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Diagenetic influences on reservoir quality of Bom Gosto formation in a sea floor-spreading related basin, Northern Brazil

by J. A. MARTINS CORRÊA*

Abstract

The Albian Bom Gosto sediments were deposited in a marine environment during the initial phase of the Barreirinhas Basin formation in the equatorial Brazilian margin. Arkose is the main type of sandstone, varying from fine to coarse grained and showing a moderate sorting. These sediments have been subjected to a complex sequence of diagenetic events. The chronological sequence of diagenetic processes consists of: 1. quartz and feldspar overgrowth; 2. non-ferrous calcite and Fe-calcite cementation and replacement followed by partial dolomitization; 3. development of secondary porosity essentially by the dissolution of calcite replacement and cement; and 4. porosity reduction by mechanical compactation and precipitation of clay minerals (mainly kaolinite), quartz, pyrite and anatase. The authigenic clay minerals are the main agents of the low permo-porosity observed in Bom Gosto sandstone, because they reduced the secondary porosity and modified the pore system through particle migration and create large amounts of micro porosity.

Zusammenfassung

Die Sedimente der albianischen Bom Gosto Formation wurden während der Initialphase der Entwicklung des Barreirinhas Beckens in einem marinen Milieu abgelagert. Die wichtigsten Sandsteintypen sind die Arkosen. Sie zeigen eine mäßige Sortierung und variieren von feinen bis groben Sandsteinen. In diesen Sedimenten bildete sich eine komplexe Folge von neuen Mineralen. Chronologisch können die diagenetischen Prozesse in vier Teile gegliedert werden: 1. Einwachssäume von Quarz und Feldspat; 2. Zementation und Verdrängung der Körner, insbesondere der Feldspäte, durch Calcit und Fe-Calcit, und am Ende Dolomitisierung; 3. Sekundäre Porosität durch Auflösung von karbonatischem Zement und Verdrängungsreaktionen von Feldspat durch Carbonate; 4. Verringerung der Porosität durch Tonmineralneubildung und Kompaktion. Der Tonmineralzement spielt ohne Zweifel eine sehr wichtige Rolle bei der Verringerung der sekundären Porosität und Permeabilität. Er verstopft das poröse System durch die Migration von kleinen Partikeln und verursacht eine Steigerung der Mikroporosität.

1. INTRODUCTION.

The clay minerals of the Bom Gosto Formation have their origin related with diagenetic phenomena. Based upon their morphology and occurrence stage, they affect the porosity, permeability and water saturation. Traces of oil and gas were observed in the Bom Gosto sandstone but some porosity and permeability problems are present. They are directly related with diagenetic cements, in particular clay minerals. The aim of this paper is to identify the diagenetic paragenese, the distribution of the authigenic minerals, mainly clay minerals, and their influence on Bom Gosto reservoir quality.

