IV Cuban Geological and Mining Congress

Geomin' 2001

La Habana, Cuba. 19-23 de Marzo/2001

Field trip guide to the Cretaceous-Tertiary Boundary in western Cuba

March 17-18, 2001

AUTORS: Dora García Delgado
Reinaldo Rojas Consuegra
Consuelo Díaz Otero
Riuji Tada
Manuel Iturralde Vinent

INDICE

1. INTRODUCTION

Cretaceous-Tertiary Boundary (KTB) sections have been long ago recorded in the Cuban literature (Iturralde-Vinent 1976-77, Kantchev ed. 1978, Fernández et al. 1989). The first paper describing the origin of some latest Cretaceous sections in relation with a possible catastrophic event was that of Pszczolkowski (1986). He described the Late Maastrichtian Amaro, Peñalver and Cacarajícara Formations as thick single-graded fining-upward calcareous megaturbidites. He argued that the megaturbidite was deposited as a consequence of a large sea wave (tsunami) and recognized two possible explanations for the origin of the wave: a large earthquake or an asteroid impact. He proposed that the earthquake took place probably along some fault located at the southern edge of the Bahamas platform. Later Bohor and Seitz (1990) proposed that the Island of Youth may have been the site of the KT extraterrestrial impact, and the "Big Boulder Beds" of the Havana Formation (Palmer 1945) part of the impact ejecta blanket. But Iturralde-Vinent (1992) demonstrated that the Island of Youth was not the site of the alleged impact, neither the Big Boulder Beds an impact ejecta. In the same paper he proposed that the megaturbidites may be originated from a large asteroid impact that took place not at the KTB but sometime early in the Late Maastrichtian and the site of the impact also located within the western Caribbean sea, south of the Protocuban platform.

1.1 GEOLOGIC SETTING OF THE KTB IN CUBA

The Cuban Mezo-Cenozoic foldbelt is represented by a group of different allochthonous units which includes the Bahamas platform and foreland sediments, the Cuban southwestern terrenes (Guaniguanico, Pinos and Escambray), the northern Ophiolites and Placetas belt, the Cuban segment of the Cretaceous volcanic arc and piggyback basins, and the Paleogene arc. Latest Eocene to Recent represents the autochthonous slightly deformed sedimentary cover (Iturralde-Vinent 1994, 1996, 1998).

The latest Maastrichtian-KTB sections are present in some of these geological contexts (Fig. 1). The Lutgarda Formation within the southern slope of the Bahamas platform (Camajuaní belt), the Amaro and Rodrigo Formations within the ProtoCaribbean ocean floor sediments (Placetas belt). The Peñalver, Mícara and Santa Clara Formations within the sedimentary basins above the Cretaceous volcanic arc, and the Moncada calcarenites and Cacarajícara Formations in the Guaniguanico terrane (Los Organos and Rosario belts) (Pszczolkowski 1986, Iturralde-Vinent 1992, Rojas et al. 1997, Dora et al. 1998 and Iturralde-Vinent et al. 2000).

2. FIELD TRIP

During the field trip will be visited the most important localities of the KTB sections in western Cuba. In these region the following units occur: Moncada calcarenites in the Sierra de Los Organos (Stop M-1), Cacarajícara formation in the Sierra del Rosario (Stop C-2), and in the Havana region the Peñalver formation (Stop P-3 and P-4), (Fig. 1).

2.1 MONCADA CALCARENITES

The Moncada calcarenites are located 18 km to the west of Viñales town, along the road to Pons, just at the entrance to the Moncada village (Fig. 1). From this locality Iturralde-Vinent (1995) described 2 m thick calcarenites at the base of the Paleocene Ancon Formation.

2.1.1 STOP M-1 (MONCADA, VALLE DE VIñALES)

Coordinate: X-207 500, Y-305 600 Sheet Minas de Matahambre

The Moncada Formation in this locality overlies dark gray-bedded limestone of the Late Cretaceous Pons Formation, and consists of a 200 cm thick sandstone unit, overlying by a 4 cm thick siltstone to claystone unit (Figs. 2 and 3).

The sandstone unit consists of alternations of coarse to medium grained olive gray sandstone layers (22 - 76 cm), and medium to fine-grained light to dark gray calcareous sandstone layers (9-17 cm). The olive gray sandstone layers are either massive or parallel laminated, whereas dark and light gray calcareous sandstone layers are generally cross-laminated.

The 4 cm thick siltstone to claystone unit consists of purplish brown claystone (2 cm) with thin fine sandstone lenses, a light brownish claystone layer (1 cm), an olive gray fine sandstone layer (1 cm), and yellowish brown clay layer (1 cm) in ascending order (Fig. 4).

The upper siltstone to claystone unit grades upward into gray fissile limestone (marly limestone), which is 35 cm thick, and then to dark gray bedded limestone of Paleocene Ancon Formation.
The Ir and Ni anomaly was found in the clay layers of the upper unit whereas shocked quartz and altered vesicular glass with pyroxene quench texture was found throughout the formation (Nakano et al. 2000; Tada et al., in press; Figs. 4 and 5).

2.2 CACARAJÍCARA FORMATION

This formation extensively outcrops in the Rosario mountains belt over an area more than 30 km long and a few kilometers wide (Fig. 1). Pszczolkowski (1978, 1986, and 1994) has described it as a megaturbidite. The type section was designated in Sierra de Cacarajícara (Hatten 1958), but an excellent exposure is found on both sides of the road from Soroa to Bahía Honda, near Loma Cornelia, as well as along the river cut running parallel to the road. In general the Cacarajícara Formation can be subdivided into two members: the Lower Los Cayos breccia member (Pszczolkowski 1978, 1994) and the calcarenites member (Fig. 6).
A grain-supported boulder to pebble breccia composes the Los Cayos member, up to 150 meters thick (Figs. 7 and 8). The age of the clasts range from late Jurassic to Maastrichtian (Pszczolkowski 1978), and include micritic limestone, foraminiferal limestone, rudist-bearing shallow water limestone, banded radiolarian chert radiolarian-bearing black chert, and less than 10% volcanic and metamorphic rock fragment. These kind of rocks are found in the underlying sections of the Los Organos and Rosario mountains (Pszczolkowski 1978), so the bulk of the clastic material belong to the Yucatan borderland because Rosario and Organos are considered to have been formed in such original position.
Cacarajícara formation is in erosional abrupt contact with the underlying rocks, represented by strata of Jurassic through Campanian age (Moreno Formation) in different localities. The Lower Paleocene Ancón or Manacas Formations rest conformably but without transition above either member of the Cacarajícara Formation.
The age of the Cacarajícara Formation has been usually identified as late Maastrichtian (Pszczolkowski, 1978, 1994), because of its stratigraphic

position and age of the younger fossils found in the uppermost part. But Cacarajícara yields a classic paleontological cocktail *sensu* Bralower et al. (1998), as well as a lithoclastic cocktail. The presence of shocked quartz and the absent of Paleocene fossils suggest that the age of the unit is KTB (Kiyokawa et al. 2000).

