the sediments in the continental margins of the northwest and west of Brazil until the latitude of Cabo Frio are rich in carbonates with percentages higher than 75% of CaCO₃ corresponding to 50 times more than the continental reserve (Martins & Santana, 1999).

Indeed, scientific researches realized in the South of Brazil, in Rio Grande do Sul state, demonstrate that a special emphasis should be given to the areas of Albandão and Carpinteiro, owing the fact that its economical potential is of 1 billion ton (Calliari et al., 1999).

Mining activities of bioclastics aggregates occur mainly in the coastal areas of Maranhão and Espírito Santo states.

**Placer deposits**

Placer concentration of heavy minerals and ore particles are being studied in different locations of inner continental shelf of Brazil for metals like rutile, ilmenite, magnetite, zirconium, monazite and apatite, and other important resources such as diamonds and gold.

The Cumuruxatiba (Bahia, Brazil) deposit involves 171,000 ton of ilmenite, 4,000 ton of monazite and 365,000 ton of zircon and rutile.

In the coastal zone of Rio Grande do Sul, Brazil, were found in the Bujuru region deposits of heavy minerals contend approximately 40,000,000 ton. Part of this accumulation are related to the modern coast line and represents usually prolonged deposits parallel and sub parallel to the beach, with 30 to 100 m width and 18 km length. Other deposits are related to Holocene dunes fields, recovering Pleistocene lands.

Heavy minerals are present along the Brazilian coast, from Piauí to Rio Grande do Sul. Mining activities occurs at Paraiba, Bahia, Espírito Santo and Rio Janeiro (ilmenite, rutile, monazite and zirconium), where emphasis is given to the high concentrations deposit of Cumuruxatiba (Bahia, Brazil) and Itabapoana (Rio de Janeiro, Brazil).

**Phosphorite**

The term phosphorite is generally applied to sedimentary deposits compounded mostly by phosphate minerals. The favorable environment to the creation of phosphorite is where the coastal upwelling supports high biological productivity in the surface waters. Accidentally this organic material is buried in sediment and the unoxidized organic detritus transformed into phosphoric nodules. The nodules diameter generally vary between 0.1 mm and centimeters, reaching centimeters layers per thousand years of nodules of phosphorite intercalated with variable quantities of detritus sedimentary material.

Widely used for fertilizers and as a source of phosphorous in the chemical industry, phosphorite has also been found and studied on the outer continental shelf and upper slope along the Brazilian continental margin.

Scientific research carried out in Brazil indicates the occurrence of phosphatic rocks on Ceara’s guyot with contents maximum of 18.4% of P₂O₅ (Santana, 1979). Later, another research described preliminarily the occurrence of phosphate nodules in the continental shelf of Rio Grande do Sul (Klein et al., 1992).

Deposits of phosphorite have been prospected in Brazil. However, they have not yet been mined.

**Evaporites**

Evaporites in the Brazilian continental margin are of Aptiana age and are formed by anhydrite, gibbsite, halite, potassium and manganese salts. Evaporites are found from the basin of Alagoas to São Paulo Plateau. The biggest width of the salt basins occurs in Santos coast, extending 650 km from the São Paulo Plateau.

The salt can be associated to structures as dome or as cushion, respectively occurring on the north and south portions of the evaporitic basin. In Sergipe and Alagoas Basins (Brazil) potassium and magnesium salts were identified, presenting 15 to 50 m thickness and located at 3,000 m deep. The same research presented the
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Salt domes occurrence with high content of halite detected in the Barra Nova dome (Espírito Santo, Brazil). The identified domes northbound Abrolhos and Mucuri (Bahia, Brazil), together with the ones from Barra Nova, can be economical interesting, as these deposits are found in relatively shallow waters and they are not distant from the coast.

Barra Nova (Espírito Santo, Brazil) presents seven domes, placed in 30-50 km of the coast line and at depths of 30-55 m. One of them is in a situation of almost outcropping and the others are sited at 106 to 900 m.

Mucuri shows two domes with the top of salt sited at 800 m. All of them located from 20 to 25 km from the coast line and covered by water layer of 20/25 m.

Brazil has been developing scientific researches aiming to define the areas with potential interest for mining evaporites, even so the explotation of this mineral resource has not yet started.

