MICROFACIES AND SEDIMENTARY ENVIRONMENT OF AN UPPER CRETACEOUS MINI-BASIN NEAR MACAU, RIO GRANDE DO NORTE, BRASIL

ERNESTO N. MOERI

KLOECKNER IND. COM. LTDA. DEPARTAMENTO GEOLOGIA E MINERAÇÃO
RUA MIGUEL CALMON, 38 — 40000 SALVADOR (BAHIA)

ABSTRACT

Within the framework of the soda-ash project of Alcalis do Rio Grande do Norte S/A - ALCANORTE for which a high quality limestone is required as one of the main raw materials, a small area of flatlying Cretaceous carbonatic rocks to the uppermost Jandaira Formation of the coastal Potiguar Basin, has been investigated in detail by means of a close spaced drilling-grid. The study of some 2500 meters of drill cores revealed a number of specific rock types. Their microfacies was refer-

red to distinct but interrelated environments of deposition, representing a regressive phase of a restricted carbonate tidal-flat with terrigenous influence and no permanent connection to the open marine sea. Post-depositional rock alteration caused selective silicification and dolomitization of the limestones, preferably along inhomogenities such as argillaceous partings or fossil debris.

A black carbonaceous ostracod-bearing shale horizon was used as a

local keyhorizon for the correlation of all sections.

Fossil content of the limestones consists mainly of gastropods, ostracods, echinoids, lamellibranchiata, bryozoans and benthonic larger foraminifera of very limited chronostratigraphic value. However, the presence of some extremely small planctonic foraminifera (*Hedbergella* sp., *Rotalipora* sp.) together with the complete lack of "orbitoids" favours an early upper Cretaceous age of the Jandaira Formation.

RESUMO

Dentro os trabalhos necessários a realização do Projeto da Alcalis do Rio Grande do Norte S/A - ALCANORTE, objetivando a instalação de uma fábrica de barrilha, para qual é necessária como matéria prima essencial um calcário de elevada qualidade, foi pesquisada em detalhe por meio de uma malha densa de sondagens rotativas, uma pequena área de rochas carbonáticas sub-horizontais do Cretáceo Superior, pertencentes ao topo da Formação Jandaira da bacia costeira de Potiguar. O estudo de cerca de 2500 metros de testemunhos de sondagem revelou vá-

rias rochas-tipo específicas. Para cada microfacies determinada em lâmina delgada foi definido o ambiente deposicional correspondente e as interrelações dos mesmos. Assim foi possível esboçar as variações de fácies de uma plataforma carbonática restrita com forte influência terrígena e sem comunicação permanente com o mar aberto. A alteração pós-deposicional das rochas resultou em silicificação e dolomitização seletiva dos calcários, preferencialmente ao longo de inhomogeneidades, tais como horizontes argilosos finíssimos ou fragmentos fossilíferos. Como horizonte-

guia local para a correlação de todas as secções utilizamos um horizonte de folhelho carbonífero preto com ostrácos. O conteúdo fossilífero dos calcários consiste principalmente em Gastrópodos, Ostracoda, Echinoidea, Lamellibranchiata, Bryozoa e Foraminíferos bentônicos sem utilidade cronoestratigráfica. Entretanto, a presença de alguns Foraminíferos planctônicos extremamente pequenos (*Hedbergella* sp., *Rotalipora* sp.?) indicada uma idade correspondente à parte inferior do Cretáceo Superior para a Formação Jandaira.

INTRODUCTION

The Cretaceous-Tertiary basin of Potiguar (Rio Grande do Norte) consists of a complete sedimentary cycle ranging from limnic carbonaceous shales (Gangorra Formation) to deltaic conglomerates and sandstones (Açu Formation), shallow and deeper marine carbonates (Jandaira Formation) and, finally, terrigenous red-bed deposits (Barreiras Formation) the lower parts of which have been locally intruded by basaltic sills and dikes. The sedimentary cycle summarized above contains various non-depositional unconformities some of which re-

present periods of uplift and erosion extending through several stages.

