Microfacies and depositional environment of the Aptian/Albian transgression (Lower Cretaceous) in San Luis Potosi (Central Mexico)

Master thesis

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November 2014

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Abstract

Results of detailed microfacies analysis of units studied in an Aptian-Albian stratigraphic sequence around San Luis Potosí in central Mexico, indicate primarily carbonate series representative for a transgressive episode that drowned the Valles- San Luis Potosí Platform during the early Albian as well as an ongoing slope and basin sedimentation. In seven sections, located on the platform, the transition and the basin, five lithostratigraphic units are established: (a) the Guaxcamá Formation (Barremian-upper Aptian): a unit of easy weathering gypsum and anhydrite, representive of a restricted shallow water facies; (b) the La Peña Formation (middle-upper Aptian): a unit of limestones interlayered with claystone and chert, representive of a pelagic basin facies; (c) the El Abra Formation (early Albian): a unit of middle to tickly bedded limestones, indicative of a deepening environment on the platform; (d) the Tamabra Formation (late Aptian- early Albian): a unit of middle to thickly bedded limestones, representive for the transition zone between the platform and the basin; and (e) the Cuesta del Cura Formation (Albian): a unit of middle bedded limestones interbedded with cert layers, indicative of an ongoing deep water facies in the basin. Differences between the sections are explained by different paleogeographical conditions and the varying distances to the platform.

1. Introduction

1.1 Geographic overview

The study area is located in central Mexico, in the state of San Luis Potosí, between two major physiographic domains, the Sierra Madre Oriental in the northeast and the Mesa Central in the southwest (Fig. 2). The Sierra Madre Oriental is a 1000 km NNW to SSE extending mountain range, which veers on the height of Monterrey to a W-E extension. The mountain range consists of folded Mesozoic sediments, which are in the south covered by volcanic deposits. Mesa Central is a high plateau region in central Mexico, with elevations between 1800 and 2300 m a.s.l.. It consists of mostly calcareous and clayey, Mesozoic sediments, whose thicknesses are generally able to reach about 4000 m and locally up to 8000 m (Lopez-Ramos 1975). The Mesa Central is bounded in the west by the Sierra Madre Occidental, in the north and the east by the Sierra Madre Oriental and in the south by the Trans-Mexican Volcanic Belt. Seven investigated sections are located around the city of San Luis Potosí of varying distances to the north (Fig. 1 and 40). San Luis Potosí is the biggest city in the south and Matehuala in the northern region. San Luis Potosí has a cold semi-arid steppe climate. The mean annual temperature and precipitation in San Luis Potosí is 18 °C and 315 mm, respectively (Wetterkontor.de). This data are based on the city of San Luis Potosí. The area is covered by grasslands (69 %), scrublands (23 %), forests (5 %), and croplands (2 %) (Weatherspark.com). Main artery in north-south direction is the highway Mex-57, which connects San Luis Potosí and Matehuala.

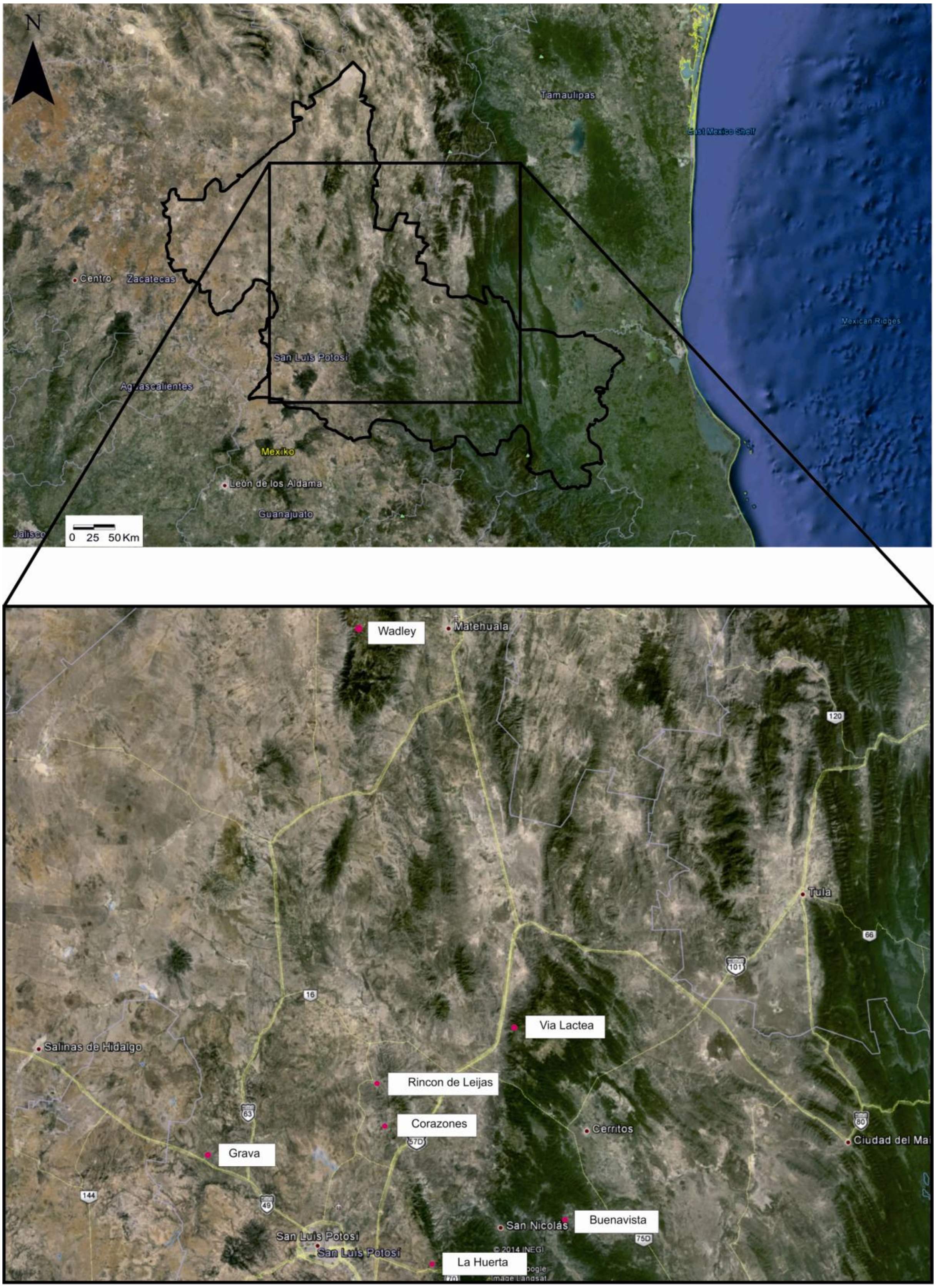

Fig. 1: Overview map with location of sections (modified Google Earth screenshot 07.11.2014)

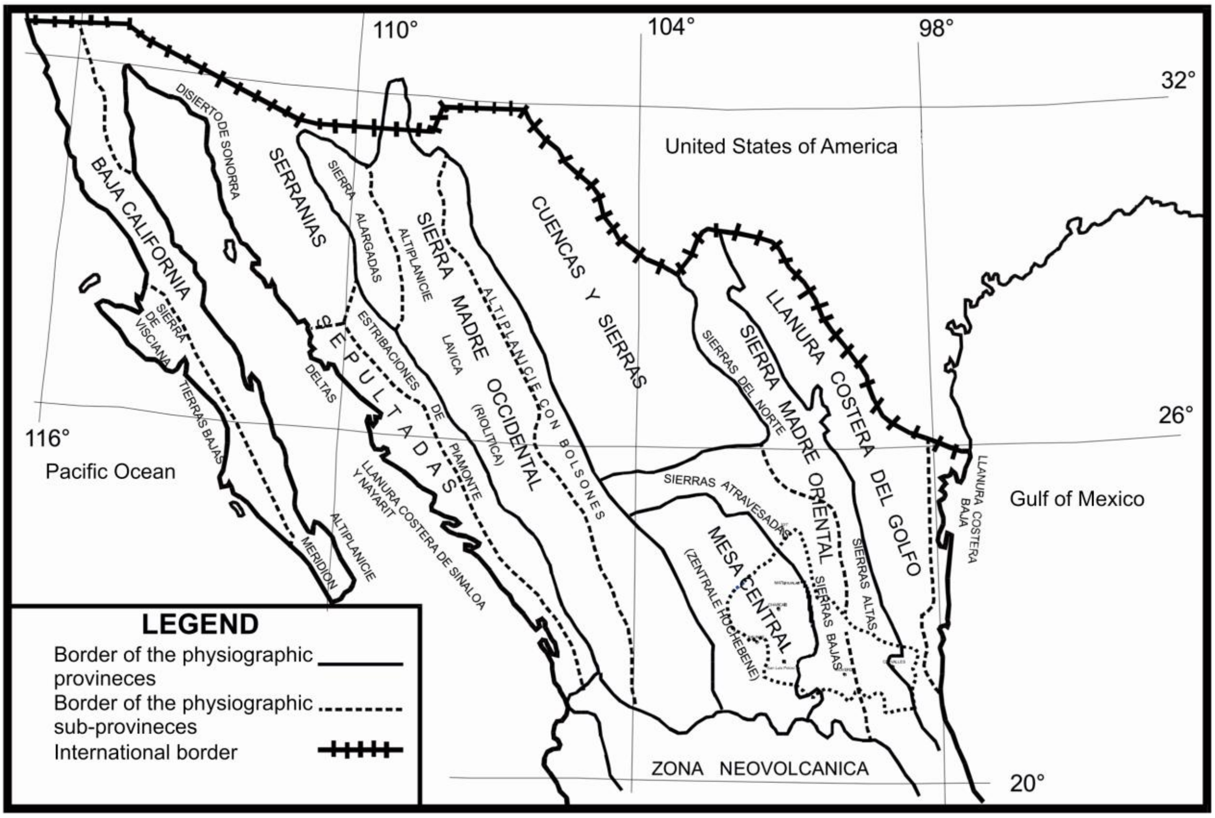

Fig. 2: Physiographic provinces of Mexico (modified after Raisz 1959).

1.2 Objective

The main goal of this thesis is to investigate the formations on the western side of the Valles - San Luis Potosí Platform during the Aptian/Albian transgression and to describe the transition between the evaporitic domain and the first calcareous sedimentation in this area. The eastern side of the San Luis Potosí platform has been studied extensively by the state owned oil company PMEX. The western side of the platform lacks oil deposits and was therefore less explored. In his doctoral thesis Dr. Rubén López Doncel examined the development of the platform in Albian / Cenomanian (López Doncel 2000). This thesis starts in the Aptian, when the transgression has just flooded the platform. On the basis of seven recorded sections, the transition between the Aptian and Albian is described. The sections are located on the platform, the transition and the basin. The microfacies and the depositional environment of each section are determined.

1.2 Methods

The work can be divided into three stages: (1) the fieldwork, (2) the preparation of the samples, laboratory work, (3) the analysis and interpretation.

The fieldwork took place from the 23.04.2013 to the 22.05.2013 in San Luis Potosí and surroundings. Together with Dr. Rubén López Doncel the sections were sampled. Standart geological equipment has been used for the sections (hammer, magnifying glass, ruler, GPS and topographic as well as geological maps). The maps used were provided from INEGI (Instituto Nacional de Estadística, Geografía e Informática) and the Instituto de Geología the Universidad Autónoma de San Luis Potosí. The sections have been taken from footwall to hanging wall in distinctive layers. With attempts to include the transition of the Aptian / Albian formations. In total, 83 samples have been collected and given a continuous character number code.

First steps for preparation e.g. washing and cutting into 2 cm thick sample plates took at Instituto de Geologia in San Luis Potosí. At GZG in Göttingen, the samples have been processed into thin sections. The dimensions of the sections are 7.5 cm x 10 cm and 10 cm x 15 cm with a rock thickness of 50 - 80 µm. The adhesive used was a two-part epoxy (Araldite).

The analysis of thin sections was accomplished in Göttingen (Germany). The samples were microscopically examined with transmitted light using a Zeiss AxioCam for photographs. The images have a magnification factor of 2.5 to 10. Overview images were taken with a Lumix FZ-62 using best fit zoom. All seven sections have been plotted using CorelDRAW (R) Graphics Suite X5 with main focus to determine the microfacies and depositional environment. The microfacies were determined according to the classification introduced by Dunham (1962) and Embry & Klovan (1972). The depositional environment and facies zones (FZ) were determined by the classification of carbonate platforms, based on Standard Microfacies Fossil (SMF) Types introduced by Flügel (2004).

2. Geological setting

2.1 Geological overview

2.1.1 Pre-Mesozoic basement

Rocks of the Paleozoic basement are occasionally found in northeastern Mexico. According to Morán-Zenteno (1994) the bedrock consists of folded Paleozoic and Triassic metamorphic rocks such as schist, gneisses and metaconglomerates.

2.1.2 Triassic

In the Triassic the continental margin was located to N-NW and supplied clastic sediments towards a S-SE located, shallow sea. The sediments consist of low metamorphic turbiditic conglomerates and sandstones. Outcrops of these rocks can be found in the Sierra de Salinas, Charcas and Zacatecas (Zacatecas Fm.; Fig. 4) (Centeno-García & Silva-Romo 1997).

Parts of Pangea's disintegration took place during the early Triassic. Due to extensional movements NNW - SSE striking horst and graben structures were formed (Carrillo-Bravo 1971). The most important horst structure in this region is the basement of the Valles San Luis Potosí Platform (VSLPP). To the west of the VSLPP a graben structure developed, forming the Mesozoic Basin Middle México (MBMM) in the late Jurassic. The Gulf of Mexico was positioned on the east side of the VSLPP. Thus, the VSLPP served as a barrier and prevented the trench to be flooded.

2.1.3 Jurassic

In the early and middle Jurassic, the terrestrial setting continued with a continental deposition environment. The deposits consist of terrestrial sandstones, conglomerates (La Joya Fm.) and volcanic rocks (Nazas Fm.). These rocks unconformably overlie Triassic rocks and again are overerlain unconformably by Upper Jurassic marine rocks (Silva-Romo 1996; Barboza-Gudiño et al. 2004). Another unconformity in the middle Jurassic is not further examined and is still controversial (Barboza-Gudiño et al. 1999; Bartolini et al. 1999). During the late Jurassic, the sedimentation switched from continental to marine environment, due to a transgression and the opening of the Gulf of Mexico (López-Doncel 2000). The graben structure, developed in the Triassic, got submerged and the MBMM arose. The late Jurassic is divided by two formations, the Zuloaga Fm. and the La Caja Fm. The Zuloaga Formation consists of transgressional limestones and dolomites, the La Caja Formation of calcareous claystones with chert layers. The formations are assinged based on the fossil content to the Oxfordian / Tithonian (Imlay 1938). At the end of the Jurassic, the paleo-VSLPP was still a mainland and served as a sediment source for the mentioned deposits.

2.1.4 Cretaceous

In the early Cretaceous, the conditions hardly changed. The pelagic sedimentation continued to take place in MBMM, Berriasian to Valanginian marl - clay stones (Taraises Fm.) and Hauterivian to Barremian limestones (Lower Tamaulipas- Fm. = Cupido Fm.). Through the constant transgression, the paleo-VLSSP was flooded for the first time at the end of the Barremian or early Aptian. In the Aptian, evaporites deposited within the platform (Guaxcamá Fm.), while in the basin pelagic sedimentation prevailed to continue (La Peña Fm.). In the Albian, transgression continued to progress, combined with a high rate of subsidence on the platform. Therefore a rapid reef growth took place (El Abra Fm.) (Morán-Zento 1994) (Fig. 3). Reef-building organisms like sessile bivalves (Rudists) were of great significance. Within the basin, the deep-water carbonates of the Cuesta del Cura Fm. were deposited. Due to the rapid platform growth in height, a steepening of the transition region took place, depositing reef debris on the slope (Tamabra Fm.) (Carrillo-Bravo 1971). In context of the Turonian sea level maximum, the reef growth stagnated and the platform aggradated in width. During the late Cretaceous, a volcanic belt emerged in the West, providing sediment to the MBMM (Centeno García & Silva-Romo 1997) filling it from West to East resulting an eastward retreating of the reefs into the middle of the platform. Until the end of the Cretaceous (Maastrichtian), the MBMM was completely filled.

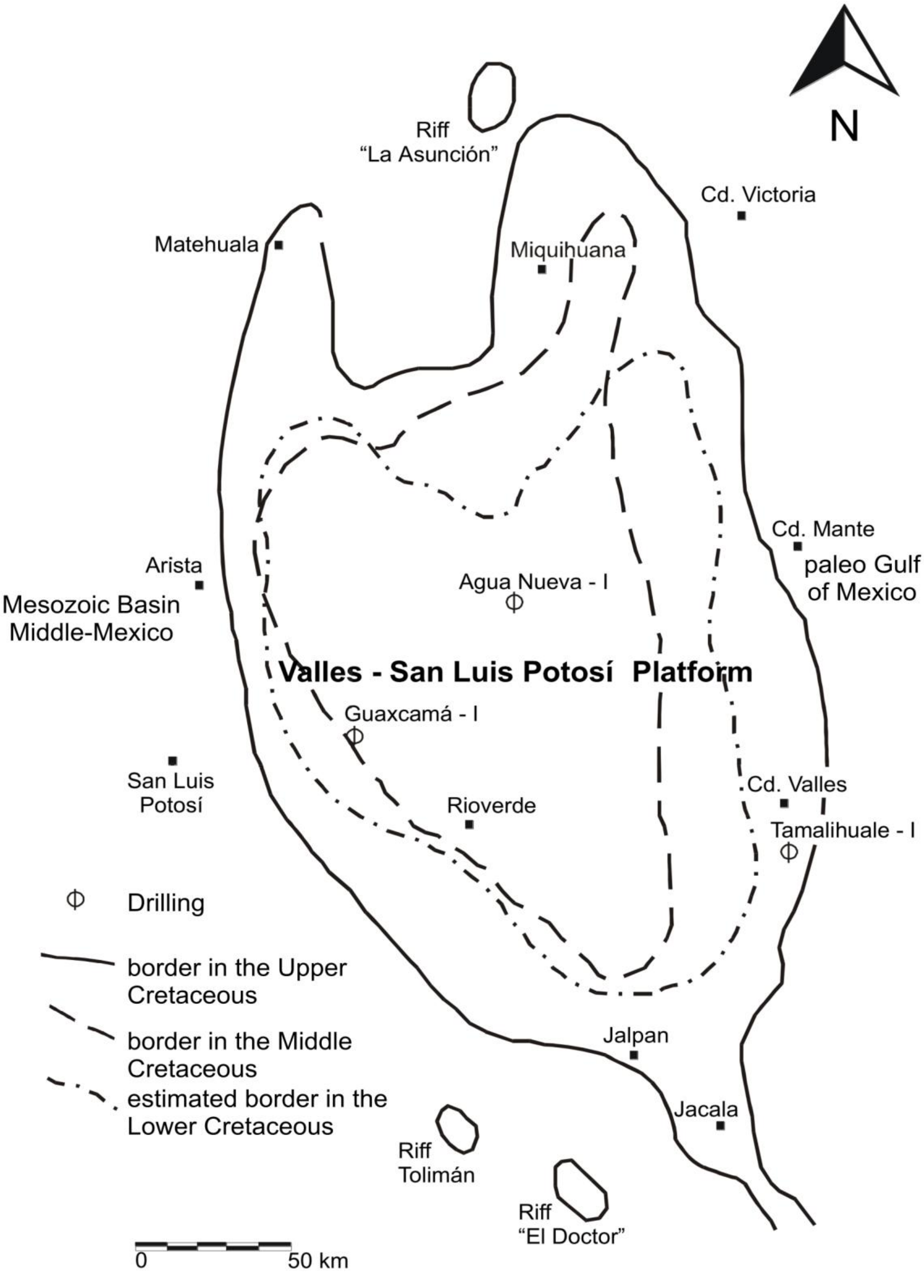

Fig. 3: Position of the platform border during the Cretaceous (modified after Carrillo-Bravo 1971)

2.1.5 Tertiary

The Laramide orogeny started during the late Cretaceous with the main phase taking place during the Tertiary. The compressive regime of the main folding phase produced NW-SE (290-320°) striking narrow folds in the Sierra Madre Oriental. In the Mesa Central, the valleys are wider and the anticlines less narrow. Due to the stable cratons of the Coahuila Platform and Tamaulipas Peninsula, compensating parts of the deformation (Morán-Zento 1994). Due to changes of direction of the North American and Farallon plates colliding, the velocity increases, resulting in a West vergent subside of the VSLPP. Entire package of rocks, beeing detached from the ground by the Cretaceous evaporites, began to slide and were folded (Morán-Zento 1994). In the Tertiary, central Mexico was mainly eroded and a colmatation with these sediments took place. The compressive phase was followed by an extensive regime, initiating the Tertiary volcanism with its main activity in the Oligocene and Miocene.

