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Limestones Strata of Poty Quarry (Paulista), State of Pernambuco

Evidences of a Catastrophic Event on the First Geological Record of the K-T Boundary in South America

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The stratigraphic record of the Cretaceous-Tertiary (K-T) boundary (the Poty quarry section) in the Pernambuco-Paraíba coastal basin, Northeastern Brazil, was the first K-T section described in South America with evidence supporting the interpretation that the impact of a bolide has caused the widespread biotic extinction at the end of the Cretaceous. The stratigraphic succession includes Gramame formation (marly biomicrites) which underlies Maria Farinha formation (intercalation of limestones and shales). Peculiarities such as iridium and fluorine anomalies, as well the occurrence of shocked quartz, spherules, tsunamiite bed, biotic extinction and other possible impact-related characteristics have been brought together in this report. A geochemical break for most of these elements is better expressed in the geological contact than in the K-T boundary, although iridium and fluorine anomalies have been determined exactly at the boundary. Palaeoenvironmental characterisation is determined by micropalaentological considerations, stable isotope data, and the presence of phosphatised fragments. Most of the particular characteristics described here, such as the geochemical anomalies (iridium, total organic carbon and fluorine) and the presence of a tsunami deposit, of possible shocked quartz grains, and of some impact-related spherules, give support to previous preliminary interpretations of this stratigraphic boundary as a sedimentary record of a catastrophic event marking the K-T boundary. All of these unique characteristics among other outcropping sedimentary sections known in Brazil justify the preservation of such geological site and its inclusion into the Brazilian Geological Heritage.

Keywords: Cretaceous-Tertiary bounday, iridium anomaly, Poty quarry, Pernambuco-Paraíba basin, tsunamiite

INTRODUCTION

The record of the geological events which occurred at the Cretaceous-Tertiary (K-T) boundary has been studied in multidisciplinary ways by different Geosciences branches and the study results have been responsible for important paradigmatic changes of geologic concepts in the last 25 years. In this aspect, the relevance of Alvarez *et al.* (1980) seminal work must be stand out. That was the starting and turning point for what is considered one of the most important scientific revolutions in Geosciences, following Kuhn (1978) definition. In the mentioned work, Alvarez and collaborators had considered the theory of an extraterrestrial impact to explain the environmental and biotic changes observed along the K-T boundary. Under this perspective, Albertão (1993) studied some outcropping and subsurface areas of the Brazilian basins, searching evidences or contrary arguments for the theory of Alvarez *et al.* (1980).

The Pernambuco-Paraíba Basin has been studied since the end of XIX century, mainly under the paleontological point of view, given the rich macrofauna, especially for clams and fish. Important aspects of the mineral exploration of this basin are related to the phosphate mining (in the contact between Beberibe and Gramame formations), which took place mostly in the decades of 1960 and 1970, and, more important, to the mining of the calcareous rocks (Gramame and Maria Farinha formations), present still in the current days. In relation to the K-T boundary approaching and its related outcrops of the Poty quarry, pioneering studies of Beurlen (1967), Tinoco (1967), Mabesoone *et al.* (1968) and Stinnesbeck (1989) must be quoted. Nevertheless, only after Albertão (1993) it is drawn a detailed description of this geologic section as an almost complete record of the K-T boundary events and determined some indications of a possible extraterrestrial impact.

The descriptions made in the present work appear more detailed in a series of works initiated by an M.Sc. thesis (Albertão, 1993, under orientation of the professor Paulo P. Martins Jr.) and continued in the period between 1996 and 2000 with the support of a project of the IGCP (International Geological Correlation Program - Project 384: Impact and Extraterrestrial Spherules). A succession of papers was published as result of such researches: Albertão *et al.* (1994a and b), Albertão & Martins Jr. (1996a and b), Marini *et al.* (2000), Martins *et al.* (2000), Albertão &

Martins Jr. (2002), Albertão *et al.* (2004) and Albertão & Martins Jr. (in press). Parallel, extensive micropaleontological studies have also been developed, resulting in some papers as well as M.Sc, and Ph.D. theses: Koutsoukos (1996), Grassi (2000), Fauth (2002) and Sarkis (2002).

Slightly weathered outcrops from the quarry and eventually other proximal areas were selected for good-quality sampling. Samples were collected for thin sections microscopic petrographic analysis, X-ray diffractometry (XRD), $\delta^{13}C$ and $\delta^{18}O$ total rock isotopic analysis (tr-IA), inorganic geochemistry (major, secondary and trace elements), micropalaeontology (foraminifera and pallinological), scanning electron microscope analysis (SEM), qualitative/quantitative chemistry in energy disperse spectrometer (EDS), determination of phosphate mineral types and petrographic descriptions of hand samples with binocular lens. As a by-product of the stable isotope analyses, the total organic carbon (TOC), insoluble residue (IR), and the $CaCO_3$ content of the sediments were also determined. The chemical determination of the abundance of 45 elements, including iridium (Ir), was conducted at Los Alamos National Laboratory by neutron activation analysis (NAA). Details on these analytical methods are described in Albertão (1993).

Spherules and quartz grains were manually separated and analyzed with binocular lens and scanning electron microscopy (SEM) with an attached semi-quantitative X-EDS system, according to the procedures described by Albertão *et al.* (1994b), Delício *et al.* (2000) and Marini *et al.* 2000. The Poty quarry was the first description of an almost complete sequence along the section of a K-T boundary in low latitudes of the South Hemisphere and in all South America, also presenting iridium anomaly. It is still the only outcropping area in Brazil with such characteristics. This peculiarity as well as many others which will be forward presented is enough justification to include this area as a geologic-stratigraphic-sedimentologic-paleontological site of the Brazilian Geologic Heritage and, consequently, to adopt the adequate actions for its protection.

LOCATION

Poty quarry is localized in Paulista county, Pernambuco State, Northeast Region of Brazil (Fig.1). The UTM coordinates are 9.117.000 N e 296.000 E. An easy access is granted through the road which connects Paulista city to the locality named Maria Farinha. From this locality one turns to the north and enter to the left accordingly the direction indicated by a road mark pointing to Votorantim mine, which owns the rights to explore the quarry.

