New Dinosaur Track sites in the Albian (Early Cretaceous) of the Istrian Peninsula (Croatia) - Part I - Stratigraphy and Sedimentology

Giorgio Tunis * and Sandro Venturini **

* Dip. di Scienze Geologiche, Ambientali e Marine, Università di Trieste, via Weiss 2, I-34127, Trieste, Italia
** ENI-AGIP-Distretto di Ravenna, via del Marchesato 13, I-48023, Marina di Ravenna, Italia

ABSTRACT - Some stratigraphical, sedimentological and paleoenvironmental topics on the existence and survival of large terrestrial vertebrates on a carbonate platform context have been developed within a research on the Istrian sites where the presence of dinosaurs has been found recently. This paper concerns track sites of the late Albian age found in two localities of the western coast of Istria, respectively the Solaris camp site, Cervar-Cervera - Tar-Torre di Parenzo (NW Istria), and Puntizela-Puntisella, Fazana-Fasana (SW Istria). High frequency changes of depositional environments and relationships between these and the presence of dinosaur footprints are described herein and, besides, comparisons and correlations at a regional scale are made between different track sites of the late Albian age. The examined footprint bearing surfaces can be stratigraphically framed around the lowermost part of the upper Albian, a few meters or some tens of meters above the important unconformity that separates the lower Aptian strata from the upper Albian strata in the carbonate succession of Istria. The paleoenvironmental setting of single footprint bearing layers (and dinoturbated ones, too) can be ascribed to tidal flat: desiccation structures and, sometimes, mud cracks give evidence of hardening in subaerial conditions. As far as the taphonomy of footprints is concerned, the basic mechanism requires episodes marked by very high sedimentation rates interrupted by very short subaerial exposures: the substrates had to be relatively damp, the footprints were rapidly sun-baked and covered by the sediments of the overlying layer. In conclusion, the influence of freshwater shown by faunal and floral assemblages, in particular charophytes, is noteworthy.

Key words : Stratigraphy, Sedimentology, Taphonomy, Paleogeography, Late Albian, Carbonate Platform, Istria, Croatia.

RIASSUNTO - Nell'ambito dello studio sui siti istriani con testimonianze di dinosauri, sono state esaminate le problematiche stratigrafiche, sedimentologiche e paleoambientali connesse alla presenza di grandi vertebrati terrestri in un contesto di piattaforma carbonatica. Il presente lavoro riguarda essenzialmente due siti albiani, situati lungo la costa istriana, rispettivamente presso Cervar-Cervera, Tar-Torre di Parenzo (Istria nord-occidentale) e presso Puntizela-Puntisella, Fazana-Fasana (Istria sud-occidentale). Sono state definite le variazioni ambientali ad alta frequenza ed i rapporti tra queste e la presenza di impronte e piste di dinosauri, ed inoltre sono stati effettuati confronti e correlazioni a scala regionale tra i vari siti improntati dell'Albiano superiore. Le superfici improntate discusse nel testo si collocano alla base dell'Albiano superiore, da pochi metri a qualche decina di metri sopra l'importante inconformità stratigrafica che separa l'Aptiano inferiore dall'Albiano superiore. Il contesto ambientale dei singoli strati improntati (e di quelli dinoturbati) risulta solitamente di *tidal flat*, con strutture di disseccamento e talora *mud cracks* che attestano un relativo consolidamento in condizioni subaeree. Per quanto riguarda la tafonomia delle impronte, risulta fondamentale l'esistenza di episodi ad altissimo tasso di sedimentazione, interrotti da brevissime esposizioni: il substrato doveva essere relativamente umido, le impronte sono state rapidamente seccate al sole e ricoperte dallo strato sovrastante. Sono infine da segnalare significativi apporti dulcicoli attestati in particolare da associazioni a Charophyta.

Parole chiave : Stratigrafia, Sedimentologia, Tafonomia, Paleogeografia, Albiano superiore, Piattaforma carbonatica, Istria, Croazia.

THE UPPER ALBIAN CARBONATE SUCCESSION OF ISTRIA

The Istrian peninsula is located in the northwestern sector of the Adriatic Platform; some Croatian workers call this sector the Istrian Platform. This platform is characterized by a succession of carbonate rocks more than 2000 m thick, the outcropping sequence of which spans from the middle Jurassic *p.p.* to the middle Eocene *p.p.* (Fig. 1); Lutetian flysch deposits overlie the carbonates (Velič *et al.*, 1995; Tišliar *et al.*, 1998 *cum bibliogr.*).

The Albian part of the succession is represented by thin, well bedded, peritidal limestones, with ostracods and foraminifers, among which *Neoiraqia insolita* (Decrouez and Moullade). This species is an important biomarker of the late Albian: its presence even in the basal part (Fig. 1) of the third megasequence of the Istrian succession, singled out by Velič *et al.* (1995), proves the hiatus of the Aptian *p.p.*-early Albian age which is assigned to the important Austrian tectonic phase. The late Albian begins with an oscillating transgression and some episodes

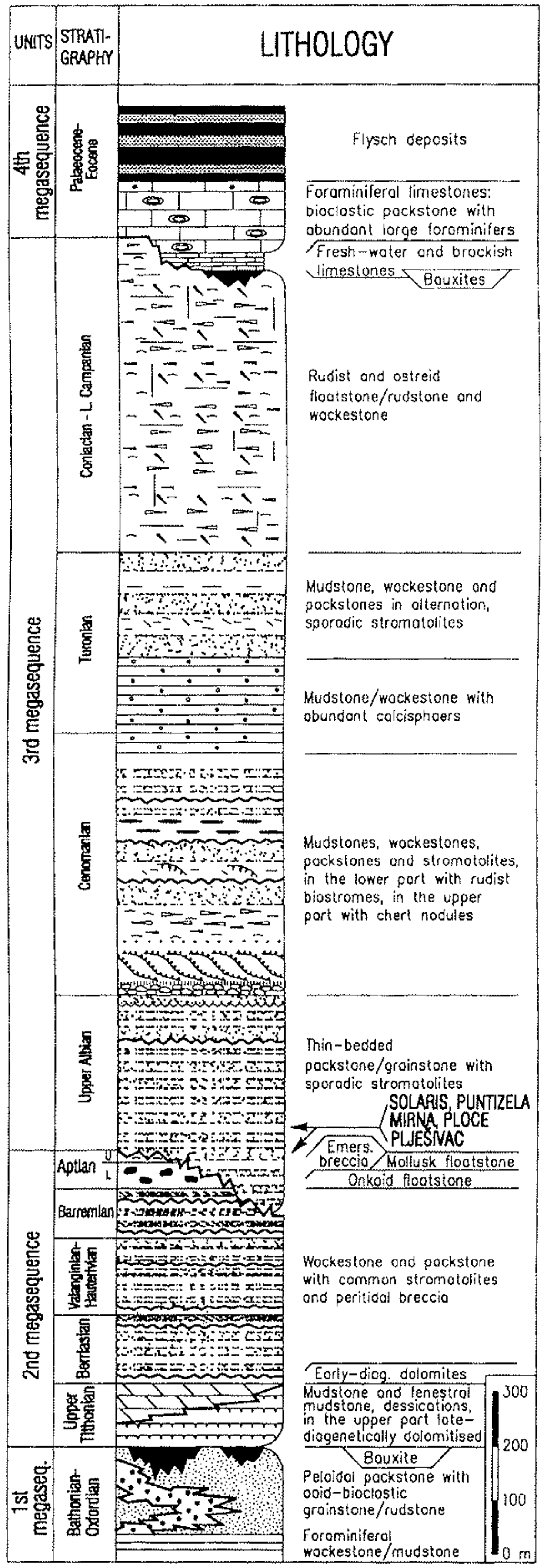


Fig. 1 - Schematic stratigraphical column of Istria showing the main three emersion phases and the stratigraphic location of the late Albian track sites quoted in the text (from Tišliar *et al.*, 1998, modified).

of subaerial exposure, often marked by pedogenic processes.

SOLARIS LOCALITY: STRATIGRAPHICAL AND PALEOENVIRONMENTAL FRAMEWORK

Detailed stratigraphical-sedimentological analyses have been carried out in this locality, mainly to recognize the facies associations, high frequency environmental oscillations and the relationships between the latter and the presence of dinosaurian footprints. The study has not been focused only on the footprint bearing layers and the limited stratigraphic interval encompassing the horizons where the traces have been found, but it has been extended to the outcrops in the vicinity of the footprint bearing surfaces (Fig. 2c) and to other late Albian track sites of Istria (Mirna-Quieto river mouth and Ploce-P. Lastra), for the purpose of reconstructing a general framework of the environmental evolution and of looking for comparisons and correlations between the different late Albian sites where dinosaur presence has been recorded.

About 200 hand samples representing the entire thickness of the examined beds were taken in Solaris camp site (Tar-Torre di Parenzo) from a few short sections (Figs 2c, 3 and 4) which altogether constitute a 15 m thick composite succession. Micro- and biofacies from 3 x 5 cm thin sections have been examined, so about two thirds of the total thickness of the succession have been microscopically investigated by a technique similar to microstratigraphy (see D'Argenio *et al.*, 1992b; Buonocunto *et al.*, 1994). Logs are synthetically illustrated in figures 3 and 4; the thin sections are deposited at the *Museo Paleontologico Cittadino di Monfalcone* (Gorizia). The correlative sections and the lateral stratigraphic-sedimentological variations of the successions encompassing the dinoturbated horizons have also been traced (Fig. 5).

The lithofacies in question are mainly represented by alternations of mudstones and peloidal fossiliferous wackestones with subordinate packstones and rare pellettiferous grainstones; sometimes, pellettiferous-peloidal facies exhibit a stromatolitic structure. Two clayey-marly levels with greenish clay (Fig. 2c, outcrop III and Fig. 4, quarry log) rich in illite/smectite mixed-layer minerals have been observed. According to Durn *et al.* (1997), smectite, present in clay mineral assemblages within the marly horizons of the Albian succession of Istria, is probably of volcanic origin.