2.1.6 Quaternary

Due to erosion in the Quaternary alluvial sediments and travertine rocks were deposited in depressions.

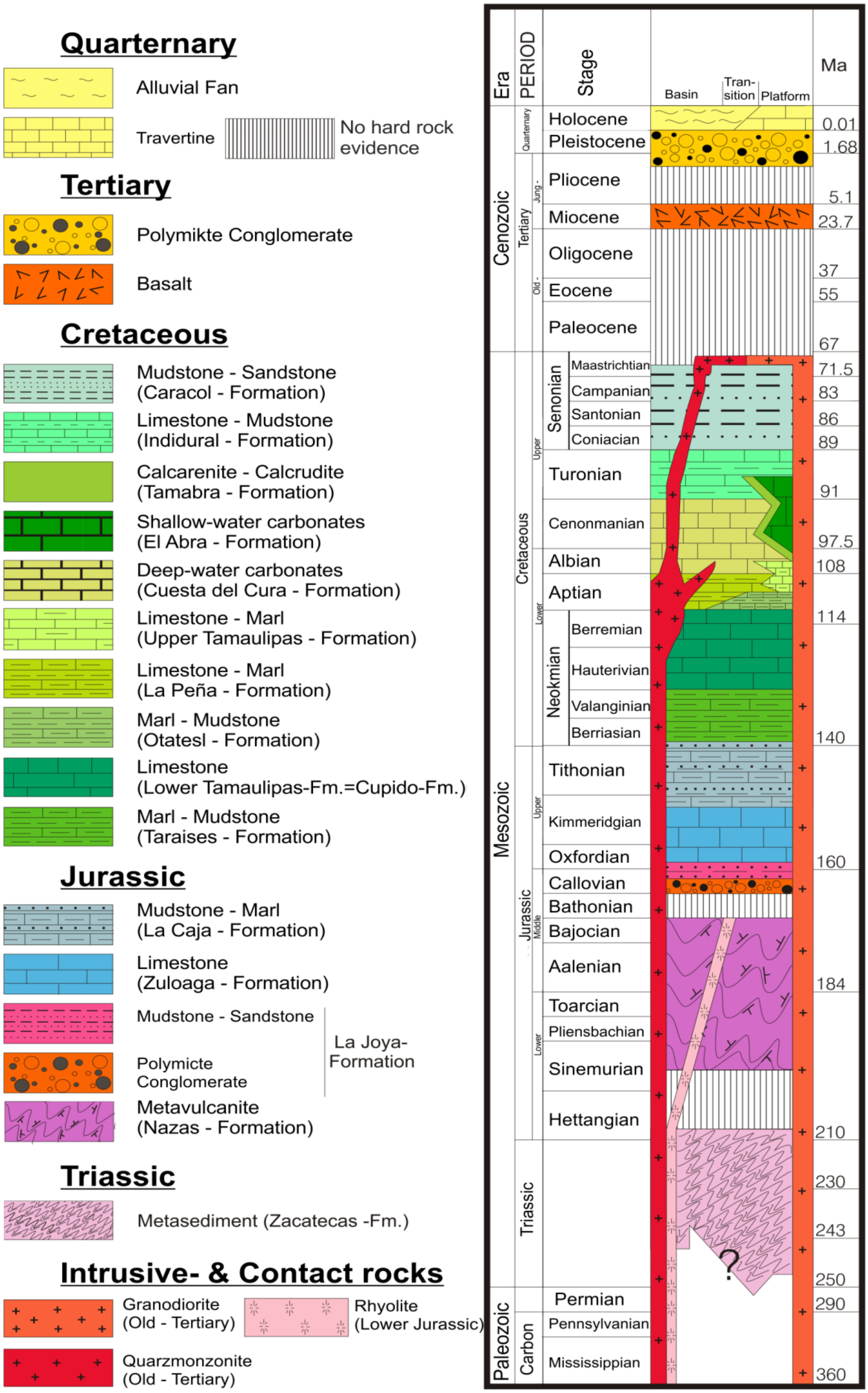

Fig. 4: Lithostratigraphy of the Mesozoic in central Mexico (modified after López Doncel 2000).

2.2 Sedimentary record of the Lower Cretaceous

2.2.1 La Peña Formation

The La Peña Formation was first described by Imlay (1936) in the Sierra de Parras. He divided the formation into two members. The lower member is 300 - 420 m thick and consists of thin to thickly bedded limestones with shaly partings. The upper member is 15 - 25 m thick in the north and increases up to 100 m southward (Imlay 1937). This member consists of thin to thickly bedded marly limestones with an abundant number of ammonites of the middle Aptian. However, Humphrey (1949) interpreted the lower unit as the upper part of the earlier occurring Cupido Formation and only the upper member shall represent the La Peña Formation. The Cupido Fm. is a shallow water facies comprised of medium- to tickly-bedded massive limestones and is overlain by the transgressive unit of the deep water La Peña Fm. The macrofauna of the La Peña Fm. contains cephalopods, other mollusks, brachiopods and echinoids. The microfauna mainly consist of pelagic foraminifera and calcispheres (Humphrey 1949). Based on the occurring ammonites the La Peña Fm. was divided into three facies zones. These are the early Aptian *Dufrenoyia justinae* Taxon Range Zone, the middle Aptian *Epicheloniceras martini* Zone and the *Parahoplites melchioris* Zone (Barragán & Maurrasse 2008). Due to the lack of *Orbitolina* (large foraminifera) it is assumed that the La Peña Fm. is limited exclusively to the Aptian. This type of large foraminifera occurred since the Albian in the Gulf of Mexico (Imlay 1945b). The La Peña Fm. corresponds to the Otates Member of the Tamaulipas limestone of southern Tamaulipas (Muir 1936). The Otates Member was later defined by Humphrey & Diaz (1956) as the Otates Formation.

2.2.2 Guaxcamá Formation

Simultaneously to the La Peña Fm. in the MBMM, the Guaxcamá Fm was deposited. on the Valles-San Luis Potosí Platform. The Guaxcamá Fm. was first described by Goldschmid (1933) in the sulfur mine Guaxcamá, 25 km SW of Cerritos. The formation has a thickness of 520 m (Alvarado 1973) to ca. 3000 m (Carrillo-Bravo 1971). The base of the Guaxcamá Fm. is not visible and can only be calculated by estimates. An exploration well performed by the State Oil Company observed an unconformable contact to pre-Jurassic clastic sediments. The high thickness can be explained by a tectonically induced rising of a diapir and the development of a rim-syncline (López-Doncel 2000). The formation consists of light to dark gray anhydrites and gypsum in 5-40 cm thick layers interbedded with few clay layers, 10-50 cm layers of fractured dark gray dolomite plus in the lower part layers of microcrystalline light gray limestones. Because of the uplift no continuous stratification can be traced. Stratigraphically, the Guaxcamá Fm. is allocated to the Barremian to Aptian.

2.2.3 Cuesta del Cura Formation

The Cuesta del Cura Formation was first described by Imlay (1936) in the Sierra de Parras. The thickness of this formation varies from 300 m in the Sierra de Parras, roughly 120 m in the Sierra Madre Oriental (López-Doncel 1991) to 80 m in the MBMM. This formation consists of thin- to medium-bedded dark gray, dense limestones, which alternate with thinner beds of dark gray, laminated shale, weathering light gray to yellow, or with thin lenses and beds of black chert (Humphrey 1949). The Cuesta del Cura Fm. can be divided into two members. The lower member being thickly, partially wavy bedded in contrast to the thin bedded upper member. The upper member shows wavy bedding and consisting of more platy limestones, which thin with the increase of shaly parts. At all, the proportion of chert is relatively low. The Cuesta del Cura Fm. represents a deep water facies. Macrofossils that were found are indeterminate Inoceramids, echinoids and belemnites. The microfauna mainly consist of pelagic foraminifera and calcispheres (Humphrey 1949). The upper contact to the Indidura Formation is concordant and marked by the appearance of thick beds of gray shale. Due to tectonic deformation the Cuesta del Cura Fm. often shows secondary knee folds (Humphrey 1949). The Cuesta del Cura Fm. has an Upper Albian terminal Cenomanian age.

2.2.4 El Abra Formation

The Abra limestones were first mentioned by Gárfias (1915), but the El Abra Formation was officially defined by Carrillo-Bravo (1971). The formation has a thickness of 1800 m at the eastern edge of the VSLPP (Aguayo-Camargo 1998) and can be divided into two members, the Taninul and the El Abra. The Taninul member represents a rudist-reef environment and the El Abra member a back-reef environment.

The Taninul member consists of massive to partly massive, light to medium-gray limestones, with often occurring reef components in various sizes (López-Doncel 2000). The fossil content consists of caprinids, echinoderms, gastropods, radiolites and rudists. This member is divided into two different sedimentary zones, based on the water circulation. These range from open marine to semirestricted to restricted water circulation. The fore-slope reef zone consists of layers and wedges of calcarenites and scattered colonies of rudist bioherms, which are lithified by fibrous calcite and internal sediment. The shelf-edge reef zone is a complex overlapping of banks, lenses, layers and wedges of unsorted grainstones which containing colonial rudists in growth position. These are cemented by neomorphic fibrous calcite and internal sediment (Aguayo-Camargo 1998).

The El Abra member consist of light to cream gray mud- and wacke-stones which occur well stratified in 1-5 m thick beds. The unconformably contact with the underlying Guaxcamá Fm. is indicated by a distinct lithological change. The most abundant fossils are miliolinid foraminifera (*Nummoloculina*), *Toucasia* banks and algal stromatolites. Furthermore gastropods, pelecypods, ostracodes, as well as several planispiral and biserial small benthonic foraminifera occur (Aguayo-Camargo 1998). The El Abra member can be divided into three sedimentary zones. A near-backreef/lagoon zone containing angular and unsorted grainstones and rudstones which are interlayered with lagoonal sediments like mudstones. The tidal-flat/lagoon zone shows even bedded mud- and pack-stones with miliolids, ostracodes and other benthonic microfossils. The lagoon zone consists of mudstone with abundant miliolids, mollusks and ostracodes. Despite a high degree of bioturbation, the primary lamination is still recognizable. The age of the formation has been much discussed. Muir (1936) stated an Albian to early Cenomanian age, based on the occurrence of *Pecten roemeri* and *Kingenia wacoensis.* Bonet (1963) specified the age at Albian due to the presence of the benthonic foraminifera *Dictyoconus* and *Orbitolina.* Aguayo (1998) described the formation at its type locality as Albian in the subsurface, early Cenomanian within the reef complex, due the occurrence of ammonites as *Mariella* (*Plesioturrilites*) *bosquensis* (Adkins) and Turonian age in the uppermost parts. The planktonic foraminifera, *Heteroelix reussi* (Cushman), *Marginotruncana canaliculata* (Reuss), *M. helvetica* (Bolli), *M. pseudolinneina* (Pessagno) and *M. sigali* (Reichel) indicate a late Turonian age.

2.2.5 Tamabra Formation

The Tamabra Fm. was first described by Heim (1940) in the area of the Poza Rica oilfield and further investigated by Bonet (1952), Barnetche & Illing (1956), Bebout et al. (1969), Beccera-H. (1970), Coogan et al. (1972) and Enos (1977). In a section east of El Lobo this formation has a thickness of 1380 m to 1582 m (Enos & Stephens 1993). Whereas thicknesses from 200 m (Coogan et al. 1972) to 860 m (Aguayo 1978) have been described further east in the Tampico embayment. The lithology is referred to as a “transitional” or “mixed facies” (Heim 1940). Three lithologies can be observed as pelagic limestone, breccia and detrital limestone. The pelagic limestones are basinal limestone, dark gray microfossil mudstone and wackestone with chert lenses. The breccia consists of coarse limestone intraclasts embedded in a mudstone or dolomitic matrix. The thickness of the layers ranges from 1 to 40 cm. The clasts can be up to 1 m in size and consists of mudstone, chert or fragments of platform fossils (Enos 1974). The mudstone contains pelagic microfossils and fragments of platform fossils (Bonet 1963). The breccias are grain supported, but some clasts are floating in a mudstone matrix. The detrital limestones are skeletal pack and grainstones with rounded fragments of rudists and other platform fossils. The grain size ranges from fine sand to pebbles and thicknesses from 1 to over 10 m. The Tamabra Fm. correlates with the El Abra Fm. and is of Albian to Turonian age. The emergence of the Tamabra Fm. is highly debated. The turbiditic beds originated after Coogan (1972) and Barnetche & Illing (1956), by a fault-related steep slope. Carrillo-Bravo (1971) and Enos (1975, 1977) interpreted the deposits as turbiditic flow of a shallow-marine deposits of the Valles-San Luis Potosí Platform in a deep marine basin. The fault theory by Coogan et al. (1972) could not be proven. The incline was formed by the rapid growth of the reefs on the VSLPP and had an elevation of up to 1000 m. While most research has been conducted on the eastern side of the VSLPP, the thesis of López-Doncel (2000) dealt with the occurrence on the western side. The Tamabra Fm. on the western edge of the VSLPP shows characteristic lithological associations of a slope range. Most abundant deposits are of the type talus, debris flows, landslides, turbidites and autochthonous carbonates. Deep marine mudstones and wackestones are interposed in all areas of the formation.

3. Lithology, microfacies description and interpretation

In the following chapter, the sections are described in detail (Fig. 5).

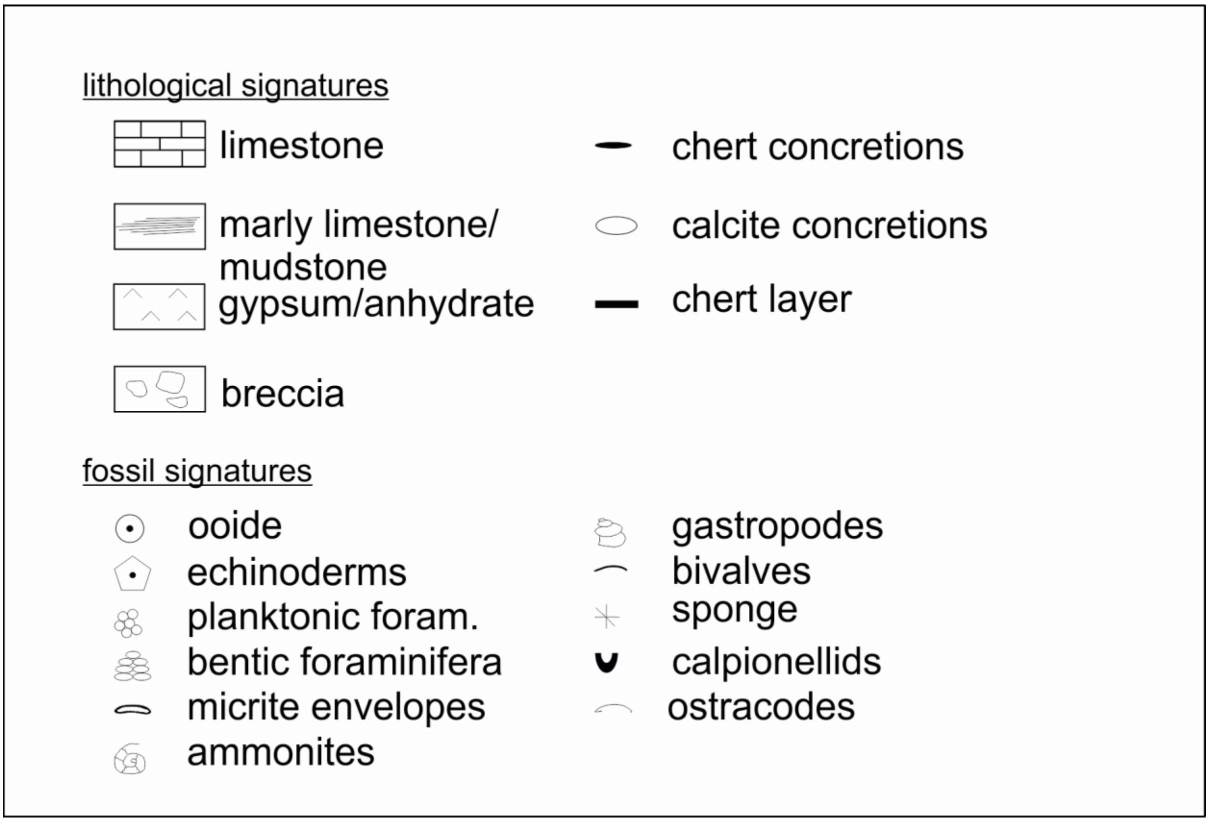

Fig. 5: Shared legend for the sections.

3.1 Section Buenavista

The section Buenavista (Fig. 1 and 8) is located about 4 km west-southwest of the town Buenavista. The strata is well exposed in a road-cut. The section has a width of about 52 m, a height of 4 m and an exposed thickness of about 32 m. The exposed strata dipping with an angel of 38° to the northeast are divided into two mayor lithological units, the Guaxcamá and the El Abra Formation.

Lithology:

The lower lithological unit is whitish-gray, fine-grained gypsum / anhydrite interspersed with fine, brown mudstone layers (Fig. 6). The stratification is only occasionally visible and is within the centimeter range. No fossils were found at this location. The gypsum is strongly altered and the rock surfaces are friable and powdery.

Fig. 6: Section of the gypsum sequence in the section Buenavista. The surfaces are weathered and highly altered.

The second lithological unit is a dark gray to light gray limestone. The unit is well stratified with a layer thickness from 10 cm to 1 m. The layer thickness is smaller in the transition zone to the underlying formation and thickens to the hanging wall (Fig. 7). Clearly visible shell residues can be found. The transition to the underlying lithological unit is not sharp and is marked by loose rock rubble. In comparison to the upper formation this appears weathering resistant and tougher. The rock surfaces are covered by gypsum dust and appear grayish white.

Fig. 7: Left: lower lithological unit of the limestone section; right: the upper section in the section Buenavista. The lower section shows thin to middle bedded limestones and the upper section thin to thick bedded limestones.