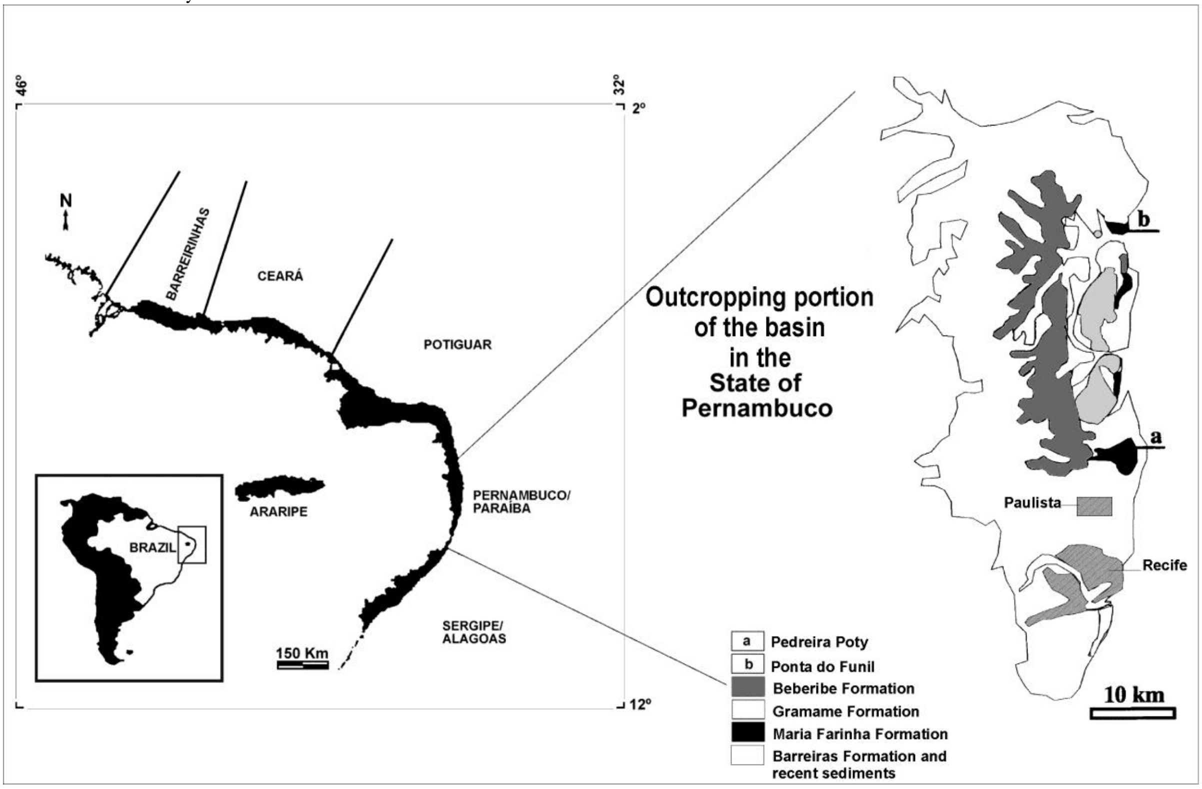

Figure 1 - Location map for the outcrops of Poty quarry (a, UTM 9,152,000N / 300,000E) and Ponta do Funil area (b, UTM 9,117,000N / 296,000E), State of Pernambuco. The two localities are about 30 km apart. Pernambuco-Paraíba basin is located among other northeastern marginal brazilian basins. Recife city (Pernambuco State capital) and Paulista town are indicated.

Figure 2 - General view of Poty quarry. First (1) level of the quarry (white) is mainly composed of Gramame Formation. Second and third levels (2 and 3) are composed by the basal portion of Maria Farinha Formation. Forth and fifth levels (4 and 5) are upper and weathered portions of Maria Farinha Formation. In fifth level Maria Farinha Formation is extremely weathered and erosively overlain by Barreiras Formation, and was not explored for limestone. Total vertical thickness of the quarry is about 25m.

Figure 3 – Present state of Poty quarry (2004). Basal portions of the quarry, seen in Fig. 2, are completely flooded by pluvial water, threatening the K-T limit beds and forming a lake about 7m deep. The outcrops just above the water level (about 2 m high) are composed by the uppermost portion of Gramame Formation and the base of Maria Farinha Formation (positive relief).

The quarry (Figs. 2 and 3) is a limestone mining with no exploitation since the beginning of the 2000. There are various benches opened for calcareous exploitation, in both Maria Farinha and Gramame formations. Pozolana clay, commonly used as refractory in industries, is presently exploited at the top of Maria Farinha formation, close to the contact zone with Barreiras formation.

Another studied area used for the subjects of the present research is Ponta do Funil, localized northern of Pernambuco State (Fig. 1), in the direction of Paraíba State.

SITE DESCRIPTION

Lithology Description

GENERAL INFORMATION

The PE/PB coastal basin is a passive-margin rift basin. Its origin is related to the South Atlantic ocean opening. The studied sedimentary succession was deposited during Maastrichtian and Danian ages and characterises a marine regressive mega-sequence, as defined by Chang *et al.* (1988).

In the Poty quarry, the outcropping sequence is composed of two formations (Gramame and Maria Farinha), which exhibit an erosive lithological contact. The Gramame formation is mostly composed by marly biomicrites of deep neritic to upper bathyal environment. The Maria Farinha formation overlays the Gramame formation and consists of alternations between limestones (biomicrites, biosparites and calcilutites) and shales deposited in a middle-deep neritic environment.

The sedimentary structures present at the transition from the uppermost Gramame formation to the basal portions of the Maria Farinha formation (such as hummocky cross-stratification, fining-upward and wavy bedding), as well as ichnofossil, geochemical, palaeontological and mineralogical data, characterise a carbonate ramp controlled by storms in a sedimentary process of progressive marine regression (Albertão, 1993). The strata are continuous and perfectly preserved with minor lateral facies variations, and present a slight structural dip (1 to 2 degrees) to the east and southeast.

Figure 4 shows the local sequence of outcropping beds, as well as the 59 main samples used in the present study. This profile is a composite of four different places of observation of the local stratigraphic record (named here points 1, 2, 3 and 4) and shows the reference level ("Datum" reference) for the profile determination; this "Datum" reference marks the lowest level of the quarry, situated in its western part, and it is here defined as the "zero" reference for all measurements. The interval from 0 cm up to 882.5 cm was measured and described in point 2; from level 882.5 cm up to 1022.5 cm in points 1 and 4, and from 1022.5 cm up to 2775.0 cm in point 3. The $CaCO_3$ content of the various beds was determined from average of XRD and calcimetry analyses performed on 46 samples and also from data obtained directly from the geological division of Poty quarry Company (Albertão, 1993). Accordingly to Flügel's (1982) criteria (Fig. 5), it was possible to classify the stratigraphic sequence of beds (Fig. 4).