This paper deals with the limestone occurrence northeast of Pendências, called Boa Vista and belongs to the uppermost Jandaira Formation. It is of particular interest because it is the only well outcropping source of lime in the vicinity of the salt-producing area of Macau, in which the ALCANORTE soda-ash plant is under construction. An area of 1000 hectares was investigated by means of some 175

diamond drill-holes representing 2500 meters of core material. The detailed investigation was directed towards the delimitation of an area which contains sufficient high-quality limestone reserves to supply the Macau soda-ash plant. Since the carbonates drilled showed extremely rapid lateral and vertical facies changes, it was necessary to carry out detailed sedimentary-petrographical studies in order to establish a valuable local correlation and to delineate the lithological trends of the various carbonate deposits.

PREVIOUS WORK

The earliest information on the sedimentary basin of Rio Grande do Norte and Ceará was given by MAURY (1924, 1934). The denomination Apodi Group for the sedimentary succession of the basin was introduced by OLIVEIRA & LEONARDOS (1943). More detailed investigation of the area of Macau was carried out by KEGEL (1957) who made use of the available deep drilling results of PETROBRAS; the author determined a number of macro- and microfossils and postulated a possible Turonian to Maastrichtian age for the Jandaira Limestone. Later SAMPAIO & SCHALLER (1968) made a new evaluation of the Potiguar Basin taking into consideration the latest, mostly unpublished data of Petrobras. The authors proposed a formal subdivision of the sedimentary assemblage which has been adopted in the present paper. Based upon benthonic foraminifera (*Siphogenerinoides* cfr. *dentata*) and ostracods (*Brachycythere sapucariensis*) they established a Turonian to Santonian age for the Jandaira Formation. In his textbook on the Geology of Brazil, BEURLIN (1970) who had previously published several notes on the Cretaceous of Rio Grande do Norte (1967, 1965, 1964, 1961) favours again a Campanian/Maastrichtian age for the Jandaira Limestone.

GEOLOGICAL FRAMEWORK

The coastal Cretaceous-Tertiary basin of Rio Grande do Norte and eastern Ceará, referred to as Potiguar Basin, represents a continuous succession of continental to shallow marine sediments which rest unconformably upon the Precambrian crystalline basement (Fig. 1). The sediments are subhorizontal with only a slight regional dip towards Northeast. In the same direction their total thickness increases from several hundreds to over thousand meters. The stratigraphic succession of the Potiguar Basin is summarized on Fig. 2.

GEOLOGY OF THE LIMESTONE DEPOSIT OF BOA VISTA

Local stratigraphy

The stratigraphic type-section (Fig. 2) is characterized by a rapid vertical change of facies which is a typical feature of shallow marine to lacustrine deposits. The argillaceous layers

are frequently interbedded with the carbonates. The sandy-argillaceous soil cover as well as the alteration zone varies greatly in thickness, being mainly controlled by local fault-systems along which karst-type weathering occurred preferentially. Limestone alteration is generally also more abundant in impure argillaceous than within pure limestones.

Microfacies and depositional environment of carbonates

Macroscopic and microscopic studies resulted in the distinction of 7 main microfacies types which are referred to particular environments of deposition interrelated genetically and spatially. These rock types which can be identified with the hand-lens in the field have proved to be traceable over several hundreds of meters and, therefore, they facilitate the lateral correlation of the drill-logs. Their description and environmental interpretation is given on Figs. 3-8.

The foraminifera content within the limestones is dominated by small benthonic calcareous imperforate ("porcellaneous") forms such as Miliolids (*Biloculina*, *Quinqueloculina*, etc) and large calcareous perforate (Rotaliids) and imperforate, partially agglutinating forms (*Rhapydionina liburnica*, *luneolina* ? etc.) Orbitoidal foraminifera, which would environmentally fit into the Jandaira limestones, are virtually absent. Planctonic foraminifera are extremely rare and are represented only by scattered small forms such as *Hedbergella* and *Rotalipora*. The overall faunal content is significant for the reconstruction of the depositional environment of the Jandaira limestones; furthermore it can be considered as an indication for the probable early-upper Cretaceous age of the formation (Cenomanian - Santonian).