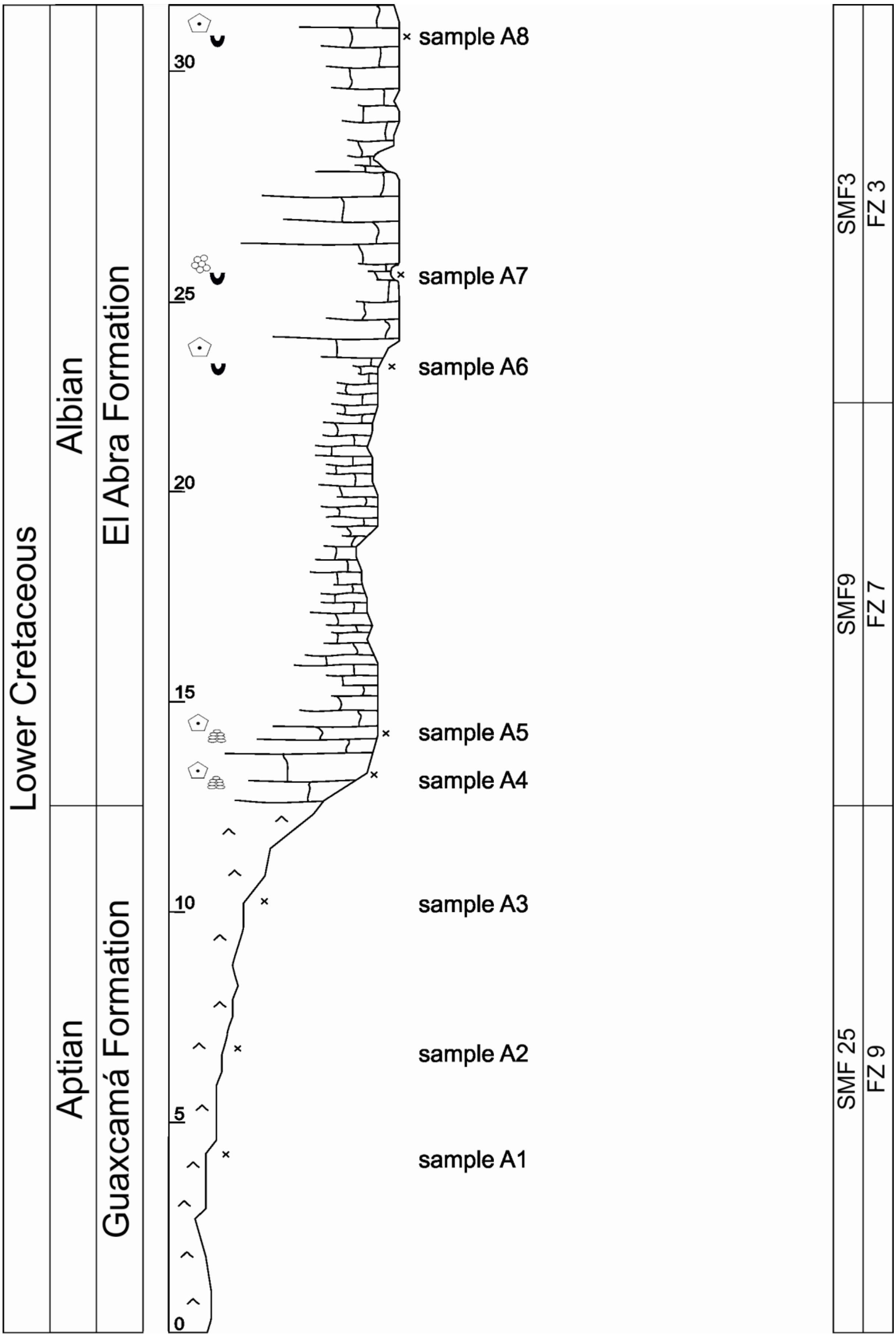

Fig. 8: Lithostratigraphy and microfacies of the section Buenavista.

Thin sections:

Samples A1-A3:

These samples contain unregulated, sometimes laminated, fossil-free, gypsum with a low proportion of clay clasts (Fig. 9).

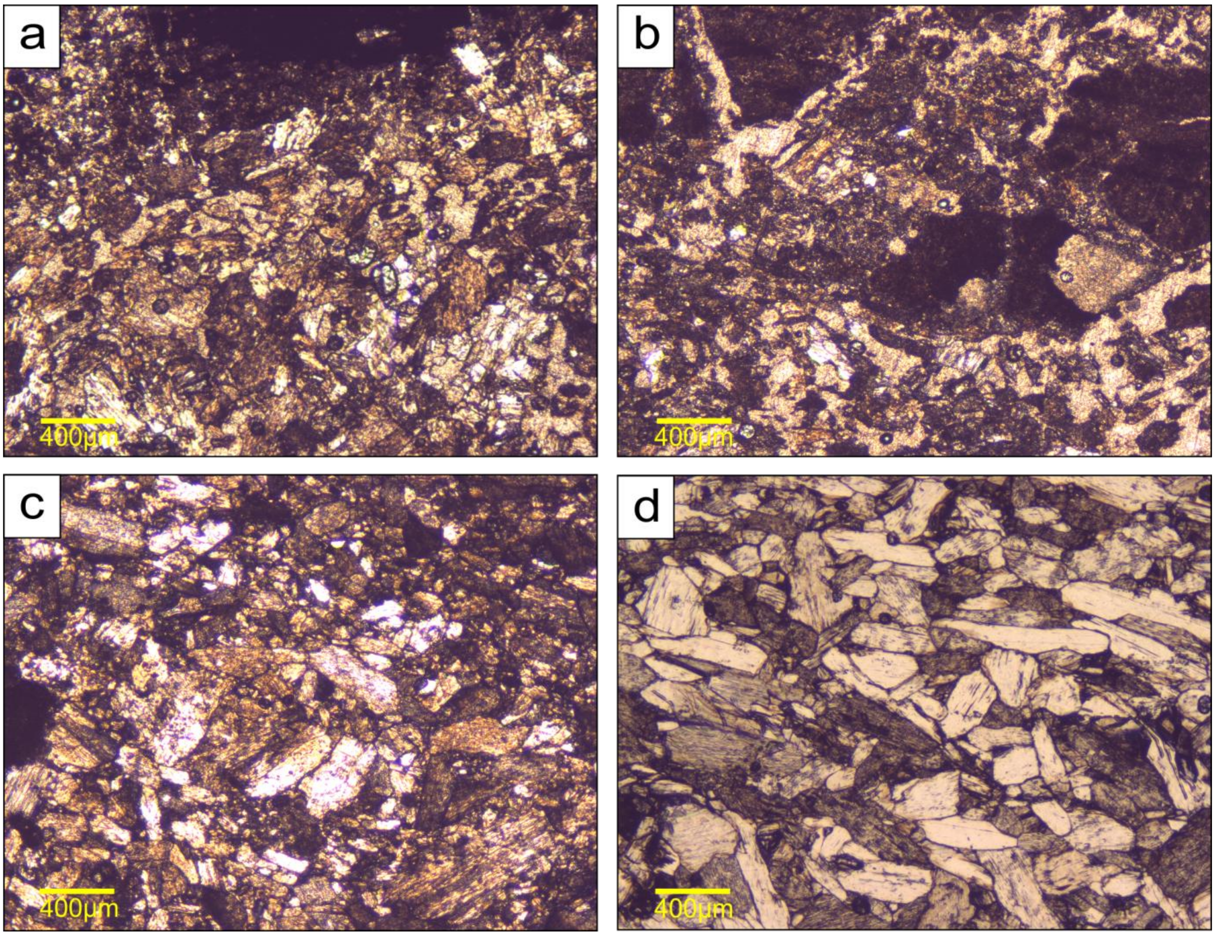

Fig. 9: Microfacies of the Guaxcamá Formation of the Buenavista section (sample A1-A3). a) Fine grained fossil free gypsum and anhydrite (A1). b) Fine grained fossil free gypsum and anhydrite as well as black mud clasts (A1). c) Fossil free unsorted gypsum and anhydrite in varying grain sizes (A2). d) Middle grained gypsum and anhydrite with orientation of minerals (A3).

Sample A4-A5:

Those sample represent a bioturbated micritic limestone with various fossil components. The ratio of matrix to components is 80-20 %. The fabric is matrix supported. The occurring fossils are echinoderms, bivalve mollusks, ostracodes, gastropods and benthic foraminifera like *Orbitolina*, *Textularia* and *Miliolina* (Fig. 10).

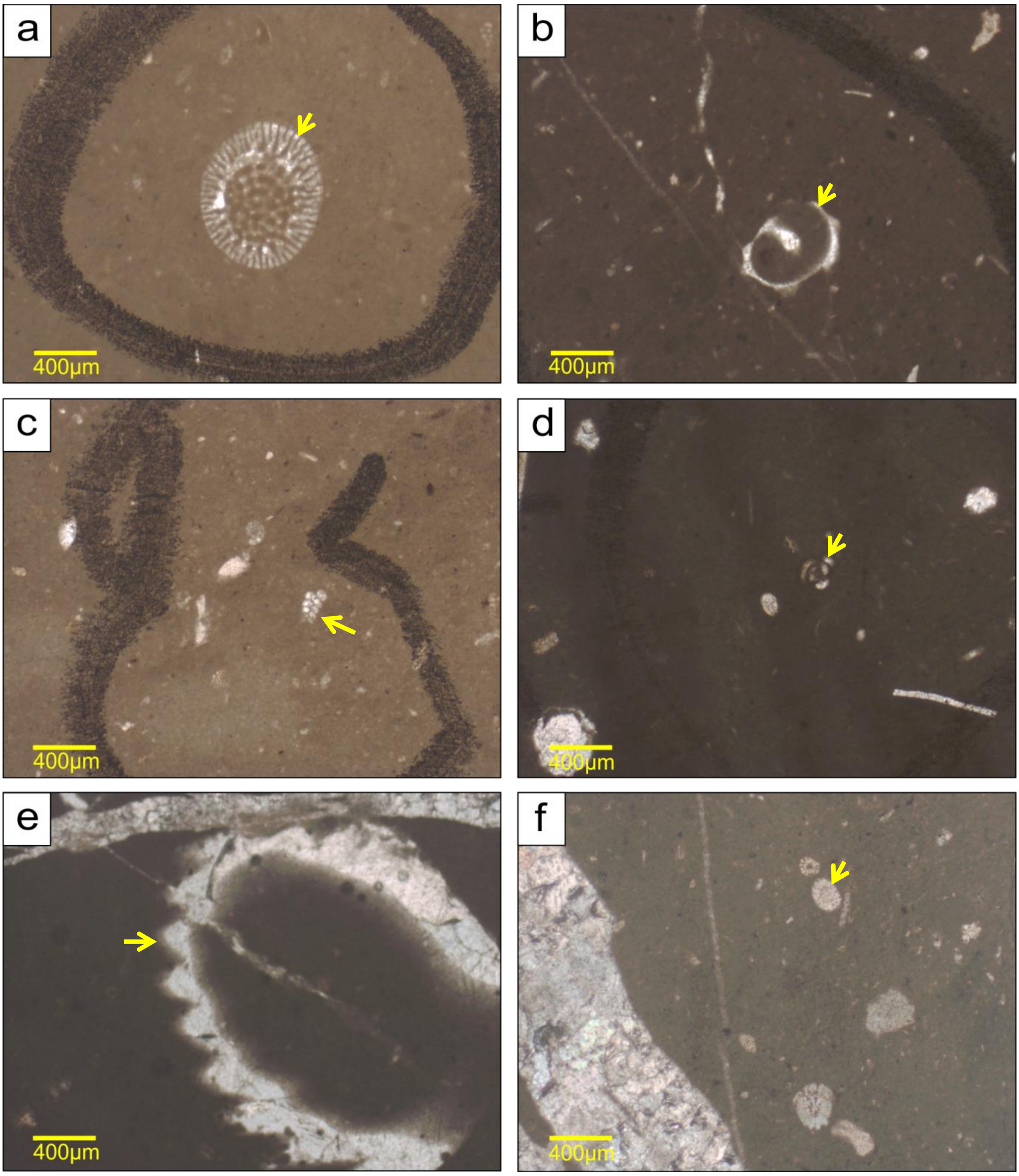

Fig. 10: Microfacies of the El Abra Formation of the Buenavista section (sample A4-A5). a) Transversal basal section of benthic large foraminifera (*Orbitolina* sp.) in micritic matrix (A4). b) Gastropod in micritic matrix (A4). c) Biserial benthic foraminifera and fragments of echinoderms (A4). d) Dense micritic mudstone and miliolinid foraminifera (A5). e) Shell of a bivalve (A5). f) Fragments of echinoderms (A5).

Sample A6-A8:

The sample represents a bioturbated micritic limestone. The ratio of matrix to components is 60-70 % to 30-40 %. The fabric is matrix supported. The occurring fossils are echinoderms, bivalve mollusks, colomiellids, ostracodes and planktonic foraminifera (Fig. 11). The planktonic foraminifera show spiked shells. The sample A7 has a slightly increased component density and no echinoderms occur.

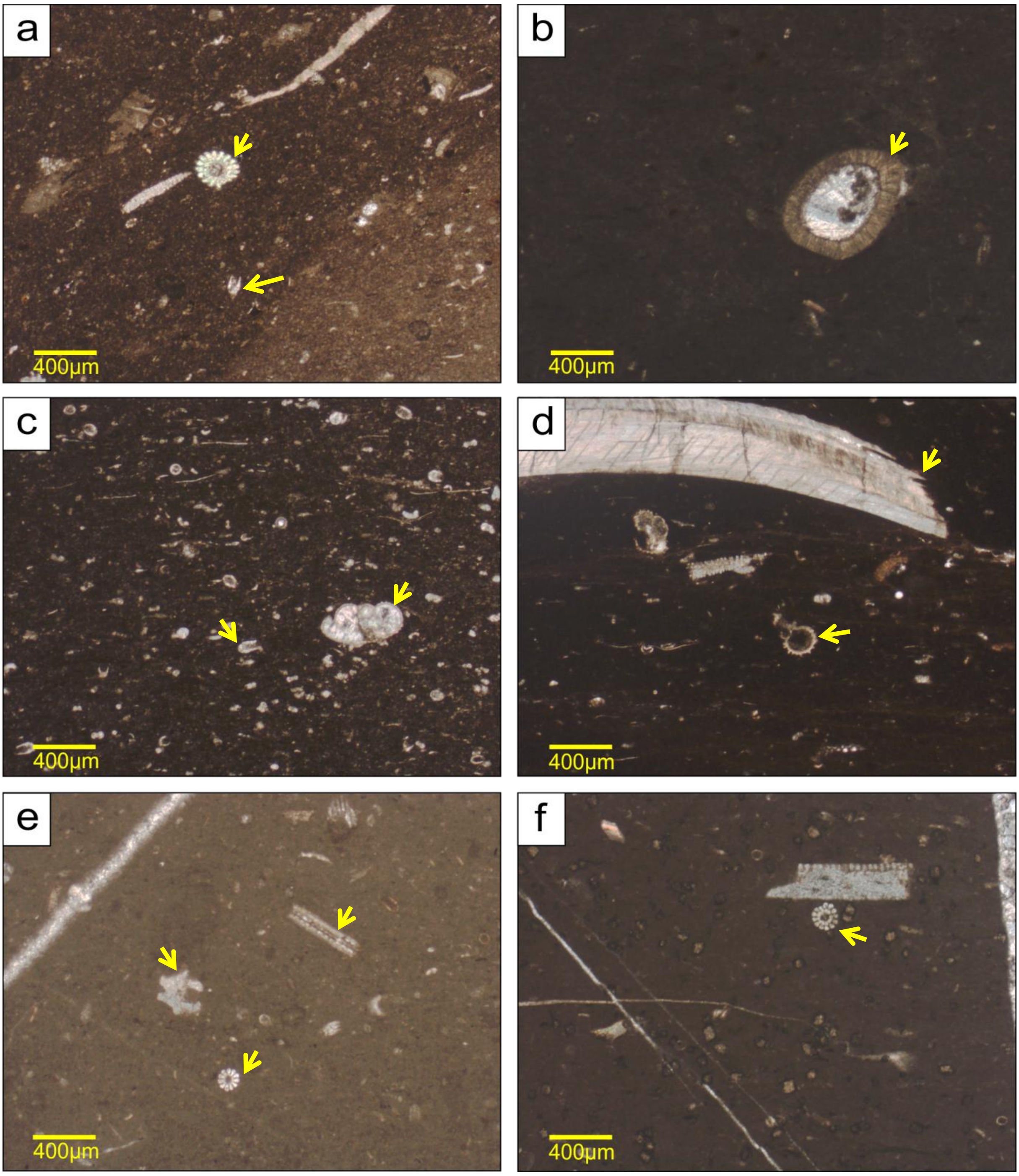

Fig. 11: Microfacies of the El Abra Formation of the Buenavista section (sample A6-A8). a) Sting of an echinoid, other echinoderm fragments and a colomiellid inside micritic matrix (A6). b) A thick shelled ostracode (A6). c) Abundant colomiellids and planktonic foraminifera (A7). d) Planktonic foraminifera with a spiked shell as well as a fragment of a bivalve shell (A7). e) Sting of an echinoid and other echinoderm fragments (A8). f) Sting of an echinoid and other echinoderm fragments (A8).

Interpretation:

Laminated Evaporite-Carbonate Mudstone (FZ9)

The samples A1-A3 can be interpreted by Flügels carbonate classification as a laminated evaporite-carbonate mudstone and relate to the standard microfacies fossil type-25 (SMF-25). From this facies the depositional environment is an evaporitic lagoon in the back reef area

(FZ-9). The rock is fossil-free suggesting for hostile, here probably hypersaline conditions. The water depth was only a few centimeters to meters. This evaporitic sequence is assigned to the local Guaxcamá Formation. During a temporarily cut off from fresh water supply the evaporite deposits formed.

Foraminifera Echinoderm Mudstone with Bivalve Shells (FZ7)

Due to the abundant occurrence of benthic foraminifera the samples A4-A5 are assigned as burrowed bioclastic mudstone to the SMF-9. By the classification of Dunham the rock is named as foraminifera echinoderm mudstone with bivalve shells. The depositional environment is open marine and located at the back reef area (FZ7). The water depth is within the photic zone, probably a few meters. Benthic foraminifera like orbitolinids occur to a depth of 70 m, miliolinid even only up to 30 m water depth. This sequence can be assigned to the El Abra Formation. Due to the occurrence of orbitolinids the age has to be Albian (Imlay 1945b).

Planktonic Foraminifera Echinoderm Wackestone with Colomiellids (FZ3)

In sample A7 planktonic conditions are assumed due to the occurrence of planktonic foraminifera and the lack of shallow water preferring benthic foraminifera. The sample is assigned to the SMF-type 3 as a pelagic mudstone/wackestone. The Dunham naming is planktonic foraminifera, echinoderm wackestone with colomiellids. The estimated FZ is number 1-3, the toe of the slope down to basin (Flügel 2004). The age still has to be early Albian, because of the occurrence of the colomiellids (*Colomiella* sp.) (Trejo 1975). The water depth must be over 200 m, therefore out of the photic zone. The samples A6 and A8 are mudstones with echinoderms being a high proportion of the fossil content. The echinoderms are mainly benthic organisms and show lower water depths for these layers.

<u>Resume:</u>

The section shows a constantly with water covered depositional environment. The unconformable transition zone marks a regression and the dry falling of the platform. The sea level starts to rise in the early Albian. At the onset of the El Abra Fm. water depths are in the range of several tens of meters. Within a short time, the environment changes from a shallow water to a marine setting. Wherein the sample A7 displays the highest water level in this section and decreases toward A8.

3.2 Section Via Lactea

The section Via Lactea (Fig. 1 and 14) is located about 3 km southeast of the town Núñez and is reached by an exit of the highway 57. The location is an active quarry which is used for degradation of industrial plaster. The section has a width of about 22 m, a height of 2 m and an exposed thickness of about 20 m. The rock layers dip with an angle of 80° to the east. The section can be divided into two mayor lithological units. These units are assigned to the Guaxcamá and the El Abra Formation.

Lithology:

The lower lithological unit is a whitish-gray, fine-grained gypsum / anhydrite interspersed with fine, brown mudstone layers (Fig. 12). The stratification is visible and is within the centimeter range. Fossils were not found at this location. The gypsum is strongly altered and the rock surfaces are friable and powdery. The transition to the overlying lithological unit is not sharp and is marked by loose rock rubble.

Fig. 12: Image of the gypsum layers in the section Via Lactea

The second lithological unit is dark gray to brown limestone (Fig. 13). The unit is well stratified with a constant layer thickness from 30 to 50 cm. The limestone is strongly dolomitized and traversed by backfilled cracks. Breccias occur more frequently in the upper part of the section. The rock is harder and more resistant to weathering. Fossils have not been found in this section.