The Poty quarry was divided into four mining benches for exploration purposes at the time of the detailed descriptions (Figs. 2 and 4): one is in the Gramame formation (the first one from the bottom of the quarry), and the other three are in the Maria Farinha formation. The complete outcropping exposure comprises an average thickness of 10 m for the Gramame formation and 18 m for the Maria Farinha formation. The lowest level of the quarry ("Datum" reference in Fig.4) occurs in the Gramame formation. Lately a lower bench was dig bringing into light older Gramame formation strata though no sedimentary trace of Beberibe formation, which is the oldest formation known around this area, was found. Fluvial sediments of the Barreiras formation truncate the top of the Maria Farinha formation (Fig. 2), but a discussion of this topic is beyond the scope of this paper.

The contact of both Gramame and Maria Farinha formations is thus identifiable at 964.5 cm (above the "Datum" reference; Figs. 4, 6 and 7a). Rock types are described accordingly to the Dunham and/or Folk system of classification (Flügel, 1982). The description below is devoted to both formations, to the contact within between them, and includes a discussion of the K-T boundary position.

THE GRAMAME FORMATION

From the base, at the reference level ("Datum" reference) to the erosive top, sediments of this unit are relatively homogeneous in composition (Figs. 2 e 4), alternating planktonic wackestones/mudstones and marls, with small variation of clays and bioclasts contents. This homogeneity is better represented in this formation than in the Maria Farinha formation. (Mabesoone *et al.,* 1968; Stinnesbeck, 1989). Primary sedimentary structures seem to be absent. In the horizontal direction the thickness of the great beds vary from a few centimetres to a few metres. Each great bed is composed of discontinuous laminae caused by bioturbation among alternating fine (millimetric) beds of limestones and marls.

Bioturbation structures are widespread in the contact between marls and carbonaceous rocks. Bioturbation structures are more conspicuous in marls. The sediments are constituted of alternating sequence of mudstones and planktonic wackestones with varying shale and bioclasts content. Micritic material is visible with a few cases of recrystallisation.

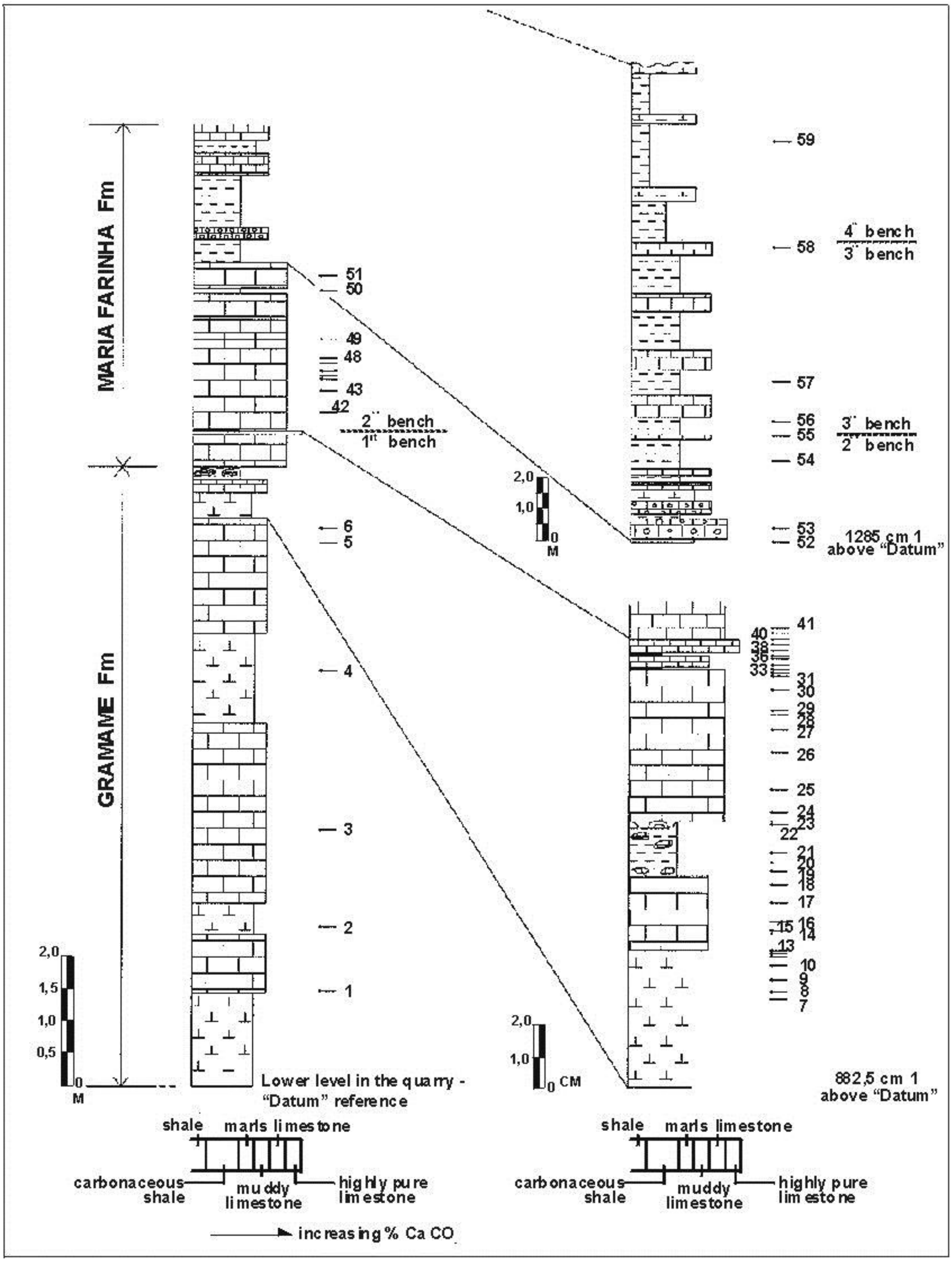

Figure 4 – Schematic geological section of Poty quarry. The stratigraphic location of samples 1-59 are indicated. Details of the section (lower part, right side of the figure) are also shown in Fig. 6. Lithological symbols are the same as in Fig. 6. See text for details.