2.2.1 STOP C-2 (LOMA CORNELIA, SOROA)

Coordinates: X-286 500, Y-339 500 Sheet Bahía Honda

In this locality the original thickness of Carajícara Formation is well preserved. Exposures are both along the road and along the river creek parallel to the road (Fig. 8). The section is underlain by the Polier and Santa Teresa Formations (Cretaceous), and overlain by the Ancon Formation (Paleocene).
In the basal part of this section occurs the **Lower Los Cayos breccia Member**, which thickness reaches at least 150 m, and it is composed by grain supported boulder breccia. This breccia include micritic limestone, foraminiferal limestone, rudists bearing shallow water limestone, banded radiolarian chert, and radiolarian-bearing black chert.
The orientation of imbricate oblate breccia suggests that the paleoflow direction of this member was from north to south, but these units were probably rotated during tectonic emplacement.
The breccia has less 1 % of dark brown matrix; and it is composed mainly of siltstone that contains small amount of foraminifers, carbonate clasts, volcaniclastics and gray color translucent spherule like grains (Kiyokawa et al. 2000).
The Los Cayos Member may be formed by a high-energy flow while calcarenite member by decantation. These two different flow patterns in a single fining upward sequence suggests that the Cacarajícara Formation be formed by a hyperconcentrated flow (Kiyokawa et al. 2000), but it is also possible that the upper calcarenite member was formed under the influence of large tsunami waves which resuspended sand and silt particles in the deep sea environment.
The **Upper sandstone-silt member**, which is approximately 350 m thick homogenous and well sorted, is composed mainly of coarse to fine massive carbonate sandstone to bedded upward single graded grindstone to wakestone. The subangular to rounded detritus include minerals (impact glass, quartz -

both detrital and shocked, plagioclase, glauconite), rocks (various sort of limestone, cherts, garnet shist, serpentinite, basalts?, sandstones), profuse fragmentary fossil elements (echinoderm, mollusks, algae, planktic and benthic forams).

Dewatering pipe or web structure is observed in the middle part of this member in the type locality. Sedimentary structures such as crossbedding, cross- to parallel-laminations and bioturbation are not observed (Kiyokawa et al. 2000). The lithology of this member, however, is similar to that of the middle part of the Peñalver Formation (Takayama et al. 2000).

The **uppermost part** of this member consists mainly of calcareous silt and clay, which contain late Maastrichtian nannofossils (*Micula murus*, *M. decussata*), and not yield any Paleocene fossil. Beside that, the Ancón formation (Paleocene) is overlaying this member at the top of the outcrop, however the contact is not well exposed (Kiyokawa et al. 2000).

2.3 PEÑALVER FORMATION

Peñalver Formation was originally described by Bronniman and Rigassi (1963) as a turbidite, overlying the Vía Blanca Formation. This type of section comprises the area of northwestern Cuba (Bahía Honda-Matanzas allochthon), where, along with vulcano-sedimentary rocks, rest tectonically above the northern ophiolites-Placetas belt, the Guaniguanico terrane and the Bahamas-Gulf of Mexico sections (Iturralde-Vinent 1994, 1998; Takayama et al. 2000).

The Vía Blanca and Peñalver Formations basin was probably located on the northern slope of the extinct Cretaceous volcanic arc, and the clastic material in both units originated within the area of the former Cretaceous volcanic arc (Albear and Iturralde-Vinent 1985; Iturralde-Vinent 1992; Rojas, 2000a,b).

The Campanian and Maastrichtian Vía Blanca Formation is up to 500 m thick and consists of hemipelagic marlstone, sandstones, shales, and calcareous turbidites, deposited between 600 m and 2000 m, based on its planktic/benthic foraminiferal ratio (Bronnimann and Rigassi 1963).

The Peñalver Formation outcrops over 200 km from west to east and disconformably overlies the Vía Blanca Formation with a sharp erosional contact (Figs. 9 and 10). The Thanetian Apolo Formation or the Danian to

Thanetian Víbora Group (Bralower and Iturralde-Vinent 1997), which consist of hemipelagic marlstone and siliciclastic or calcareous turbidites conformably, overlies the Peñalver Formation.
Peñalver Formation have been usually dated as late Maastrichtian, because of the age of the youngest fossils found in the uppermost member (Bronnimann y Rigassi 1963, Pszczolkowski 1986, Rojas et al. 1995). The reworked assemblage in the Basal member of the Peñalver Formation consists of fragmented and abraded latest Campanian-Maastrichtian rudist's shells. The most part of the rudists specimens were redeposited from the latest Maastrichtian carbonate platform (*Titanosarcolites giganteus, Macgillavriyia nicholasi, Praebarrettia porosa, Biradiolites* sp.), nevertheless some species (Hippuritids) could be eroded from the volcanoclastic units within volcanic arc. These facts point to the extinct Cretaceous volcanic arc domain and it's sedimentary cover as the main source area for the Peñalver deposits (Iturralde-Vinent 1992, Rojas 2000a, b).
The presence of abundant reworking of latest Cretaceous fossils in Peñalver and the fact that the underlying Vía Blanca Formation is of Latest Maastrichtian age suggests that Peñalver may well be of KTB age (Díaz-Otero et al. 2000). Moreover, Takayama et al. (2000) based in nannofossils tightly constrains the age of Peñalver Formation between 65.4 and 65.0 Ma.

2.3.1 STOP P-3 (PEÑALVER QUARRY, LA HABANA)

Coordinates: X-374 140; Y-362 850 Sheet 3785-III La Habana

The type locality of the Peñalver formation is situated on the road Avenida Monumental between The Vía Blanca and the National Highway, some kilometers to the east of the Havana City.
This locality is a large abandoned quarry (Fig. 11).
At this type locality it is very easy to observe the contact with the underlying Vía Blanca Formation (Fig. 10), all the members of the Peñalver Formation and it characteristic sedimentological features, such as: water escape structures pillar and conical-cylindrical (Fig. 12), the fining upward size grains, the green rounded mudstone intraclasts (bigger than 30 cm), the parallel to massive texture and the thickness of these unique KTB deposits.

Based in the outcrop of this type locality recently the Peñalver Formation was subdivided into five members (Takayama 1999, Takayama et al. 2000): The **Basal member** consists of up to 25 m poorly sorted, grain-supported massive calcirudite with irregular erosional surface at the base. Characteristically contain rip up intraclasts of up to 1 m in diameter.

The **Lower Member** consists mainly of 20 m thick coarse- to medium-grained calcarenite with frequent intercalations of thin conglomerate beds with spherical to ellipsoidal pebbles of mudstone and a small amount of rudist fragments. Pillar structure similar to stress pillars which are considered to be formed during settling of a dense sediment cloud (Lowe, 1975) occurs in calcarenite of the upper part of this member.

The **Middle Member** consists of 40 m thick massive, well-sorted, medium- to fine-grained calcarenite which shows upward fining. Water escape structures, such as pillar and conical-cylindrical are generally developed perpendicular to bedding. They are deformed plastically suggesting soft-sediment deformation. The **Upper Member** consists of > 40 m thick fine-grained calcarenite which shows several tens cm to several m thick faint bedding (Fig. 13).

The **Uppermost Member** consists of 40 m thick massive, calcilutite which rarely contains angular clasts of black shale of < 3 cm and green rounded mudstone clasts of < 1 cm. Evidence of bioturbation is absent throughout the formation. Vesicular glass of probable ejecta origin occur in the Basal and Lower members, and one brownish altered glass spherule of ~ 280 um in diameter (a microtektite?) was found in the middle part of the Basal Member. Lamellar quartz grains occur in the Lower, Middle and Upper Members (Fig. 14).

2.3.2 STOP P-4 (QUARRY OF MINAS TOWN, LA HABANA)

Coordinates: X-367 600, Y-365 400 Sheet 3785-II Jaruco

Big quarry of the Peñalver Formation. The KTB deposits here are composed by a great thickness of the calcarenites package, calcilutites and limestones, while the basal and lower members of the formation are absent. Tectonic contact with the Vía Blanca Formation is present at the northern side of the quarry, marked by a tectonic breccia in its lower boundary.

