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THE COLÔNIA ASTROBLEME, BRASIL

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RESUMO

A estrutura de Colônia está localizada a cerca de 35km ao sul do centro da cidade de São Paulo. Ela apresenta formato circular, com 3,64km de diâmetro, estando preenchida por pelo menos 263m de sedimentos, correspondendo a uma provável estrutura de impacto, ou astroblema.

Essa feição é delineada por um anel externo circular, de relevo colinoso, desnivelado de até 125m em relação a uma planície aluvial interna pantanosa.

Este artigo apresenta um esboço da geologia regional da área e discute as diferentes hipóteses concernentes à origem da estrutura, bem como os parâmetros morfológicos pertinentes à compreensão desta feição extremamente particular.

São apresentados também os resultados preliminares do estudo das amostras obtidas por vibrotestemunhador.

ABSTRACT

About 35km south of the city of São Paulo, near Colônia, within Precambrian crystalline basement rocks, there is a well-defined ring feature, with 3.64km in diameter and filled by at least 263m of sediments, which corresponds to a probable astrobleme.

It is defined by a hilly circular outer rim up to 125m higher than an inner alluvial plain presently occupied by a large swamp.

This paper explains the regional geology of the area and discusses the different hypothesis as to the origin of the structure as well as the morphological parameters pertinent to an understanding of this feature.

Preliminary vibrocore data are also presented.

1 INTRODUCTION

Fewer than 150 impact structures of celestial or interplanetary bodies at the Earth's surface, the so-called astroblemes, are recognized over our planet (GRIEVE & ROBERTSON, 1979, 1987). The study of astroblemes has recently increased because impact cratering was a fundamental process in the evolution of all the terrestrial planets (SHOEMAKER, 1977), hence its importance in comparative planetology.

About 35km from São Paulo, near Colônia (fig.1), there is a conspicuous ring feature, 3.64 km in diameter, centered at 23°52'S, 46°42'20''W, within Precambrian crystalline basement rocks, and defined by a hilly circular outer rim up to 125 m (figs. 2 and 3) higher than an inner alluvial plain presently occupied by a large swamp, where the present-day water level may be, in part, controlled by the Billings reservoir just to the east.

The structure is located in the border of the Serra do Mar, a coastal mountain chain originally covered by the "Mata Atlântica" tropical rain forest with localized occurrences of *Araucaria angustifolia* (Bertol). Kuntze.

The hypothesis that this feature is a probable impact structure has long been postulated, ever since the first studies carried out in the area (KOLLERT *et al.*, 1961).

In this paper the regional geology is briefly explained, different hypothesis as to the origin of the structure are discussed, and morphological parameters pertinent to an understanding of this feature are given. Preliminary vibrocore data are also presented.

2 REGIONAL GEOLOGICAL SETTING

The Colônia structure is located within the domain of the Ribeira Fold Belt (HASUI *et al.*,

FIGURE 1 — Location of the Colônia Astrobleme.

1975). According to SADOWSKI (1974) and COUTINHO (1980) the main rock types of the region are gneisses, migmatites, diorites, mica schists, quartzites, mylonites, amphibolites, metabasites, granites and granodiorites (fig. 4). The general structural trend of the basement rocks is ENE.

Sedimentary rocks are exposed along the southern and southeastern borders of the structure and are probably related to the Middle Eocene/Early Oligocene (MELO *et al.*, 1986) or more precisely Oligocene (RICCOMINI *et al.*, 1987) deposition of the São Paulo Formation, prominent in the São Paulo Basin located just to the north.

All the rock types have been very intensely weathered, which makes geological observations difficult. Colluvial and alluvial deposits of probable Quaternary age are also present in the region.

3 THE COLÔNIA STRUCTURE: HYPOTHESIS AS TO ITS ORIGIN

As mentioned above, ever since the first studies of this structure, the hypothesis of a probable impact structure has been popular (KOLLERT *et al.* 1961). Further studies, mainly those by CROSTA (1982, 1986), based on morphological parameters, have reinforced this idea. The presence of higher altitudes in the southwestern part of the rim has led COUTINHO (1987, oral communication) to suppose a body trajectory from northeast before the shock.