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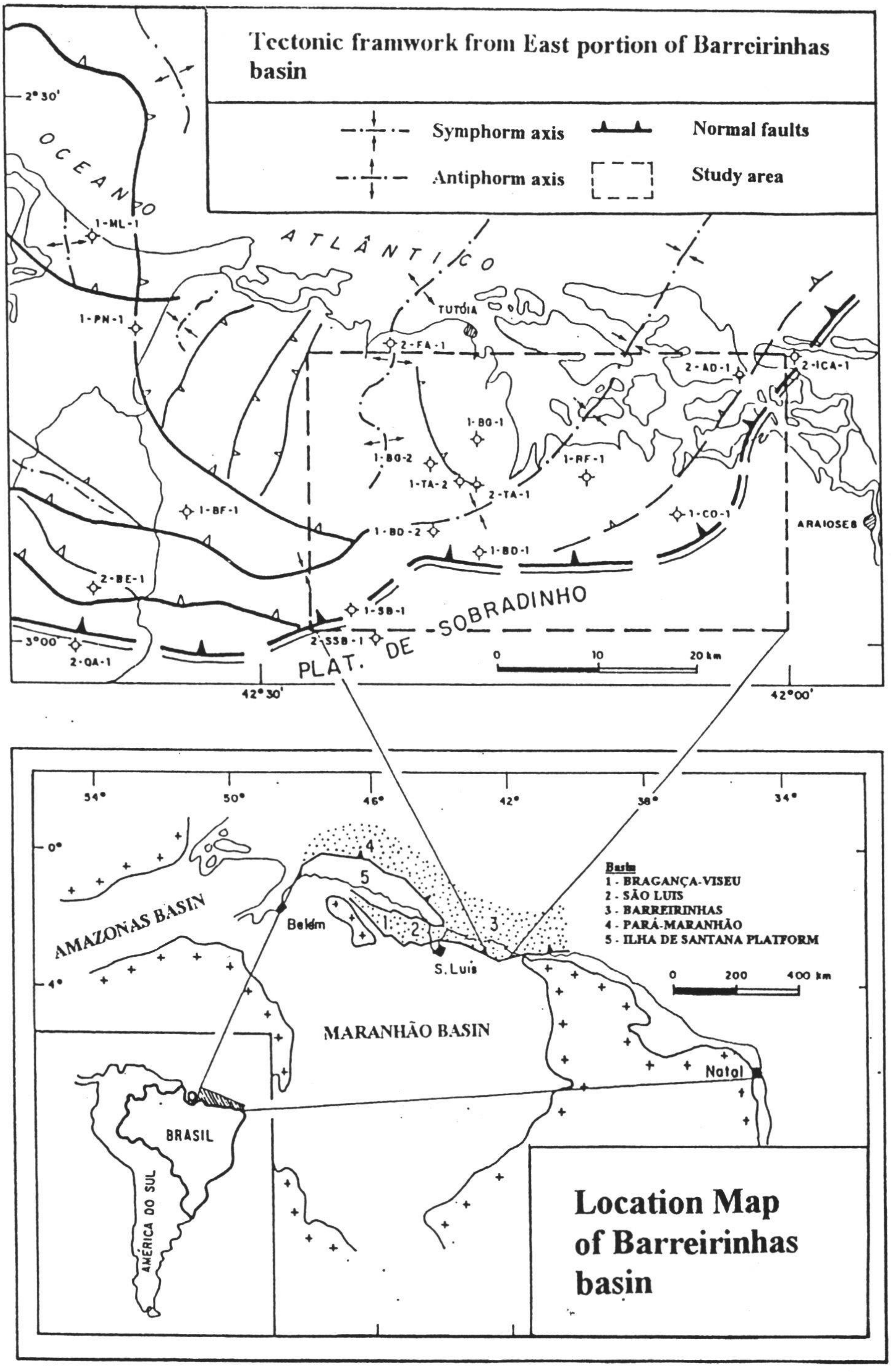

Fig. 1 - Location map of Barreirinhas basin.

2. GEOLOGICAL SETTING.

Stratigraphie

The Barreirinhas basin (Fig. 1) had initiated its sedimentation processes during the Early Cretaceous. The 6 km of sediments have been generally divided into two groups: the Canárias Group (Clastic lower) and the Caju Group (pelitic-carbonate) (NOGUTI 1967). In 1969, Pamplona added the Humberto de Campos Group and located it above the Caju Group. Based upon modern and more reliable seismic data and time lines, FIGUEIREDO et al. (1982) proposed a significating modification in the stratigraphic column (Fig. 2). The new proposal divided the cretacic sequence into 11 formations that were distributed through the 3 old groups. The Canárias Group has now five formations, named: Arpoador, Bom Gosto, Tutoia, Barro Duro and Sobradinho. The Bom Gosto formation occurs mainly at the east and south-central part of the basin, and overlies the Pre-Cretaceous embasement and the Arpoador formation. RODRIGUES et al. (1969) characterized this formation as had been deposited through turbiditic flows in a marine environment and proposed a Proximal Turbidits as depositional model.

Tectonic Setting - The spreading of the equatorial Atlantic

The Brazilian continental margin and the adjacent ocean floor is one of the best known Atlantic-type margins (ASMUS & BAISCH, 1983). They are characterized by three main types of structural features (ASMUS, 1982): normal faults, hinge lines and transverse structures. Particularly along the northern continental margin there also occur compressional structures, such as folds and reverse faults (ASMUS, 1984).