Post-depositional rock alteration

Dolomitization

Dolomitic horizons of various thickness can be observed in most of the drill-cores at different stratigraphic positions. They can occur as discrete brown saccharoidal dolomite beds ($MgCO_3 > 20\%$) with thicknesses of 0.1 to 1.5 meters. A typical rock type of such a horizon was described in the foregoing chapter (Fig. 7). A prominent bed of saccharoidal dolomite is generally present in the hanging wall of the black carbonaceous key-horizon (Fig. 10).

Another type of more or less dolomitic horizons contains scattered, irregularly outlined greenish-grey dolomite schlieren which consist of clusters of dolomite rhombs within a limy matrix (Fig. 6-B). The amount of repla-

cement of the lime mud by dolomitic cement varies greatly vertically and horizontally. It appears to be mainly a function of the amount of argillaceous matter present in the limestone. This argillaceous matter occurs as paper-thin, partly stylolitic partings and, less frequently, also as disseminated argillaceous suspension within the lime-mudstone. The $MgCO_3$ -content of this second dolomite type is generally lower than 15%.

Silicifications

Superficial silica crusts are abundant throughout the investigated area. They are, however, stratigraphically confined to the uppermost horizons and are obviously a product of the semi-arid weathering characterized by strong evaporation and, therefore, supersaturation of amorphous silica-gel in superficial soil solutions.

Brown and light-grey chert nodules with irregular, schlieren-like outlines were found at different localities in natural outcrops as well as in drill-cores. There does not seem to exist any preferred stratigraphic horizon to which the chert nodules are confined. They are, however, more abundant within dense mudstones and wackestones than in any other rock types (Figs. 5, 6A). Since these dense limestones, some of which contain abundant birds-eyes, are of primarily very shallow marine origin, it is not surprising that no traces of siliceous fossils which might be regarded as source of the silica, such as sponges or radiolarians, could be found in thin-sections. Fossils of this type are ecologically restricted to open marine environment and would not fit into the shallow marine near-shore environment of the uppermost Jandaira Formation. The hydrous silica is probably of inorganic terrigenous origin and the chert nodules might represent an ancient analogue to the recent model described in the Coorong Lagoon of Southern Australia by PETERSON et alii (1965), the amount of silica replacing the carbonate micrite varies from 5% to more than 50% in single hand specimens. The silicification appears to have started preferably from fossil debris, birds-eyes or other inhomogenities from where it grades into the barren micrite.

Chalky texture, Porosity

Soft chalky patches are commonly encountered within the hard homogeneous limy micrite (Fig. 6B). The development of soft chalky texture appears to be related to rusty surfaces along bedding planes which are believed to represent periods of non-deposition and/or erosion (hardgrounds). The white soft patches are considered to represent organic bores

and burrows which later were filled by sediment of scant compaction.

Another type of porosity is confined to grainstones (Fig. 7). Their interparticle porosity is due to the close packing of more or less rounded carbonate particles which were cemented only incompletely during diagenesis.

Finally we observed a third type of porosity which occurs within the saccharoidal dolomites (Fig. 8) and is related to the late diagenetic replacement of calcite by dolomite, a process accompanied by a reduction of the rock volume due to the higher density of dolomite.

Correlation of lithological units

A characteristic feature of shallow subtidal to supratidal sediments is an extremely rapid vertical and lateral facies change. Thus it could not be expected that the specific carbonate rock types could be traced over great distances since they most often represent very restricted micro-environments. However, the marl and shale layers which exhibit a distinct continental influence show a relatively good lateral persistence. A carbonaceous, ostracod-bearing black shale which served as key-horizon throughout the investigated area was especially useful for correlation purposes (Fig. 9). The brown and green marl horizons are of secondary importance; they could usually be traced along several hundreds of meters before they pinched out or graded laterally into argillaceous limestone.