Alternative hypothesis, such as (1) sinkhole, (2) structural interference pattern, (3) intrusion and (4) crypto-explosion (phreato-magmatic structure related to a kimberlite), among others, may be rejected, respectively, by (1) the absence of carbonate rocks in the region, (2) the persistence of the ENE structural trend of the basement, (3 and 4) the lack of structures and/or minor intrusive bodies (dikes, sills, etc.) that should be associated with such intrusions, and the excessively unusually large dimension for a kimberlite pipe. The hypothesis of a massive landslide structure as proposed by ERISMANN *et al.*, (1977) for the Köfels structure, near Innsbruck (Tirol, Austria), previously believed to be an impact crater (*e.g.* SUESS, 1937; STORZER *et al.*, 1971), is probably not applicable to Colônia, mainly because of fundamental differences in the geometry of the two structures, Colônia being circular and Köfels, irregular, roughly elliptical, a shape not common among known astroblemes.

Despite the above argument, no direct evidence of an impact, such as shock metamorphism, has yet been observed in the area, most likely due to the intense weathering. The peculiar circular shape and the typical depth/diameter ratio (CROSTA, 1982, 1986), as well as the semicircular outcrop pattern of the sedimentary rocks of the São Paulo Formation along the southern and southeastern inner part of the rim, are the main indicators of an astrobleme. The lack of convincing proof of endogeneous process also reinforces this hypothesis.

An interesting outcrop was referred to by COUTINHO (1979, oral communication) close to the Colônia structure. Field observations for the present study revealed a probable thrust zone, striking WNW and dipping NNE. This outcrop is relatively well exposed one kilometer southward from the structure, along the secondary road to Engenheiro Marsillac (site A, fig. 2). Sandy to pebbly mudstones, probably of the São Paulo Formation, are tectonically imbricated within Precambrian gneisses of the basement. An ENE subvertical family of joints is well developed in these sediments, leading to the assumption of an ENE compression axis (σ_1) and a NNW extension axis (σ_3). This situation could represent a part of the overturned rim. Nevertheless, this