The evolution of the continental margin passed through four stages (ASMUS & BAISCH, 1983): 1) Pre-rift (or intumescence), in the Late Jurassic-Early Cretaceous; 2) Rift, in the Early Cretaceous, 3) Proto-oceanic (transitional), in the Early Cretaceous (broadly Aptian), and 4) Oceanic (drift or migration), from the Early Mid-Cretaceous onwards. In this last stage general tilting and development of homoclinal structures took place, with transcurrent faulting along the northern margin, associated with deposition of marine sediments (ASMUS & BAISCH, 1983). The sedimentary sequences formed during these evolutionary stages are termed Continent, Lake, Gulf, and Sea sequences, respectively (ASMUS, 1982).

The seismic, stratigraphic and tectonic data of Barreirinhas basin show that it has a particular development that is only partially in agreement with the evolutionary stages proposed by ASMUS & BAISCH (1983). The Barreirinhas basin was submitted to a wrench tectonics during the early stages of its development (Late Jurassic). Its basement is characterized by local structural highs, lows and intermediate areas, these being evidence of the strong tectonic activity that affected the basin since its formation. FIGUEIREDO et al. (1982) observed that the axis of the »en echelon» folds system were disrupted by transcurrent faults and the sedimentary sections show an abrupt Facies variation. AZEVEDO et al. (1985) proposed for the Barreirinhas basin three tectonic-sedimentary phases that include: 1) Pre-shear phase (Late Jurassic - Early Cretaceous) dominated by a compressive tectonic that was caused by the South-Atlantic rifting, 2) Pull-apart phase (Aptian), when the divergence between the African and South-American plates occurred; 3) Drift phase (Albian-Cenomanian to Tertiary), when oceanic conditions predominated.

DICKINSON & SUCZEK (1979), DICKINSON & VALLONI (1980), MACK (1983), SUTTNER & DUTTA (1986) and many others demonstrated a close correlation between sandstone composition and plate-tectonic setting. The proportions of detrital framework grains