Content of $CaCO_3$ in wt%	Classification
[0-20)	shale (clay minerals)
[20-40)	carbonaceous shale
[40-65)	marls
[65-80)	muddy limestone
[80-95)	limestone
>95	high-purity limestone

Figure 5: Criteria for the characterisation of stratigraphic beds accordingly to the $CaCO_3$ content in the Poty quarry (after Flügel, 1982).

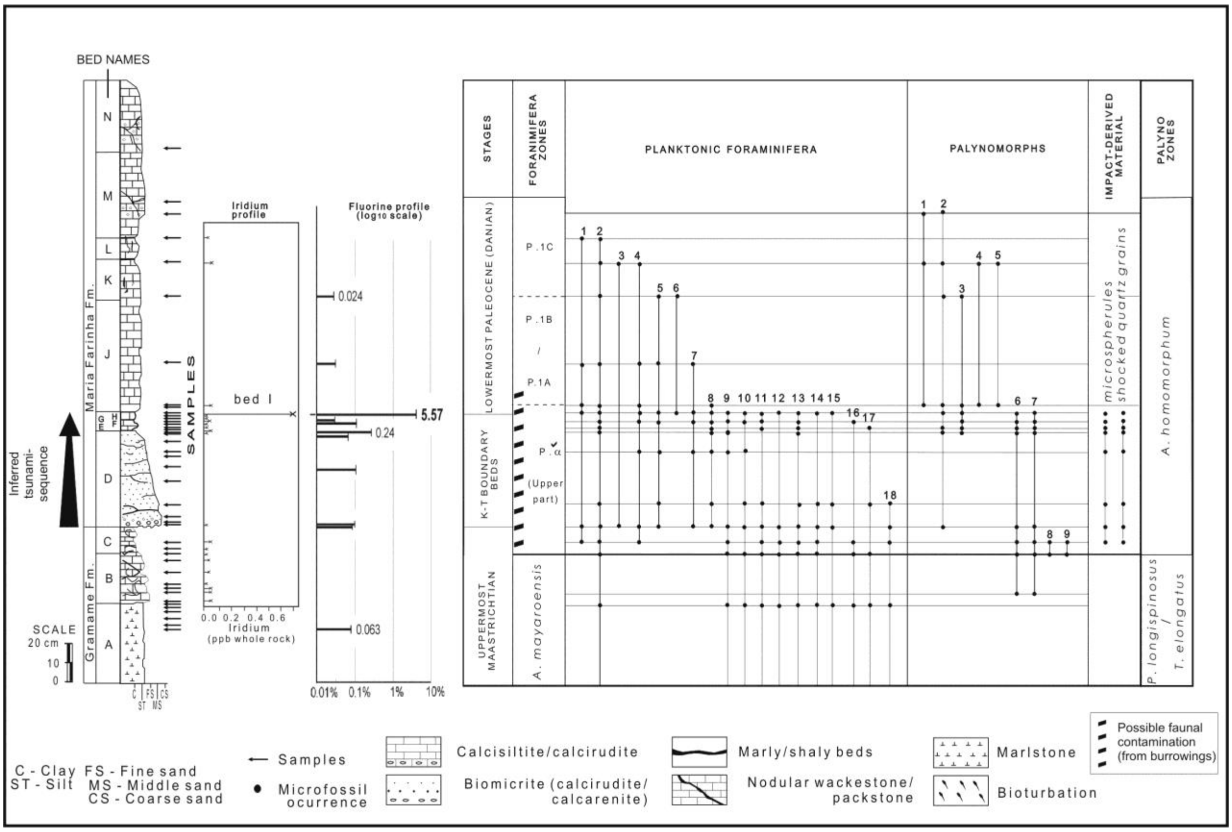

Figure 6– Litho- and chemostratigraphy (iridium and fluorine) and distribution of microfossils across the measured K/T boundary section in the Poty quarry. Observe the iridium and fluorine anomalies in a 2-3 cm thick claystone (bed **I**, in planktonic foraminífera zone upper P.α). Original foraminifera zones from Koutsoukos (1996) and Albertão et al. (1994b) are taken into account, although for the K-T boundary placement beds **D** to **I** are considered as boundary beds. Possible faunal contamination under bed **I** is also taken into account. **Planktonic Foraminífera** (analysis by dr. Eduardo A. M. Koutsoukos): *(1) Woodringina hornestownensis; (2) Guembelitria cretacea; (3) Parasubbotina pseudobulloides; (4) W. claytonensis; (5) P. aff. pseudobulloides; (6) Eoglobigerina eobulloides; (7) Praemurica taurica; (8) Parvularugoglobigerina eugubina; (9) Pseudotextularia nuttalli; (10) Pseudoguembelina costulata; (11) P. palpebra; (12) Rugoglobigerina ex gr. rugosa; (13) R. scotti; (14) Contusotruncana contusa; (15) R. reicheli; (16) Globotruncana aegyptiaca; (17) Racemiguembelina fructicosa; (18) Globotruncana falsocalcarata.* **Palynomorphs** (analysis by dr. Marília S. P. Regali): *(1) Proxapertites cursus; (2) Pterospermopsis sp.; (3) Veryhachium reductum; (4) Schizeoisporites eocenicus; (5) Echitriporites trianguliformis; (6) Ariadnaesporites sp.; (7) Dinogymnium spp.; (8) Cricotriporites almadaensis; (9) Crassitriapertites vanderhammeni.*

Planktonic foraminifera predominate over bentonic ones. Calcispherulids, radiolaria and echinoderms are also present. Fragments of phosphatised vertebrates and grains of siliciclasts, mainly silt-size quartz, are rare.

The neighbourhood of the contact between the Gramame and the Maria Farinha formations is characterised by 14 beds that are named here by letters from **A** to **N**. Their petrographic and fossil content is described in figure 8 and illustrated in figures 4, 6 and 7. Beds **A**, **B** and **C** are in the Gramame formation whilst beds **D**, **E**, **F**, **G**, **H**, **I**, **J**, **K**, **L**, **M**, and **N** are in the Maria Farinha formation. In figure 6 the succession **A**-**N** is complete and schematically represented, meanwhile in Figure 7a it is visible the lithologic contact and beds **B** to **H** can be identified.

In between beds **C** and **D**, a conspicuous break of the sedimentary depositional regime occurs, which characterises the lithological contact of both formations. Beds **A,** **B** and **C** have similar characteristics which are also similar to those of the underlying rock beds. From bed **D** upward there is an increasing lithological variation with complete distinction from the underlying beds (see description in figure 8 and illustration in figures 4, 6 and 7).