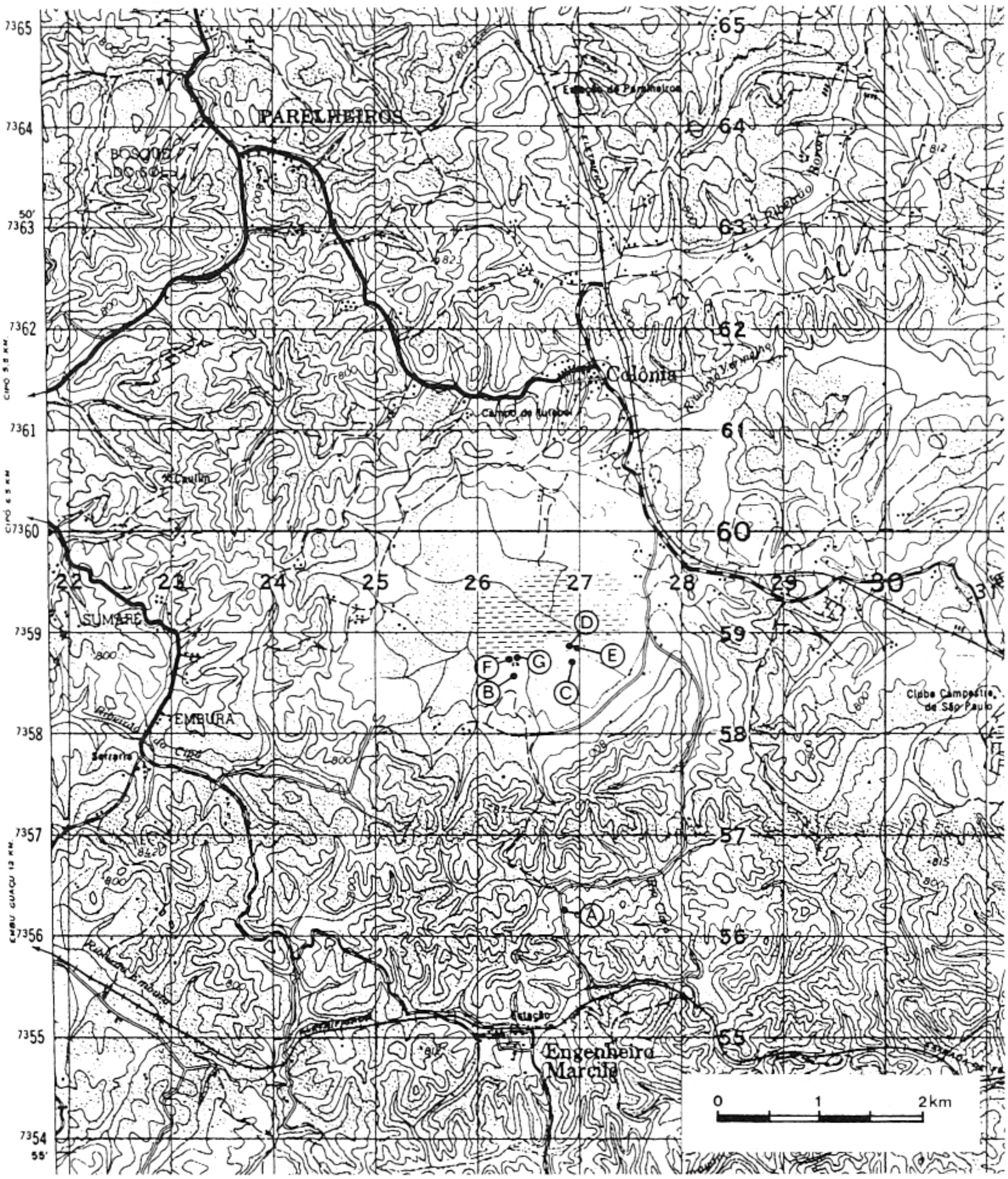

FIGURE 2 — Topographic map of the Colônia Astrobleme (57 to 61 × 24 to 29) with locations (A-G) of sites mentioned in the text. Contour interval 20m. Source: Instituto Geográfico e Geológico de São Paulo, 1971.