Subaerial exposure episodes are proved by abundant desiccation structures, sometimes by microcavities filled by vadose crystal silt, and by small size structures similar to *Microcodium*. Mud cracks and rare wave-formed ripples have been also observed. However, the photo taken during the winter of 1978 documents the large surface with mud cracks (Fig. 6) exhibiting noticeable widths that represented the basal levelled surface of the quarry (Fig. 2c, outcrop III) before the settlement of Solaris camp site.

The basal part of the succession of Solaris camp site is partly dolomitized, with fine to coarse replacement of dolomite. Frequent small cavities enlarged by dissolution processes, in part originated by meteoric weathering and, to a lesser degree, generated by probable recent dedolomitization processes have been observed.

The micropaleontological assemblages of this composite section are dominated by ostracods with subordinate *Aeolisaccus*, Ataxophragmiidae, Ophtalmidiidae,

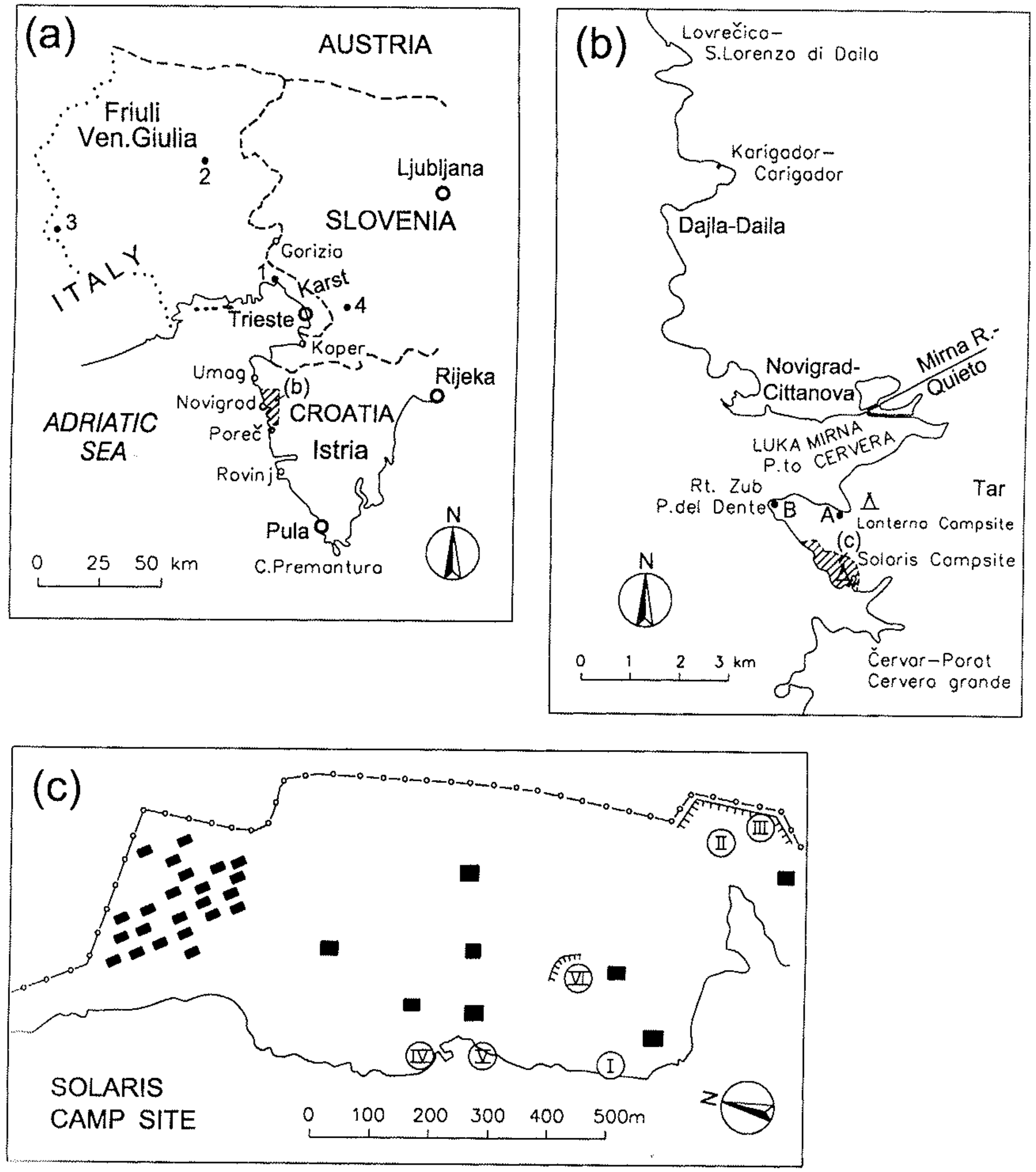


Fig. 2 - (a) Geographic map of the NE Italy, W. Slovenia and W. Croatia (Istria) with the names of some localities and regions mentioned in text. 1. Villaggio del Pescatore. 2. Bernadia Mounts. 3. Sarone. 4. Kozina. (b) Location of the study area with names of the localities and track sites quoted in the text. A. Track site inside the Lanterna camp site (Mirna-Quieto river mouth), B. Rt. Zub-P. del Dente. (c) Plan of the Solaris camp site and location of the outcrops. I. Track site on the shore. II. Vast track-bearing surface. III. Quarry. IV. Storm beds at the small harbour. V. Breccia layer along the shoreline. VI. Small quarry.

Miliolidae, *Glomospira*. Rare molluscs and Dasycladaceae have been also observed.

The micropaleontological content of some storm layers (Figs 5 and 7) outcropping close to the shore (Fig. 2c, outcrop IV), about 3 m above the footprint bearing surface, is significant from a biostratigraphic point of view. Storm beds consist of normally graded grain supported deposits, arenitic to calciruditic in size, with large sized carbonate clasts up to 4 cm and, sometimes, with frequent molluscs, among which nerineids and rudists, and echinoids. These storm beds are markedly dolomitized at outcrop IV (content of dolomite is around 30%), but an easy survey of the outcropping beds along the shore allowed the sampling of the same horizon at Rt. Zub-P. del Dente (Fig. 2b, B). The minor dolomitization herein permitted us to recognize the micropaleontological association which consists of molluscs, echinoids, *Nezzazatinella picardi*, *Cuneolina pavonia* and one fragment of

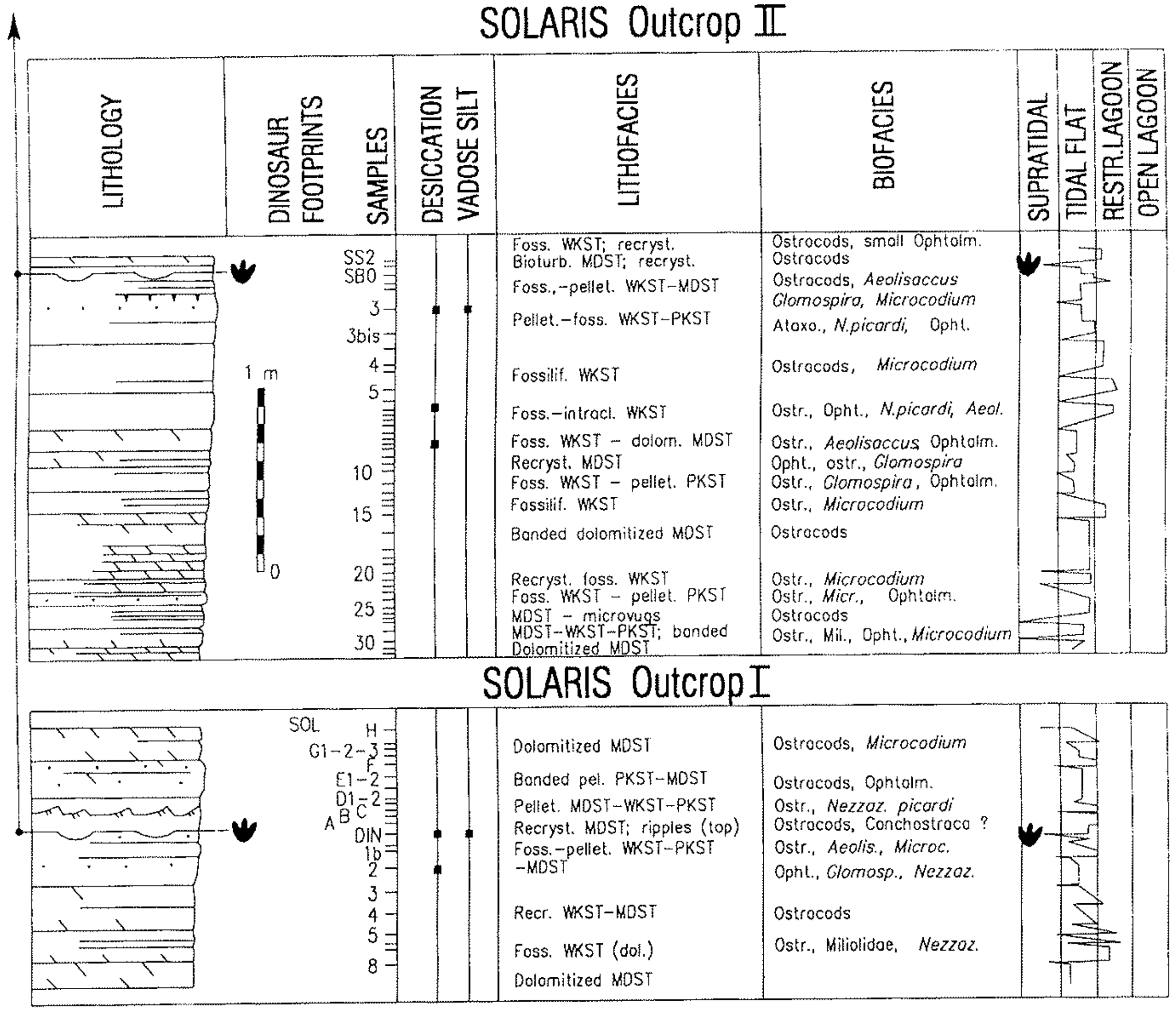


Fig. 3 - Litho-biostratigraphic logs of outcrop I and outcrop II (Solaris camp site).