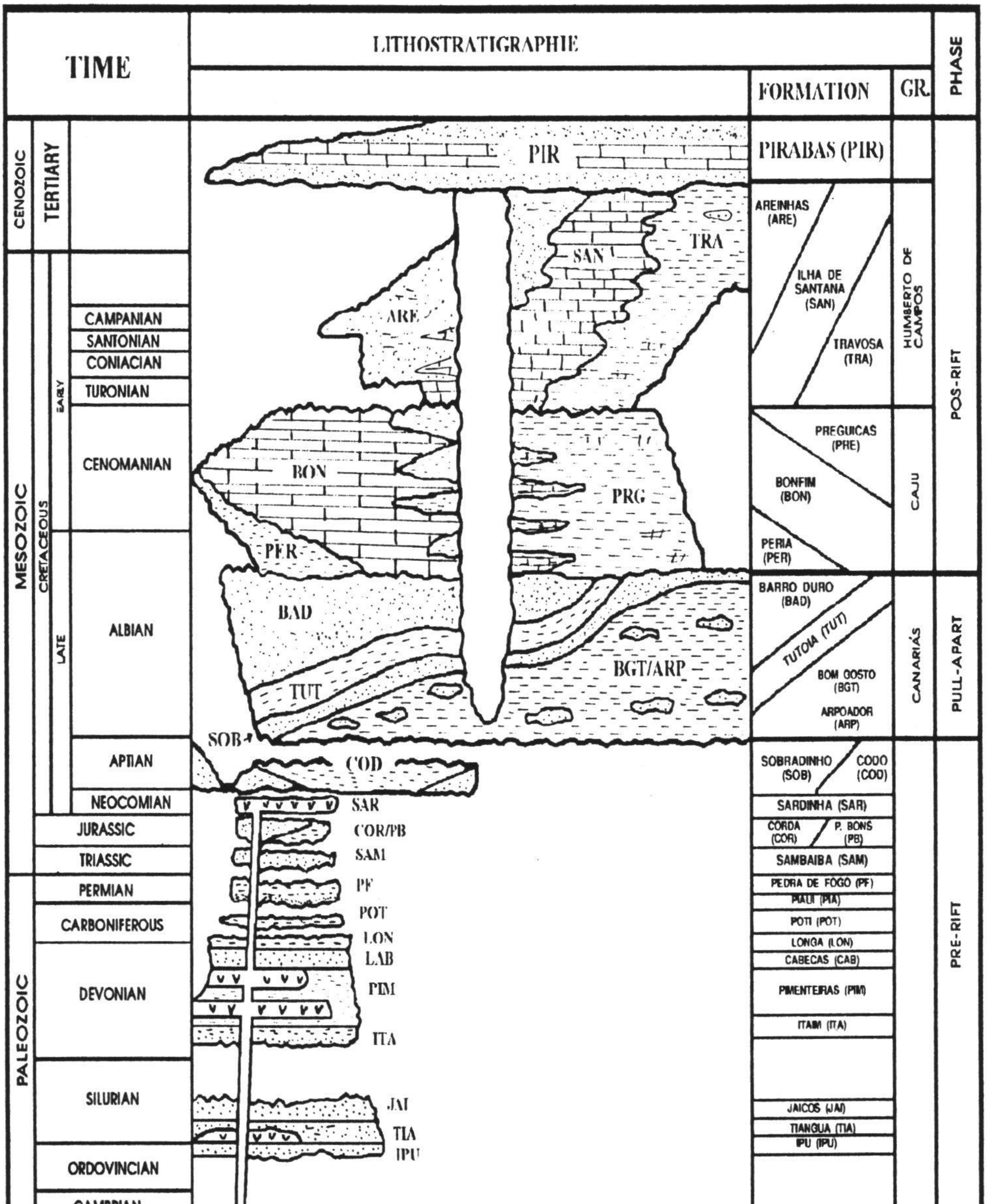

Fig. 2 - Stratigraphic column of Barreirinhas basin (after FIGUEIREDO et al. 1982).

plotted on triangular diagrams effectively discriminate among a variety of plate-tectonic settings and provide a powerful tool in the interpretation of plate interactions in the geologic past. The analysis of Bom Gosto Sandstones with this method (CORRÊA & TRUCKENBRODT, 1988) indicate a Continental Block Provenance (Transitional to Uplifted Basement) that agrees with the actually basin model proposed by AZEVEDO et al. (1985). The sands of Bom Gosto Formation shed from fault-bounded uplifts of continental basement rocks and accumulate mainly in nearby yoked basins without much transport in form of turbidit flows in a flat semi-restrict environment during the Aptian.

3. ANALYTICAL METHODS.

Total 116 samples were studied using optical petrography, scanning electron microscopy (SEM) and X-ray diffraction. The carbonate cement was distinguished after Dickson's method, which differentiates between ferrous phases in calcite and dolomites, and is capable of revealing subtle growth zones on cement crystals. The mineralogy of diagenetic phases - that of clay minerals in particular - was confirmed using XRD techniques described in THOREZ (1975). The clay fraction of the sandstone (both < 5 μm and 2 μm fractions) was separated by sedimentation and centrifugation processes. The textural information, necessary to interpret the authigenic mineral sequence, was obtained through S.E.M. examination of gold coated, fractured surfaces of material from all representative samples.