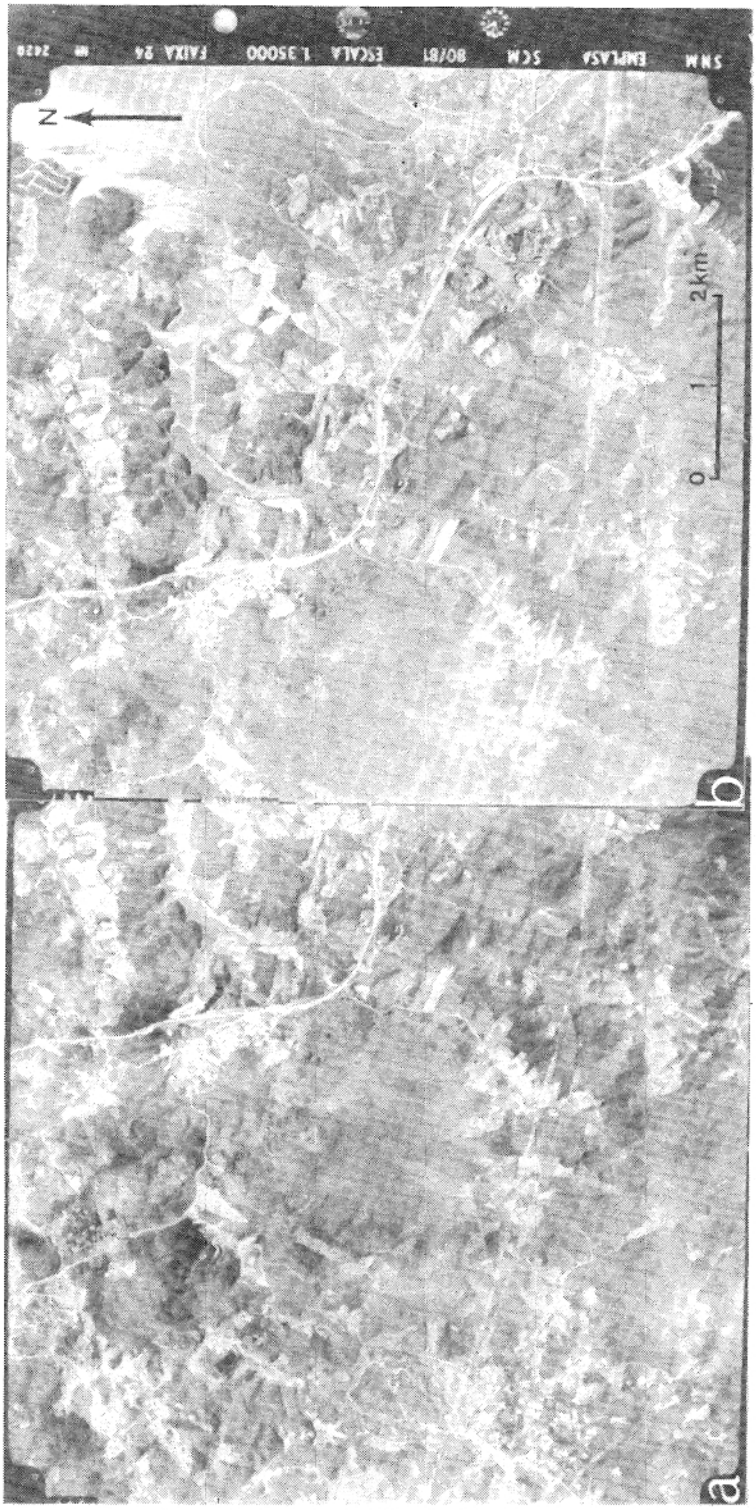

FIGURE 3 — Stereo-pair of the Colônia Astrobleme. Original scale of the photos 1:35,000. Source TERRAFOTO/EMPLASA, 1980-1981.

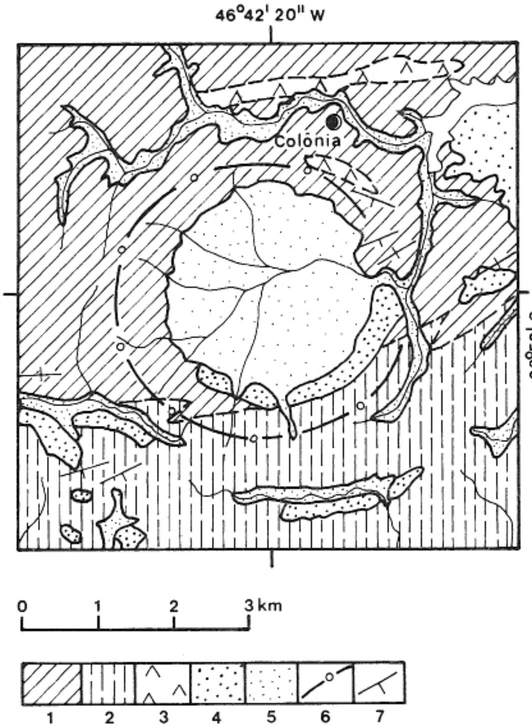

FIGURE 4 — Geology of the Colônia area, after COUTINHO (1980), simplified. Precambrian: 1 — mica schists, quartzites, locally mylonites; 2 — gneisses, migmatites, also locally mylonites; 3 — diorites and quartz diorites. Tertiary: 4 — São Paulo Formation. Quaternary: 5 — alluvial deposits. Structures: 6 — crater rim; 7 — structural trend of the Precambrian basement.

deformation pattern is not completely incongruous with the transpressional event of post-Oligocene to Pleistocene age observed in the region (RICCOMINI *et al.*, 1989).

All of the above considerations concerning the pattern of Tertiary sedimentation point to an Oligocene or younger geologic age for the impact event.