Fig. 13: Part of the limestone sequence in the section Via Lactea.

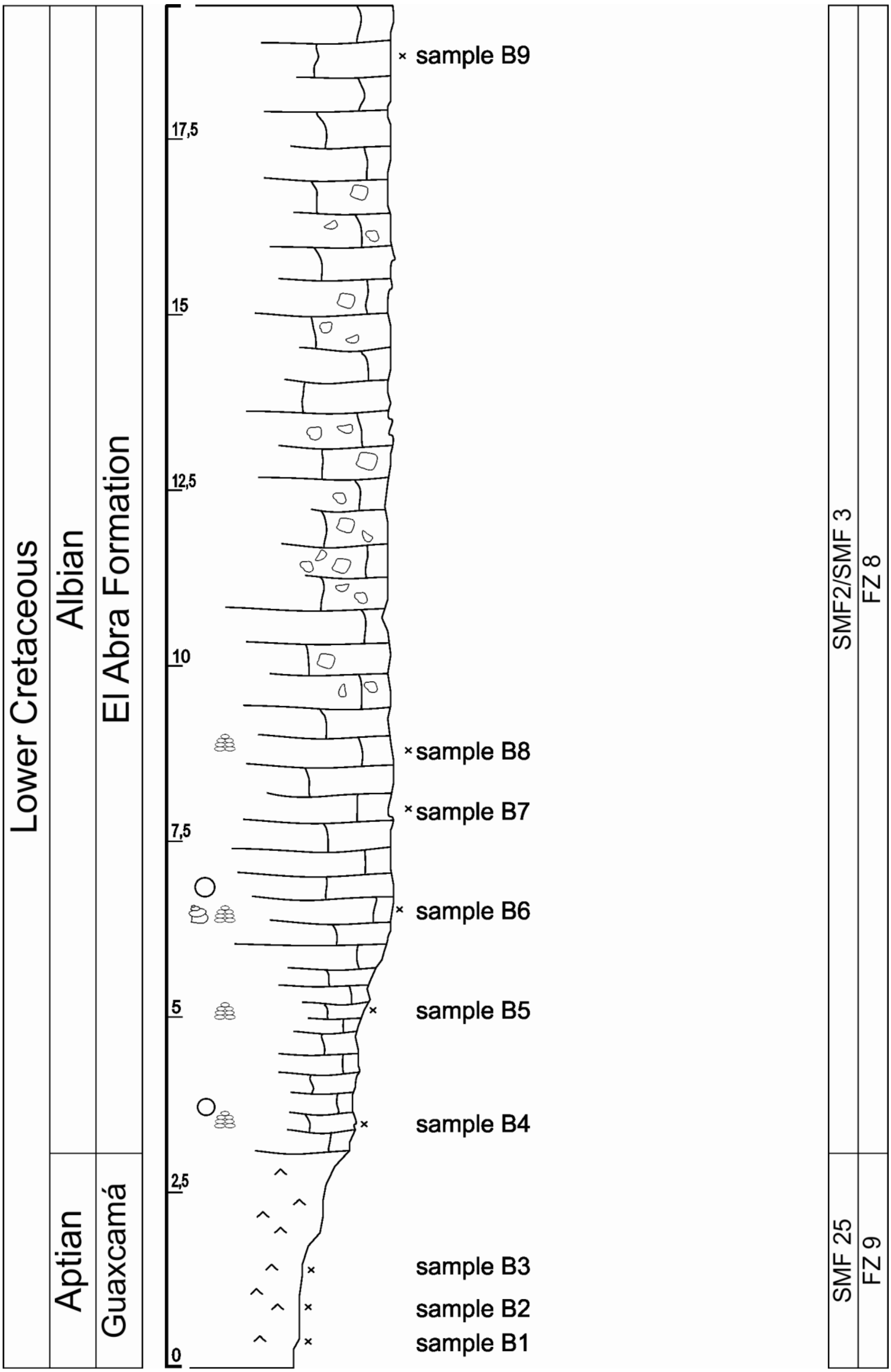

Fig. 14: Lithostratigraphy and microfacies of the section Via Lactea.

Thin sections:

Sample B1-B3:

The samples consist of unregulated fine grained fossil-free gypsum with a low proportion of clay clasts (Fig. 15).

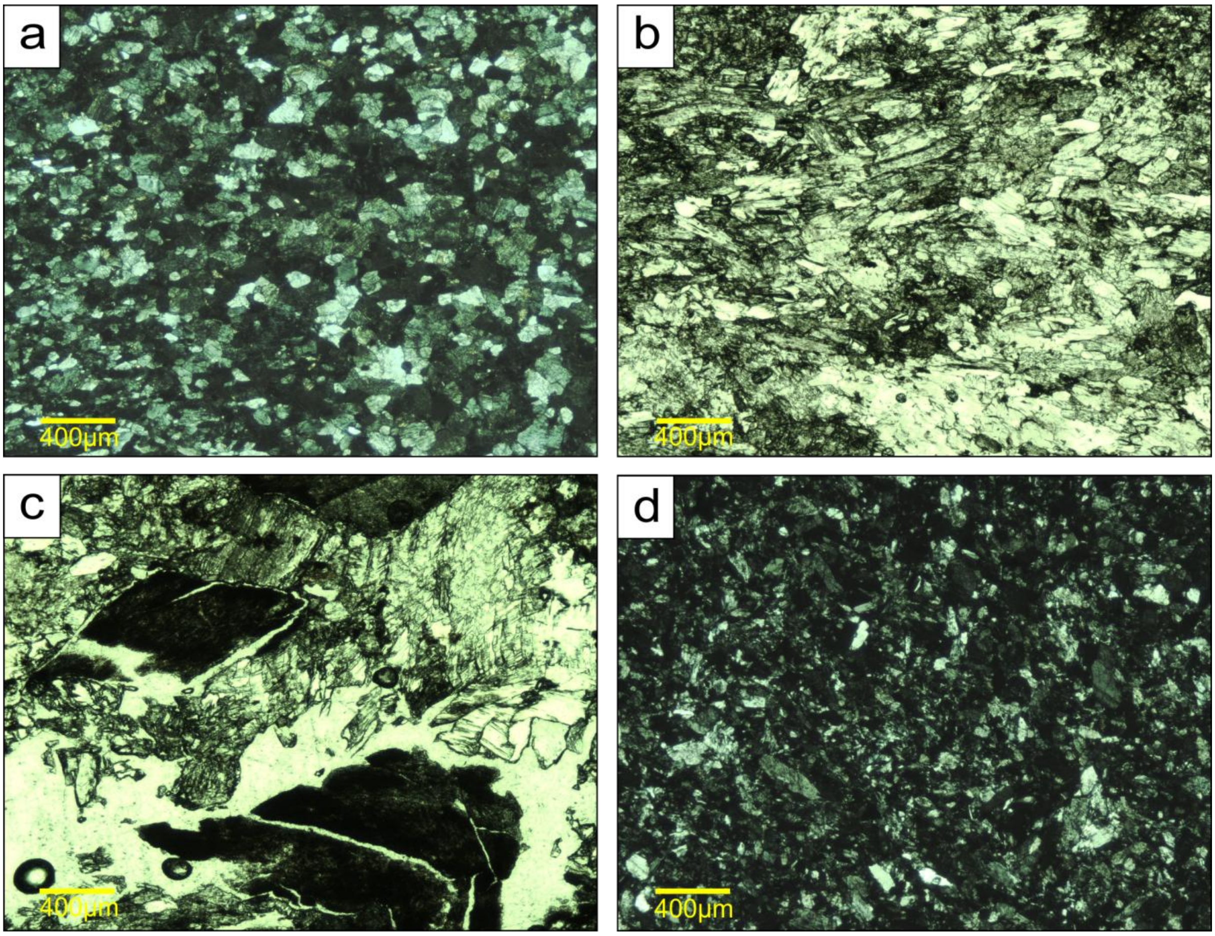

Fig. 15: Microfacies of the Guaxcamá Formation of the Via Lactea section (sample B1-B3). a)-b) Fine grained fossil free gypsum and Anhydrite (B1). c) Fossil free mud fragments inside the gypsum (B2). d) Fine grained fossil free gypsum and anhydrite (B3).

Sample B4-B9:

The samples represent a micritic partly dolomitized limestone. The fossil content is visible only in some places. The matrix / component ratio is estimated to be 90 % to 10 %. The fabric is matrix supported. Occurring fossils are gastropods, benthic foraminifera like miliolinids, lenticulinids and sponge sclerites (Fig. 16). The rock is strongly diagenetically overprinted. The fossils are poorly preserved.

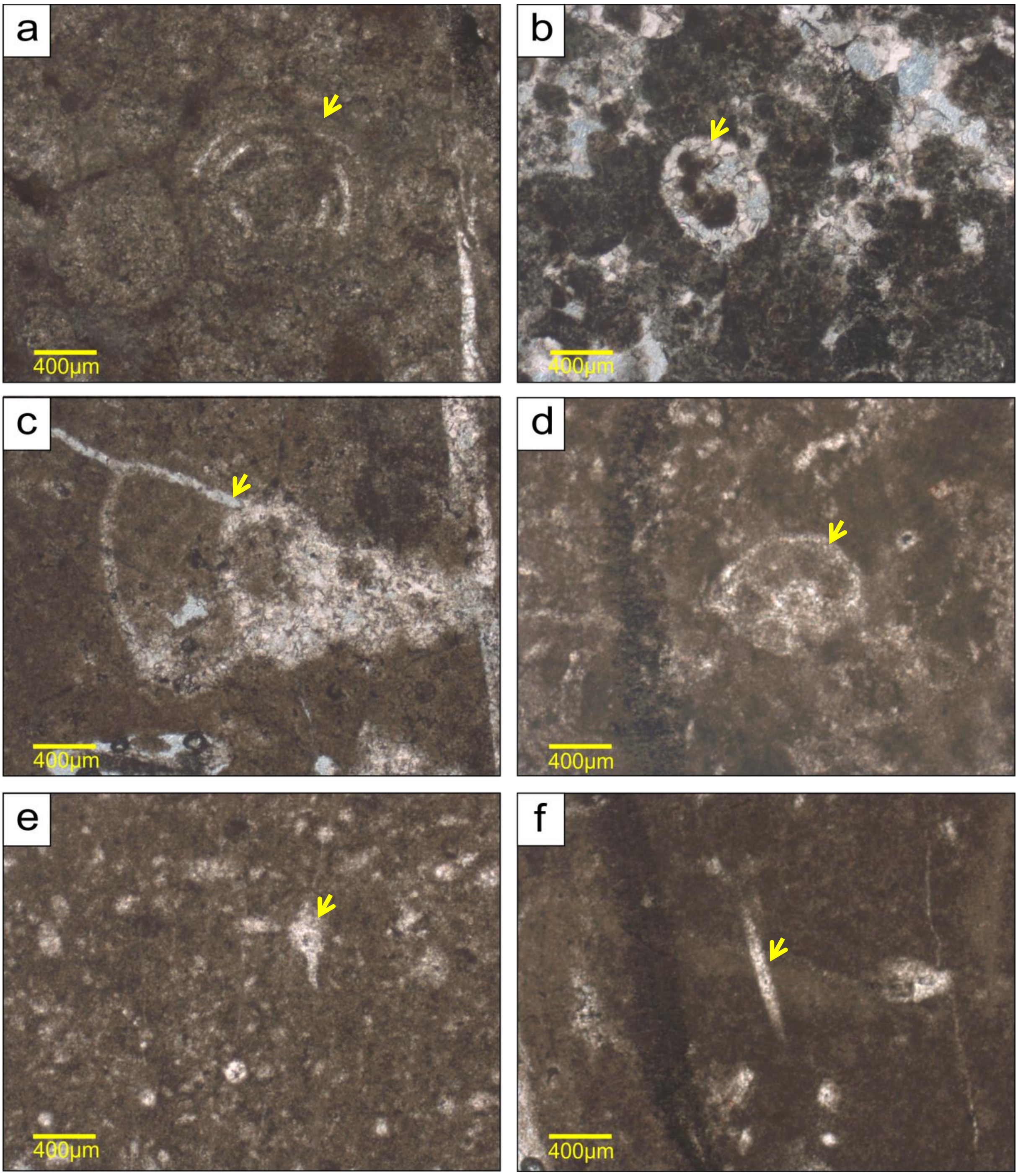

Fig. 16: Microfacies of the El Abra Formation of the Via Lactea section (sample B4-B9). a) Highly altered *Miliolinid* foraminifera (B4). b) Altered gastropode. c) Gastropode (B6) (B5). d) Altered benthic foraminifera (*Lenticulina*) in micritic matrix (B6). e) Calcispheres of unknown origin (B6). f) One sponge sclerite (B6).

Interpretation:

Laminated Evaporite-Carbonate Mudstone (FZ9)

The samples B1-B3 are similar to A1-A3. The rock is a laminated evaporite-carbonate mudstone and can be associated to an evaporitic lagoon in the back reef area (FZ9). The facies is a hypersaline shallow water environment. No fossils can be found. The sequence was continuously covered by water and temporarily cut off from freshwater supply (sabhka environment).

Benthic Foraminifera Gastropode Mudstone (FZ8)

The facies is similar to the lower part of the El Abra Fm. in the section Buenavista. Shallow water organisms like benthic foraminifera and gastropodes occur. The salinity seems higher and the depositional environment is a restricted lagoon within the back reef area (FZ8). The water depth is in the range of a few meters. The lagoon is temporarily cut off from the fresh water supply. The number and diversity of organisms is restricted and vanishes in the upper parts of the section.

Resume:

The section Via Lactea shows a transgressive trend. In the lower parts (Guaxcamá Fm.) the sea level is constant and starts to rise at the beginning of the El Abra Fm. The depositional area keeps being restricted. Typical back reef organisms like gastropodes and benthic foraminifera (*Miliolina*) occur.

3.3 Section La Huerta

The section La Huerta (Fig. 1 and 18) is located about 29 km east of the city San Luis Potosí inside an orchard (Santa Cruz de Puerto de La Huerta). The section is reached via the highway 70. The rock formation is exposed on a flat mountain slope. The rock surfaces are highly altered and covered with soil and vegetation such as cacti. The section has a recorded thickness of 61.45 m. The section comprises the La Peña Formation and Tambara Formation.

<u>Lithology:</u>

The rock is a light to dark gray micritic limestone (Fig. 17). In addition to the limestone chert occurs in layers and concretions. In the upper parts of the section the limestone shows yellow and red colors with breccia occurring. The layers are interspersed with calcite veins. The layer thickness ranges from 10 to 40 cm. Macroscopically no fossils are recognizable. Due to the weathering, the chert areas are especially accentuated and limestone show a black coloration.

Fig. 17: Terrain photo of La Huerta section.

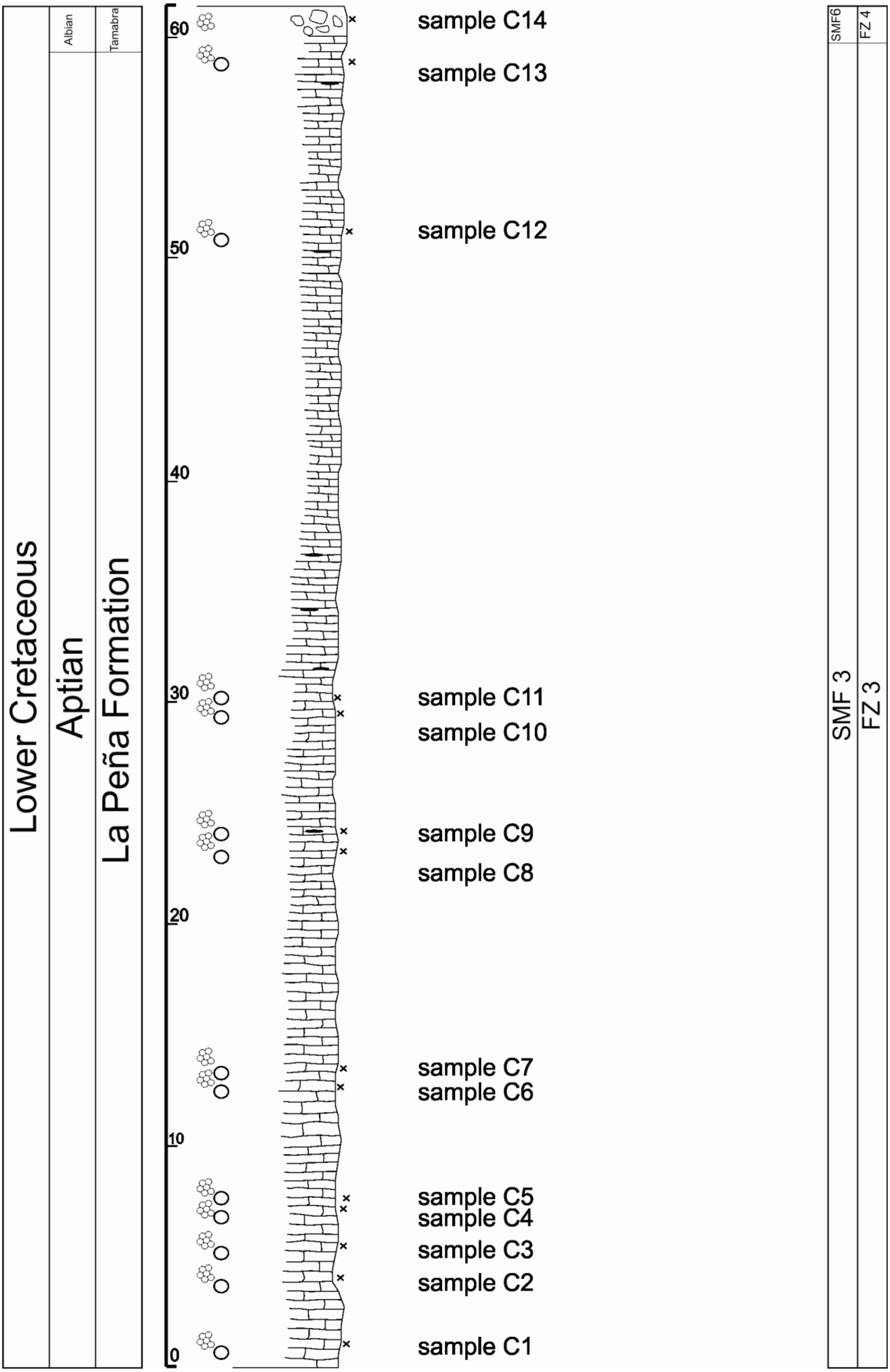

Fig. 18: Lithostratigraphy and microfacies of the section La Huerta.

Thin sections:

Sample C1-13

The samples represent a bioturbated micritic limestone. The ratio of matrix to components is 80-90 % to 10-20 %. The fabric is matrix supported. Occurring fossils are planktonic foraminifera, benthic foraminifera (*Textularia*), echinoderms and calcareous dinoflagellate cysts, furthermore referred to as c-dinocysts. (Fig. 19). The c-dinocysts appear most frequently and in greater numbers and occasionally areas with peloid grains occur.