FACIES PATTERN

A detailed evaluation of all the available drill-cores permitted the (-) reconstruction of the local facies pattern (Fig. 11).

A shallow marine platform with predominant carbonate deposition is surrounded by dolomite - and mudflats. A permanent connection to open-marine conditions does not seem to exist. Hence the carbonate platform is part of an epicontinental restricted sea which suffers sporadic ter-

igenous influence from the alluvial plain in the hinterland. The main siliclastic influx originates from northern, eastern and southwestern directions. An interfingering of predominantly clastic red-beds with shallow marine carbonates the northeastern was repeatedly observed within the drill-cores, especially in the northeastern part of the investigated area (Fig. 9) where the sandy limestones of the Jandira Formation seem to grade into the typical reddish continental deposits of the Barreiras Formation.

CHEMICAL PROPERTIES OF THE LIMESTONES

A total of 300 samples of well-defined rock types were analyzed for CaO , MgO , SiO_2 and R_2O_3 ($= \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$). They revealed a close relationship between microfacies and chemical composition of the respective limestones.

As a general rule high SiO_2 - and R_2O_3 - values are coupled with a high MgO - content, which is the chemical confirmation of the spatial and genetic relationship, observed previously, between argillaceous impurities and dolomitization. The limestones with the most favourable characteristics for the production of soda-ash ($\text{CaO} > 50\%$, MgO , SiO_2 , $\text{R}_2\text{O}_3 < 2\%$ each) are the fine-grained mudstones (Figs. 6A, 6B). They were deposited in very shallow intertidal respectively «deeper marine» subtidal environments with practically no terrigenous influx and, therefore, relatively high carbonate sedimentation rate. The poorest values ($\text{CaO} < 45\%$, $\text{MgO} + \text{SiO}_2 + \text{R}_2\text{O}_3 > 10\%$) were obtained from dolomitic and sandy wackestones and packstones (Figs. 3, 4, 8) formed in shallow marine near-shore environment with strong terrigenous influence.

A relatively high amount of SiO_2 and R_2O_3 of many of the limestones which do not contain any visible quartz sand is due to the presence of finely disseminated argillaceous material which becomes enriched in areas with small carbonate sedimentation

rate. This material has been investigated by X-ray diffractometry; it consists of illite, caolinite and montmorillonite, in order of decreasing abundance.

CONCLUSIONS

The Potiguar Basin shows environmental characteristics similar to those of many carbonate basins within the worldwide realm of upper Cretaceous shallow marine deposits.

In the course of a resource-evaluations project for a soda ash-plant, the limestone deposit of Boa Vista near the salt-producing area of Macau was investigated in detail. Sedimentological studies permitted to correlate different rock units and to delineate the lithological trends of the carbonates. A close relationship could be proved to exist between microfacies and depositional environment on one hand the physical properties and the chemical composition of the limestones on the other hand. Hence it was possible to delimitate a relatively small area within the outlined carbonate platform with sufficient high-quality limestone reserves to supply the nearby soda-ash plant of ALCA-NORTE for the next decades.

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Fig. 1 Geological map of the Cretaceous-Tertiary Potiguar Basin (Rio Grande do Norte) with indicated area of investigation. Explanations: 1 = Aluviões, dunas 2 = Grupo Barreiras indiviso 3 = Formação Jandaíra 4 = Formação Açu 5 = Embasamento Precambriano

Fig. 2 Schematic stratigraphic column of the Potiguar Basin with indicated sequence of detailed investigation (type-section).

Fig. 3 Biotritical sandy limestone with intercrystalline porosity (5—10%) **Biosparite** (1) (Packstone) (2).

The biotritical components consist of fragments of echinodermata and lamellibranchiata. Scattered micritic intraclasts are pigmented with organic material and occasionally accompanied by disseminated pyrite. The coarse crystalline cement consists mainly of calcite with subordinate dolomite (idiomorphic rhombs). The siliciclastic grains (quartz, feldspar, mica) are poorly sorted and are angular to subangular in shape. The high porosity is due to the diagenetic leaching of intercrystalline vugs.