**Sulphur**

All basins with hydrocarbon tend to contain sulphur. Sulphur may occur in stratified layers or be present in ‘caging’ rocks of salt domes. Consequently, is probable the occurrence of sulphur deposits very expressive in the Brazilian continental shelf due to the presence of the extensive evaporitic basins.

The origin of sulphur is related to the reduction of the anhydrite sulfate to sulfide gas by action of bacteria in the presence of hydrocarbon and subsequent oxidation of the gas which liberates sulphur in the elementary form.

In Brazil the sulphur deposits are found in the north of Abrolhos. Three domes are situated from 60 to 70 km from the coast, with the top of the salt located on 300 m, in a depth of 20-30 m.

In addition, in the mouth of the Doce River, domes are found from a distance from 30 to 50 m from the coast, covered by a water column of 30 to 70 m. Named Yemanjá, Janaina, Yara, Inaê, Mucuná, North Doce River and South Doce River, the five formers present a salt top of 270, 300, 750 and 800 m respectively. The North Doce River possesses a water column of 15 m, while the South Doce River was not determinate.

Despite this discoveries Brazil has not yet exploited sulphur.

**Polymetallic Nodules**

Polymetallic nodules are porous, concretionary objects of various sizes and shapes, found in thin discontinuous superficial layers on the floor of the ocean, occurring at depths of 5,000 m. An average nodule is slightly ellipsoidal with a diameter of 2.5 to 10 cm. Internally nodules are formed by concentric layers, which indicate different phases of development. Polymetallic nodules are also found in all oceans.

The existence on the deep ocean floor of potentially valuable polymetallic nodules has been known for over a century. Scientists investigating these nodules found they contained valuable metals such as nickel, manganese, copper and cobalt. Initially, because the nodules were located in the very deep water, in excess of 5,000 m, commercial mining was not considered viable. By the late 1960s, with advanced technology, it appeared that harvesting of the nodules would soon become a commercial reality.

In Brazil, dredges made in the Pernambuco Plateau at 1,750 and 2,000 m depth recovering 150 kg of material indicates that it is predominantly constituted by polimetallic nodules, of high sphericity, dense metallic covertures and with diameters from 2 to 12 cm. Around 90% of the recovered nodules presented a core of phosphatic rocks with concentric layers of 0.5-0.7 cm of thickness. The composition of the concentric layers was variable with 28% of P₂O₅ in the core, and 20-30% of manganese, 30% of iron, 0.6 to 1.5 of cobalt, 0.04 to 0.23 of copper, 0.08 to 0.53 of lead and 0.12% of metallic zinc (Santana, 1999).

A recent research indicates also promising areas offshore in the South Atlantic as the nodules of adjacent oceanic basin to Trindade island (Souza et al., 2006).

**Cobalt-rich oceanic crusts**

The use, particularly of the cobalt, the manganese, and nickel, is to confer to the iron specific proprieties as: hardness, resistance and prevention against corrosion.

The commercial explotation of cobalt-rich oceanic crusts in Brazil does not exist yet and the information about it occurrence still are
insufficient. Nonetheless, planned projects aim to fill this lack of information.

Coal

Coal has been drilled along the southern Brazilian margin. Near to the beach of Santa Terezinha, situated between Torres and Tramandai (Rio Grande do Sul), the CPRM drilled, identifying, at 700-800 m depth, coal layers with thickness varying from 0.35 to 2.65 m.

This deposit reveals, in scientific researches realized until the moment, characteristics that demonstrate the elevated economic potential. Despite being located in relatively high depths, the significant thickness of the layers will permit mining high volumes of ore in reduced areas. A Project has been designed to locate the extent of the coal under the continental shelf and evaluate its mineral potential for metallurgic use (Martins & Souza, 2008).

Gas Hydrates

Usually related to the slope and to the continental rise the hydrates of methane are unusual hydrocarbon deposits consisted of solid, frozen water molecules that form small cagelike structures in the sediment, each ‘cage’ trapping a single molecule of the natural gas methane – CH₄. Of biogenic origin, methane hydrates constitute the biggest reservoir of carbon in the global environment.

The quantity of methane in marine clathrates is enormous; equivalent in energy value to about twice conventional hydrocarbon resources worldwide (Clennel, 2000).

Until the moment, the studies in Brazil of the occurrence of gas hydrates are in small numbers. The occurrence of gas hydrates on the Brazilian southern and equatorial margins was reported in two large regions: the Rio Grande deep sea fan, and the Amazon deep sea fan, respectively on the southern and equatorial Brazilian continental margins.