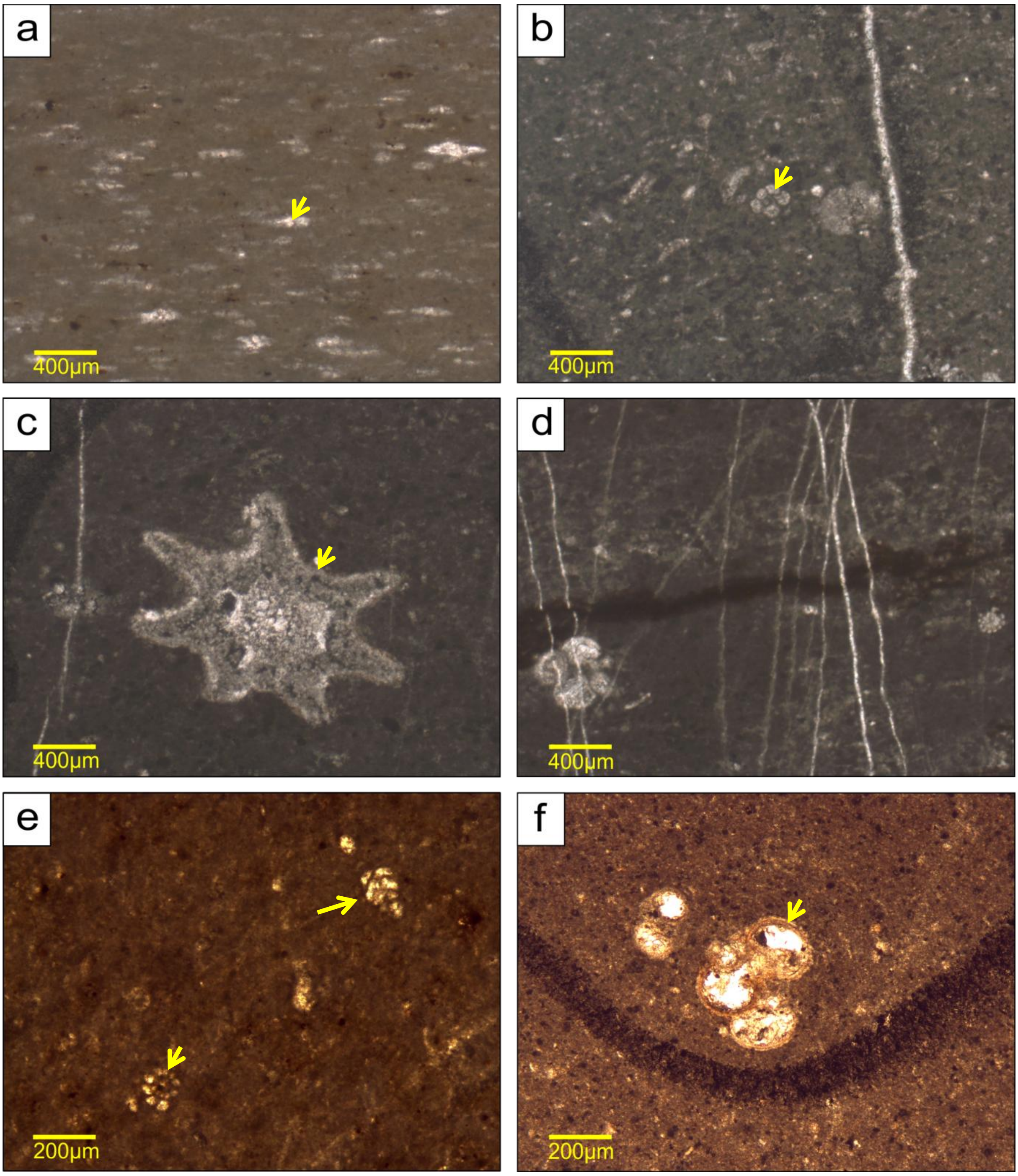

Fig. 19: Microfacies of the La Peña Formation of the La Huerta section (sample C1-C13). a) Steered c-dinocysts (C1). b) Planktonic foraminifera (C2) c) Echinoderm (C7). d) Planktonic foraminifera (globigeroid foraminifera) and echinoid sting (C7). e) Benthic foraminifera (*Textularia*) (C10). f) globigeroid foraminifera in micritic matrix (C13).

Sample C14

The sample represents an allochthonous bioturbated micritic limestone breccia. The ratio of matrix to components is 30-40 % to 60-70 %. The fabric is partly grain and partly matrix supported. Occurring components are planktonic foraminifera, c-dinocysts and lithoclasts. Benthic foraminifera are embedded in the lithoclasts (*Miliolina*, *Textularia*) as well as corals (*Scleractinia* sp.), red algae (*Corallinacea* sp.) and peloids (Fig.20).

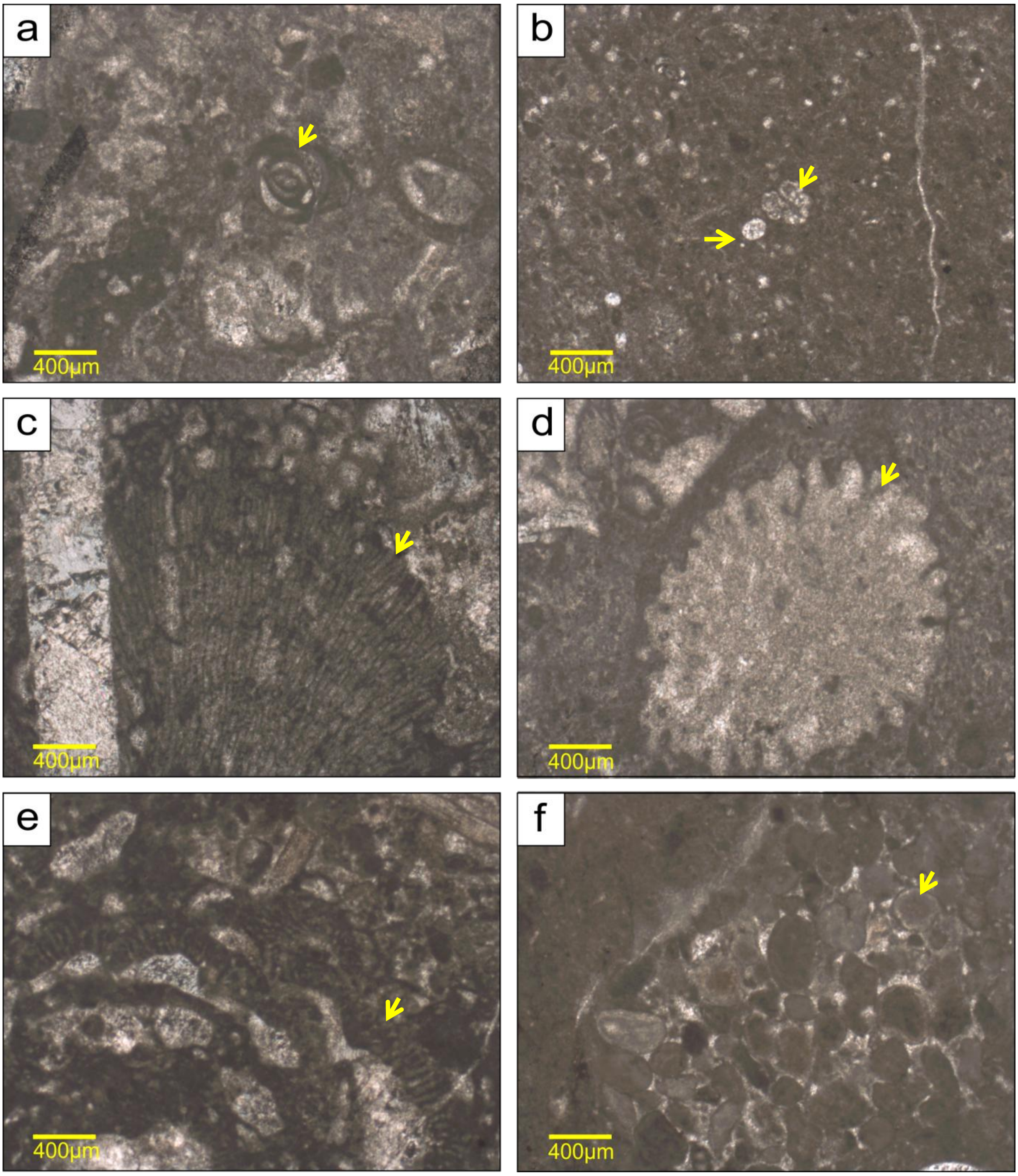

Fig. 20: Microfacies of the beginning Tamabra Formation of the La Huerta section (sample C22). a) Extraclastic fragment with benthic foraminifera (*Miliolina*). b) Planktonic foraminifera and c-dinocysts in micritic matrix. c) Extraclastic fragment with cyanobacteria. d) Extraclastic fragment with a single coral chalice (*Scleractinia* sp.). e) Red algae crusts (*Coralinacea* sp.) form an onkoid. f) Extraclastic fragment with peloids.

Interpretation:

Planktonic Foraminifera C-Dinocysts Wackestone with Echinoderms (FZ1-3)

The samples C1-C13 with planktonic foraminifera represent a pelagic depositional environment. The occasionally occurring benthic foraminifera refer to higher deposition areas. The water depth is approximately over 200 m and outside the photic zone. The estimated facies zone is the toe of the slope down to basin (Flügel 2004). The SMF-Type is pelagic mudstone (SMF 3) and the Dunham classification is planktonic foraminifera c-dinocysts wackestone with echinoderms. The peloid grains mark sliding events or areas that are not bioturbated. The sea level is constant throughout the formation and there are no major changes in fossil content. The depositional area is the MBMM proximal to the VSLPP.

Extraclast Planktonic Foraminifera Rudstone (FZ4)

The occurring lithoclast originate from the El Abra Formation on the platform. These extraclasts are composed of reef organisms such as corals, red algae and shallow water benthic foraminifera (*Miliolina, Textularia*). The matrix is filled with planktonic foraminifera and no shallow water organisms. Therefore water depth remains over 200 m. The extraclasts formed on the platform are transported into the basin. The clasts are not rounded and the transport path can be assumed to be short. These breccia can be assigned to the Tamabra Fm. The depositional environment is the slope (FZ4). The SMF-Type is densely packed reef rudstone.

Resume:

The La Peña Fm. shows a constant sedimentation in the MBMM. The peloid grains may be the first indication that the depositional environment is located on the slope. The breccia is the evidence of the growth of the VSLPP in the East. The platform progrades to the West and growths in height. The result is a development of a larger and bigger slope, resulting a sliding of fragments.

3.4 Section Wadley

The section Wadley (Fig. 1 and 24) is located to the west of the Sierra de Catorce about 9 km east of the town Wadley. The rock sequence can be found in the curve of a winding road and can be easily measured at the edge of the road. The section has a width of about 70 m, a height of 3 m and an exposed thickness of 44.6 m. The whole section is tectonically highly stressed. With the lower part dip at an angle of about 80° to the northwest. This is followed by a stratigraphic gap and continuous with thinner layers dipping 40° to the northwest. The upper sequence exhibits several folds as well another disorder (Fig. 23). The section comprises the Otates and La Peña Formation.

Lithology:

The rocks in the lower parts of the section are light gray to middle gray limestones (Fig 21). The limestone shows uniformly a layer thickness from 10 to 30 cm.

Fig. 21: Thickly bedded limestones in the lower part of the section Wadley.

The lithology in the upper part of the section is composed of light to dark gray, thin to middle bedded micritic limestones interbedded with yellow and red thin bedded mudstones (Fig. 22). Thin chert layers and lenses occur. No fossils were recognizable. In the uppermost part of the section, the claystone proportion increases and the thickness of the limestone decreases. Compared to the shale, limestone and chert show a higher weathering resistance.

Fig. 22: Interbedding of limestones and shale in the upper parts of the section Wadley.

Fig. 23: Northwest vergent anticlinal fold in the section Wadley.

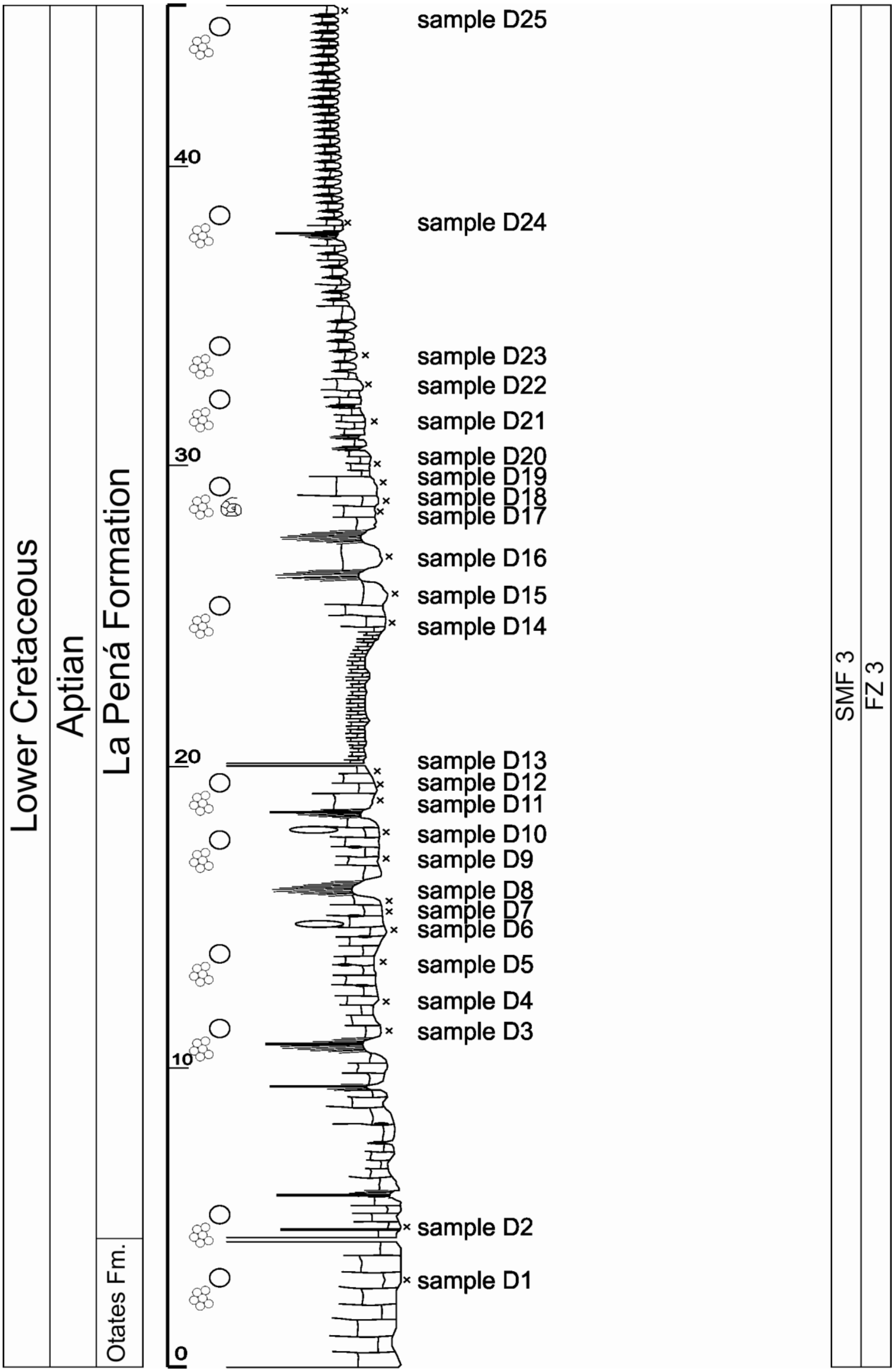

Fig. 24: Lithostratigraphy and microfacies of the section Wadley.

Thin sections:

Sample D1-D25

Thses samples represent bioturbated micritic limestones, chert and claystones but hardly differ in the fossil content. The ratio of matrix to components is 80-90 % to 10-20 %. The fabric is matrix supported. Occurring fossils are c-dinocysts, planktonic foraminifera, ammonites and sponge sclerites (Fig. 25). The main difference is the lithology and the component abundance.

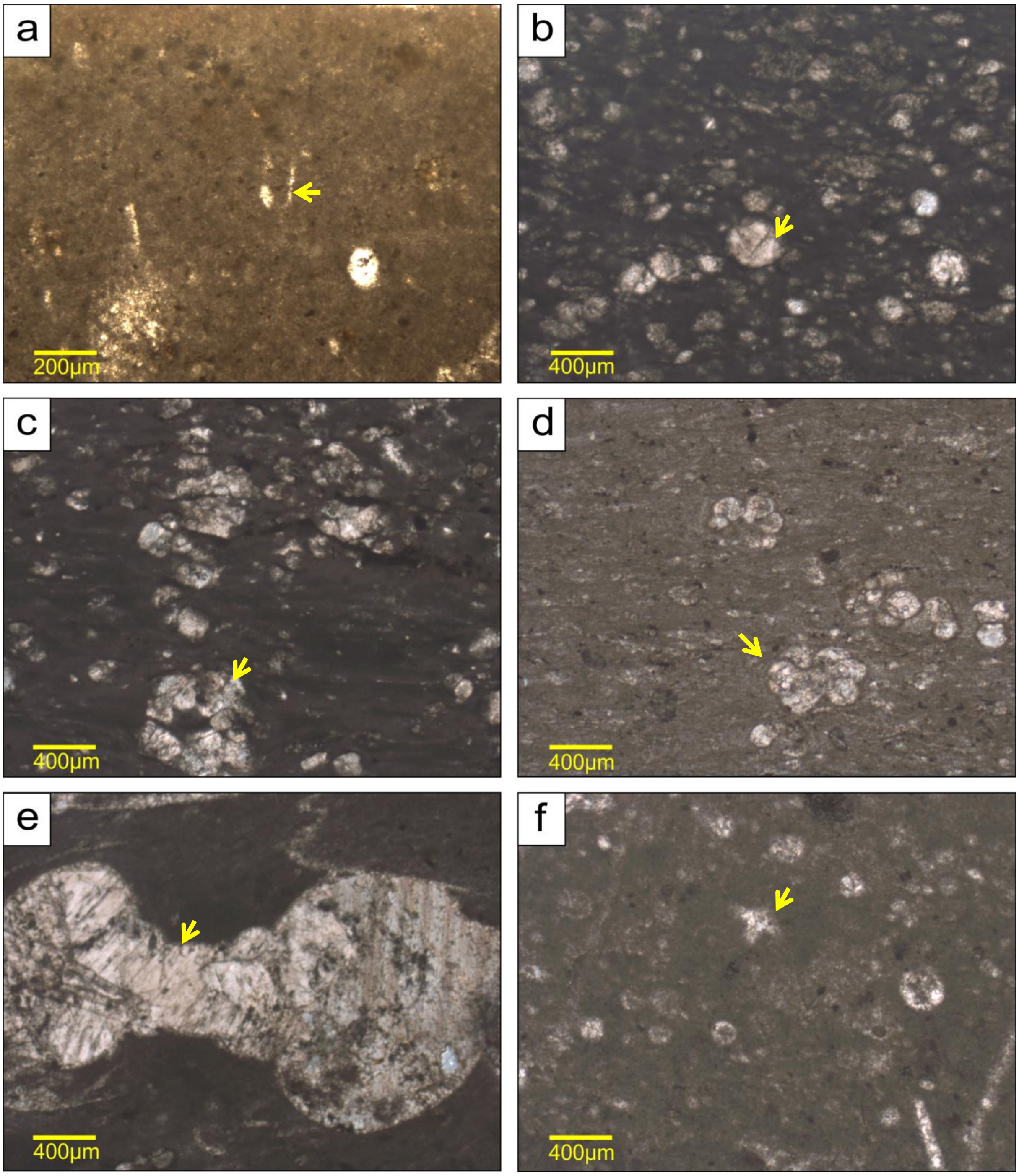

Fig. 25: Microfacies of the La Peña Formation of the Wadley section (sample D1-D25) a) A colomiellid (*Colomiella* sp.) in the center of the picture. b) C-dinocysts in micritic matrix. c)-d) Planktonic foraminifera. e) Small sized ammonite. f) Hexactinellid sponge sclerites.

Interpretation:

Planktonic Foraminifera C-Dinocysts Wackestone (FZ1-3)

The planktonic foraminifera and the c-dinocysts are an indicator for pelagic depositional conditions. The water depth has to be over 200 m due the lack of benthic organism such as benthic foraminifera. In the section, there is a constant change in limestone and clay sedimentation but the fossil record to keeps stable. The SMF-Type is a pelagic wackestone and the depositional environment is toe of the slope down to basin (FZ1-3). The Dunham classification is a planktonic foraminifera c-dinocysts wackestone.