A thick layers (1-2 m) represent the stratified to massive deposits. The grain size varies from calcarenite (with fragments of brown shales), until mudstone of dark gray color.

Stratified brown shales, of supposed Paleocene age cover the uppermost limestone layers (Figs. 15 and 16).

The deposit body is part of the big fold, in which bedding are lying from almost vertical till subhorizontal, showing the strong compressional tectonic underwent by the region. Also, some faults are observed with remarkable displacement of blocks.

3. CONCLUSIONS

Cuban Region	Geological Formation	Paleogeographical Domain
Western region	Moncada Cacarajícara	Yucatan continental slope
	Peñalver	Above extinct volcanic arc
Central region	Santa Clara Vaquería	Above extinct volcanic arc
	Lutgarda	Slope of the Bahamas platform
	Amaro Rodrigo	Protocaribbean ocean floor
Esthern region	Mícara	Above extinct volcanic arc
Along the north part of the Island	Olistostrome deposits?	Northern slope of the extinct volcanic arc

Table 1: Some of paleographical domains in which were originated a variety of the KTB deposits related to Chubxulub impact, are present along the Cuban territory.

As it is showing (Table 1), should Cuban territory be a paradise of KTB deposits in the whole Earth globe? May be it is!

Thank you and Good look!

References:

1. Albear, J. y M. Iturralde-Vinent (1985) Estratigrafía de las provincias de La Habana. en Iturralde-Vinent, M. (ed) Contribución a la Geología de las provincias de La Habana y Ciudad de La Habana, Editorial Científico-Técnica, La Habana, p. 12-54.
2. Bralower, T.J., Paull, C.K. and Leckie, R.M. (1998) The Cretaceous-Tertiary boundary cocktail: Chicxulub impact triggers margin collapse and extensive sedimentary gravity flows. Geology, 26:331-334
3. Bralower, T., M. Iturralde-Vinent (1997) Micropaleontological dating of the collision between the North American continental margin and the Greater Antilles Volcanic Arc in Western Cuba. PALAIOS 12:133-150.
4. Bronnimann, P. and D. Rigassi (1963) Contribution to the geology and paleontology of the area of the city of La Habana, Cuba and it´s surroudings. Eclogae. Geol. Helv, 56(1): 193-43.
5. Díaz Otero, C.; M. Iturralde-Vinent and D.García Delgado (2000) The Cretaceous-Tertiary buondary "cocktail" in Western Cuba, Greater Antilles. Abstract of the Intern.Confer. on Catastrophic Events and Mass Extintions: Impacts and Beyond. July 9-12, 200. University of Viena, Austria.
6. Fernandez, G.; Quintas, F.; Sánchez, J. R. y Cobiella, J.L. (1989) El límite Cretácico-Terciario en Cuba. Progr. Inter.Correl. Geol. Proyecto No. 165. Correl. Estratigr. del Caribe (inédito).
7. García-Delgado, D. E.; C. Díaz-Otero; S. Gil-González; R. Rojas-Consuegra (1998) Contribución al estudio bioestratigráfico de algunas formaciones comprendidas en el límite K/T en Cuba. En: Geología y Minería, Memorias I (III Congreso de Geología y Minería), La Habana. pp. 297-300
8. Hatten, C. W. (1968) Concesiones de la costa norte de Cuba; Inf. geol. área Rancho Veloz, No. 54. Ofic. Nac. Recur. Mineral. La Habana (inédito).
9. Iturralde-Vinent, M. (1976-1977) Estratigrafía de la zona Calabazas-Achotal, Mayarí Arriba, Oriente. Rev. La Minería en Cuba. Part I: (5): 9-23; Part II: (6): 32-40.
10. Iturralde-Vinent, M. (1995) Field Guide. Sedimentary Geology of Western Cuba. 1st SEPM Congr. on Sediment. Geology, St. Pete Beach, Florida, 21 p.
11. Iturralde-Vinent, M. (1998) Late Paleocene to early middle Eocene Cuban island arc. in Ali, W., A. Paul and V. Young On, (Eds.)1998. Transactions of the 3rd Geological Conference of the Geological Society of Trinidad and Tobago and the 14th Caribbean Geological Conference, Volume 2: 343-362.
12. Iturralde-Vinent, M. Ed. (1996) Ofiolitas y arcos volcánicos de Cuba: First Contribution IGCP Project 364: 265 p. Miami, Florida.
13. Iturralde-Vinent, M. (1994) Cuban Geology: A new plate tectonic synthesis. Journal of Petroleum Geology, 17 (1):39-71.
14. Iturralde-Vinent, M. , D. García-Delgado, C. Díaz-Otero, R. Rojas-Consuegra, R. Tada, H. Takayama, S. Kiyokawa (2000) The K/T Boundary Impact layer in Cuba: Update of an International Project. Abstract of the Intern.Confer. on Catastrophic Events and Mass Extintions: Impacts and Beyond. July 9-12 (2000) University of Viena, Austria. LPD Contribution No. 1053:76-77
15. Iturralde-Vinent, M. 1992. A short note on the Cuban late Maastrichtian megaturbidite (an impact-derived deposit?): Earth & Planetary Science Letters, 109: 225-228.
16. Kantchev, I. ed., 1978. Geología de la provincia de Las Villas. Resultados de las investigaciones geológicas y levantamiento geológico a escala 1:250 000 realizados durante el período 1969-1975(Inédito). Instituto de Geología y Paleontología. MINBAS. La Habana.
17. Kiyokawa, S.; R. Tada; T. T. Oji; E. Tajika; Y. Nakano; K. Goto; S. Yamamoto; R. Rojas; D. García; M. A. Iturralde-Vinent and T. Matsui (2000) More than 500m thick k/t boundary sequence; Cacarajicara Formation, Western Cuba. Impact related giant flow deposit. Abstract of the Intern.Confer. on Catastrophic Events and

Mass Extintions: Impacts and Beyond. July 9-12, 200. University of Viena, Austria. LPD Contribution No. 1053:100-101

18. Lowe, D. R. (1975) Water scape structures in the coarse-grained sediments. Sedimentology, 22:157-204.

19. Nakano, Y; R. Tada; T. Kamata; E. Tajika; T. Oji; S. Kiyokawa; H. Takayama; K. Goto; S. Yamamoto; K. Toyoda; D. García; R. Rojas; M. A. Iturralde-Vinent and T. Matsui (2000) Origen of cretaceous-tertiary boundary in Moncada, Western Cuba and its relation to K/T event. Abstract of the Intern.Confer. on Catastrophic Events and Mass Extintions: Impacts and Beyond. July 9-12, 200. University of Viena, Austria. LPD Contribution No. 1053:148-149

20. Palmer, R. H. (1945) Outlines of the Geology of Cuba. Jour. Geol. 53:1-134, Chcago, USA.

21. Psczczlkowski, A., 1986. Megacapas del Maestrichtiano en Cuba occidental y central. Bulletin of the Polish Academy of Earth Science, 34(1): 82-94.

22. Pszczolkowski, A. (1978) Geosynclinal sequences of the Cordillera de Guaniguanico in western Cuba, their lithoestratigraphy, facies development and paleogeography. Acta Geol. Polonica, 28(1):1-96.

23. Pszczolkowski, A. (1986) Megacapas del maestrichtianpo de Cuba occidental y central. Bull. Polish Acad. Sci., Earth Sc.34(1):81-87.

24. Pszczolkowski, A. (1994) Litostratigraphy of mesozoic and paleoge rocks of Sierra del Rosario, western Cuba. Stud. Geol. Polon. 105 (1994): 39-66.