Neoiraqia insolita. Considering the presence of this last species, the Solaris succession can be set in the late Albian. The same biomarker has been recognized along the shore, 1.5 km NE of Rt. Zub-P. del Dente, inside the Lanterna camp site (Fig. 2b, A), close to the Mirna-Quieto river mouth, where an outcrop with teropod footprints has been described by Dalla Vecchia *et al.* (1993).

The sedimentary environment ranges from open lagoon to restricted lagoon to tidal flat, to a supratidal-terrestrial setting in a general framework of interior carbonate platform.

Besides the recurrent but temporary subaerial exposures marked by desiccation structures, probable brackish-freshwater facies are noteworthy. These are recorded by laterally discontinuous layers of clayey marls with high carbonate content, more or less rich in greyish to greenish clays, that contain micromolluscs, thin shelled ostracods, rare charophyte gyrogonites and phosphatic remains. Marly horizons hold small relic carbonate clasts from older carbonates which show severe alteration, pervasive karstic dissolution and sometimes root formed structures. On the whole, these elements suggest a prolonged exposure phase of the platform carbonates, foregoing and co-eval to the deposition of the clayey marly horizon.

The common lithofacies, made by fossiliferous wackestones rich in ostracods but lacking in foraminifers, may be a sign of the decrease of water salinity, and this may represent a markedly schyzoaline environment. The sporadic presence of small Conchostraca would indicate a setting with perceptible freshwater influx. Conversely, facies with *Glomospira* and *Aeolisaccus* would prove a hypersaline zone environment.

The previously quoted storm layers represent the only high energy episodes recorded within the Solaris succession.

Stratigraphy, Sedimentology and Taphonomy of the Footprint Bearing Layers

Comparisons made between the three short logs (Figs 3 and 4) allow, with good approximation, the correlations between outcrops I, II and III (Figs 2c and 5). The correlations allow us to recognize the footprint bearing layer of the outcrop II within the succession of the quarry front, too. The footprint bearing layer (outcrop II) consists of 30-35 cm thick whitish limestone (Fig. 8), with faint internal joints clearly seen where recent meteoric weathering is particularly strong. The upper part of the bed consists of pelletiferous-fossiliferous wackestones alternating with millimetric levels of mudstones. The micropaleontological content is characterized by ostracods, *Aeolisaccus*, rare Ophtalmidiidae, small *Glomospira*, rare *Microcodium*. The uppermost part of the bed is characterized by pervasive desiccation structures such as fenestral cavities and rare mud cracks.

A dense network of microfractures, always filled by vadose cements, has been locally recognized on the topmost surface and, mainly on the displacement rims of the footprints. It is common to observe probable bioturbated structures. A thin millimetric clayey drape, greenish coloured if it is not weathered, and, conversely, ochreous coloured is locally observable. This clayey drape has created a clear discontinuity between the substrate and the filling sediments; this effect is particularly visible inside the footprints, but also upon the vertical outcrop of the quarry front (Fig. 9) where one made use of this bedding surface as a main plain for limestone block excavation.

The footcast infill is made of beige coloured peloidal fossiliferous wackestones-packstones with clasts up to 5

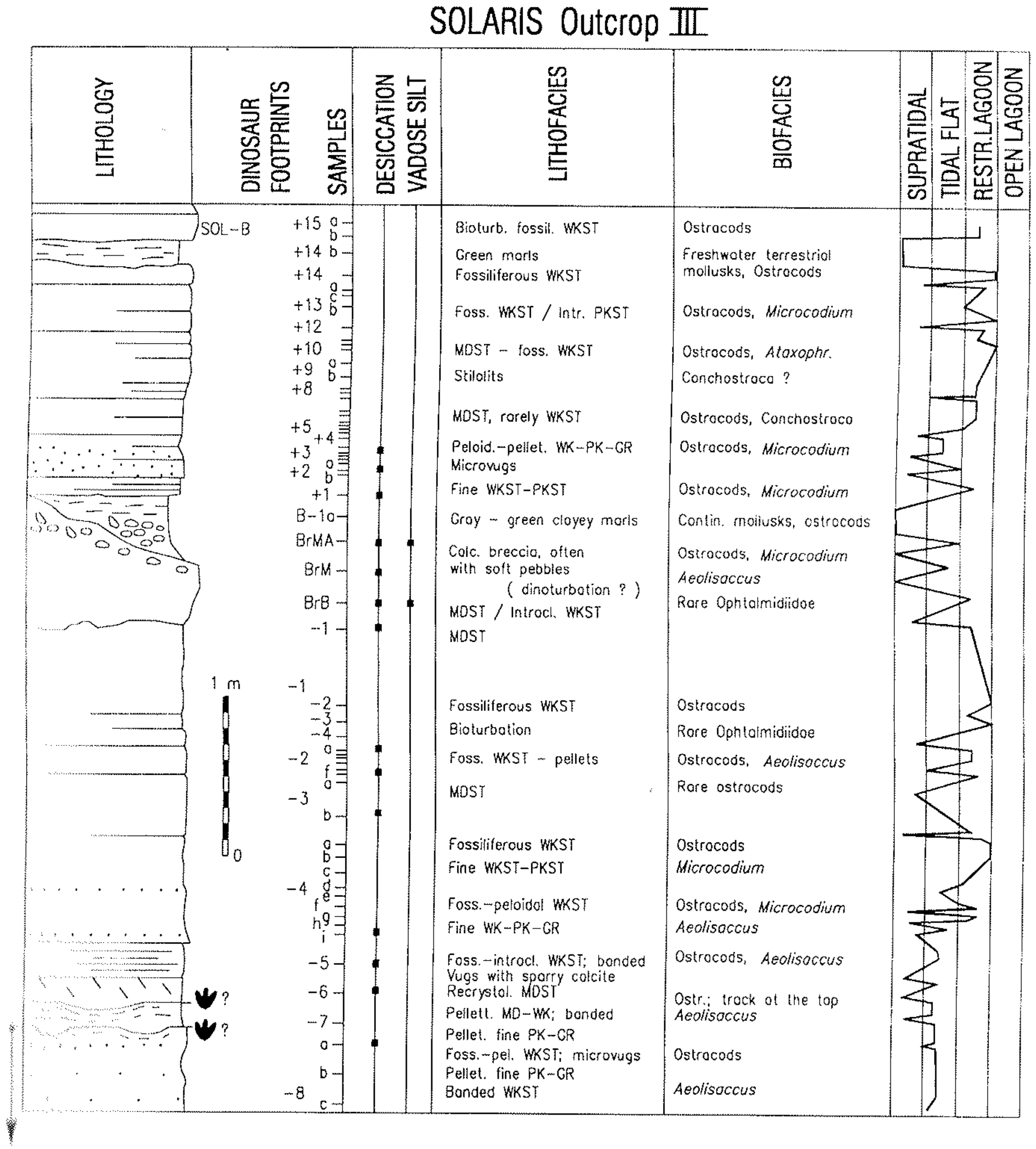


Fig. 4 - Litho-biostratigraphic log of outcrop III: quarry log (Solaris camp site).