THE CRETACEOUS-TERTIARY (K-T) BOUNDARY

The K-T boundary at the Poty quarry has been located in two different places (Albertão, 1993; Albertão *et al.,* 1994a; Koutsoukos, 1996; see figures 6, 7 and 8).

The first location is a continuous and very thin marly bed (bed **I**). The boundary is defined by micropalaeontological analysis, with biotic extinction (Albertão, 1993), geochemical anomalies, such as Ir, with a maximum value of 0.69 ppb, (Albertão, 1993; Albertão & Martins Jr., 1996a; Figures 6, 7a, 7b) and TOC (Albertão, 1993; Albertão & Martins Jr., 1996a), spherules crystals (Albertão *et al.*, 1994b; Albertão & Martins Jr., 1996a), some of them containing fluorite

(Marini & Albertão, 1999; Marini *et al.,* 2000), and some rare, possibly shocked, quartz (Albertão *et al.,* 1994b; Albertão & Martins Jr., 1996a). Despite the fact that fluorine (F) is not generally accepted as an indicator of a K-T boundary, a distinct F anomaly of 5.57 wt.% (in stark contrast with F contents of less than 0.3 wt.% in all other samples) has also been detected in the same bed **I** (Marini *et al.*, 2000).

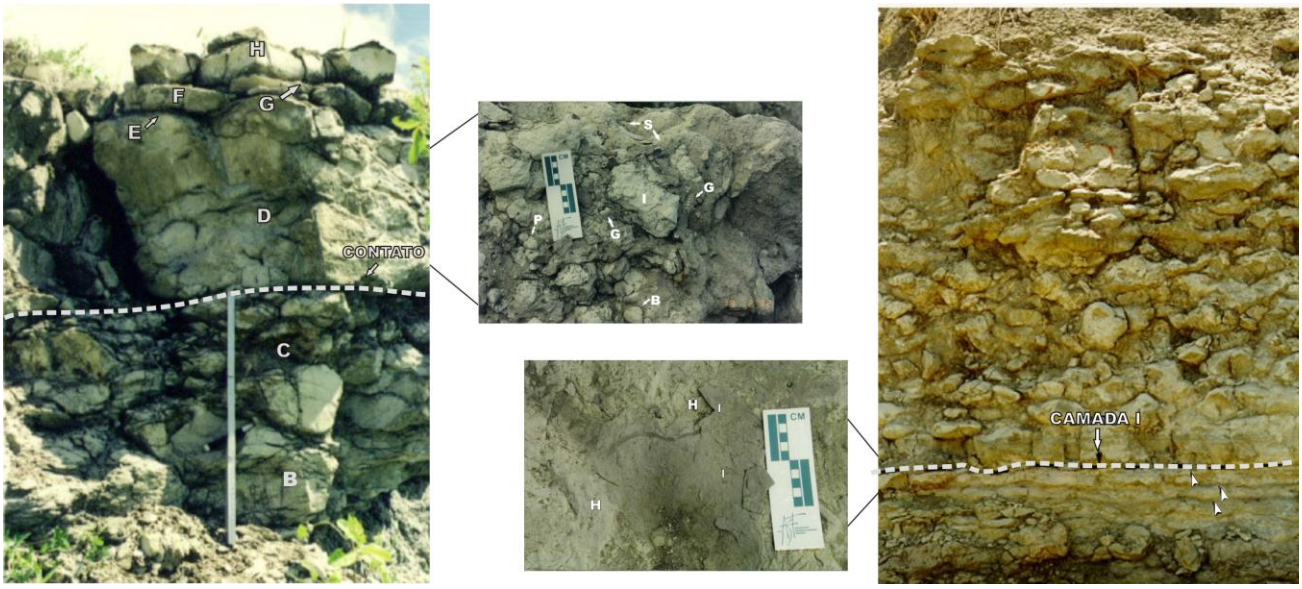

Figure 7a – Photograph showing the lithological contact ("contact" indicated by an arrow) between Gramame and Maria Farinha formations. (Poty quarry). From the base to the top, beds **B**, **C**, **D**, **F** and **H** are represented. Beds **E** and **G** are fine marls between respectively beds **D** and **F**, and **F** and **H**. Bed **I** overlies bed **H,** but is not visible in the photo. Bed **A** underlies bed **B,** but is covered by debris in the photo. It is possible to observe the erosive character of the contact between beds **D** and **C**, the interference ripples (like a wavy bedding) structures above bed **D** and the breccia-aspect of bed **C** (scale bar in the photo: 1.0m).
Detail of 7a - Block of bed **D** (Poty quarry) with its characteristic heterogeneous composition (phosphatised fragments -**P**-, fragments of gastropods -**G**- and bivalves -**B**-, siliciclasts -**S**-, intraclasts-**I**-) and coarse grain size.

Figure 7b - Continuous and non-weathered portion of the section across bed **I** in Poty quarry. Beds **D** (base) to **N** (top) are shown in the photograph. Marly beds **E**, **G** and **I** (the Ir-rich bed, designated "limit" in the figure) are indicated by arrows. It is possible to observe interference ripple structures in the couplets **E**/**F** and **G**/**H**. Total thickness of the sequence in the photography is 2.5 m.
Detail of 7b - Poor and rare preservation of bed **I** in the swales (formed by the ripples) at the top of bed **H**. Bioturbation across beds **H** and **I** is observed. Bed **I** is usually less than 1cm thick at these swales; it exhibits Ir, TOC and fluorine anomalies.

The other location is at the top of a non-graded, nodular carbonate mudstone to wackestone (bed **B**), situated about 75 cm below bed **I** (Fig. 5). At this very position, after a very detailed foraminifera investigation, the first Danian planktonic taxa were determined (Albertão *et al.*, 1994b; Koutsoukos, 1996). Also more recent biostratigraphic analysis on marine ostracodes and dynoflagellates (Fauth, 2000; Sarkis, 2002) indicate a possible boundary position at the top of **B**.

Albertão & Martins Jr. (1996a) discussed this ambiguous and controversial situation, and suggested the possibility of contamination by post-depositional biogenic burrowing, which permitted microfossils to migrate from the more recent stratum to the older one. This situation is described elsewhere in K-T boundary sections (Albertão, 1993).