4. RESULTS.

The mineralogical composition of Bom Gosto sandstone is summarized in Table 1. When classified according to PETTIJOHN et al. (1973), sandstone includes arkosic arenites (88 %), lithic arenites (7%), subarkoses (3%) and sublithic arenites (2%). We have to attend therefore, that these classification did not consider the significant effect caused by the diagenesis, for example, dissolution and substitution of framework grains. The Bom Gosto sandstones were strongly affected by the diagenesis and would had been originally more feldspatic and lithic.
The major authigenic minerals present are quartz, feldspar, iron-calcite, iron-dolomite, calcite, dolomite, ankerite, anatase, pyrite and clay minerals like kaolinite, chlorite, illite, illite/smectite (Fig. 3).
Quartz is present in two distinctive generations: a) syntaxial quartz overgrowths on detrital quartz grains; b) microcristalline quartz. Quartz overgrowth formed apparently early in the diagenetic sequence, in absence of most other cements. The overgrowth develops crystal faces if the pores permit, and is in crystallographic continuity with the host grains (Fig. 4a). In some cases the margins of framework grains do not permit to distinguish between cement and host grain. The quartz microcristalline was revealed with SEM examinations. The microcristalline quartz occurs into the secondary pores and was formed after the dissolution of carbonate cement. It is characterized by their size (5 to 10 μm) and euhedral morphology and are usually associated with authigenic clay minerals.
Feldspar occurs as overgrowth on detrital feldspar grains and filling secondary intraporosity. The intrapores show sporadically columnar aggregates with complex twinning.
Carbonate is the most abundant cement, occurs as a mosaic of blocky anhedral spar

Table 1- Average composition of sandstone samples from Bom Gosto formation, east area of Barreirinhas basin.

Wellls		2-TA-1	1-TA-2	1-BG-1	1-BG-2	2-AD-1	1-BD-2	1-SB-1	Aver.
	Quartz	42.5	46.7	42.2	42.6	34.5	43.0	40.5	41.7
Framwork	Plag.	1.4	1.0	0.8	0.2	tr.	0.5	0.7	0.6
Grains	K-Felds.	23.4	27.4	23.4	23.4	17.0	28.7	17.3	23.0
	Rock Frg.	10.8	10.0	8.6	9.2	18.0	10.2	9.2	10.8
	Mica	3.7	4.0	6.5	5.0	2.2	4.7	4.2	4.3
Authigenic	Kaol.	1.9	5.0	2.2	2.0	5.1	2.0	3,3	3.0
Minerals	Carbonat	8,9	2,3	8,2	8,8	18,0	7,2	21,2	10.6
	Por	3.9	2.0	5.0	4.4	3.2	2.5	0.8	3.1
	Matrix	1.7	-	0.5	2.2	tr.	tr.	tr.	0.6
	Others	2.0	1.6	2.6	2.2	2.0	1.2	2.8	2.0

crystals, partially or completely infilling the pore space or as poikilotopic fabric. This cement precipitated early in many sandstones and shows a pre-compactation fabric, where detrital sands appear to be «floating» in the calcite. The principal types of carbonate observed are: calcite, dolomite, Fe-calcite, Fe-dolomite and subordinately ankerite. Calcite after Dickson's staining method shows an irregular zonation, with a calcite nucleus and a Fe-calcite border. The dolomite shows the same zonation that indicates a dolomitization process. Ankerite is however difficult to recognize, occurs as a diminute rombohedral crystals into secondary porosity and is generally near the crystals of biotit.

The minor authigenic minerals are pyrite and Ti-oxides, mainly anatase. The pyrite observed has a framboidal form and occurs as aggregates into secondary pores. The anatase shows different crystal sizes, but the size of 10 µm dominates. Different associations of anatase were observed: 1) engulfed in quartz overgrowth; 2) engulfed in carbonate cement; 3) alone in secondary pores; and 4) outgrowth in opaque minerals.
The clay minerals are generally of authigenic origin. The distinction between authigenic and detritic clay minerals is based upon the following criteria: a) morphology (perfect and delicate crystals) and absence of deformations and pseudomorphic substitutions; b) distribution (absence of fringe on grain contact, disseminated filled pores, filling fractures, lining of authigenic constituents) (WILSON & PITTMAN, 1977). Among the observed clay minerals, kaolinite is the most abundant. Its size, more than 5 µm, makes their identification with optical microscopy easier. Kaolinit occurs in two forms: 1) pseudomorphic substitutions of feldspars grains and 2) filling partial or entirely secondary pores. Two types of habit were observed: a) platy aggregates »booklets»; and b) vermicular aggregates (Fig. 4b, c).
Chorite is the second most important clay mineral in Bom Gosto sandstone. Occurs as lining on the grain surface and as alterating product in micaceous minerals (Fig. 4a, d). The alterated mineral shows a failure of birrefringence colour, mainly on the boards,