25. Rojas, R.; M. Iturralde-Vinent and P. W. Skelton (1995) Age, stratigraphic position and composition of Cuban rudist faunas. Revista Mexicana de Ciencias Geológicas. 12(2):272-291

26. Rojas-Consuegra, R. (2000a) El límite Cretácico/Terciario en la Formación Peñalver (Cuba Occidental): observaciones tafonómicas, paleoecológicas y paleogeográficas. V Congreso Geológico de España. Julio, 2000. Rev. Geotemas 1(2): 355-358

27. Rojas-Consuegra, R. (2000b) Taphonomic and Palaecolological observations on the Peñalver Formation, Western Cuba. Abstract of the Intern.Confer. on Catastrophic Events and Mass Extintions: Impacts and Beyond. July 9-12, 2000. University of Viena, Austria. LPD Contribution No. 1053:183-184

28. Rojas-Consugra, R.; C. Díaz-Otero y D. García-Llanes (1997) Probable presence of Cretaceous-Tertiary Boundary in Cuba. Trird Egerian Meeting on Sphaerules, Abstracts pp.37-38

29. Tada, R.; Y. Nakano; M. Iturralde-Vinent; S. Yamamoto; T. Kamata; E. Tajika; K. Toyoda; S. Kiyokawa; D. García; T. Oji; K. Goto; H. Takayama; R. Rojas; T. Matsui (in press) Complex tsunami waves suggested by the Cretaceous/Tertiary boundary deposit at Moncada section, western Cuba. Geol. Soc. Amer. Spec. Publ.

30. Takayama, H; R. Tada; T. Matsui; M. Iturralde-Vinent; T. Oji; E. Tajika, S. Kiyokawa; D. García; H. Okada; T. Hasagawa; K. Toyoda (2000) Origen of the Peñalver Formation in northwestern Cuba and its relation to K/T boundary impact event. Sedimentary Geology 135:295-320

31. Takayama, H. (1999) Origin of the Peñalver formation in northwestern Cuba and its relation to K / T boundary impact event. Thesis. Geological Instite, Faculty of Science, University of Tokio. Japon. 122pp.

Figure 1. Outcropping areas of the Cacarajicara, Peñalver and Moncada Formations.

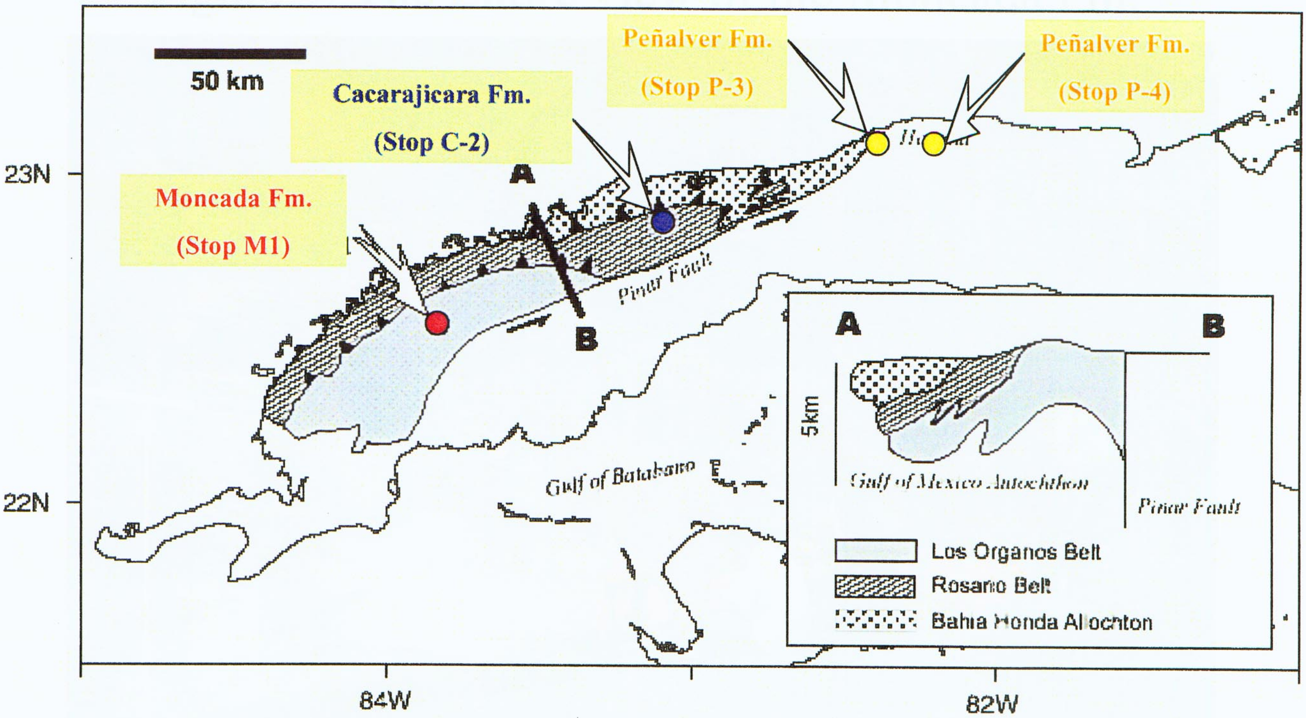
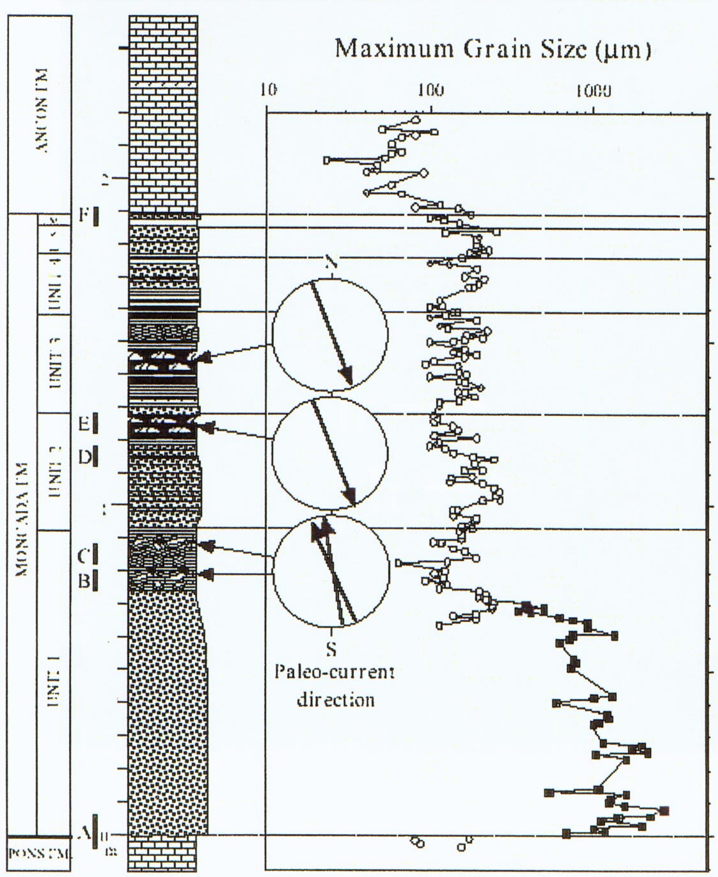


Figure 2. A columnar section of the Moncada Formation with maximum grain size and paleocurrent directions