However, a third point of view must be considered. Catastrophic events and their related products require unusual sedimentologic and paleontological approaches (Shiki, in press; Albertão & Martins Jr., in press). In the case of sudden mass extinction, the disappearance of the older fauna/flora should be considered as the reference to the boundary placement, and not the first appearances, which may be misleading: it is possible that animals and plants may have appeared at the end of a determined age and survived to another one, despite dramatic environmental changes after the catastrophe. In addition special attention has to be paid to sediment reworking, which may produce deposition of reworked older fossils in younger sediments; in this case reworked/older and *in-situ*/younger fossils would appear mixed in K-T beds (as it is the case of beds **D** to **H** in Poty quarry; see figure 6). Finally, one has to consider that in case of catastrophic events the time scale to be used is very different from that of "normal" sedimentation: a unique bed, of meters in thickness, can be deposited in some minutes or a few hours; this is a well-known fact related to turbidites deposition (Dott, 1983). Based on such discussion, we propose that (see figure 6):

- top of bed **C** is the final record of Upper Maastrichtian;
- beds **D** to **I** represent indeed the boundary beds: base of bed **D** marks the beginning of the tsunami event while beds **E** to **I** are the record of its end (see ahead in next topics), and it is impossible to establish any time-stratigraphy, based on the fossil content, throughout this bed sequence;
- top of bed **I** and base of bed **J** represent the beginning of Danian sedimentation;

The recognized geologic characteristics point to a catastrophic event in the proximity of the K-T boundary: the presence of possible tektites and shocked quartz in beds **D** to **I** and for more the iridium anomaly in layer **I** are indications which give some support to the extraterrestrial impact hypothesis at the K-T boundary; one has to take into account the Chicxulub event, at Yucatán Peninsula (Mexico) which was probably responsible for the worldwide record of this impact (Hildebrand *et al.*, 1991). Bed **D** (Fig. 7a), as it is characterised ahead, has unique characteristics which give support to the hypothesis of a deposition induced by a tsunami as a late result of the impact.

The occurrence of microspherules and possible shocked quartz is restricted to the sequence of beds **D** to **I**. The microspherules have external aspect very similar to tektites described in other K-T boundaries over the world (Fig. 9a), but their impact origin in Poty quarry is not entirely evident (Marini *et al.*, 2000). The majority of the sampled spherules in the PE/PB basin are composed mainly of F-rich apatites and strongly differ from Al- or Fe- rich phosphates described elsewhere (Marini *et al.*, 2000), from altered K-T boundary impact glasses.

On the other hand, spherules with fluorite crystals (*white* class), which are present only in bed **I,** although diagenetic, may have an indirect impact relation, considering the high F-abundance in this stratigraphic level (Marini *et al.*, 2000; Fig. 6). This hypothesis is supported by the following observations: [1] a F anomaly occurs in the same bed as the Ir anomaly, and [2] evaporitic rock sequences, such as those that were impacted at Chicxulub (Hildebrand *et al.*, 1991), are usually F-bearing sediments. Abnormal and global fluorine release should be taken into consideration if further studies confirm increasing occurrence of diagenetic fluorite (and other F anomalies) close to the K-T boundary in other, more classical, sections.

Some fragments of shocked quartz grains with multiple sets of deformation lamellae also occur in beds **C** (extremely rare) to **I** (Fig. 6). The intersecting sets of straight planar lamellae (Fig. 9b) were most probably formed by shock-metamorphic processes and are similar to those of shocked mineral grains found in rocks from known impact structures (Jansa, 1993) and from other K-T boundary sites (Bohor, 1990).

THE MARIA FARINHA FORMATION

Overlying the Gramame formation and underlying the Barreiras formation, the Maria Farinha formation (Figs. 2, 4, 6 e 7) is about 18 m thick in the quarry area. It is composed of alternating beds of limestones, marls and shales. From the base upwards, there is a general tendency of a progressive decrease of the $CaCO_3$ content and an increase of marly sediments. There is also both an increase of the abundance of siliciclasts and an increase in the frequency of dolomitised material. Structures such as swaley cross-stratification are of metre size.

Bioturbation with *Thalassinoides* (greater than 2 cm) and *Fugichinia* structures are common, especially around the horizon of contact between marls and limestones. The limestones are predominantly wackestones/packstones and show some fining-upward and wavy bedding structures. Bioclasts are more common in sediments with gastropods, worm tubes, ostracods, and phosphatised fragments. Large foraminifera (*Nummulites* up to 2 mm) are common in clay-rich layers, although bentonic foraminifera dominate in the sediments.

Planktonic/bentonic ratios decrease from the bottom upwards, whereas the content of siliciclasts and clay increases. Locally, micro- and macro- bio-structures, such as burrows and other trace fossils are also present. Figure 8 presents a description of all beds across the K-T boundary and also of the lithological contact, as shown in figure 7a.

Geochemical considerations

Neutron activation analysis provided data for a geochemical description of the relative abundance of 35 elements across K-T boundary at the Poty quarry. These elements were selected because they were determined in most of the analyzed samples. The number of elements and samples permitted the statistical treatment of the analytical data, which aids in the description of the sedimentary processes (Albertão, 1993; Albertão & Martins Jr., 1996b; Albertão & Martins Jr., 2002).

It must be clear that the main geochemical discontinuity occurs just in the contact between Maria Farinha and Gramame formations (in between beds **C** and **D**), and this is coherent with the observation of an erosive event at the base of bed **D** (Figs. 4, 6 and 7a). Bed **I** (Fig. 7b) also marks a minor geochemical break for these described elements but this is exactly the bed which presents conspicuous Ir and F anomalies. Given the importance of Ir for the characterization of the K-T boundary, the following discussion goes deeper into the subject.