4 ANALYSIS OF THE MORPHOLOGICAL PARAMETERS OF THE STRUCTURE

DENCE (1972) has classified terrestrial impact craters in seven different levels or degrees of preservation: 1: ejecta largely preserved; 2: ejecta partly preserved; 3. ejecta removed and rim partly preserved; 4: rim largely eroded and crater-fill products preserved; 5: crater-fill products partly preserved; 6: only remnants of crater-fill products preserved, with crater floor exposed; 7: crater floor removed, substrate exposed.

GRIEVE & ROBERTSON (1979), studying the morphology of the 140, proven, probable and possible, impact structures known throughout the world, have verified a 600 Ma recognizable life for craters less than 20 km in diameter, according to DENCE's seven-stage scale. The Colônia structure lies between preservational degrees 3 and 4, i.e., a structure with ejecta removed, rim partly preserved, although deeply eroded, and crater-fill products preserved. GRIEVE & ROBERTSON (1979) have established an empirical relationship between diameter, age and preservational degree of impact structures, in order to estimate the maximum age of structures with a given dimension. The observed preservation degree is plotted against a preservation index defined by the ratio between the diameter in kilometers and the age in Ma. Given the 3.64 km diameter and the preservational degree between 3 and 4 of the Colônia Astrobleme, the maximum impact age would range between 36.4 Ma (Eocene-Oligocene boundary) and 5.2 Ma (Miocene-Pliocene boundary), dates well in agreement with the maximum age of Oligocene postulated on other grounds.

Also according to GRIEVE & ROBERTSON (1979) the depth-diameter relationships for simple craters with diameters less than 3.8 km in crystalline targets are described by the functions:

$$Pt = 0.326\ D^{0.786} \quad ,$$

$$Pa = 0.159\ D^{0.829} \quad ,$$

where *Pt* and *Pa* are, respectively, the true and apparent depths in kilometers and *D* is the rim diameter also in kilometers. The true depth corresponds to the altitude difference between the top of the rim and the base of the crater-fill, whereas the apparent depth is the difference between the top of the rim and the top of the crater-fill. Using these relationships, the *Pt* and *Pa* parameters for the Colônia structure are respectively 900 and 464 meters. Theoretically, therefore, the crater-fill should be 436 meters thick.

The present vertical distance from the top of the rim to the top of the crater-fill is around 125m. The difference with respect to the calculated *Pa* may be explained by the action of intense weathering and erosion.

There is no available data on the maximum crater-fill thickness. Geophysical (gravimetry and resistivity) surveys indicated 300-400 m for the depth to the crystalline substratum within the crater. A water-well, originally 190 m in depth (site B, fig. 2) was drilled in the southern part of the structure, about 650 m from its center, and does not reach the basement (CEPAS, 1989). Later this well was continued down to 263 m depth, where it was reported that the drilling had reached the basement. It is possible, however, that