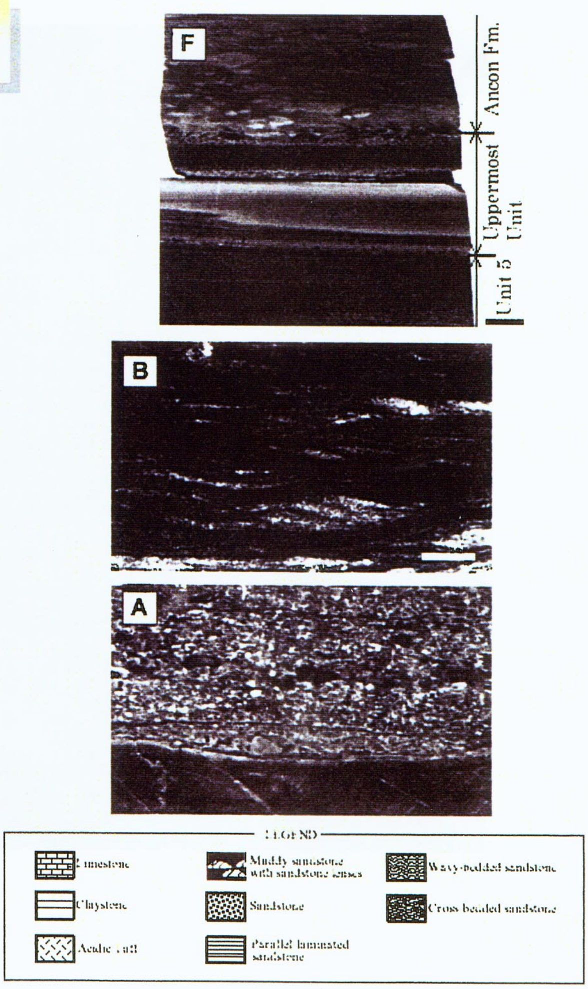


Figure 3. The Entire view of the Moncada Fm.

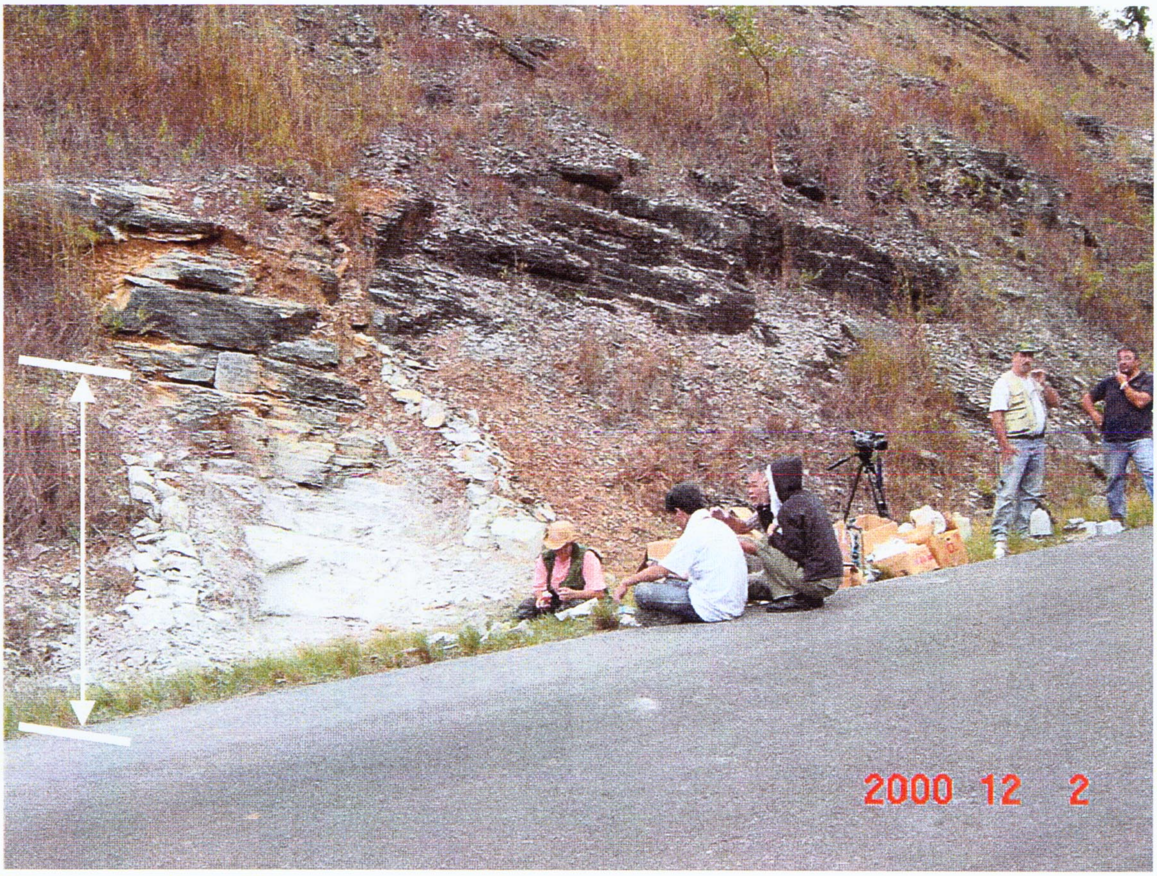


Figure 4. Ir-enriched claystone at the top of the Moncada Fm.