On the Amazon Deep Sea Fan, located within longitudes 47° and 51° W and latitudes 2° to 5° N, gas hydrates were previously reported in an area of 28,000 km², in water depths of 600 to 2,800 m, presenting a thickness of 450 m.

Gas hydrates on the Amazonas Basin Mouth occur in water depths ranging from 900 to 2,500 m on the upper 400 m of sediments below the seafloor. The hydrates stability zone for these depths is associated with water temperatures ranging from 10° to 20°C for the average local geothermal gradients (Tanaka et al., 2003).

In the last years a significant quantity of financial resources was addressed to scientific researches and in the development of new technologies for mining gas hydrates in Brazil once that, in addition to the traditional sources of oil and gas, the discovery of huge deposits of gas hydrates in the Brazilian continental shelf hold the promise of new potentially enormous sources of energy.

Oil

The acquired Brazilian experience in the oil field along the years is noteworthy. Oil and gas production in Brazil has grown and the additions to reserves have far outstripped the production rate, and yet in December of 2007 were set a new daily production record: 2 million and 238 barrels (Petrobras, 2007).

The principal highlight of 2007, in Brazil, was the discovery of huge reserves in ultra-deep waters of the Tupi area. The area is located 320 km off the coast of state of Rio de Janeiro, within the Santos Basin, and the find is under a layer of salt that is 2 km in thickness. Evaluation of the oil-bearing potential of the pre-salt geological strata of basins indicates volumes of oil that will significantly raise the country’s reserves. Tupi, the first area to be assessed, has recoverable volumes estimated to be between 5 and 8 billion barrels, which would make it the largest oil field in the world to be discovered since the year 2000.

A numerous technological challenges had to be overcome in order to reach the pre-salt reservoirs. The salt layer is about 2,000 m thick and the wells penetrate over 7,000 m below sea level, in ultra-deep waters. In the area of exploration, one of the greatest advances was a new version of the Basin Simulator, which provides even more precise information about geological strata, including data on the rock below the salt layer, interpretation of which is hindered by distortions caused by the salt. Computer simulations were used to determine the technology and materials necessary for
establishing wells passing through a layer of salt. For cement lining the wells, a new process has been developed that is adapted to the characteristics of salt dealing with the greater corrosiveness and instability of the salt.

Posterior to the computer simulations, ground-breaking lab methods, using nuclear magnetic resonance, helped to determine the scale for systems of water injection drainage and high pressure microscopy, in order to guarantee the flow of the future production system.

The operational start-up of the high performance Underwater Centrifugal Pumping System, at the Campos Basin’s Jubarte field, was another important achievement. Production from the well in which the system was installed jumped from 10,000 to 24,000 bpd, an increase of 140%. This technology is applicable both to large-scale deposits, where it raises the recovery coefficient, and to smaller reservoirs, previously considered not to be commercially viable. It also facilitates production in deep water fields, especially those containing heavy oil.

The potential of the pre-salt layer was confirmed in January 2008, with the identification of a large deposit of natural gas and condensate in the Santos Basin.

**Other projects**

Among the projects planned for 2009 is the scientific research of hydrothermal vents located in the Brazilian economic exclusive zone and of the cobalt-rich crusts from the international areas adjacent to the Brazilian continental shelf. These areas of research include the study of the geological settings of the areas where these mineral resources occur.

Another project planned for 2009 is the organization of the geology of the South and Equatorial Atlantic Ocean in geographical information system. This project is in continuity with the one carried out by the Geological Survey of Brazil on the geology of the Brazilian Continental Shelf and Adjacent Ocean Areas. The aim of this project is to represent the state-of-the-art in the geological knowledge of the South and Equatorial Atlantic Ocean integrated with and correlated to a wide variety of geological information, tectonics and mineral resources in a single geo-referred environment.

Among the projects planned for 2010 are the economic, technical and environmental feasibility studies of the sites where mineral resources have great potential for mining.

Marine scientific research in Brazil has the support of oceanographic vessels from the Directorate of Hydrography and Navigation (Brazilian Navy). Vessels from Universities and the Brazilian Institute for Environment and Renewable Natural Resources are also used. A total of 208 days at sea is planned for the year 2009. As part of the projects, modern scientific research equipment has been acquired. Training for staff from the Geological Survey of Brazil and scientist from the universities has started.