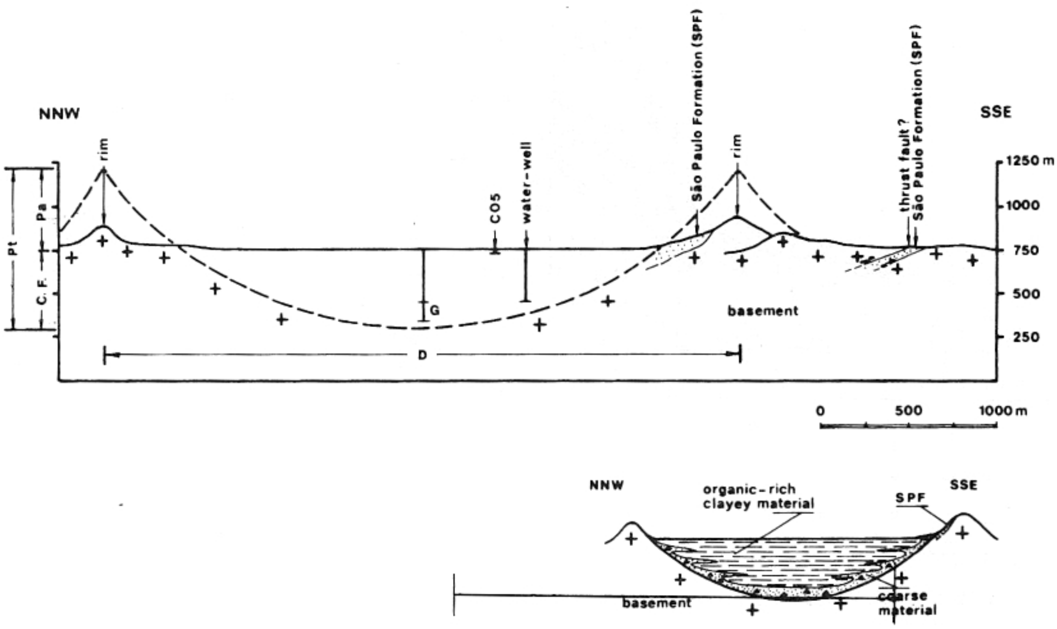

FIGURE 5 — Upper: idealized section across Colônia Astrobleme, showing available data (heavy lines), and theoretical parameters after GRIEVE & ROBERTSON (1979, dashed line). Pa: apparent depth; Pt: true depth; D: diameter; C.F.: crater-fill thickness; G: depths according to geophysical data. Below: interpretation of sedimentary deposition.

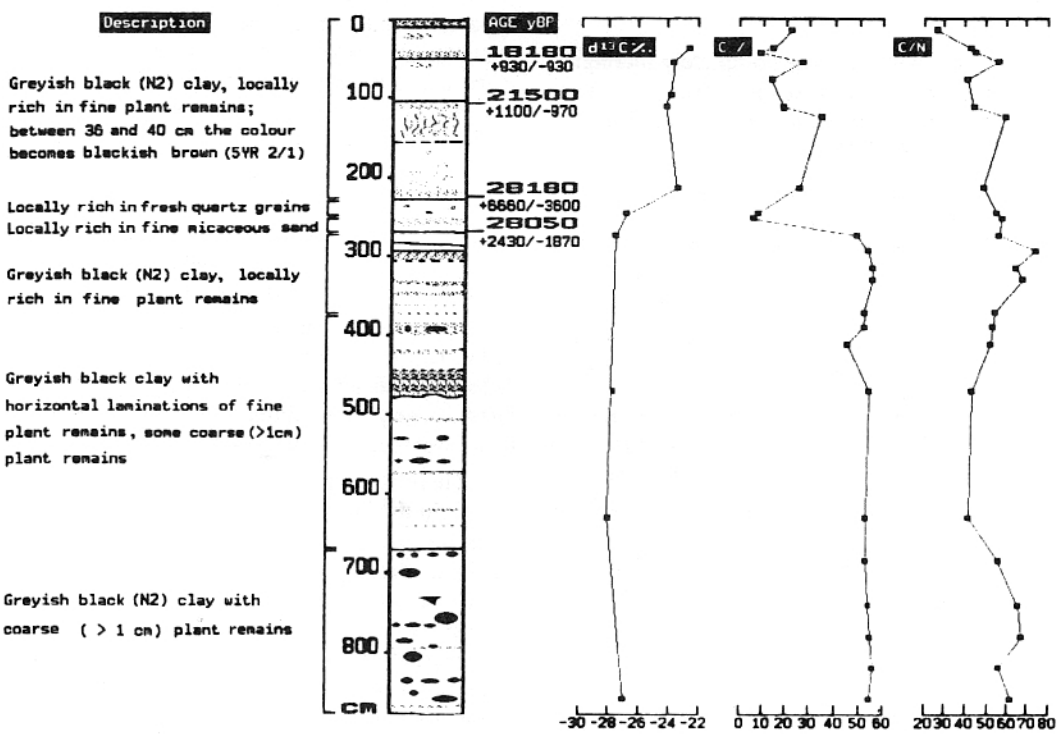

FIGURE 6 — Core C05: description, $\delta^{13}C$ ‰, C%, C/N.

this level, 263 m below the alluvial plain, could merely represent the top of the initial, coarse, crystalline fill eroded from the slopes of inner part of the rim.