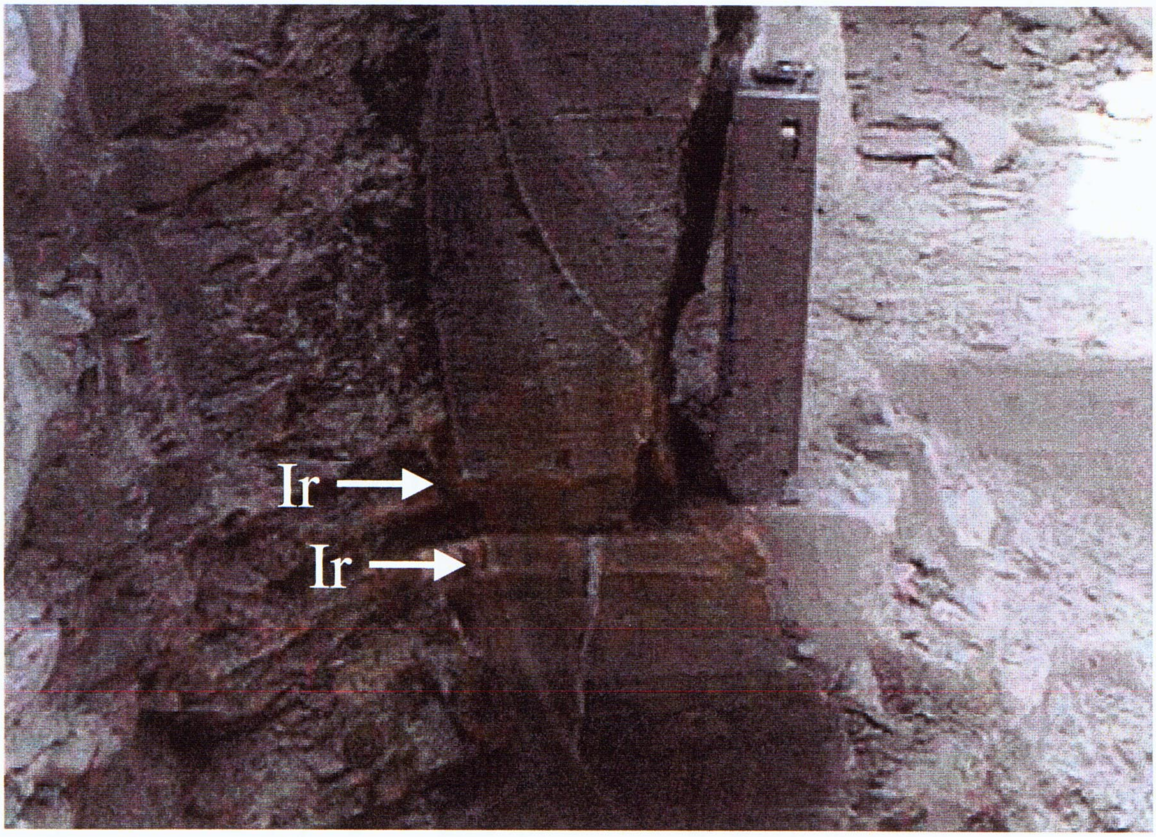
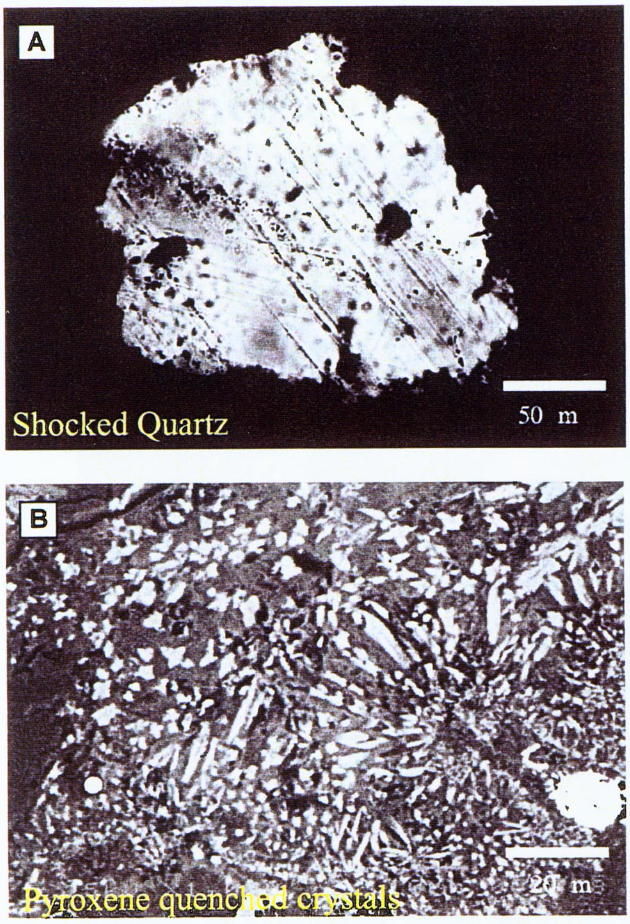
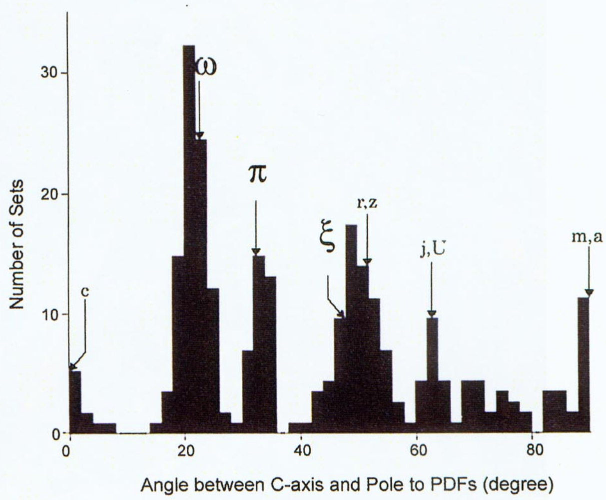


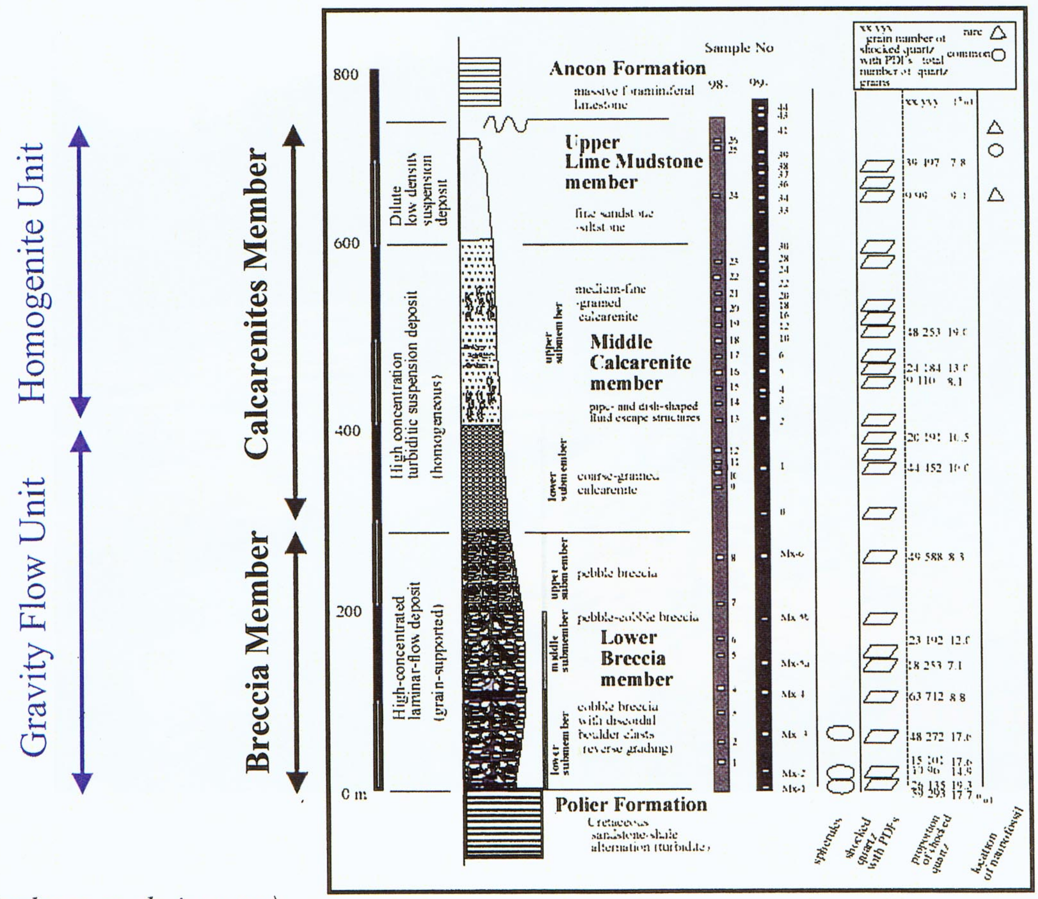
Figure 5. Ejecta in the Moncada Fm.





(From Tada et al., in press)

Figure 6. A columnar section of the Cacarajicara Formation



(Kiyokawa et al., in press)

Figure 7. Breccia of the Cacarajicara Fm.

Figure 8. Exposure of the Lower breccia member of the Cacarajicara Fm. Along the river.