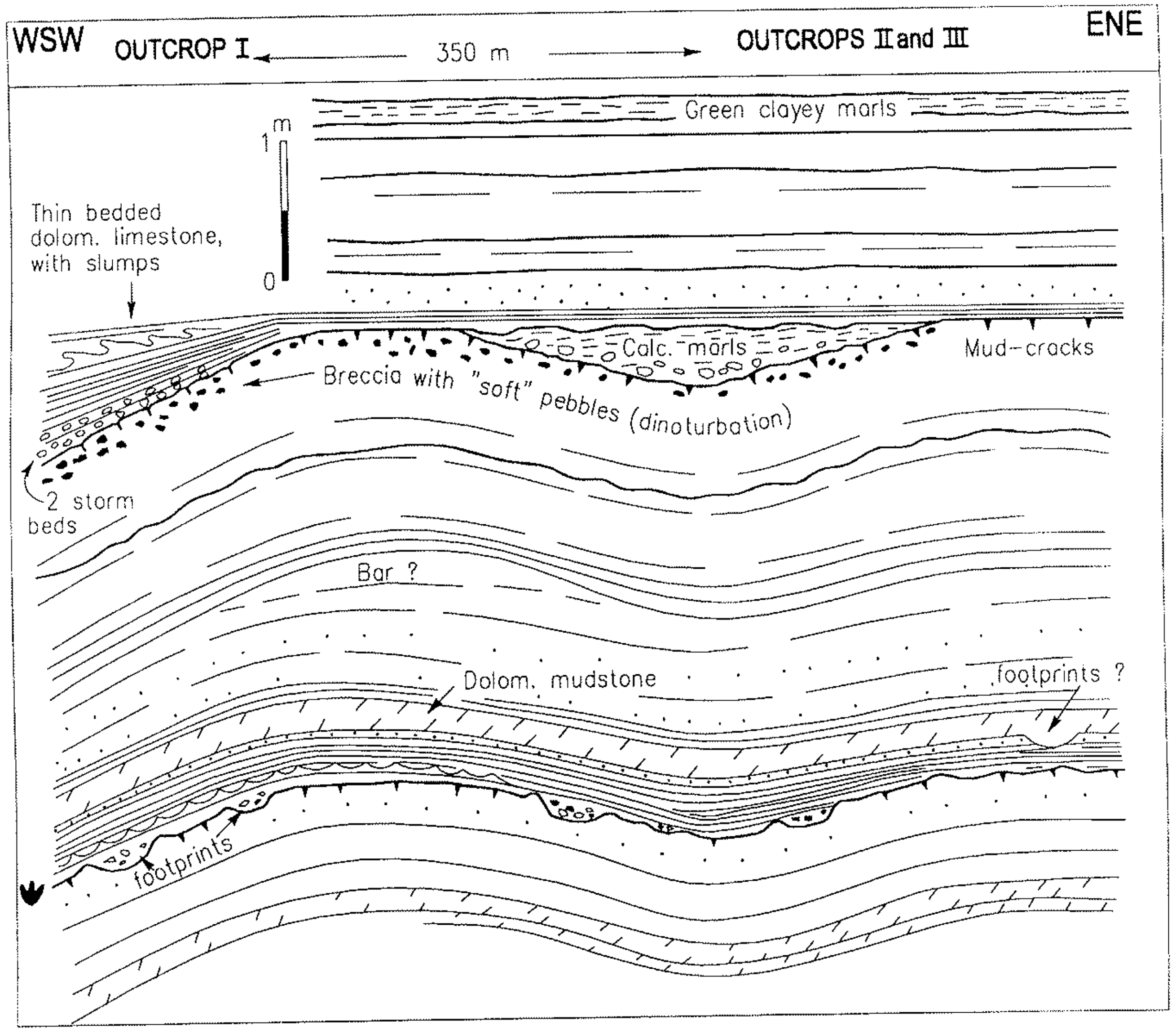


Fig. 5 - Stratigraphic sketch of the zone characterized by the presence of footprint bearing surfaces and dinoturbated beds (Solaris camp site).

cm in size, in a few cases the filling sediments show breccia fabric. Wackestones contain, besides abundant ostracods, small bivalved organisms with very thin shells characterized by dense small ribs with sinusoidal trends, which are similar to *Estheria,* small conchostracans typical of brackish/freshwater settings. Small phosphatic remains were observed within the filling material of a few shallow footprints.

Some footprints (Fig. 10) at outcrop I show a first filling stage represented by wackestones with small loose carbonate clasts and, successively a thin breccia lense (Fig. 11); in this case, the displacement rim is clearly more prominent than that of other footprints where infilling material is characterized by frequent clasts up to 4 cm in size from the absolute base.

Two lithofacies can be distinguished among the clasts found amidst the infilling sediments: (*i*) mudstone/fossiliferous wackestones/pellettiferous wackestones with ostracods and rare foraminifers, greyish, whitish and hazel coloured, characterize by angular edges, sometimes with desiccation structures ("hard clasts"); (*ii*) mudstones/wackestones with ostracods and Ophtalmidiidae, hazel-yellowish coloured, characterize by frayed edges ("soft clasts").

Frequently, an ochreous, weathered, clayey spreading of millimetric thickness has been observed on the surface of the clasts. Clasts in the most shallow footprints are flattened ("flat pebbles"). The matrix shows bioturbation which may be the cause of the amalgamation of the sediments.

A few structures similar to *Microcodium* have been observed in some fills. They suggest the presence of small root systems and, implicitly, the short periods of emersion of this area of the platform. Lastly, recurrent microvugs characterized by replacement/infilling of microsparite have been noticed.

The layer overlying the footprints which may be up to 10 cm thick is in its turn overlain by a 2 cm thick layer of mudstone which is characterized by the traces left by burrowing organisms. These structures occur very frequently at outcrop II.

Small current-formed ripples on the topmost surface of a layer and recurrent alternations of mudstones/wackestones-greyish pelletiferous, sometimes fossiliferous packstones containing ostracods, rare Ataxophragmiidae and

Fig. 6 - Wide mudcracked surface representing the basal levelled surface of the quarry (outcrop III, Solaris camp site). The photo was taken by A. Tarlao during the winter of 1978.

Ophtalmidiidae, very rare *Nezzazatinella picardi* have been observed at outcrop I, immediately above the thin layer of mudstone. The ripples show a northwestward direction. The orientation of the crests of other ripples on another bed, stratigraphically some tens of centimetres below the footprint bearing layer at outcrop I, shows an apparent NW-SE direction, roughly perpendicular to the former.

Other Probable Trampled Layers

A 80 cm thick bed, with faint internal bedding planes (joints) and with a breccia fabric face in the upper part, can be observed 3 m above the footprint bearing layer (Fig. 2c, outcrop V). This breccia is made of soft pebbles characterized by the same lithofacies as the matrix (Fig. 12); its thickness varies from 0 to a maximum of 30 cm with an abrupt lateral and vertical passage to limestone lacking in any apparent structures. Well preserved mud cracks (Fig. 13) are to be locally seen on the topmost surface of this bed; sometimes large clast with mud cracks are inserted within the breccia (Fig. 14). This brecciated horizon can be well observed along the coast as far as outcrop V (Fig. 2c) and, inland, along the quarry front (outcrop III). The sedimentological characteristics of this layer suggest a mechanical rather than a diagenetic origin of the breccia, which may be interpreted as having been caused by extensive and prolonged trampling by large vertebrates.

A depression, 20 cm long and 3 cm deep has been observed in cross section on the quarry front (Fig. 15), about 30 cm above the top of the main footprint bearing layer. The underlying laminated bed is strongly deformed and fractured and the filling material is made of recrystallized mudstone with scattered clasts. This depression could be a cross sectioned dinosaurian print.

Sedimentological Observations and Interpretation of the Solaris Outcrops

Analysis of the precise setting where the trampling of dinosaurs did occur has been initially focused on a careful distinction between true footprints and possible underprints. True footprints are proved by the presence of both well recognizable filling material unconformably resting on the depression profiles of the hollows and of the displacement rims.

The surfacial layer shows desiccation structures like *fenestrae* but sediment was moist a few centimeters below this crust as demostrated both by the displacement rims, sometimes quite thick, and by the flow of semifluid mud into the deepest footprints (see Dalla Vecchia and Tarlao, this volume). The degree of desiccation is fundamental for the formation of impressions: too soft or too hard sediments may inhibit the formation of individual well recognizable footprints.

Water saturation in the near-surface layer excludes the occurrence of significant processes of cementation, but we cannot exclude the formation of a salt crust. In fact, a relatively high content of salt seems to affect the sea-water foregoing the exposure; this is shown by the micropaleontological assemblage with *Aeolisaccus* and *Glomospira*, typical of the desiccated horizon.

From a general point of view, trampling probably occurred within a tidal flat setting.

Fig. 7 - Storm bed outcropping along the shoreline (outcrop IV, Solaris camp site). Nerineid and echinoid fragments are also visible. Pen for scale.

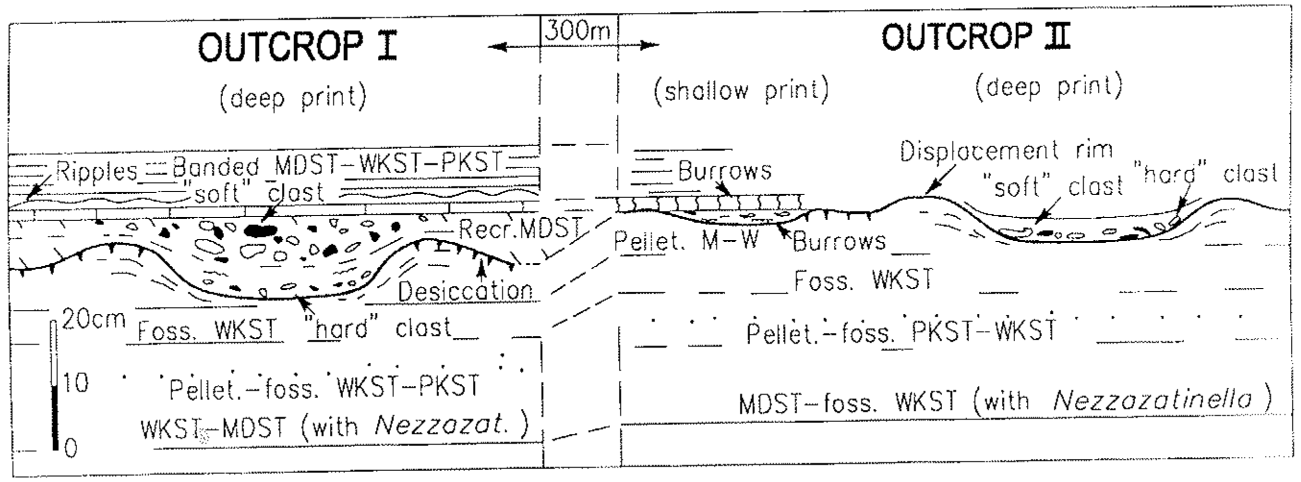


Fig. 8 - Representation of the footprint bearing layer and of the forecast infill.

Fig. 9 - Outcrop III, Solaris quarry front; the arrow indicates the footprint bearing layer.

Presumably there was a very short lapse of time between trampling, filling and burial of the footprints. A few weeks survival without major deterioration of the footprints of modern large mammalians in East Africa before burial is considered an unusual occurrence (Cohen *et al.*, 1991).

Considering the large number and good preservation of the dinosaur footprints, it is very probable that these were quickly filled, and then preserved from weathering. The first transgressive phase following the short subaerial exposure caused the transport of intraclasts into the less prominent footprints characterized by low displacement rims. Part of the clasts may have originated by the erosion of the displacement rim itself. Successively, all footprints were filled with breccias and fine-grained breccias, while clasts are less frequent around their sides. The depressions seem to have acted like traps for the coarsest sediments. Footprints with a prominent displacement rim are filled only at the top by a coarser microbreccia; the microbreccia may go over and extend beyond the rim itself. Conversely, only small clasts are present at the base of the fillings; they have been observed partly within fossiliferous-peloidal wackestones-packstones, partly packed within a millimetric thick level made of ochreous clayey marls which represents the initial draping of the printed surface. Clay may be washed away from the neighbouring emerged areas.