**FINAL REMARKS**

The recent report on marine minerals issued by the Centre for Strategic Affairs of the Presidency (NAE) and the Brazilian Centre for Management of Strategic Studies (CGEE) makes several recommendations for the development of marine mineral resources of the Brazilian continental shelf and adjacent oceanic areas (CGGE, 2007). The reports urge several activities to be carried out progressively from 2008 to 2020, including:

- Strengthen Brazilian marine research networks;
- Create a national administration centre for scientific vessels and equipment;
- Organize geological data and information;
- Identify geological and geomorphological seabed features in the areas of economic, social and environmental relevant interest;
- Carry out feasibility studies for marine planning and management;
- Strengthen national research institutions, including capacity building;
- Prospect and exploit sand, gravel, carbonates and phosphorites from the continental shelf;
- Identify new marine mineral resources;
- Recover eroded coastline based on assessments of sand and gravel resources from the continental shelf;
- Update the legal framework, taking into account each marine mineral resource;
- Prospect and explore mineral resources in the international seabed area;
- Promote international and regional cooperation;
- Develop new and sustainable technologies.
The report also developed a ranking of the non-living resources in two categories: a) resources of socio-economic importance and b) resources of political and strategic priority as show in the tables 1 and 2.

Table 1. Mineral Resources of the Continental Shelf.

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>MINERAL RESOURCE</th>
<th>URGENCY</th>
<th>IMPORTANCE</th>
<th>VALUE</th>
<th>PRIORITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beach Nourishment</td>
<td>Sand and Gravel</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>1</td>
</tr>
<tr>
<td>Construction Industry</td>
<td>Sand and Gravel</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>1</td>
</tr>
<tr>
<td>Fertilizers and general industry</td>
<td>Bioclastic Aggregates (carbonates)</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>1</td>
</tr>
<tr>
<td>Fertilizers and chemical industry</td>
<td>Phosphate</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>1</td>
</tr>
<tr>
<td>Various (placers)</td>
<td>Heavy Minerals</td>
<td>medium</td>
<td>high</td>
<td>high</td>
<td>2</td>
</tr>
<tr>
<td>Energy</td>
<td>Coal</td>
<td>medium</td>
<td>high</td>
<td>high</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Gas Hydrates</td>
<td>low</td>
<td>high</td>
<td>high</td>
<td>2</td>
</tr>
<tr>
<td>Fertilizers and chemistry</td>
<td>Sulphur</td>
<td>medium</td>
<td>high</td>
<td>high</td>
<td>3</td>
</tr>
<tr>
<td>Food and Chemistry</td>
<td>Salt</td>
<td>low</td>
<td>medium</td>
<td>high</td>
<td>4</td>
</tr>
<tr>
<td>Potassium salts</td>
<td>Evaporites</td>
<td>low</td>
<td>medium</td>
<td>high</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: Souza et al. (2007).

Table 2. Mineral Resources of the International Seabed Area in the South Atlantic Ocean.

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>MINERAL RESOURCE</th>
<th>URGENCY</th>
<th>IMPORTANCE</th>
<th>VALUE</th>
<th>PRIORITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>Cobaltiferous Crusts</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>1</td>
</tr>
<tr>
<td>Industry (biotechnology)</td>
<td>Polymetallic Sulfides</td>
<td>medium</td>
<td>high</td>
<td>high</td>
<td>2</td>
</tr>
<tr>
<td>Industry</td>
<td>Polymetallic Nodules</td>
<td>low</td>
<td>high</td>
<td>medium</td>
<td>3</td>
</tr>
</tbody>
</table>

Source: Souza et al. (2007).

The interest of Brazil is to know the real mineral potential of its continental shelf and the adjacent international area. However, due to the high cost of deep sea activities, the report recommends that Brazil develop a convenient international and regional cooperative structure to carry out this type of work.

In recent decades Brazil has been the leader of several regional initiatives to study the South West Atlantic, such as the regional component (Brazil, Uruguay and Argentina) of the Programme on Ocean Science in relation to Non living Resources – OSNLR, a global study shared by the Intergovernmental Oceanographic Commission – IOC (UNESCO) and the Division of Ocean Affairs and Law of the Sea – DOALOS (UN).

The published results of the Programme show that Brazil, in cooperation with international organization and other States (Martins & Santana, 1999), fulfill all the necessary conditions to conduct deep-water research with regard to the exploration of marine minerals.

REFERENCES


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