Beds	Local names	Width (cm)	Rock types and content description
A	Marga I	40	Wackestone / packstone with planktonics / phosphatised grains / fossils / some worms' tubes *Hamulus* / bioturbation mainly *Thalassinoides* / pelecypods, echinoderms, foraminifera
B	Poty I	25	Doubtful K-T boundary (Koutsoukos, 1996) / nodular limestone / wackestone – locally packstone / bioturbation / more planktonic foraminifera than bentonic ones / *Hamulus*, echinoderms, ostracods, calcispherulids / phosphatised fragments
C	without local name	15	Same as **B** though **C** is more "marly" / spherule occurrences / first observation of very rare and thinly Danian foraminifera
D	Capim	50	Erosive lithological contact (at the base) / Packstone upgrading to wackestone-mudstone / rare bioturbation / spherule occurrences / rare, possibly shocked quartz grains / bio and siliciclastic gross sands / phosphatised fragments (partially glauconitised – pyritised), of foraminifera, gastropods, pelecypods, worms' tubes, echinoderms, shark's teeth, wood (rare)
E *	without local name	2	Continuous marl / spherule occurrences / bentonic and planktonic foraminifera / echinoderms / phosphatised fragments / siliciclasts
F *	Topo do Capim	3	Similar to upper **D** bed / mudstone-wackestone / spherule occurrences
G *	without local name	2	Marl / spherule occurrences / planktonic foraminifera / echinoderms, fragments of worms tubes / less siliciclasts and phosphatised fragments than **E**
H *	Batentinho	4	Recrystalised limestone / mudstone / rare bioclasts, mainly foraminifera / spherule occurrences / bioturbation – *Chondrites*, *Planolites*, worms' tubes / **E***, **F***, **G***. **H*** - alternating mudstone/marl thin beds with complex interference ripples structures throughout the quarry
I	without local name	2	"Marly" mudstone / most probable K-T boundary end-layer / spherule occurrences / rare, possibly shocked quartz grains / globigeriniform planktonic foraminifera, bentonic ones / few siliciclasts and phosphatised fragments / Ir, F, and TOC anomalies
J	Vidro	58	Apparently recrystalised micritic mudstone / tiny planktonic and bentonic foraminifera / echinoderms, rare calcispherulids / slightly bioturbated
K	without local name	20	Similar to **J** / bioturbation / bioclasts with glauconite grains and rare phosphatised grains
L	Topo do Vidro	23	Intensively bioturbated / almost brecciated / gastropods fragments / foraminifera / phosphatised and glauconitised grains
M	Enfornação do Vidro	35	With some elements of **L** / wackestone-packstone / fining-upward / abundant bioclasts / some phosphatised fragments / large (up to 7 mm) gastropods fragments/ worms tubes (serpulids), arthropods, mainly bentonic foraminifera, rare bryozoa / phosphatised pellets eventually from *Calianassa* arthropod /
N	Batente	28	Similar to **M** / thicker grains size at **N** basis than at the top of **M**

Figura 8: Summary description of field and petrographic observations of the neighbourhood of the lithological contact between Gramame (beds **A**, **B** and **C**) and Maria Farinha (bed **D** up to bed **N**) formations; see also figures 2, 4, 6 and 7.

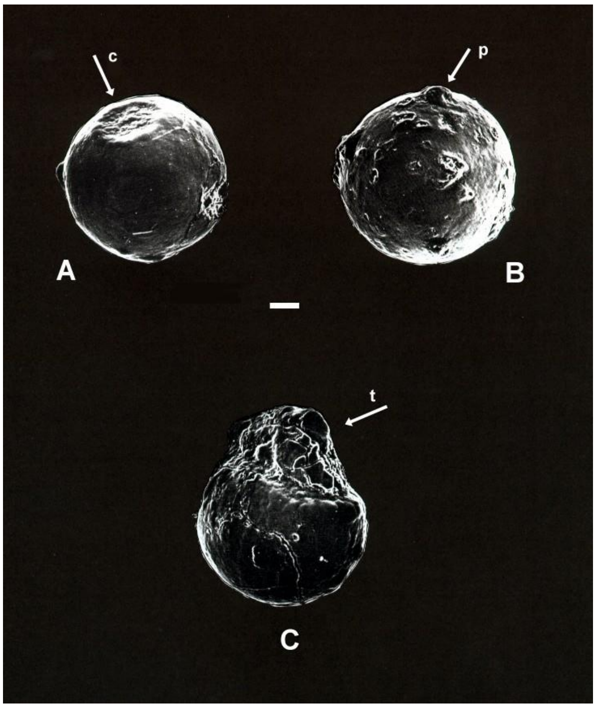

Figure 9a - Scanning electron photomicrographs of three selected microspherules recovered from the Poty quarry section (bed **I**) -reveal their external aspects. Scale bar = 20µm. Microspherule (A) presents conspicuous "crater-like" pits (c), circular to irregularly shaped, and a very smooth surface. Microspherule (B) exhibits a more corroded surface with protruding mounds or protrusions (p). Microspherule (C) exhibits an upper portion similar to a tail (t).

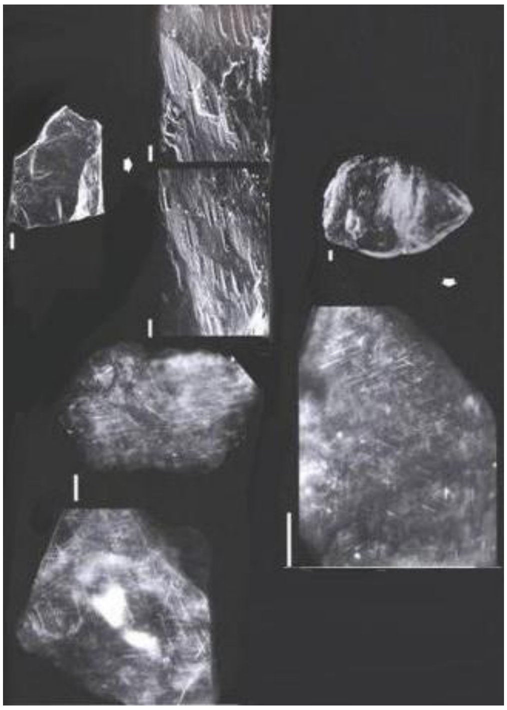

Figure 9b - Photomicrography (with details on SEM) of possible shocked quartz grains from bed **D** (sample from the Poty quarry), exhibiting intersecting sets of sharp and straight planar lamellae. Scale bar = 120 µm. OBS.: Photographs of Fig.9 are courtesy of Eduardo A. M. Koutsoukos.

Iridium, as a representative of the platinum-group elements (PGEs), is an important indicator of the possible presence of extraterrestrial material in sediments, if its content is significantly higher than typical crustal values. Such significant enrichments in Ir and the other PGEs have been found in the K-T boundary samples from locations all over the world, including the PE/PB coastal basin. Sample 39 of bed **I** (Figs. 4 and 6) has an elevated content of Ir compared to average crustal abundances, which is in general lower than 0.1 ppb. The measured content (0.69 ppb) is about 26 times higher than the average measured for the other samples from the Poty quarry analysed in the present paper.