Figure 9. A columnar section of the Peñalver Formation

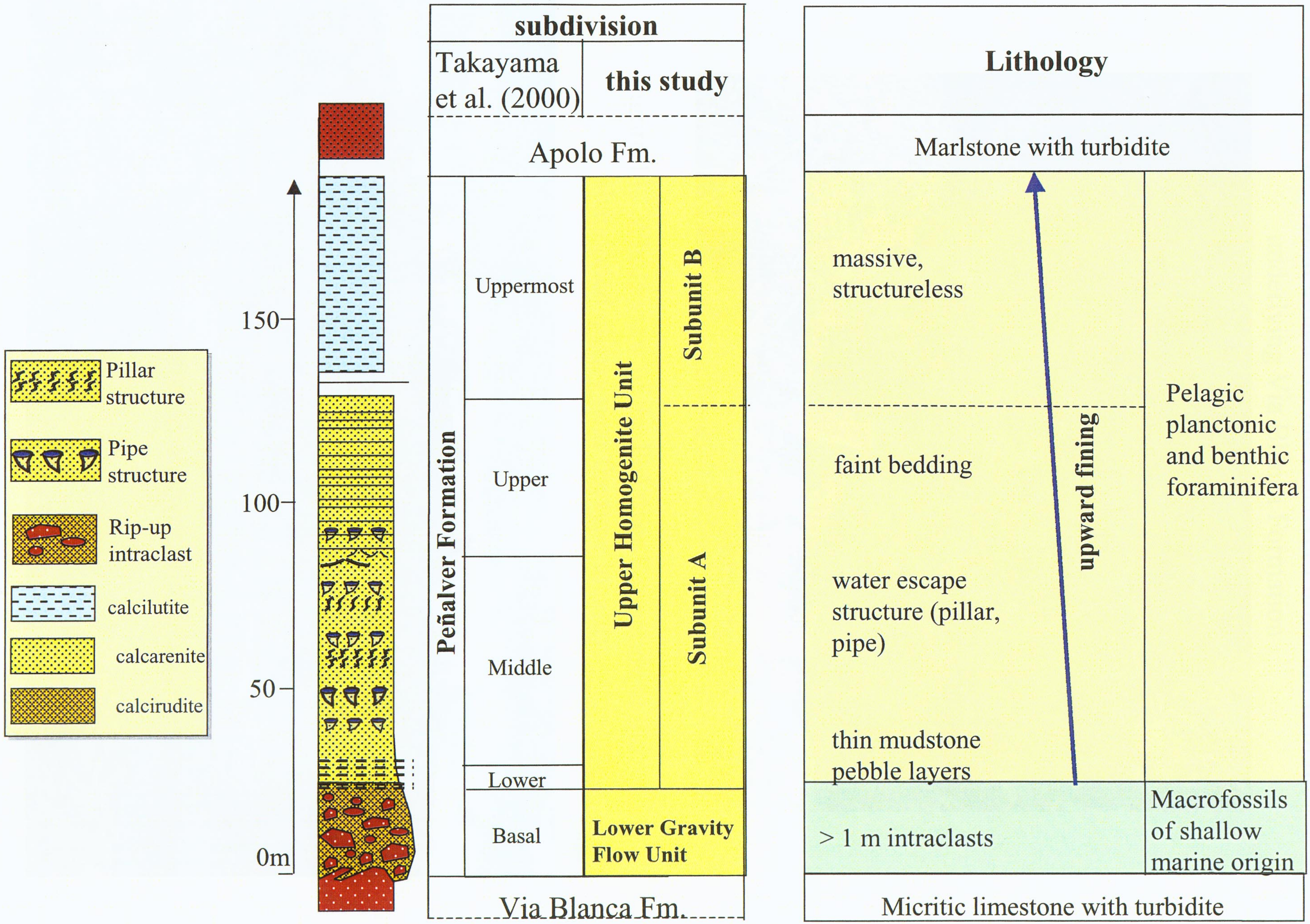


Figure 10. Basal contact of the Peñalver Formation with the underlying Via Blanca Formation

Figure 11. Whole view of the Peñalver Formation at the abandoned quarry near the type locality