frequently followed by enlargement of crystal cleavage as a fan. Chlorite linings grow perpendicular to surface grains, and are in general associated with quartz crystals (2nd generation). Where chlorite linings are well developed, quartz overgrowth or microscristaline show little development. Some chlorite plates are engulfed into authigenic quartz. This suggests that it was originated earlier or concomitant to quartz.
Illite and mixed-layer illite/smectite occur in reduced quantities. They are usually alteration product of detritic constituents or chemical precipitates. Illite occurs as irregular flakes with lath-like projections, that occasionally bridge the gap between adjacent detrital sand grains. Illite/smectite occurs as coating in secondary pores.

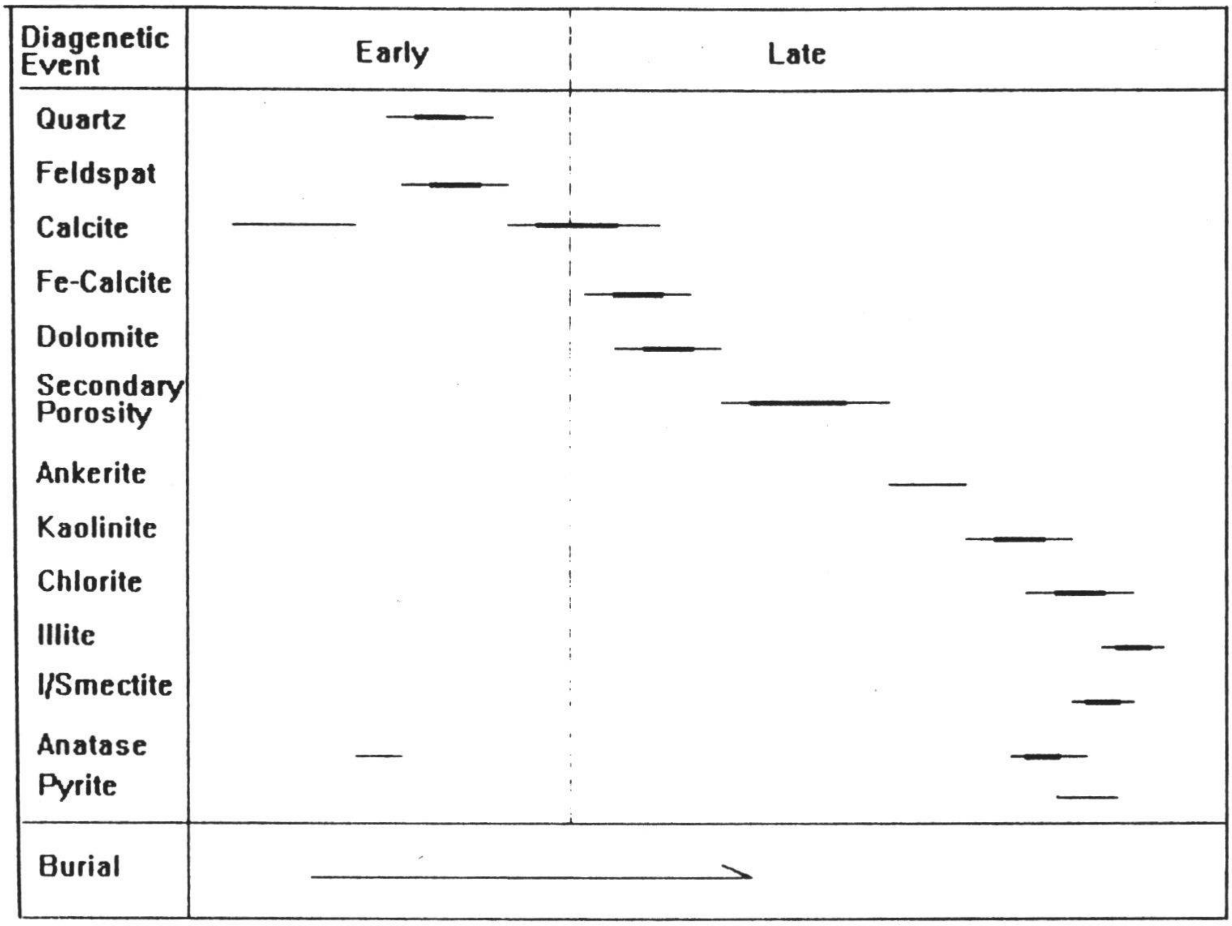

Fig. 3 - Diagenetic sequence of Bom Gosto sandstone.