Depositional environment: shallow marine (subtidal?), low-energy, with strong terrigenous influence. Probable post-depositional exposure with resulting late-diagenetic dolomitization.

(1) Nomenclature according to FOLK, 1962 (2) Nomenclature according to DUNHAM

Fig. 4 Laminated sandy limestone with shell-fragments; **Biomicroite** (Packstone).

The fragments of bivalve shells, diplopods, gastropods, echinoids, bryozoans and others are embedded in a microcrystalline carbonate matrix. Most of the fragments are subrounded and show well developed micrite envelopes which indicate that the skeletal debris have been colonized and bored by algae (BATHURST, 1971). The siliciclastic grains (quartz, feldspar) amount to less than 2%, poorly sorted (very fine to coarse sand) and angular to subangular in shape. The micritic matrix is partly recrystallized to fine-grained sparite (30-50 microns). Depositional environment: shallow marine, intertidal with terrigenous (eolian?) influence; low energy.

Fig. 5 Dense biogeneous limestone; **Biomicrite (Packstone)**. The skeletal debris (lamellibranchiata, ostracods, gastropods, echinodermata, miliolids and rotalids) are mostly recrystallized and embedded within a micritic matrix.

Depositional environment: shallow marine, subtidal, low-energetyc (protected).

Fig. 6 A

Fig 6A Dense limestone with birds-eyes; **Micrite (Mudstone)** Irregularly outlined vugs within dark-grey micritic matrix. The vugs represent birds-eyes (B) which result from entrapment of gas bubbles and desiccation, always related to the subaeric exposure of the unconsolidated sediment surface. The vugs are filled by secondary calcite/dolomite cement. Scattered dolomite rhombs can also be observed within the micritic matrix. Fossil debris are virtually absent. Depositional environment: shallow marine, intertidal supratidal with temporary emersion.

Fig. 6 B

Fig 6B Dense limestone with rusty spots; **Fossiliferous Micrite (Mudstone)**. The rock consists of a dense micritic matrix with scattered small benthonic and planctonic foraminifera (F) and coccoliths (?). Most fossils are strongly recrystallized by blocky calcite cement. Isolated dolomite rhombs can be observed, scattered within the micritic matrix as well as adjacent to the recrystallized patches. Depositional environment: shallow marine, subtidal, low-energetic; no terrigenous influence.

Fig. 7 Strongly porous Pseudo-oolite; Intrasparite (Grainstone). The well-sorted and rounded intra- and bioclasts are bound together by a coarse crystalline calcite cement. Fossil content is predominantly composed of coated miliolids. The interparticle porosity (approx. 10%) is of primary origin and due to incomplete diagenetic cementation of the sedimentary particles.
Depositional environment: shallow marine, highenergetic offshore-bar (sub-to intertidal); no terrigenous influence.

Fig. 8 Strongly dolomitized, biogenetic limestone; Dolomitic Biomicrite (Crystalline Carbonate; depositional texture not recognizable). The rock consists of relict, partly fossiliferous micritic patches surrounded by scattered dolomite rhombs. The latter total approximately 60-75% of the whole rock. Dolomitization is believed to be of late-diagenetic origin (coarse crystalline, destruction of fossils).
Depositional environment: inter- to supratidal shallow marine with post-depositional exposure.

GEOLOGICAL CROSS - SECTION 400 N SEÇÃO GEOLÓGICA

Fig. 9 Generalized geological E-W cross-section
(Location of axis see Fig. 11)

DETAILED GEOLOGICAL CROSS - SECTION 2300 W SEÇÃO GEOLOGICA DETALHADA

Fig. 10 Geological N-S cross-section through the future mining area with distribution of different rock-types.
(Location of axis see Fig. 11)

Fig. 11 Sketch map of the investigated area with drill-grid and reconstructed facies-pattern.