The transgressive phase (*i*) largely reworked the clay drape, which stains several clasts and the matrix of the filling materials; (*ii*) remobilized clasts formed by desiccation of the printed surface (several flat pebbles have been observed in the shallowest footprints); (*iii*) increased water saturation in the topmost layer, facilitating the erosion of the printed surface, removal of displacement rims and formation of soft clasts. The soft clasts contain micropaleontological assemblages typical of lagoon/tidal flat settings, identical to those of the substrate. Conversely, abundant ostracods, besides probable Conchostraca, indicating a lower salinity environment than that of tidal flat, were recognized within the matrix of the infillings.

The burial of the footprints might not be necessarily connected to a marine transgression, but rather be due to the influx of meteoric waters, which washed in clayey marls from neighbouring emerged areas. Run-off from the hinterland may have rapidly covered the coastal lowland, including imprinted surfaces, with sediments.

Correlations illustrated in figure 8 suggest a gentle morphology of the trampled surface with the overlying layer being thickest at outcrop I. Gentle depressions of the ground separated by small scale hillocks may have undergone higher sediment accumulation rate, favouring the rapidity of fossilization of the footprints at outcrops I and II. The same bedding plane surface shows remarkable alteration processes at outcrops III and VI.

Wave-formed ripple bedforms characterize the upper surface of the layers overlying the footprints; these layers contain rare marine faunas.

The succession follows upwards with facies characteristic of tidal flat and lagoon environments. At outcrop VI (Fig. 2c), repeated lensoidal beds might indicate localized bars of pelletiferous muds (see Fig. 5).

This part of the succession is punctuated by a few, more or less prolonged, supratidal events, the most spectacular of which is represented by the brecciated bedding surface with soft clasts (Figs 3, 5 and 12). The same sedimentological features were identified on some Barremian strata in southwestern Istria (Fig.19b) (Dini *et al.*, 1998) and were interpreted as the result of intense trampling by dinosaurs ("dinoturbation"). In the case of the Solaris horizon, only the last few centimeters, near the upper surface of the layer, were hardened by desiccation, as suggested by the large fragments of the early lithified crust. These co-exist with partially lithified intraclasts with undefined edges, included in a matrix of the same composition. This breccia is due to the trampling that probably occurred at times when most of the sediment was soft, probably semifluid. Sedimentological differences, observable at outcrop scale between the trampled bed and the underlying imprinted surface may be ascribed to a higher/lesser passage of dinosaurs or to relatively more or less prolonged subaerial exposure duration.

An extensive irregularly thick (*maximum* thickness = 40 cm) horizon of clayey marls with carbonate clasts is developed above the dinoturbated horizon (Figs 5 and 16).

These marls wedge out laterally and disappear both on the eastern (landward) and western (seaward) sides of the quarry. In the central sector of the quarry, at the lower boundary of the marls, a several centimeters-thick layer of breccia is present (Fig. 17), with scarce terrigenous matrix. Black pebbles are present amidst the clasts. Lithofacies and faunistic-floral content of the sediment indicate a clear change of paleoenvironment, from tidal flat to continental, quite isolated from the sea. These sediments contain the diagnostic biota of low-salinity environment and perceptible terrigenous influx. The alteration which affected most of the extraclasts suggests strong pedogenic processes in the hinterland. The broad depression where clayey marls have deposited is caused by a gentle undulation of the substrate (Fig. 5) which may have been originated by mild synsedimentary tectonics.

The upper boundary of the marls is affected by small amplitude undulations sutured by grey laminated limestones. The laminated limestones extend as far west as the coast (Fig. 18) where they contain two storm layers, approximately 10 cm-thick. Both the laminated limestones

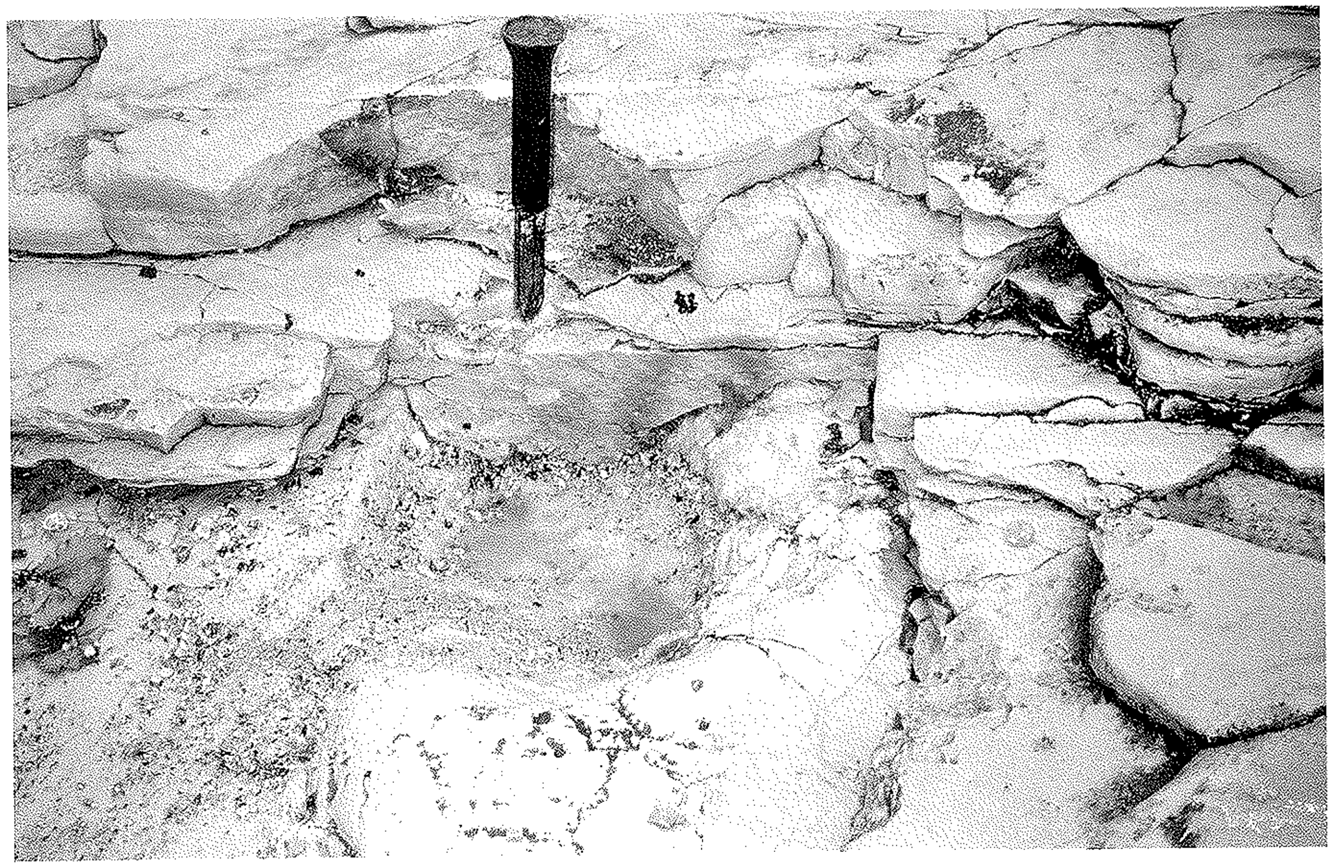


Fig. 10 - Footprint on the shoreline (outcrop I, Solaris). The photo was taken during the excavation to show the footprint. Note the infilling and the displacement rim. Chisel for scale.

Fig. 11 - Breccia fill of a footprint (upper part of the fill of Fig. 10). Scale in cm.