Resume:

The sequence shows a constant sedimentation in the MBMM. The depositional shows hardly influence of the platform.

3.5 Section Corazones

The section Corazones (Fig. 1 and 28) is located 4.7 km east of the town Corazones in the Sierra del Coro. The rock sequence is well exposed in a dry riverbed. The section has a width of about 15 m, a height of 5 m and an exposed thickness of 8.33 m and comprises the Tamabra and Cuesta del Cura Formation.

Lithology:

In the lower part there is a medium to dark gray, micritic limestone (Fig. 26), as well as blocks of breccia occurring as loose debris and therefore may have been transported. A prominent horizon shows a conglomerate layer. The thickness of the layers varies from 15 to 90 cm. Macroscopically, ammonites and belemnites can be found. The rock is characterized by its hardness, resistance to weathering and changes its surface color to yellow and orange. Sedimentary structures can be recognized by the changing component sizes.

Fig. 26: Lower part of the section Corazones.

In the upper part, a dark gray micritic limestone occurs, which yield some chert layers (Fig. 27). The thickness of the layers is about 20 to 30 cm. Due to weathering, the rock color changed to brown or red. No fossils were found.

Fig. 27: The upper section of the section Corazones. The layers are thin to middle bedded limestones with chert.

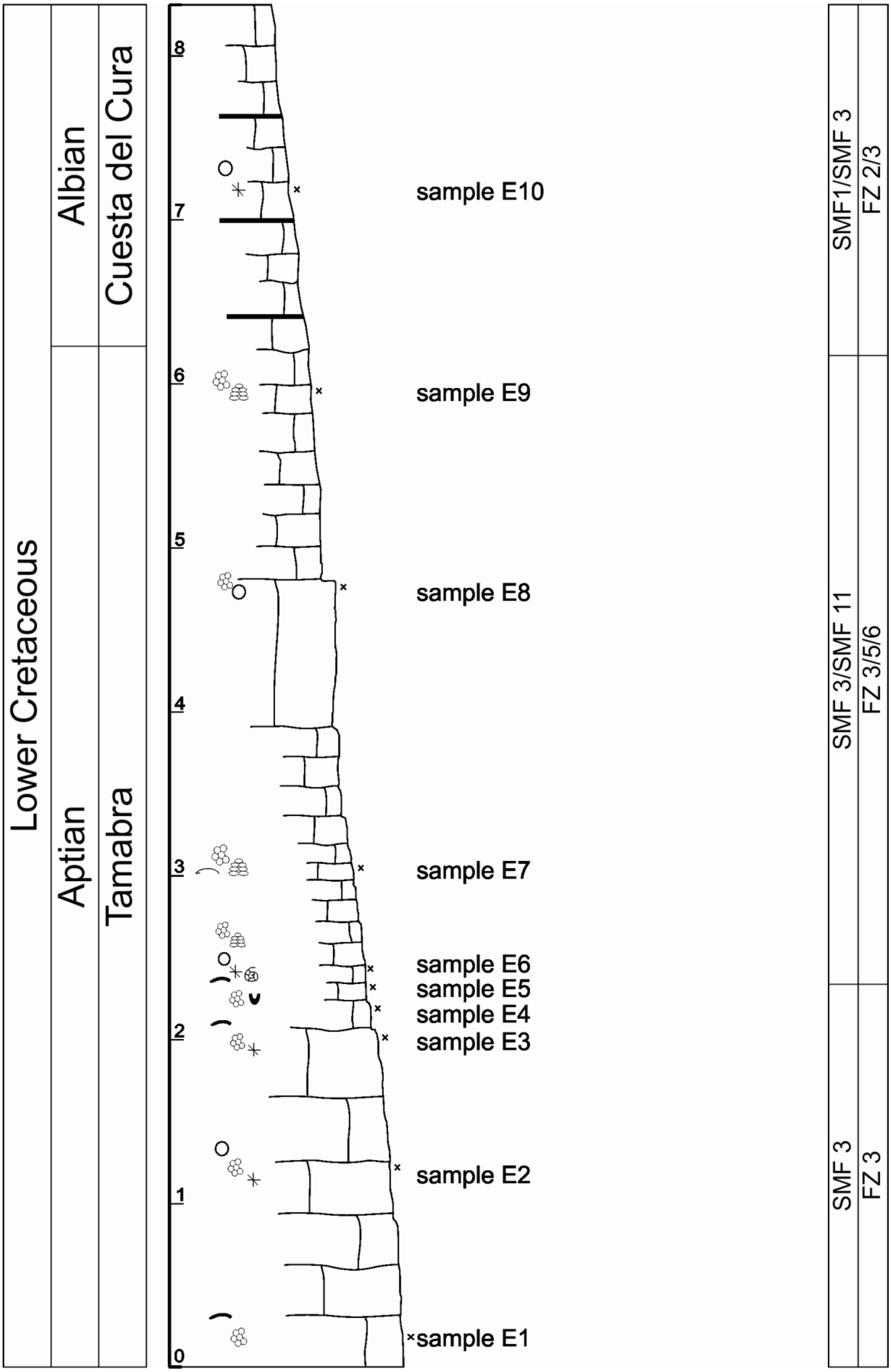

Fig. 28: Lithostratigraphy and microfacies of the section Corazones.

Thin sections:

Sample E1-E5

The samples represent bioturbated micritic limestones. The ratio of matrix to components is 70-80 % to 20-30 %. The fabric is matrix supported. Occurring fossils are c-dinocysts, planktonic foraminifera, ammonites, hexactinellid sponge spicule, colomiellids and bivalve shells (Fig. 29).

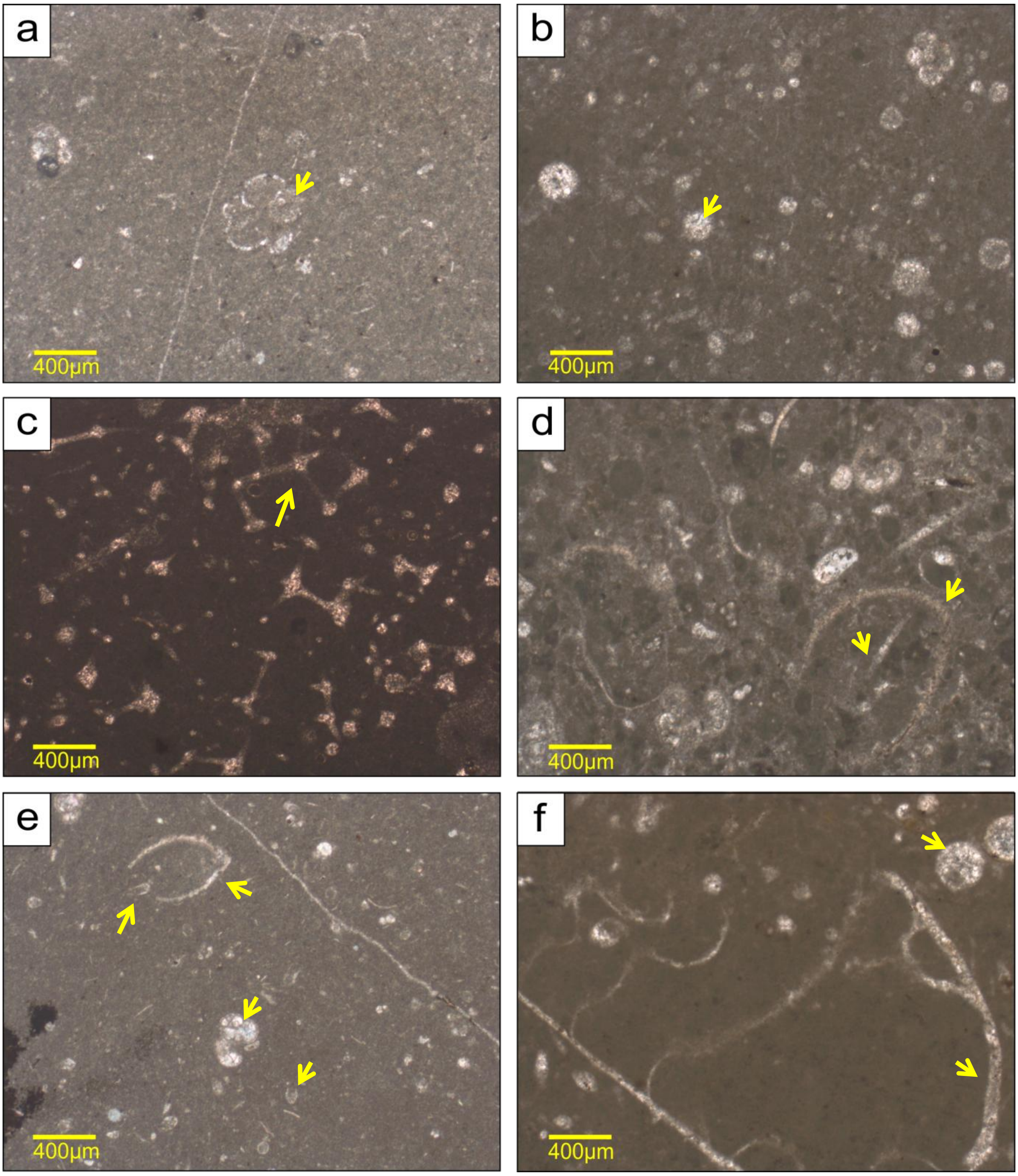

Fig. 29: Microfacies of the La Peña Formation of the Corazones section (sample E1-E5). a) Planktonic foraminifera in micritic matrix (E1). b) C-dinocysts and planktonic foraminifera (E3). c) Dictyonal meshwork of a hexactinellid sponge (E3). d) Various bioclasts like c-dinocysts, sponge sclerites, bivalve fragments (E3). e) Abundant colomiellids, bivalve shells and planktonic foraminifera (E4). f) Ammonite and c-dinocysts (E5).

Sample E6-E9

Most samples are composed of two different facies, a bioturbated micritic limestone and a biogenic sparse limestone. The micritic limestone has a matrix to components ratio of 80-90 % to 10-20 %. The fabric is matrix supported. Occurring fossils are c-dinocysts, planktonic foraminifera, ammonites, sponge sclerites and ostracodes. The sparse limestone has a cement to components ratio of 20-30 % to 70-80 %. The fabric is grain supported. The occurring components are peloids, benthic foraminifera (*Textularia*, *Miliolina*) and planktonic foraminifera (globigeroid foraminifera). The top layer of sample E6 comprises conglomerates. These conglomerates show a pelagic facies and are embedded in bioclasts (Fig. 30).

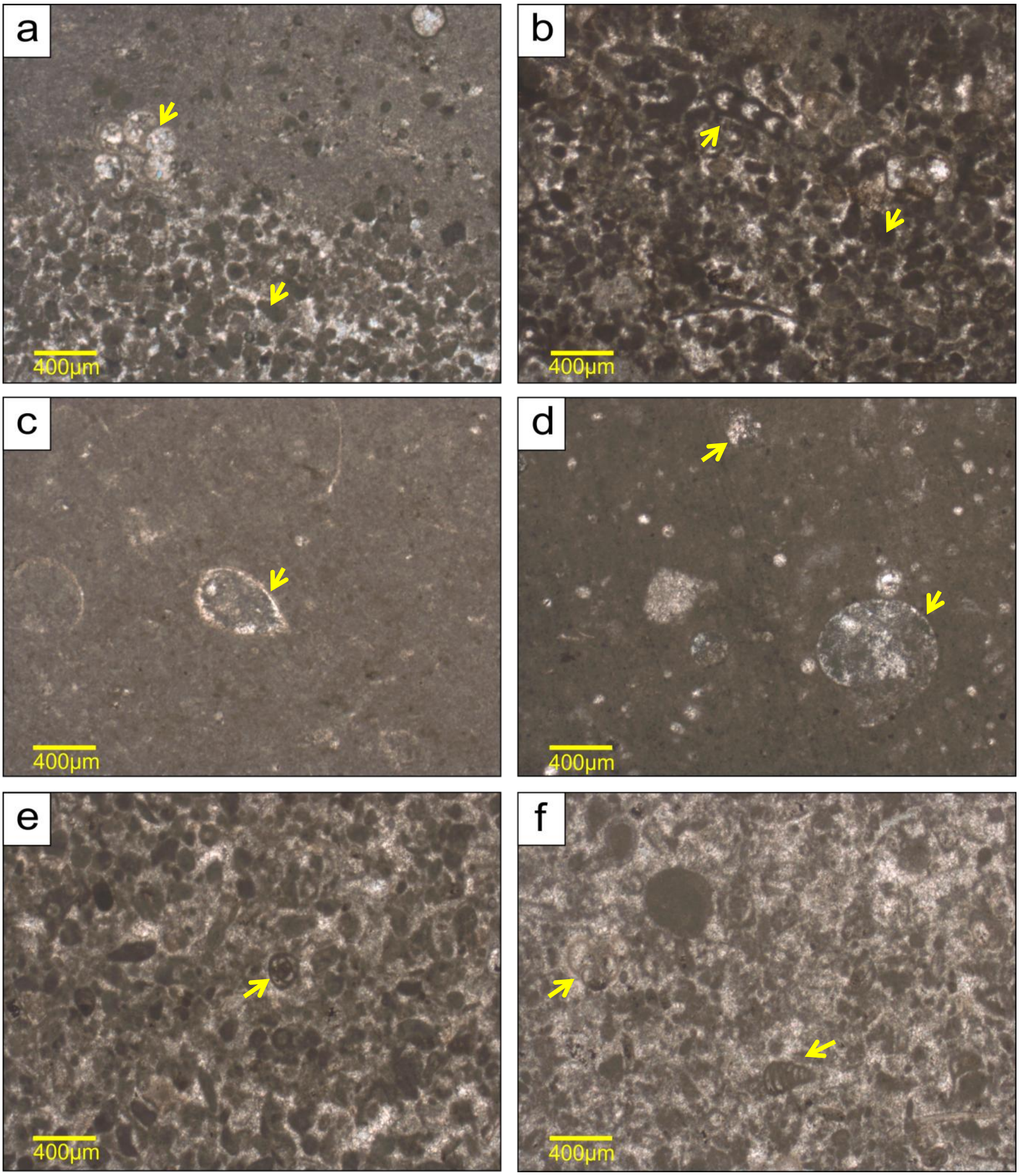

Fig. 30: Microfacies of the Tamabra Formation of the Corazones section (sample E6-E9). a) Planktonic foraminifera in micritic matrix in the upper half and dense packed peloids in a calcite cement in the lower half (E6). b) Benthic foraminifera and peloids in sparse cement (E7). c) Ostracode in micritic matrix (E3). d) A small ammonite and c-dinocysts (E7). e) Benthic foraminifera (*Miliolina*) and peloids in sparse cement (E8). f) Benthic (*Textularia*) and planktonic foraminifera, peloids in sparse cement (E8).

Sample E10

The sample represents a bioturbated micritic limestone. The matrix / component ratio can be divided into two sections. The first section has a 90 % to 10 % matrix to component ratio; the second section has one of 70 % to 30 %, respectively. Both fabrics are matrix supported. Occurring fossils are planktonic foraminifera (globigeroid foraminifera), c-dinocysts, thin bivalve shells, Colomiellids and sponge sclerites (Fig. 11).

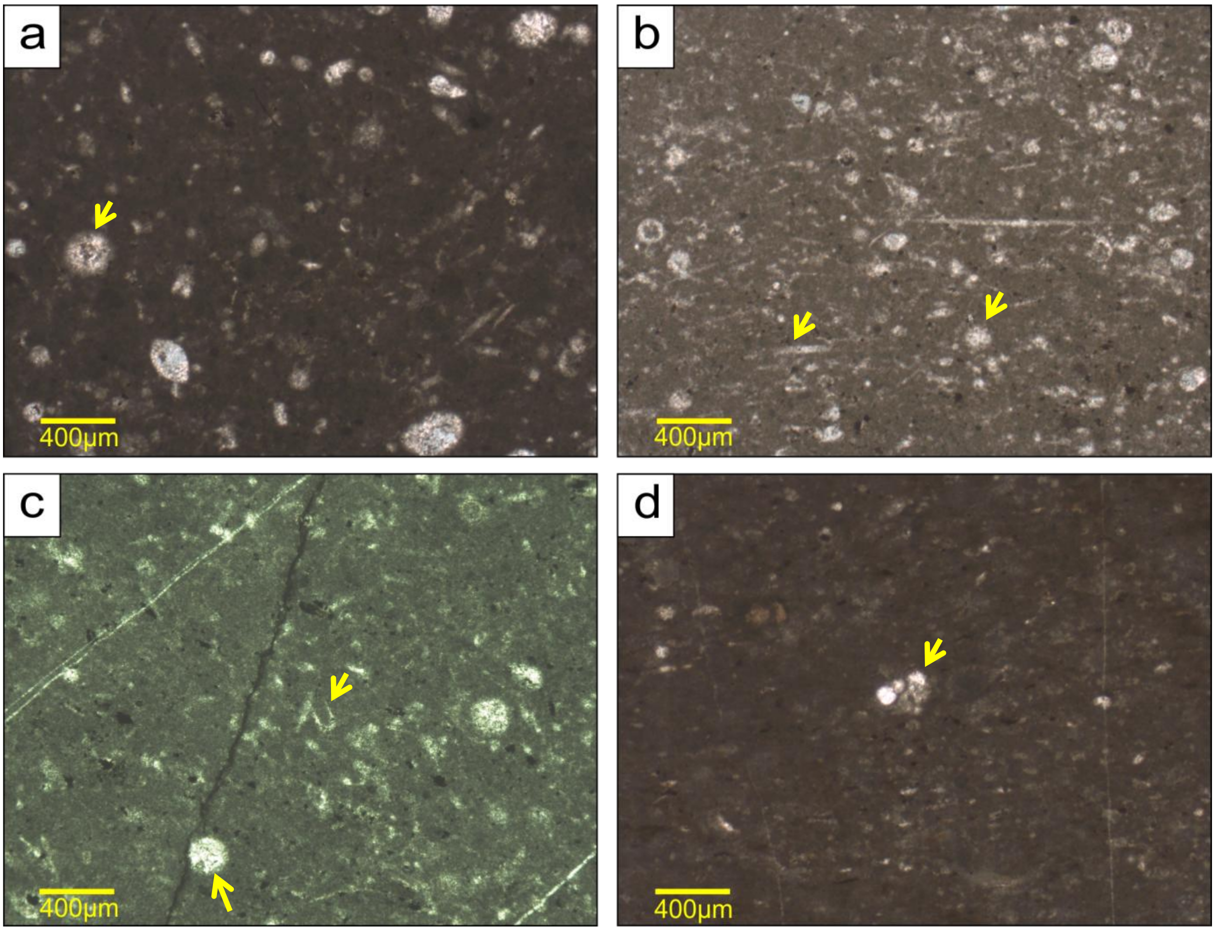

Fig. 31: Microfacies of the Cuesta del Cura Formation of the Corazones section (sample E10). a)-b) C-dinocysts and sponge sclerites in micritic matrix. c) Colomiellid d) Planktonic foraminifera (globigeroid foraminifera).

<u>Interpretation:</u>

Planktonic Foraminifera C-Dinocysts Wackestone with Sponge Spicules (FZ1-3)

The occurring planktonic foraminifera and c-dinocysts in the samples E1-E5 are indicators for a pelagic depositional environment. The ammonites only occur in a fully open marine facies. The water depth has to more than 200 m due to the absence of benthic foraminifera. The SMF-Type is a pelagic wackestone and the depositional area is the toe of the slope down to basin (FZ1-3). The sequence can be assigned to the La Peña Formation. The occurring Colomiellids of the type *Colomiella* sp. are evidence for a late Albian age.