Drilling has revealed essentially organic-rich clayey material. As shown in Fig. 5, however, the 263 meters drilled depth and the 300-400 meters obtained by geophysical survey are in agreement with the theoretical values for the thickness of crater-fill sediments based on the parameters *Pt-Pa* (C.F.).

5 LATE PLEISTOCENE SEDIMENTATION

The Colônia depression, as a small basin with high sediment accumulation, is a good site for paleoclimatic studies. Such studies are being supported by the "Intertropical Paleoclimates" program of ORSTOM-CNPq accord and by the GEOCIT program of ORSTOM. In 1987 field work resulted in the collection of 5 vibrocores of 4.65, 7.52, 7.80, 5.60 and 8.78 m, respectively cores CO1-CO5 (sites C-G, fig. 2).

The vibrocorer is a conception of one of the authors (L.M.). Vibrocores were taken in two different zones of the depression, in accordance with the possibilities of transportation. Only the preliminary results of analises of core CO5 are presented here (fig. 6).

The sediments, along the 878 cm of core CO5, are organic rich, with a greyish-black (N2) to brownish-black (5YR 2/1) color (fig. 6). They are mainly made up of clays. Some fresh quartz grains, with diameters of 1 to 3 mm, appears below 227 cm depth. Between 253 and 265 cm the facies is a greyish black micaceous fine sand. Beneath this limit the sediments continue clayey and organic rich with an alternation of fine-laminated plant fragments and larger plant remains (fig. 6). The quantity of large plant remains, including fruits and spines, increases in the last two meters at the base of the core.

The 14C dates obtained in ORSTOM laboratories in Bondy (France) show that the sediments are Pleistocenic, almost all the core being older than the latest glacial maximum: at 54-57 cm depth the radiocarbon age-date is 18,180 +/— 930 years BP. The sedimentation rate between 54 and 225 cm is about 0.02 cm/y.

The sandy sedimentation event is difficult to date precisely because of the broad margin of error for the obtained values: 28,180 (+6660,—3600) years BP for the minimum age (222—225cm), and 28,050 (+2430,—1870) years BP for the maximum age (267-270cm).

Organic carbon fluctuates between 8 and 35% from the top of the core to the sandy layer, where it attains 5.6%. It increases abruptly below this level with values between 44 and 56% (fig. 6).

The carbon to nitrogen ratio (C/N) is high, attaining a maximum of 74 immediately below the sandy facies. High C/N correspond to terrestrial (non-planktonic) vegetation. Further studies of *in situ* vegetation are necessary for the interpretation of C/N variations.

Analysis of the stable isotopic carbon ratio (δ 13C) were performed by CENA/USP, Piracicaba. The δ13C also presents a drastic change in the sandy bed (fig. 6). The values lie between —22.72 and —24.29 per mille in the upper part, and between —27.02 and —28.56 per mille in the sandy layer and below, these last values corresponding to a vegetation with C3 photosynthetic cycle. Higher δ 13C values in the upper part of the core may be due to the introduction of plants with C4 cycle, such as grasses, or plants with a crassulacean acid metabolism (CAM).

The available data show that at the site of the CO5 core the filling-up, of the depression nearly stopped after the glacial maximum of 18,000 years B.P.

Preliminary pollen studies (LORSCHEITTER *et al.*, 1990) showed between 7.50 and 6m the presence of forest vegetation, probably corresponding to a mild climate. There follows a gradual forest decreasing and a field vegetation increasing up to about 2.73m (28,050 B.P.), probably related to a cold climate of semi-aridity. From 2.73m to the upper part of the CO5 vibrocoring there is a drastic reduction of forest elements, coinciding with a big increasing of field elements, indicating a dry paleoclimate until 18,180 B.P.

6 FINAL CONSIDERATIONS

In spite of the lack of direct evidence, the Colônia structure is probably an astrobleme. Preliminary studies of the Quaternary sedimentation are promising and further studies should be undertaken, such as (1) study of present sedimentary environments and the ecology of this particular swamp, (2) a second set of vibrocorings in order to sample the Holocene period, and, mainly, (3) the realization of a deep core through the complete crater-fill in order to obtain a continuous record of Quaternary and eventually earlier deposits.

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