5. DISCUSSION.

The textural criteria show that clay minerals in Bom Gosto sandstone are authigenic. These late authigenic clay minerals are probably a product of thermal instability of organometalic aluminocomplexe, that were formed in presence of carboxylic acids. The instability might occurr above 120°C and the aluminium would precipitate with clay mineral like illite, chlorite and chiefly as kaolinite. After HOFFMAN & HOWER (1979) kaolinite in sandstone will be instable above 140-150°C, although dickite is stable in higher temperatures. The relationships between the development of secondary porosity and kaolinite formation has been intensively documented. SURDAM et al. (1984) and SURDAM & CROSSEY (1985) have showed experimentally that at 100°C the presence of

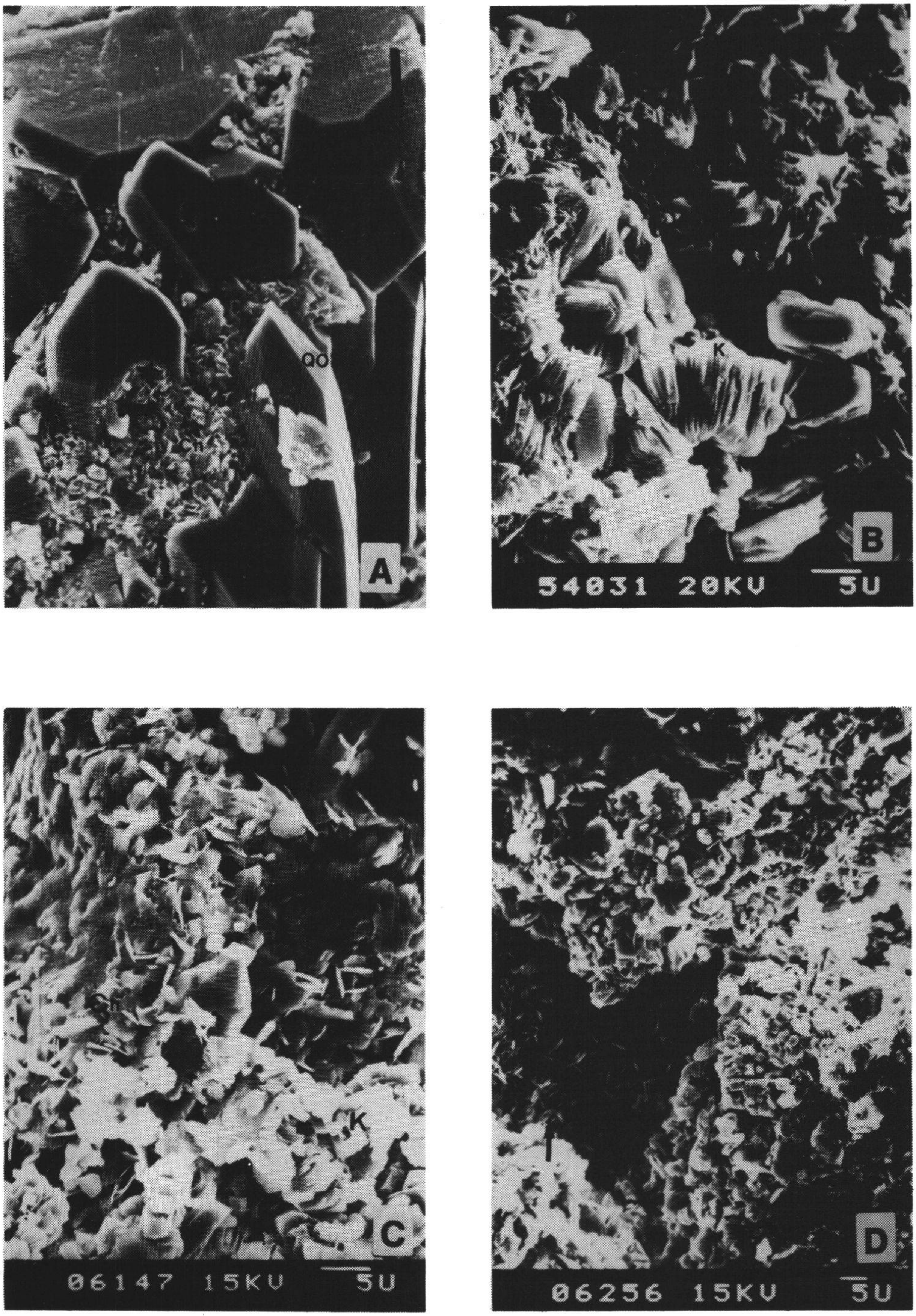

Fig. 4 - (a) Quartz overgrowth (QO) overlying Chlorit rim, scale bar 50 μm; (b) Kaolinit (K) filling secondary porosity, note the vermicular form of the crystals; (c) Kaolinit as attacked pseudohexagonal plates and Chlorit (Ch) rim; (d) Chlorit rim in secondary pore space (see arrow).

difunctional carboxylic acid anions in oil field waters can increase the solubility of aluminium by more than three orders of magnitude with respect to gibbisite. These acid interstitial solutions deeply generated during the thermocatalytic degradation of kerogen, could be responsible to dissolve and transport significative quantities of metals, inclusive aluminium as organic complexes. If the pH of the fluid increases (changes temperature p.ex.), the complex may be destabilized, precipitating a mineral phase such as kaolinite (CURTIS 1983 and SURDAM et al. 1989). The tendency observed in Bom Gosto sandstone, which shows a decrease in kaolinite content with depth, indicates that mass transfer would have been relatively efficient and the pH increased in direction to more shallowed parts of the sequence probably due to the dissolution of carbonate, the increasing distance between fluids and its origin and the decrease in the temperature.