Planktonic Foraminifera C-Dinocysts Wackestone (FZ1-3) and Peloid Benthic Foraminifera Packstone/Grainstone (FZ8)

The samples E6-E9 show two different types of facies. The first is a pelagic wackestone with planktonic foraminifera. The depositional area is the toe of the slope down to basin (FZ1-3). The water depth has to be more than 200 m due to the lack of benthic organisms. The second facies is a peloidal packstone/grainstone, the typical depositional environment is a restricted back reef lagoon (FZ8). The conglomerate layer may be a tempestite deposition. The conglomerates seem to be worked up material of the present sea beds. These deposits result from embankments of a platform shallow-water facies in a fully marine basin. The embankments are the first evidence of the platform in the east and the steepening of the slope. This unit can be assigned to the Tamabra Formation.

C-Dinocysts, Sp**icules Wackestone with Colomiellids (FZ4)**

The sample E10 shows a change in the depositional facies compared to the other samples. The amount of planktonic foraminifera is less; instead bivalve shells and sponge spicules occur in greater numbers. The estimated depositional area is the slope (FZ4) and the SMF-Type is a limestone with shell concentrations. At the beginning of the Albian the platform starts slightly to grow in height and in width. The slope has extended into the area of the section and the water depth is slightly lower than in the underlying formation. The occurring colomiellids of the type *Collomiella* sp. are evidence for a late Aptian or an early Albian age.

Resume:

The section shows the development from a pelagic basin facies to a slope facies with beds of a shallow water platform environment. Instead of a transgression a progradation of the platform and its slope is notable. The deposition area is located at the lower end of the slope, because mainly fine material is deposited and larger transported components do not reach this area. The angle of the slope plays a role too, but this cannot be determined exactly. The section shows the range from the late Aptian to the early Albian formations due to the colomiellids. The genus Collomiella occurs towards the end of the Aptian for the first time and disappears during middle Albian (Trejo 1975).

3.6 Section Rincón de Leijas

The section Rincón de Leijas (Fig. 1 and 33) is located about 1.4 km south of the town Rincón de Leijas in the Sierra del Coro. The rock formation is exposed on a mountain slope. The surfaces are highly altered and covered with soil and vegetation such as cacti. The section has a recorded thickness of 70 m and comprises the Tamabra and Cuesta del Cura Formation.

Lithology:

The lithology of the section is composed of brown and gray micritic limestones interbedded with brown to red thin bedded claystones (Fig. 32). Also thin chert layers and lenses occur. The thickness of the layers varies from 15 to 40 cm. Macroscopically belemnites can be found, as well as corals embedded in the chert layers. Compared to the clay, limestone and chert show a higher weathering resistance.

Fig. 32: Part of the section Rincón de Leijas. Shown are middle bedded limestones with chert layers.

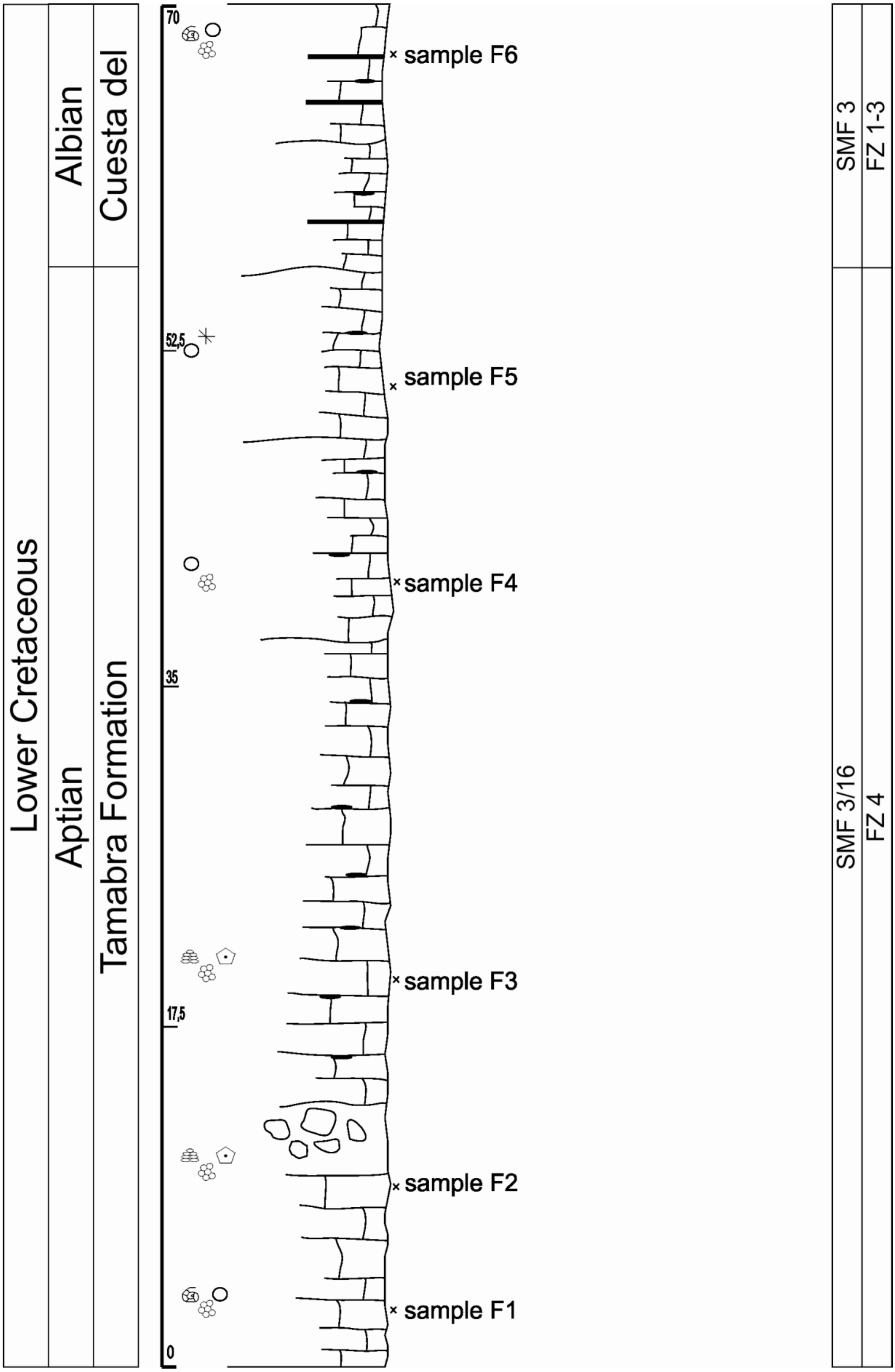

Fig. 33: Lithostratigraphy and microfacies of the section Rincón de Leijas.

Thin sections:

Sample F1-F4

The samples represent allochthonous bioturbated micritic limestones. The ratio of matrix to components is 70-80 % to 20-30 %. The fabric is matrix supported. Occurring fossils are c-dinocysts, planktonic foraminifera (globigeroid foraminifera), benthic foraminifera (*Textularia*), echinoderms, peloids, ammonites, belemnites (Fig. 34 a-b). The samples show parts with a fine lamination.

Sample F5

The sample represents allochthonous bioturbated micritic limestones. The ratio of matrix to components is 70 % to 30 %. The fabric is matrix supported. Occurring fossils are c-dinocysts, benthic foraminifera (*Textularia*), peloids, ammonites, belemnites and hexactinellid sponge spicule (Fig. 34 c-d). The samples show parts with a fine lamination.

Sample F6

The sample represents an allochthonous micritic limestone. The ratio of matrix to components is 80 % to 20 %. The fabric is matrix supported. Occurring fossils are c-dinocysts, planktonic foraminifera (globigeroid foraminifera) and ammonites (Fig. 34 e-f).

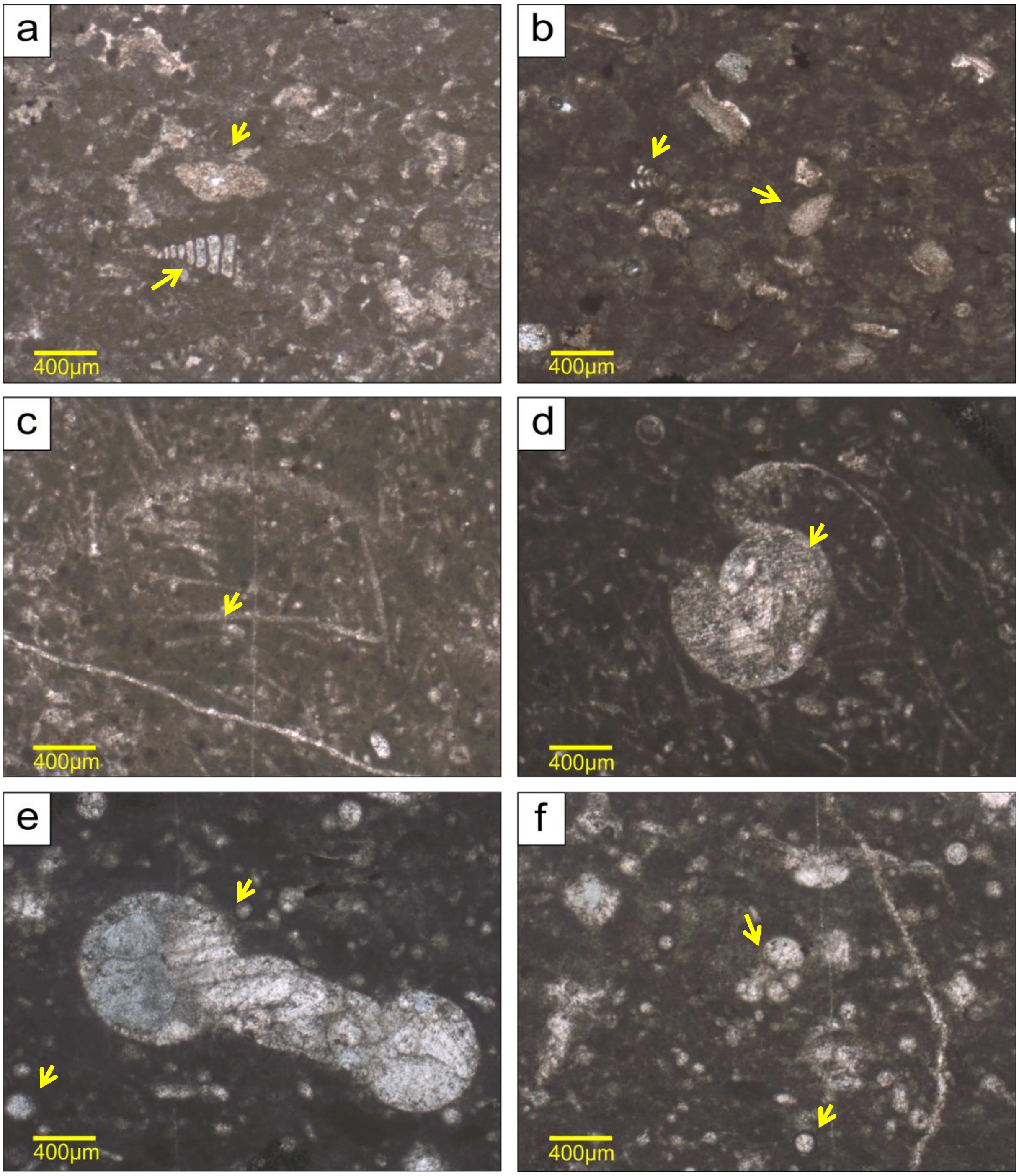

Fig. 34: Microfacies of the La Peña Formation of the Rincón de Leijas section (sample F1-F6). a) Benthic foraminifera (*Textularia*), fragments of echinoderms and peloids in sparse cement (F1). b) Benthic foraminifera (*Textularia*) and fragments of echinoderms in micritic matrix (F1). c) Abundant sponge spicule (F2). d) Ammonite and sponge spiculae in micritic matrix (F2). e) An ammonite and c-dinocysts in micritic matrix (F4). f) Planktonic foraminifera and c-dinocysts (F5).

Interpretation:

Benthic Foraminifera Echinoderm Wackestone/Packstone (FZ4)

The depositional area can be interpreted as a typical slope. The basic components are fine beds of benthic foraminifera and echinoderms, as well as peloids. The ammonites, belemnites and planktonic foraminifera are indicator for an open marine environment. The beds of echinoderms, peloids and benthic foraminifera originate from a different area and are deposited on the slope.

C-Dinocysts, Sp**icules Wackestone/Packstone (FZ4)**

This sample represents a depositional area on the slope, too. Abundant sponge sclerites and c-dinocysts as well as peloid debris are evidence of an energetic depositional environment. The belemnites are a sign that open marine conditions continue to prevail

Planktonic Foraminifera C-Dinocysts Wackestone (FZ1-3)

The samples represent a pelagic wackestone with planktonic foraminifera. The depositional area is the toe of the slope down to basin (FZ1-3). The water depth is more than 200 m due the lack of benthic organisms.

Resume:

The section shows a slope depositional area that evolves to a pelagic environment. Samples 1-5 are dominated by deposits of the platform. Benthic organisms appear in variety and are embedded in micritic layers. In the latter sample benthic organisms no longer occur and have been replaced by pelagic. However, the sheet-like character is still slightly present. The transgression is experiencing a push and sedimentation cannot keep up.

3.7 Section Grava

The section Grava (Fig. 1 and 36) is located about 40 km northwest of the city San Luis Potosí, between the towns Santa Teresa and San Augustin de Clavellinas. The Location is an active quarry for gravel and sand production and can be reached over the highway 49. The rock surfaces are slightly altered and covered with dust from the factory. The section has a width of about 20 m, a height of 4 m and a recorded thickness of 8.77 m and comprises the La Peña Formation.

Lithology:

The lithology of the section is composed of middle to thickly bedded light to middle gray sparse limestones (Fig. 35). In the upper part of the section these limestones are interbedded with brown to red thin bedded claystones. No fossils were found. The limestones show a higher weathering resistance than the marls in the upper part of the section. A fine lamination can be recognized in some of the rock layers.

Fig. 35: The picture shows the lower part of the section Grava. The middle to tick bedded limestone is covert with dust from the quarry.

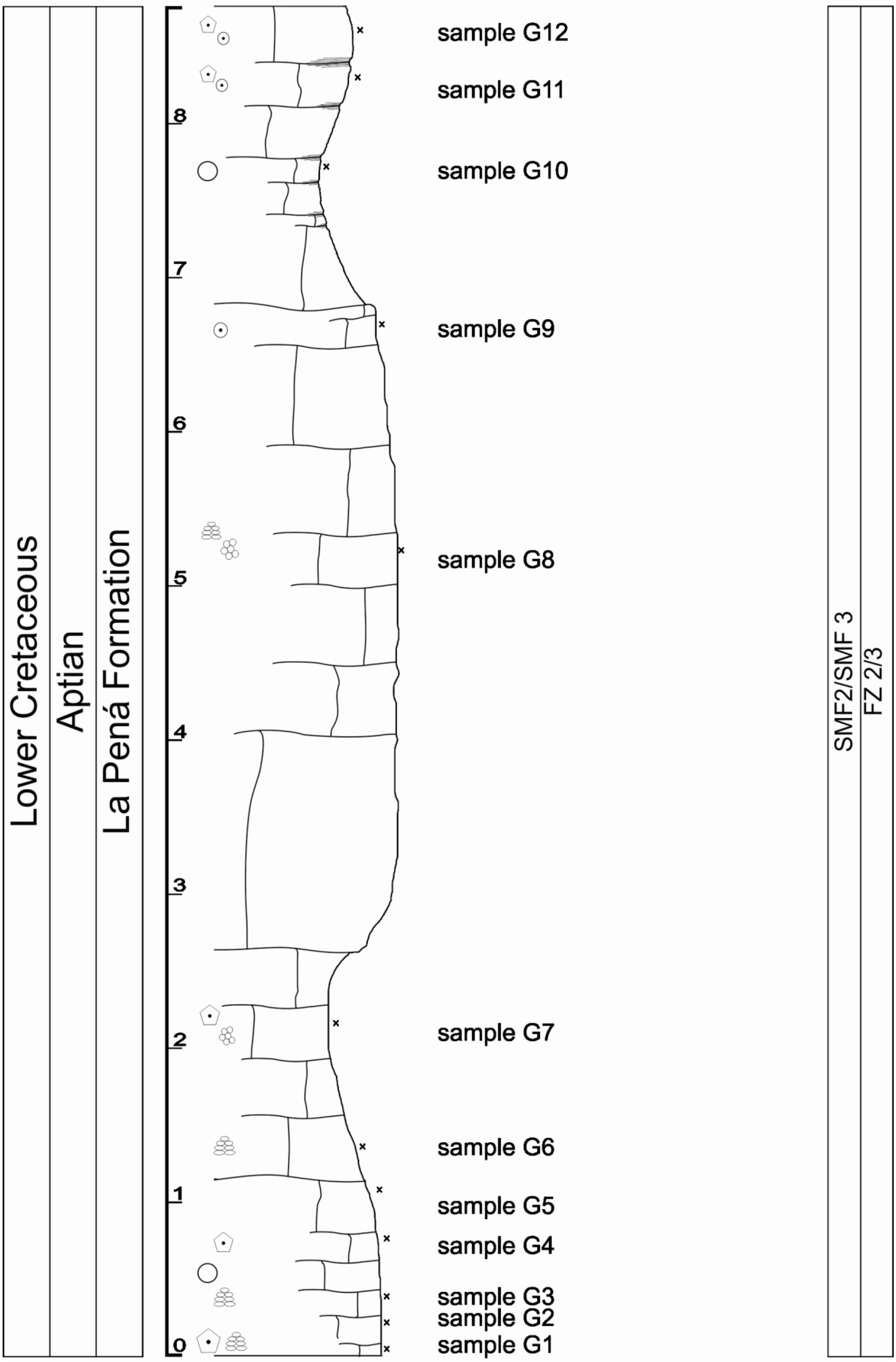

Fig. 36: Lithostratigraphy and microfacies of the section Grava.

Thin sections:

Sample G1-G12

The samples represent allochthonous sparse limestones. The ratio of cement to components is 30-40 % to 60-70 %. The fabric is grain supported. Occurring fossils are c-dinocysts, planktonic foraminifera, benthic foraminifera (*Textularia*, *Lenticulina*), echinoderms, ooids, peloids and cortoids (bioclasts with micrite envelopes). A fine lamination of the components and more micritic areas is recognizable. The samples G2 and G10 show micritic limestone. The ratio of matrix to components is 80-90 % to 10-20 %. The fabric is matrix supported. Occurring fossils are c-dinocysts, planktonic foraminifera (globigeroid foraminifera) (Fig. 37).