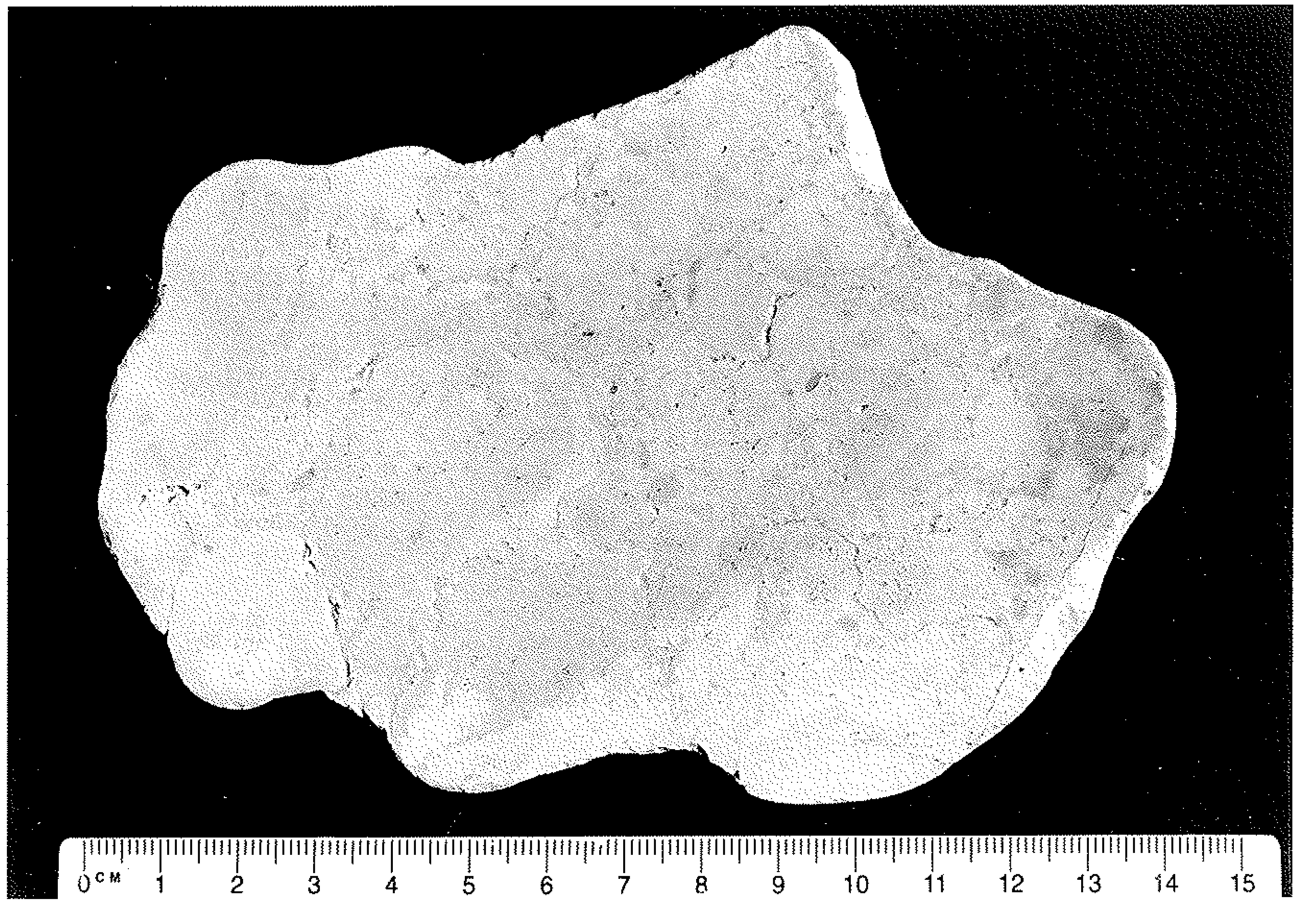


Fig. 12 - Polished slab of the dinoturbated bed with soft pebbles outcropping a few tens of meters from the small harbour (outcrop V Solaris). Scale in cm.

and the storm layers here overlie the dinoturbated horizon and suture, by a clear wedging out, a shallow depression at the top of the breccia bed. Laminites show slumping with local debris flow. Small, badly preserved, fish remains were found within the laminated facies close to Cervar-Porat-Cervera grande (Fig. 2b).

The stratigraphic and paleoenvironmental setting is quite complex in detail and is probably controlled by gentle tectonics. Storm layers partly eroded the substrate, producing local bioclastic rudstones; laminites too were subject to tectonics as proved both by their geometry and sedimentary structures.

The upper clayey-marly horizon documents a further terrigenous input associated with the restoration of a brackish-freshwater setting. However, this second horizon shows a wider lateral continuity in comparison with the former.

PUNTIZELA-PUNTISELLA LOCALITY: STRATIGRAPHICAL AND PALEOENVIRONMENTAL FRAMEWORK

A detailed stratigraphical-sedimentological analysis has been carried out also at Puntizela-Puntisella (Fig. 19b, 19c: outcrops I, II, III, IV). The two stratigraphic sections where the footprint bearing layers can be observed have been entirely sampled. The older section (outcrop I) is represented by a few metres of limestones (Fig. 20), while the younger one (outcrop II and III) is thicker and can be examined on the shoreline (outcrop II) and in a small abandoned quarry (outcrop III) very close to the sea. As far as the southern outcrops (II and III) are concerned, about 14 meters of succession are synthetically sketched in figure 21 in order to document the environmental changes recorded in an organic fashion. Outcrops I, II and III, and IV are separated by some extensional faults (also covered by pebbles in the Cuf inlet, Fig. 19c) of small stratigraphic throw which lower the succession on the southern side. Anyhow, the upper part of the log at outcrop I and the lower part of the log at outcrop II are not seemingly correlable.

As far as outcrop I is concerned, differences between the part of the section underlying the footprint bearing surface and the overlying one are easily noticeable at the outcrop scale (Fig. 20). The lower part is characterized by pelletiferous, lime mud with ostracods which, in general, may be referred to a tidal flat setting. The upper part is characterized by lithofacies suggesting a relatively more energetic environment, such as intraclastic-fossiliferous grainstones-packstones. A probable storm layer showing normal grading, with abundant fragments of bioclasts and desiccation structures at the top, is intercalated. The litho-biofacies present in the upper part of this short section suggest deposition in an open lagoon. Several specimens of *Neoiraqia insolita* ascribable to the late Albian have been recognized in thin section only from samples of the storm layer and of a thin level, rich in gastropods, too (among them nerineids), characterized by crossed lamination. The microfaunistic assemblage of these two layers consists also of *Nezzazatinella picardi*, *Cuneolina* sp.,

Fig. 13 - Mud cracks at the top of the dinoturbated bed. Key-holder for scale. Same outcrop as Fig. 12.

Fig. 14 - Fragments of mud crack fills (see arrows) involved in the dinoturbated bed. Same outcrop as Figs 12 and 13. Key-holder for scale.

Fig. 15 - Possible footprint seen in bed cross section (see arrow), about 20 cm above the footprint bearing layer. Front of the quarry, outcrop III Solaris. Width of the depression is about 20 cm.

Pseudotextulariella sp. The succession is topped by a subaerial exposure episode marked by microkarstic structures. The rhythm of bedding also documents the environmental variations: tidal flat lithofacies show thin bedding whereas those typical of open lagoon do not show, at a first glance, well visible bedding and only colour tonalities due to different grain sizes of limestones can be observed.

The upper section (outcrops II and III, Fig. 21) is characterized by a wide range of lithofacies, among which breccias and marls. Prevalent lithofacies are represented by fossiliferous wackestones and peloidal, pellettiferous and fossiliferous packstones with intercalated intraclastic-fossiliferous grainstones and mudstones. Mudstones with ostracods, sometimes with mud cracks of noticeable width, prevail in the basal part of the section, below the footprint bearing layer; paleoenvironment herein is interpreted as tidal flat, except for some thin horizons of packstones with *Cuneolina* sp. and *Praechrysalidina* sp. ascribable to a relatively open lagoon setting.

Three beds with breccia fabric, separated by interlayers of ochreous or reddish clayey wackestones, overlie the footprint bearing surface. The lower bed exhibits a highly variable thickness ranging from 0 to 20 cm (Fig. 22); at intervals, a slightly clayey matrix is present. The bed makes a transition laterally to limestone lacking any evident breccia fabric. The intermediate bed shows breccia fabric only in the upper part (Fig. 23) and contains rare black pebbles. It underlies a laminated horizon a few centimeters thick of reddish clayey wackestone. The upper bed is characterized by centimetric parallel lamination and, locally, exhibits breccia fabric throughout its whole thickness (Fig. 24). Sudden, breccia horizons show a lensoidal shape at decimetric scale and were probably involved with synsedimentary deformations. As far as the paleoenvironmental interpretation is concerned, the base of the upper bed, and the base of the bed immediately overlying the footprints, may be ascribed to an open la-

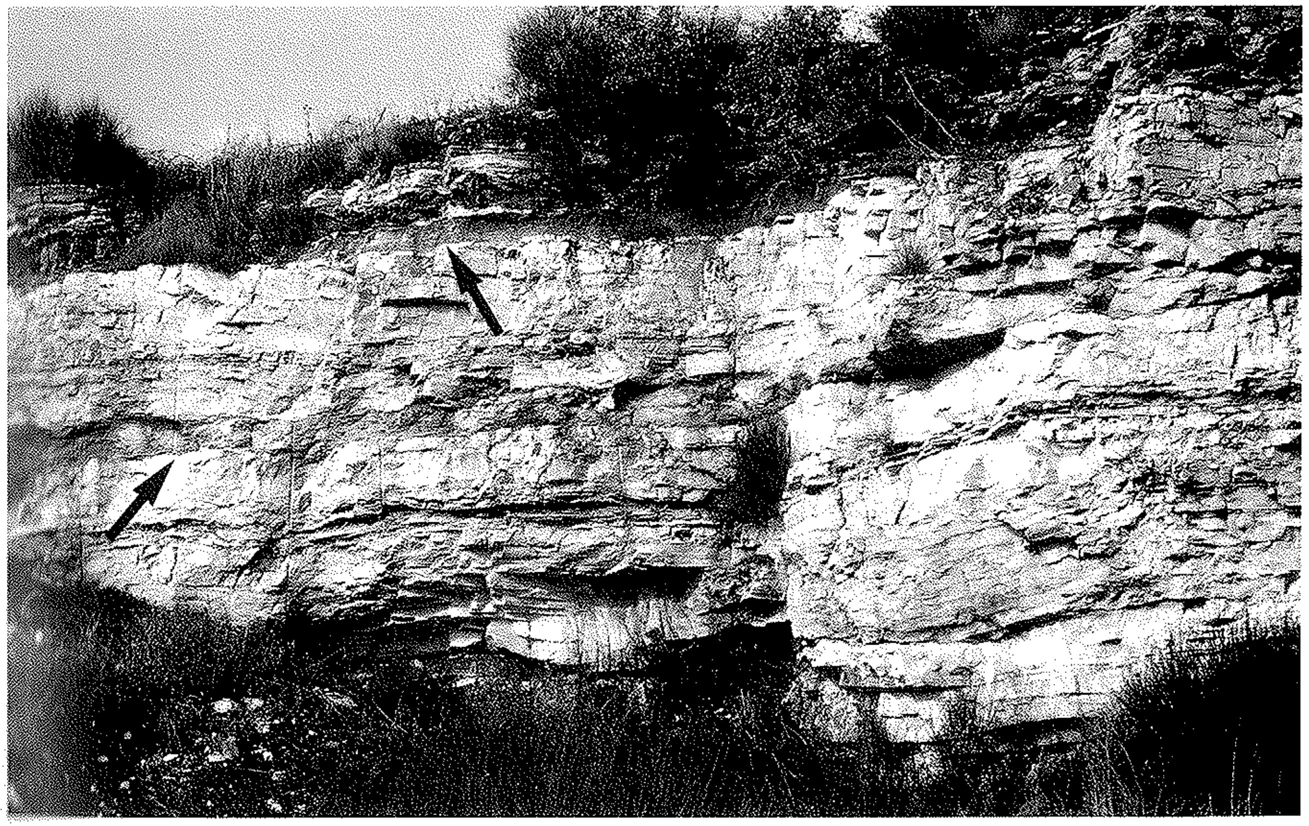


Fig. 16 - Quarry front during the winter of 1978 (outcrop III Solaris, photo by A. Tarlao). The two arrows show two greenish clayey-marly horizons: the lower level rapidly thins out to the SE (right side of the photo).