The geochemical analyse of the Bom Gosto oil shows that it was generated out of the Canárias Group, possibly in greater depth (REGALI, 1984). We suppose that when the oil migration occurred, the Bom Gosto reservoir were relatively colder (120°C) and these difference in temperature produced the precipitation of the clay minerals. They precipitated from the interstitial solutions originated due to mixing of solutions from the deeper formation and solutions from Canárias Group. Consequently a porosity and permeability reduction prevented the formation of good reservoirs. In addition, the original composition of the Bom Gosto sandstone, rich on feldspar and rock fragments (granitic and metamorphic compositions) would have favoured the crystallisation of clay minerals.

6. EFFECTS OF AUTHIGENIC CLAY ON RESERVOIR PROPERTIES.

The principal cause to inferior quality of Bom Gosto reservoirs are undoubtedly the clay minerals. The pore filling and pore lining form of occurrence reduced drastically the secondary porosity and permeability (porosity range values between 5 to 15 vol.% of rock total, and the permeability between 1 to 85 md, Petrobras intern Report). The Bom Gosto sandstone reservoir contains abundant authigenic clays with associated micropores, so that it would be expected to have a long transitional oil-water or gas-water contact because of the adsorbed water associated with high surface area.
The kaolinite, the most abundant clay mineral, is the principal responsible of reservoir damage. Its presence in Bom Gosto sandstone reservoirs causes production problems for two main reasons: a) its loose attachment to the host grains, and b) the large size of individual particles. A fluid turbulence, particularly in areas close to the well bore, within a pore can detach the delicately attached kaolinite and the loosened, relatively large crystal will migrate to the pore throat where it lodge and act as a check valve. The presence of chlorite, illite and illite/smectite in Bom Gosto reservoirs contributed either to well-Enginering problems. The illite occurs in form of laths and is associated with illite/smectite and, nevertheless it occurs in reduced quantities, it can create large volumes of micro porosity. This microporosity can bind water to the host grains and results in high, irreducible water saturation.

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