Fig. 12. Water-escape structures in the calcarenite of the Peñalver Formation

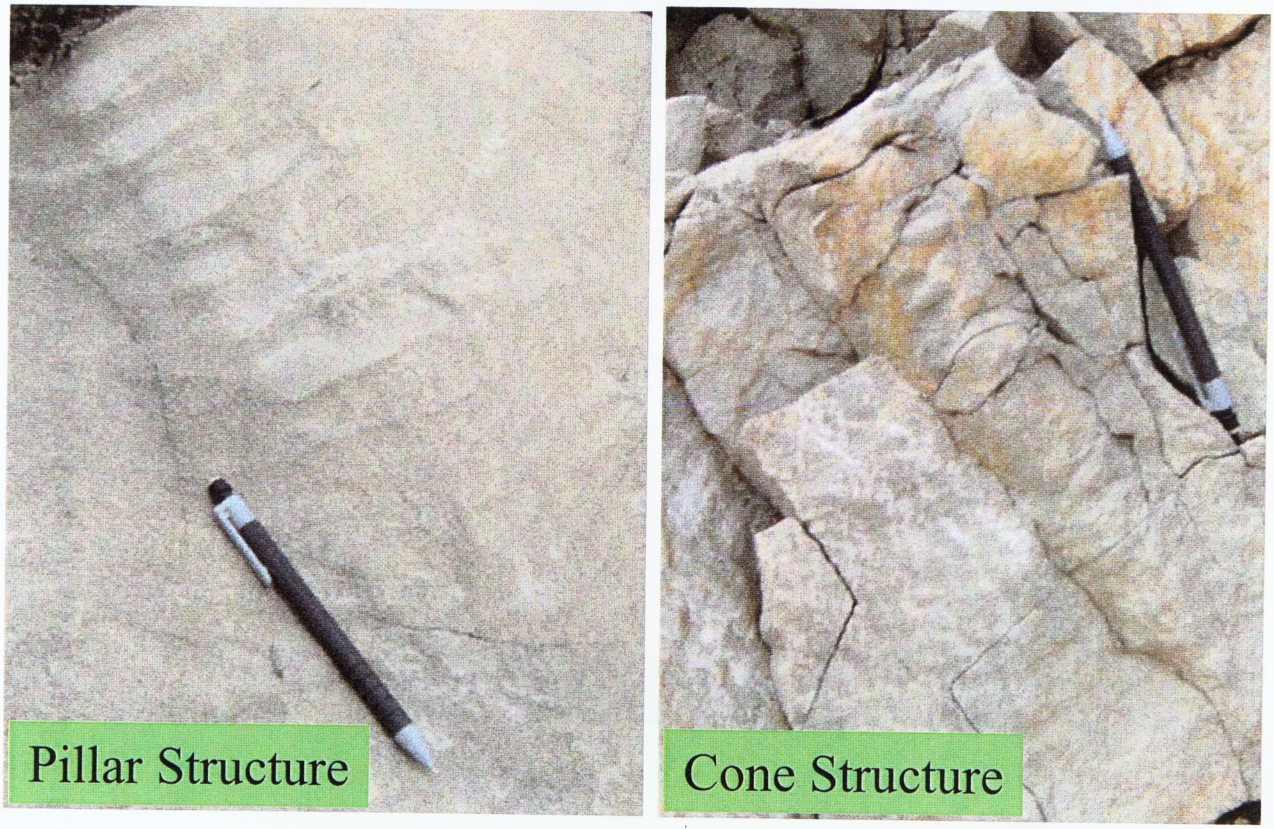
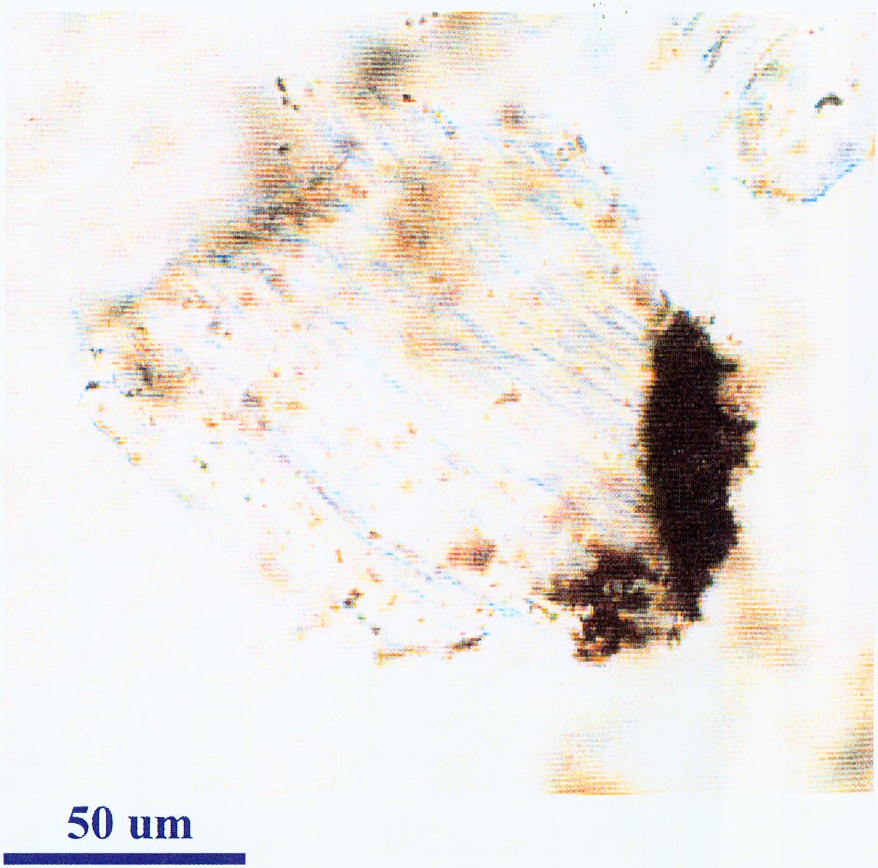
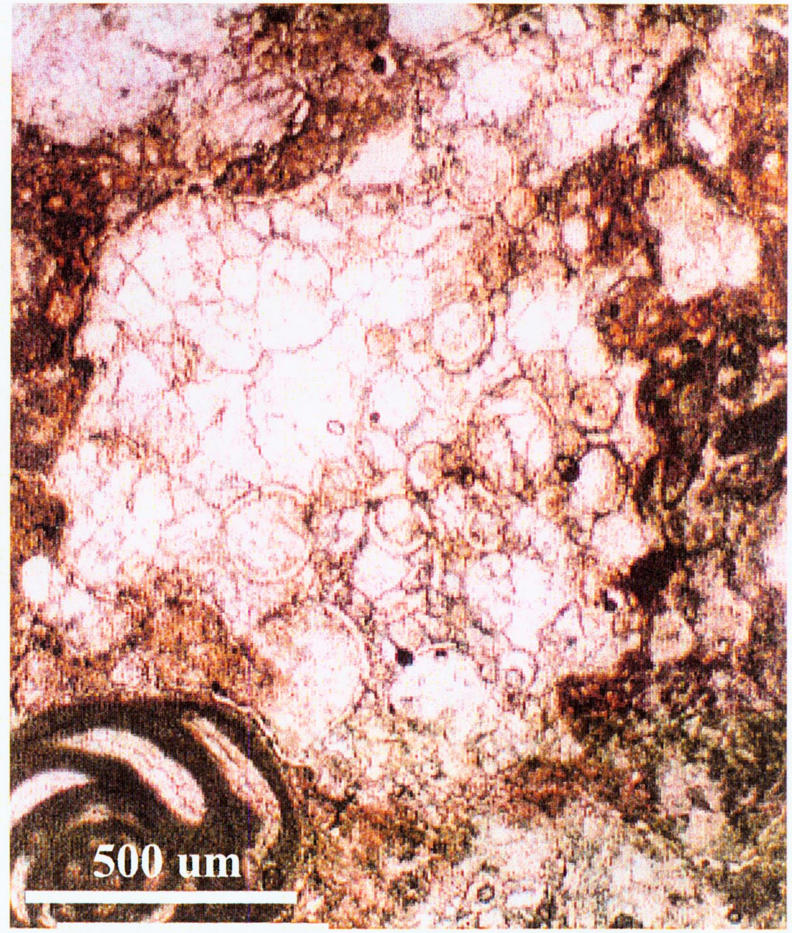


Fig. 13. Faint bedding in the upper member of the Peñalver Formation

Figure 14. Shocked Quartz and Vesicular Glass in the Peñalver Formation



Shocked Quartz
(The Upper Unit)



An altered vesicular glass
(The Lower Unit)

Figure 15. The contact between the Penalver Formation and the overlying Apolo Formation at Minas

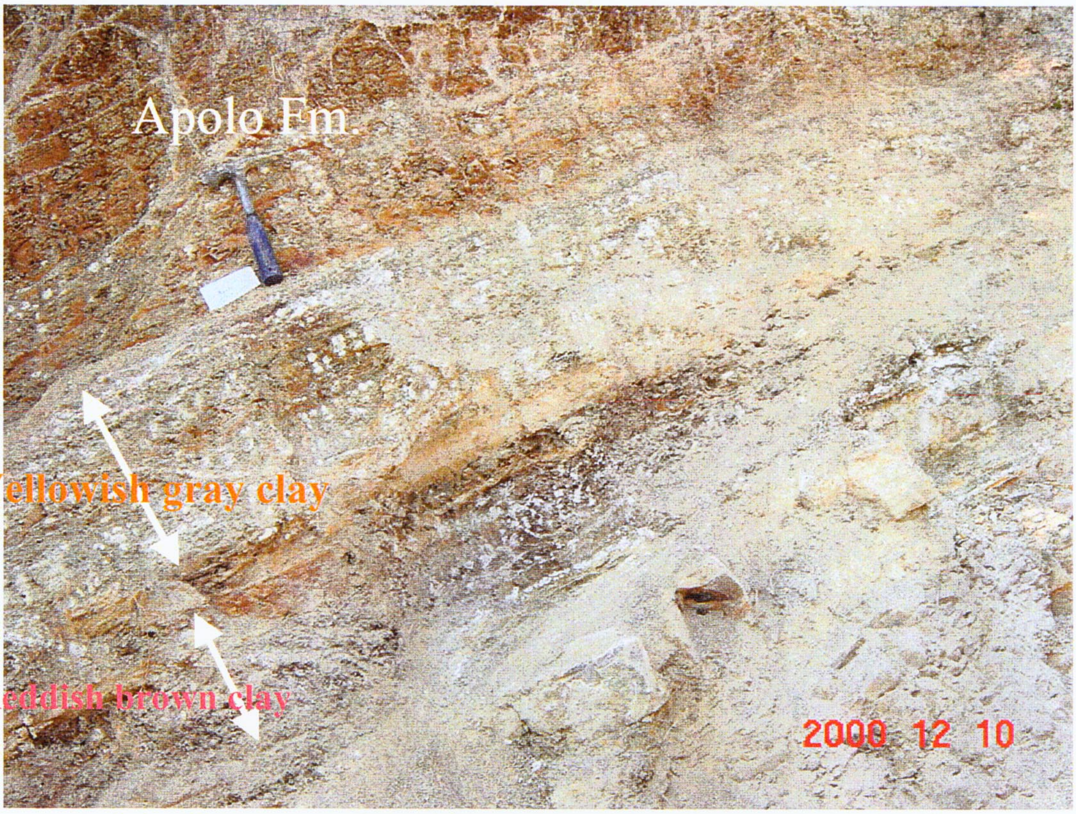


Figure 16. The uppermost part of the Penalver Formation with turbidite intercalations with bioturbation at their tops