Fig. 17 - Lower marl horizon (central part of quarry front, outcrop III Solaris). The basal-lower part, about 50 cm thick, of the level is very rich in carbonate clasts resembling a breccia fabric. This breccia also contains black pebbles (see arrows). A partly altered horizon characterized by an irregular-subplanar microfracture network passing laterally to the dinoturbated layer (towards the shoreline) can be observed at the top of the underlying layer.

goon setting, as documented by the occurrence of *Neoiraqia insolita* and Dasycladaceae. The upper part of the same bed indicates an intertidal/supratidal setting, particularly, the reddish, strongly altered, marly interlayers barren of fossils may represent a terrestrial episode.

The succession continues with a new transgressive phase recorded by fossiliferous packstones with bivalves at the base and by a level characterized by current-formed ripples with an apparent transport direction towards ENE (Fig. 25) at the topmost surface. Typical lithofacies of restricted lagoon setting and a few lithofacies rich in Dasycladaceae, representing open lagoon areas, follow upwards at outcrop III. This part of the succession terminates with a breccia layer displaying variable thickness (Fig. 26). This layer is capped by greenish-grey clays (Fig. 27) containing thin lenses of clayey wackestone and carbonate clasts. The abundant faunal-floral content of this clayey horizon points to an episode of continental sedimentation (see below). Lithofacies consisting of pellettiferous-peloidal-fossiliferous mudstones, wackestones-packstones with ostracods, *Aeolisaccus*, rare Ophtalmidiidae and Ataxophragmiidae, which may be ascribed in general to a tidal flat setting, can be observed above this clay horizon (Fig. 21). Mud cracks can be frequently observed at the topmost surfaces of these layers.

Further upwards, a thick bed of intraclastic-fossiliferous grainstones-rudstones with mud chips, bivalves, nerineids, miliolids, *Cuneolina pavonia*, is noteworthy. These features suggest an open lagoon domain characterized by relatively high hydrodynamic energy.

The section ends with a second green clay horizon similar to the previous one, but thinner and discontinuous; the amount of carbonate clasts herein is noticeable.

Stratigraphy, Sedimentology and Taphonomy of the Footprint Bearing Layers

The lower layer bearing dinosaur footprints (outcrop I) consists of pelletiferous mudstones-wackestones with rare ostracods and *Aeolisaccus*. This level occurs at the top of an interval consisting of thin bedded limestones ascribable to a tidal flat setting. A thin centimetric level of the same lithofacies can be observed above the footprint bearing surface but it is immediately overlain by sediments typical of a markedly open lagoon setting.

The upper track bearing bed (outcrop II) occurs at the top of an interval of sediments ascribable to a tidal flat setting. This interval consists of mudstones-wackestones with rare Ophtalmidiidae and ostracods and frequent desiccation structures. The layer with footprints is capped by a thin layer of intraclastic pellettiferous-fossiliferous packstones with Dasycladaceae, miliolids and *Nezzazatinella* suggesting an open lagoon setting. Locally, small scale mud cracks can be observed on the trampled layer, near the track. One of the footprints of the track is not well preserved but in its place a shallow depression filled with flat pebble fine grained breccia occurs. The breccia consists of clasts a few mm in diameter (see Dalla Vecchia and Tarlao, this volume). Both the presence of the narrow mud-cracked surface a few meters away from the track and birdseyes observed in thin sections of the same sediments indicate that the preservation of footprints was favoured by the desiccation of the exposed surface. Desiccation probably occurred in a very short time span judging from the modest areal extent, width and low penetration of the cracks. During the following microtransgressive phase, the deepest depressions were filled with peritidal microbreccias. We postulate that the depressions had moister sediments than those where footprints had been preserved.

Other Probable Trampled Layers

Lithofacies characterized by an evident breccia fabric can be observed at outcrop II (Fig. 21a), in the interval overlying the footprint bearing layer. The sedimentological characteristics, like the presence of soft pebbles, and the lateral-vertical transition from breccia fabric to undisturbed limestone, recall the supposed dinoturbated structures of

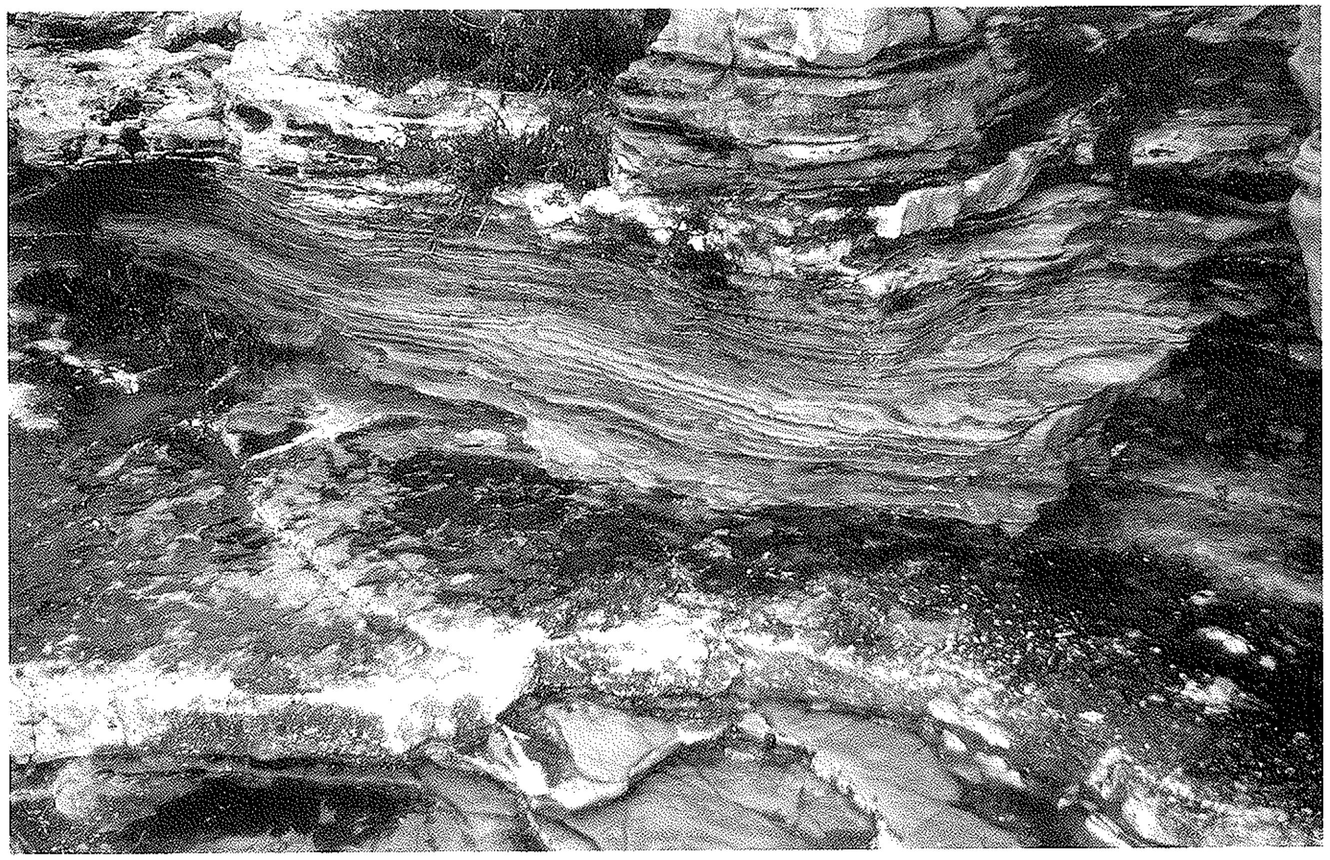


Fig. 18 - Thin bedded dolomitic limestones with local small slumps and microdebrites, not illustrated in the photo, overlying the storm beds at outcrop IV Solaris. The uppermost storm bed is 7-10 cm thick.

outcrop V of Solaris. Besides angular clasts, several plastically deformed clasts characterized by edges penetrating and fraying into the matrix, can be observed. According to Dini *et al.*, (1998), this characteristic feature depends on loading and incomplete amalgamation of the sediments. Another layer, at the base of the lower thick clayey-marly horizon (Figs 21a and 26), appears heavily disturbed and often shows breccia fabric at outcrop scale, but correlative texture is difficult to recognize in thin section. Several irregular holes can be observed on the rugged surface at the top of this bed; speculatively they could be attributed to severe trampling by heavy animals. An intense brecciation all around the unspecified depressions at outcrop IV (Fig. 26) is worth mentioning, whereas limestones farther away do not seem much disturbed. Infillings of fine terrigenous material within the millimeter size interstices of these "brecciated" limestones were observed in thin sections. The presence of fine terrigenous sediments enhanced the modern meteoric weathering, thus displaying the strong deformation of the substrate (Fig. 28).