Michel *et al.* (1985) observed that an increase in Ir content may be correlated with a decrease of the $CaCO_3$ content in sediments. These authors have suggested that this is the result of normal sedimentary processes, where sediments richer in clay minerals are also richer in Ir. It is well-known that the clay content is usually inversely proportional to the $CaCO_3$ content of sediments. Therefore, Michel *et al.* (1985) suggested that it is important to determine the ratio Ir/clay content to determine if the high values of Ir present in sediments are really anomalous or if they are just "artifacts" of clay content influence.

According to Michel *et al.* (1985 and 1990), high contents of Fe and Al are representative of the presence of clay minerals. Thus, examining the ratios Ir/Fe and Ir/Al, it is possible to determine if indeed there is an enrichment in Ir compared to normal sedimentary values. Another way to verify the ratio Ir/clay content is directly through the ratio Ir/clay minerals, with the clay minerals content obtained from XRD analyses. In all of these examined cases (Ir/Fe, Ir/Al and Ir/clay minerals) for this present study it is evident that there is a strong anomaly of the ratio Ir/clay content in bed **I** of Poty quarry.

Bed **I** also has a TOC anomaly. The soot enrichment in K-T boundary layers was associated to possible occurrence of global fires caused by the entrance of the extraterrestrial bolide into the atmosphere (Wolbach *et al.*, 1988).

Paleoenvironmental considerations and geological processes across the K-T boundary

Palynological data give a good definition for level **I** as the last level deposited during the Cretaceous (Albertão 1993) and may also serve as a controlling factor for determining other extinction such as those of foraminifera or other taxa. In general, palaeontological data clearly show a period of crisis at the very end of Cretaceous, with the extinction of pollen and foraminifera. The relatively high abundance of smooth and ornate trilets spores of palms just above the K-T boundary gives the impression of an "explosion" of opportunist forms. The Ir anomaly is precisely at the boundary at which fossils become extinct, which confirms the crisis at the very end of Cretaceous.

Stable isotopes data (Albertão, 1993; Albertão & Martins Jr., 2002) indicate that minimal values of $\delta^{13}C$ occur close to the K-T boundary; this is interpreted as a result of possible reduction in primary productivity. Increasing values of $\delta^{13}C$ in the same intervals point to a trend of paleotemperature reduction. These observations are coherent with worldwide observed data of other K-T boundary sections.

Phosphatised fragments (intraclasts and bioclasts, usually fine to coarse sand in size, but eventually reaching cobble size in bed **D**; see detail of figure 7a) occur in two parts of the main sequence: on the base of the Maria Farinha formation (base of bed **D**) and on beds **M** and **N**, mostly on **M** (see figure 8). The following observations may suggest that phosphatised fragments are the result of reworking from underlying beds: (1) round shape of phosphatised intraclasts; (2) partially oxidised external borders of intraclasts; (3) indiscriminate phosphatisation of many different materials, such as fecal pellets (mainly from *Calianassa*), pelloids, various bioclasts (molluscs, echinoderms, foraminifera, worm tubes, etc.) and intraclasts; (4) presence of fining-upward structures that occur not only in phosphatised fragments, but also in siliciclasts and non-phosphatised bioclasts, particularly in bed **D**. High $\delta^{13}C$ values occur at the same very position of strong phosphatisation what may indicate upwelling events. From this one can interpret that beds **D**, **M** and **N** could be the bad preserved remaining portions of such events.

Bed **D** has been interpreted as a tsunami deposit (Albertão, 1993; Albertão & Martins Jr., 1996a; Albertão & Martins Jr., in press). The unique stratigraphic and sedimentological characteristics of bed **D** indicate rapid deposition:

1. a sharp erosive base (Fig. 7a);
2. following a fining-upward succession composed of shells, siliciclasts and abundant phosphatised fragments at the base (Figs. 6, 7a and detail of 7a);
3. extensive mixing and fragmentation of fossils derived from different palaeobathymetries and reworked from older strata (detail of figure 7a);
4. presence of very different grain sizes from fine sand to pebbles (detail of figure 7a);
5. coarse grain-size of intraclasts and bioclasts (of up to 9 cm in diameter; detail of figure 7a);
6. scattered presence of possibly impact-derived products (spherules and possibly shocked quartz grains; Fig. 9);
7. interference ripples immediately above the top of bed **D** (present at beds **E**, **F**, **G**, **H** e **I;** Figs. 7a, 7b and detail of 7b);
8. great lateral continuity in the basin, for at least 30 km in Pernambuco.

The great lateral continuity of bed **D** is one of its most conspicuous characteristics, because it is possible to follow this bed from the Poty quarry to the Ponta do Funil area, which are around 30 km far apart (Fig. 1). Between these two areas is Itamaracá Island, from where the same bed **D** was recovered in a core of the well 2-Ist-1-PE, drilled by Petrobras (Petróleo Brasileiro S.A.).

Semi-quantitative modelling performed for the particular characteristics of bed **D** (see Albertão & Martins, 1996a, for details on the modelling parameters) has indicated the plausibility of the action of a tsunami as the responsible process for its deposition.

It is noteworthy the necessary wave energy for the deposition of sediments with such grain sizes, given the existing water depth (paleobathymetry data obtained from foraminifera analysis in underlying and overlaying strata), and the rapid energy decreasing. This interpretation is based on the existence of interference ripples at the top (beds **E** to **H**; Figs. 6 and 7); deposition of layer **I** (detail in Fig. 7b), with the Ir anomaly, ends this sedimentary sequence of events.

SITE PROTECTION

The quarry where the K-T limit is located is apparently no longer in exploitation and there is no administrative instance in charge of its conservation. Votorantim Corporation is the owner of this area as well as the one responsible for the limestone mine. In the case of an active mining, the geologic site would be possibly menaced by the calcareous extraction, although the main part in terms of the K-T boundary interest is out of the area prepared for mining exploitation. This fact grants in principle the preservation of this geologic monument without losses by the mining company. On the other hand, presently, special attention must be given to the effects of natural agents, particularly rain.

More recently, in 2004, during a field work, it was possible to observe that rain waters have already formed a large and deep pond which covers most of benchs excavated in Gramame formation (Fig.3), strongly menacing the beds of the K-T boundary.

These authors strongly suggest a joint action of institutions (eg.: SBG - Geological Brazilian Society), universities (eg.: UFPE - Pernambuco Federal University), national agencies (eg.: CPRM - Brazilian Geological Survey - and DNPM - National Department for Mineral Production), as well as large companies (eg.: Votorantim and Petrobras) to protect this site, safeguarded the economic interests of the company which withholds the rights of mineral exploration.

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