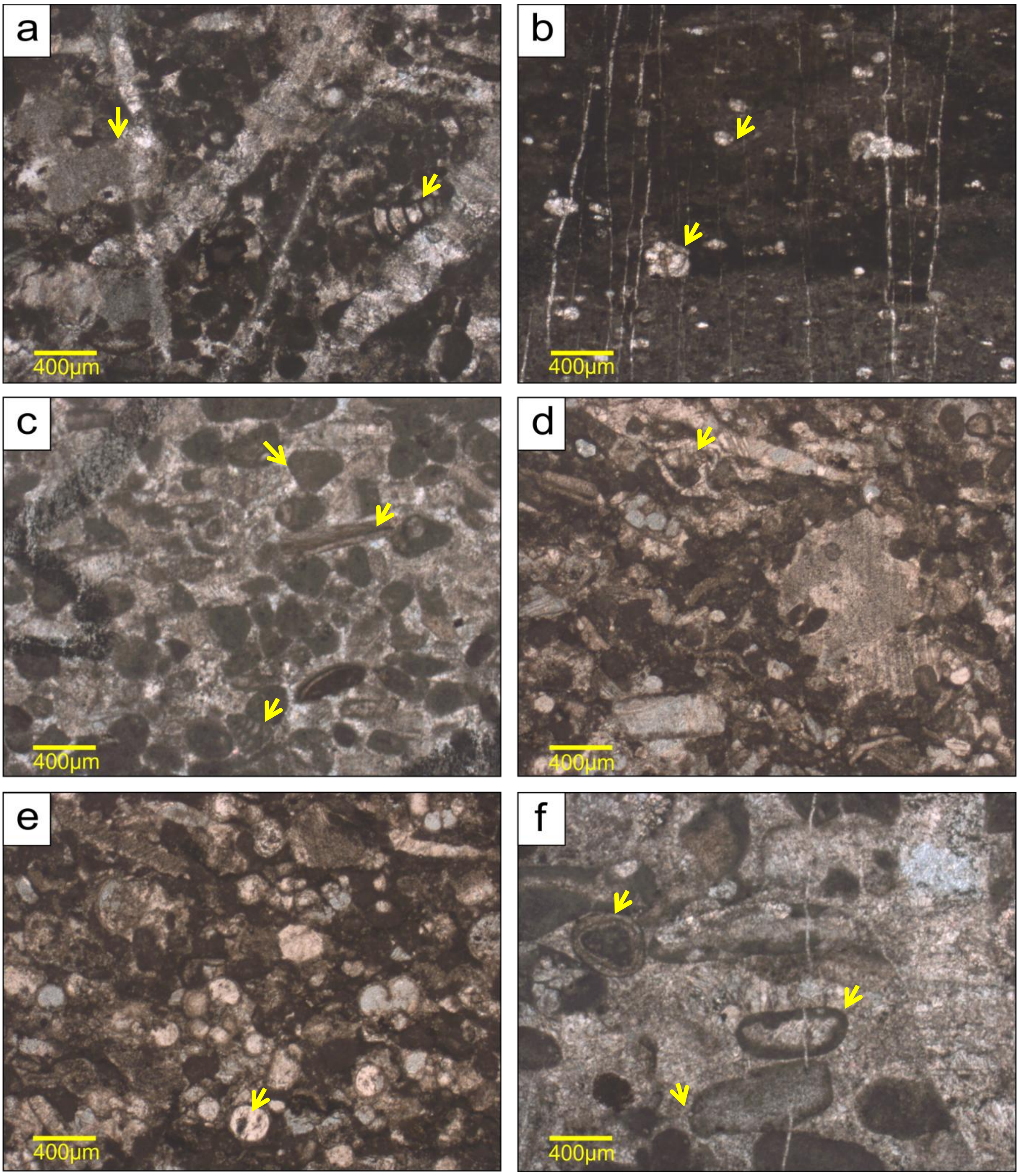

Fig. 37: Microfacies of the Peña Formation of the Grava section (sample G1-G12). a) Echinoderms and benthic foraminifera (G1). b) Planktonic foraminifera and c-dinocysts in micritic matrix (G2). c) Benthic foraminifera (*Textularia*), bivalve shells and lithoclasts in sparse cement (G4). d) Benthic foraminifera (*Lenticulina*), echinoderms and lithoclasts in sparse cement (G7). e) C-dinocysts (G7). f) Ooids, cortoids and lithoclasts in sparse cement (G9).

<u>Interpretation:</u>

Peloid Bioclast Packstone/Grainstone (FZ6)

Except in the samples G2 and G10 the dominant fossils are peloids, bioclasts and echinoderms. The bioclasts often show a micritic edge, so called micritic envelopes caused by drilling cyanobacteria. The micritic envelopes are evidence for a depositional environment in the photic zone. The estimated depositional area is platform margin sand shoals (FZ6) and the SMF-Type is a coated bioclastic grainstone.

C-Dinocysts Wackestone with Planktonic Foraminifera (FZ2-3)

The samples G2 and G10 show abundant c-dinocysts, some planktonic foraminifera a micritic matrix. This environment is located at the edge of the slope or within the basin (FZ1-3). The water depth is over 200 m due to the lack of benthic organisms.

Resume:

The section shows a shallow marine environment with two events of deep shelf-basin facies. The section is located to the west of the city San Luis Potosí and should be in the distal MBMM. One possible explanation is a sea threshold originated from a horst structure. This structure could create a relief that reaches up into the photic zone and make sand shoals possible. This theory would not explain the two embedded deep sea facies samples. These may triggered by a temporary high sea level rise. Another explanation may be that the depositional area is located right next to the horst structure and the bioclasts slid in the deep basin environment. This would correspond with the fine lamination of some samples.

4. Discussion:

In the depositional environments on the west side of the VSLPP three different zones can be distinguished: The platform (1), the transition zone (2) and the basin (3).

4.1 The platform zone

The platform zone facies is evident in the sections Buenavista and Via Lactea (Fig. 38 /39). During the Aptian, facies is described as gypsum deposits in a lagoonal evaporitic area. The VSLPP was covered by shallow water and in many areas the supply with fresh water was interrupted. Due to the high evaporation rate, the deposits are formed.

With the beginning of the Albian there is an increased transgression. From here on, the development of the two sections differ. While the Via Lactea sections further maintains its restricted facies character, the sections Buenavista developed very quickly from a shallow water facies to an open marine habitat with water depth over 200 m. The differences can be explained by the morphology of the platform, it can be assumed that the surface is not uniform and there are depressions and elevations. Due to Schlager (1981) Shallow-water carbonate platforms and reefs are drowned when tectonic subsidence or rising sea level outpaces carbonate accumulation, and benthonic carbonate production ceases. Whether a reef or platform survives or drowns depends on the balance of the rate of relative sea-level rise and the maximum rate at which the system can aggrade and maintain a flat top in the photic zone (Schlager 1999). Since no terrigenious input is detected, local subsidence and the sea level rise are the processes that drowned the platform. The transgression correlates with the global long term sea level curve from Haq et al. (2014) (Fig. 41). In consideration of short term sea level curve, the regression event KAp7 (Haq et al. 2014) on the border between Aptian and Albian may result in a temporarily dry out of the platform and could explain the discordant transition between the Guaxcamá and the El Abra Formation. The observed fluctuations in water depth between samples A6-A8 could be a signs for the eurybatic sea level fluctuations observed by Haq et al. (2014).

4.2 The transition zone

The transition zone facies is evident in the sections La Huerta, Corazones and Rincón de Leijas (Fig. 38 /39). Due to Schlager (1979) layers of coarse sediment provide the criteria to define facies belts such as marginal escarpment with its coarse talus, the gullied bypass slope with only discontinuous layers of sand and rubble, and the basin floor with a rhythmic sequence of graded sands and mud. The transition zone is not yet pronounced during the

Aptian. The transition between the platform and the basin is flat. In the sections Corazones and Rincón de Leijas, which have the same distance to the platform, occur beds of very fine material. Larger components cannot be transported because of the distance and the lack of potential energy. Also in the section La Huerta, which is positioned geographically closer to the platform, is hardly influential of the ramp or platform to see. In addition to the fine grained beds the pelagic background sedimentation dominates.

In the Albian breccia occur in the section La Huerta. These breccias contain components of the reef and are embedded in mudstones of pelagic background sedimentation. The breccias indicate the proximity of the platform and the occurrence of reef areas. In the section Corazones the beds from the platform remain. However, the pelagic character disappears gradually. The slope grows faster than the transgression progresses. The section Rincón de Leijas shows fully marine conditions, bedded components from the platform or shallow waters disappear completely. It shows completely opposite conditions, the transgression was progressing much faster than can be compensated by the growth of the ramp.

4.3 The basin zone

The basin zone facies is evident in the sections Wadley and Grava (Fig. 38 /39). The section Wadley shows continuously a uniform pelagic sedimentation. Although permanent changes in lithology occur, no effect on the fossil content is visible. The section is located far away from the platform, so no influence of the slope is apparent. The section Grava is located even further from the platform and should also show a pelagic basin facies. Contrary to the presumptions, the section shows a shallow water facies with ooids and micro bacterial influence. Since several layers with a pelagic facies occur it can be assumed that the shallow water components were not formed at this location instead they were transported. Thus, a depositional environment within the photic zone must be near. An explanation approach is a geological horst, peaking up in the upper water layers. From this horst the material is relocated to the lower basin areas. Also the pelagic sedimentation can be explained by eurybatic short term sea level changes (Haq et al. 2014). The setting on a horst structure is preserved, but no relocation is necessary. But since there is no indication for the location in the Formation, this is highly theoretical. In the basin zone is no facies development between the Aptian and Albian detected.

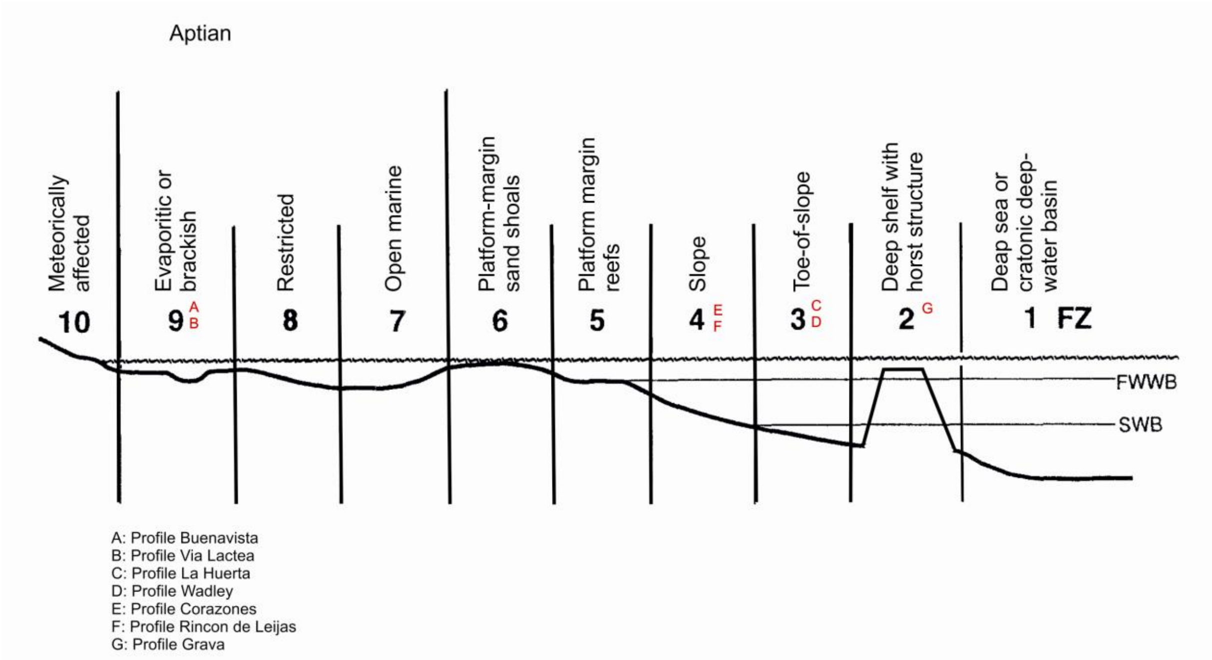

Fig. 38: Depositional environment overview of the sections in the Aptian (modified after Flügel 2004).

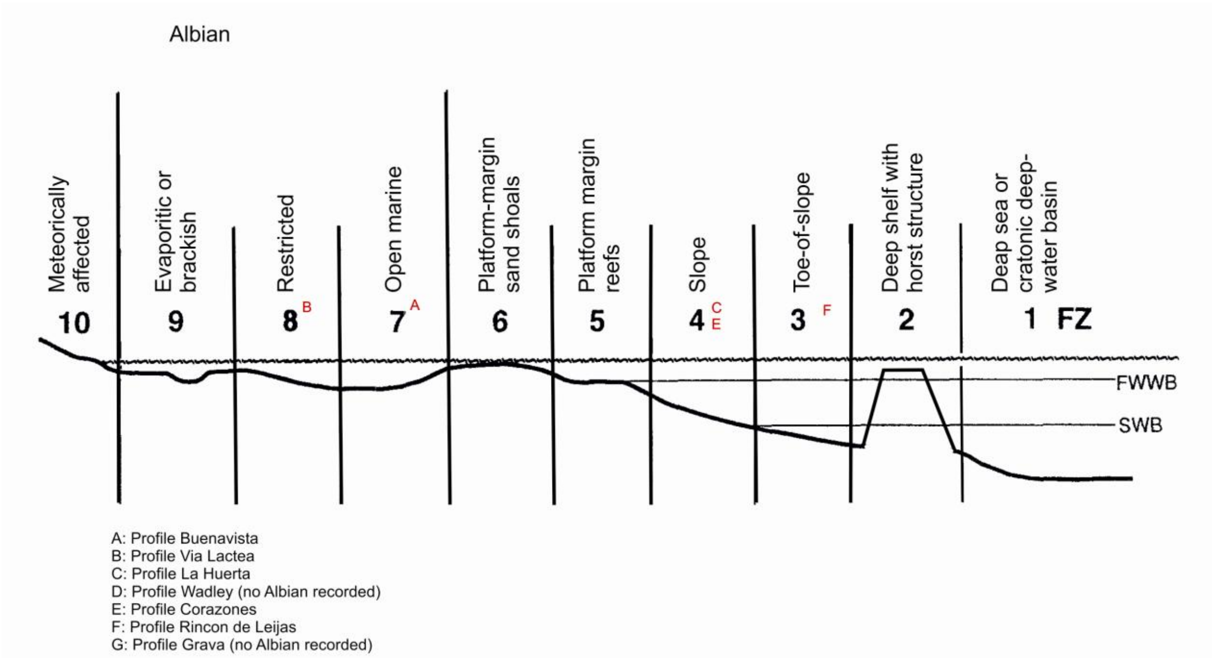

Fig. 39: Depositional environment overview of the sections in the Albian (modified after Flügel 2004).

5. Conclusion

The Aptian-Albian stratigraphic sequence exposed around the city San Luis Potosí in central Mexico is divided into three different environments.

The sections on the platform are representative of a significant change of facies which is indicative of the transgressive episode that apparently drowned the Valles-San Luis Potosí Platform during the early Albian. After a constant period of evaporitic deposits in a restricted environment during the Aptian. The deposits shift from shallow-marine carbonates of the lower El Abra Formation, composed mainly of benthic foraminifera, echinoids and gastropods in the early Albian, to pelagic carbonates in upper parts of the El Abra Formation, composed mainly of planktonic foraminifera, collomiellids and echinoids still in the early Albian, are indicative of sea level rise in combination with the local subsidence.

The sections on the slope are representative of a change of facies which is indicative for shallow water carbonate sedimentation on the Valles-San Luis Potosí Platform during the Aptian, the transgression in the early Albian, and the proof of the transition zone in the form of a slope during the Aptian. The deposits shift from a pelagic carbonates of the La Peña Formation, composed mainly of planktonic foraminifera and c-dinocysts in the in the late Aptian to turbiditic deposits of the Tamabra Formation, composed mainly of shallow water and reef components bedded in pelagic sediments in the late Aptian and early Albian. The transgression and the following pelagic sedimentation of the Cuesta del Cura Formation, composed mainly of planktonic foraminifera and c-dinocysts, is only in the section Rincón de Leijas recorded.

The sections in the basin differ in the paleogeographical conditions. The Typical basin sediments of the La Peña Formation show a pelagic environment, mainly composed of planktonic foraminifera, c-dinocysts and a few colomiellids in the Aptian. The facies located on a horst structure is mainly composed of peloids, cortoids, echinoderms and ooids.

6. Acknowledgements

I would like to thank my supervisor Dr. Frank Wiese for his support and his several suggestions to improve this work. Dr. Rubén López Doncel for suggesting the topic and his support while staying in San Luis Potosí. I'm thankful to Mr. Axel Hackmann for his help preparing the thin sections.

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8. Appendix

Buenavista	E: 363117.00 m	N: 2454482.00 m
La Huerta	E: 326952.00 m	N: 2445363.00 m
Via Lactea	E: 347868.00 m	N: 2508080.00 m
Wadley	E: 305912.00 m	N: 2613737.00 m
Corazones	E: 313266.00 m	N: 2486280.00 m
Rincón de Leijas	E: 311379.00 m	N: 2494361.00 m
Grava	E: 265260.00 m	N: 2475207.00 m

Fig. 40: Measured eastings and northings of the sections.

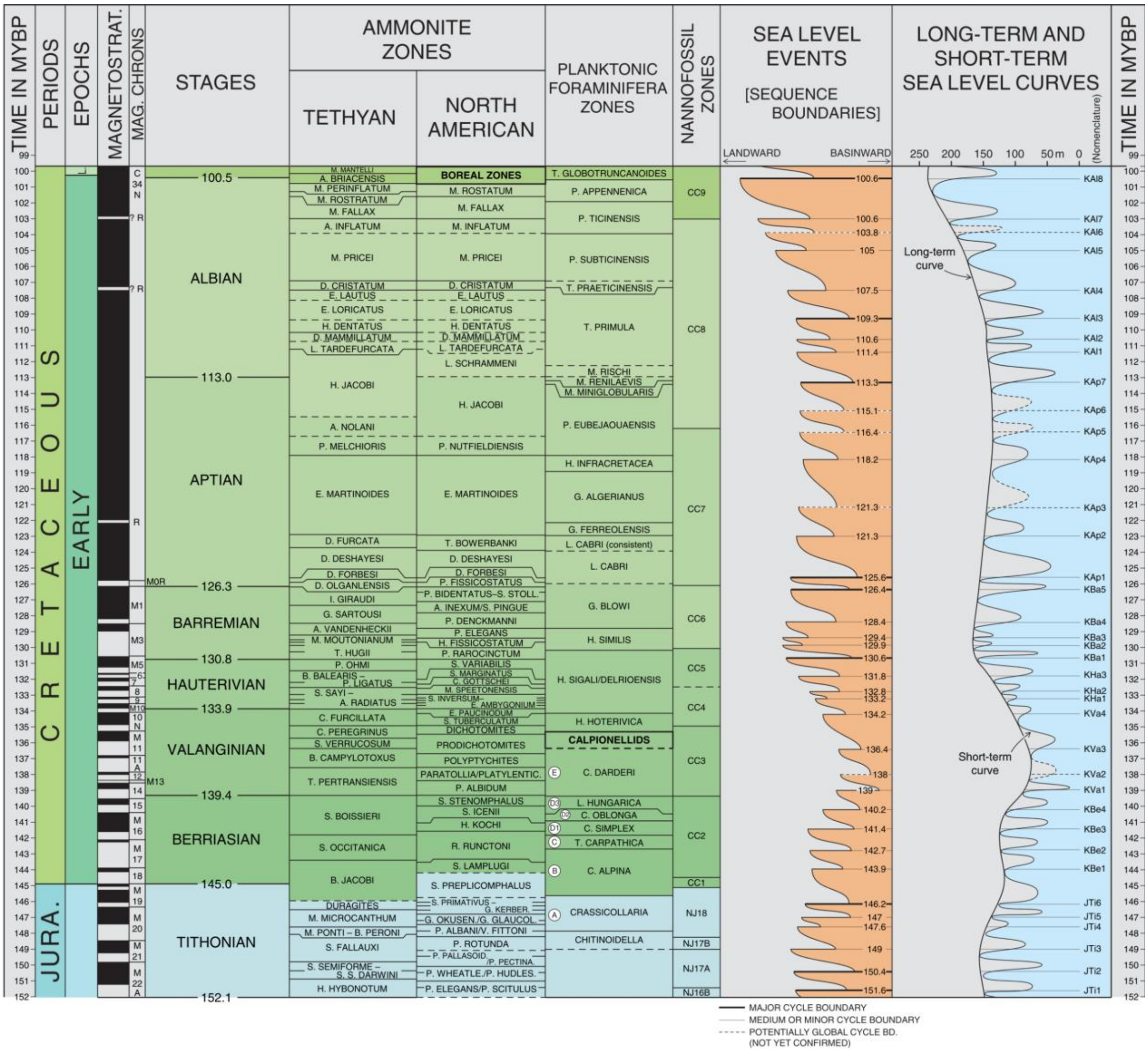

Fig. 41: Early Cretaceous eustatic cycle chart (Haq et al. 2014)

STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

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