Clayey - Marly Levels

At least four 20 to 90 cm thick clayey-marly levels were found in the upper part of the Puntizela-Puntisella succession (outcrop III and south of outcrop II towards Cape Prostina-P. Cristo, Fig. 19b): the first two outcrops are represented in the logs in figure 21. Thin, laterally discontinuous horizons, consisting of fossiliferous wackestones, with desiccation structures and crystal vadose silt, are intercalated within the predominant clay marls in the oldest level, which locally shows a thickness in excess of 90 cm. The clays contain abundant carbonate clasts near the base; locally, the amount of clasts (outcrop IV) gives rise to a true breccia fabric which passes to the clayey marls laterally (Fig. 29). It is common to observe strongly altered small clasts within the marls: both marls and limestone lenses contain small bivalves and gastropods, smooth shelled ostracods, recurrent charophyte gyrogonites and stems (Fig. 30). Frequent gyrogonites of *Atopochara trivolvis* Peck were found among the charophytes; more important is the systematic presence of fragments of stems which shows that this floral assemblage fossilized *in situ*, in a tranquil setting. As far as the small molluscs are concerned, the fragility of their thin shells made extraction and preparation of entire specimens very difficult (despite the excellent fossilization that preserved colour marks). Specimens with morphologies and ornamentations similar to those of Clausiliidae, Viviparidae and Limneidae and *Valvata* and *Melanopsis* were found. Moreover, rare specimens may be referred to Helicidae and Planorbidae. The taxonomy of these fossils is approximative, mainly because of the difficulty in finding similar Cretaceous assemblages in the Southern Tethys Realm and of the the scant literature available on Albian continental malacofaunas. It is probable that these molluscs are new species and/or genera thus requiring a better preparation and careful taxonomic studies.

Anyhow, the "continental", possibly lacustrine, character of the malacofauna is supported also by the recurrent presence of charophyte gyrogonites and stems, smooth shelled ostracods and by the absolute lack of foraminifers.

SEDIMENTOLOGICAL OBSERVATIONS AND INTERPRETATION OF THE PUNTIZELA OUTCROPS

The two successions of Puntizela-Puntisella (Figs 19, 20 and 21) exhibit, in general, a different environmental and facies evolution above the two respective footprint bearing surfaces. In fact, some probable dinoturbated breccia beds with thin, faintly terrigenous interlayers are present at outcrop II within the 1 m thick interval of the succession above the footprint bearing layer. Whereas, lithofacies with fossiliferous horizons characterized by an energetic hydrodynamics (as noticed by the presence of probable storm layers and crossed laminations) typical of an open lagoon setting are found above the footprint bearing surface at outcrop I.

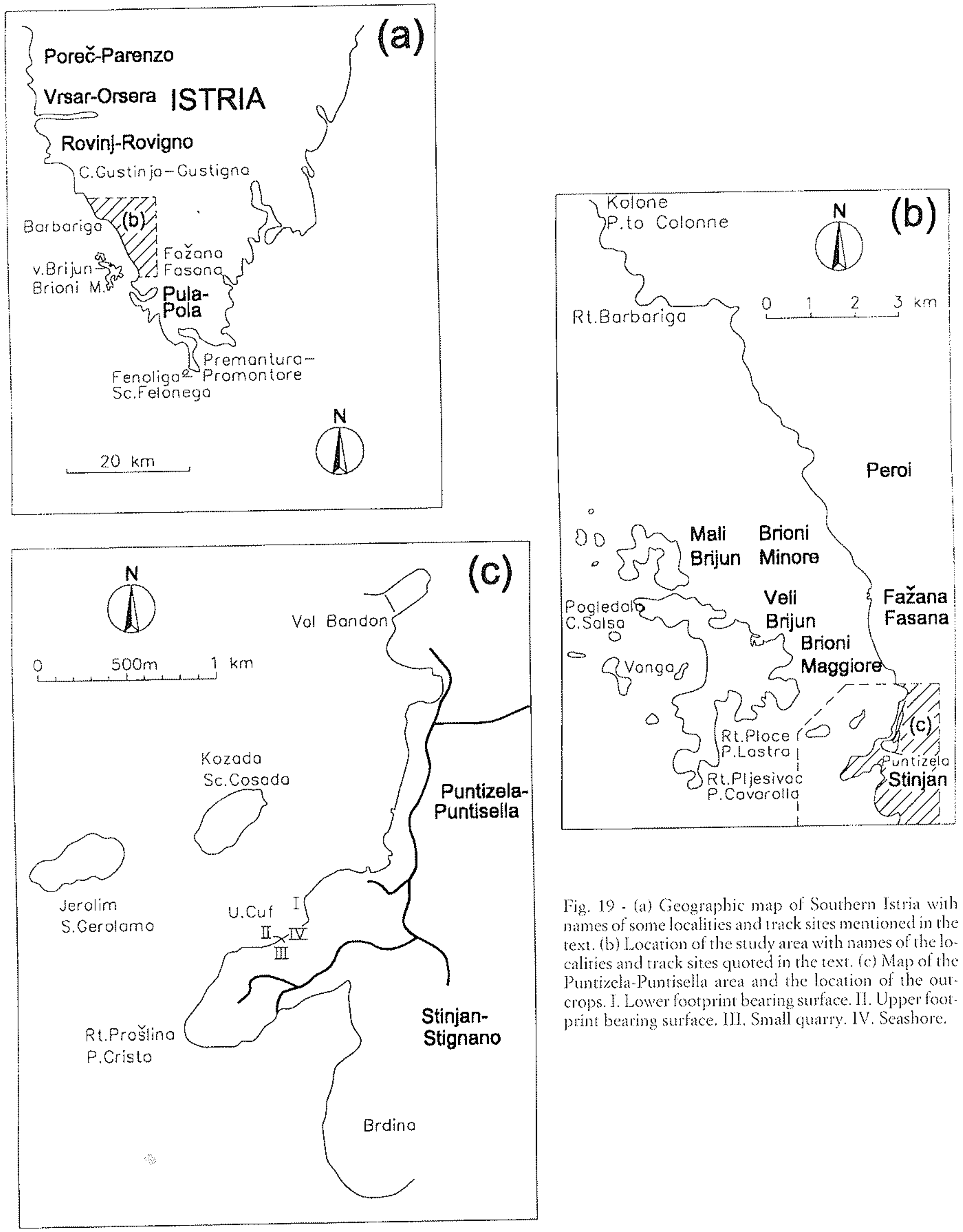


Fig. 19 - (a) Geographic map of Southern Istria with names of some localities and track sites mentioned in the text. (b) Location of the study area with names of the localities and track sites quoted in the text. (c) Map of the Puntizela-Puntisella area and the location of the outcrops. I. Lower footprint bearing surface. II. Upper footprint bearing surface. III. Small quarry. IV. Seashore.

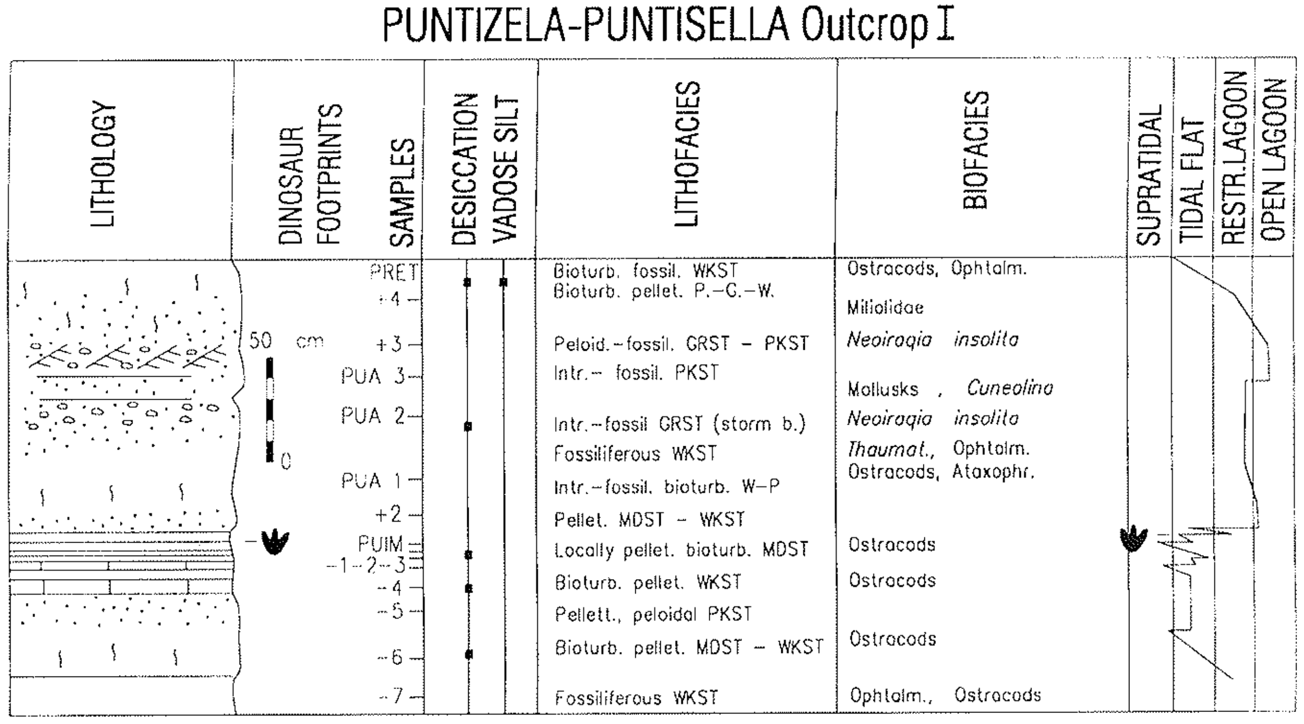


Fig. 20 - Litho-biostratigraphic log of outcrop I Puntizela-Puntisella.

Some relatively high energy episodes have also been recorded within the younger succession (Fig. 21), but, in general, a lithofacies association suggesting a restricted lagoon setting prevails; moreover, facies typical of tidal flat predominate above the first marly horizon.

The succession, on the whole, besides some significant environmental oscillations, shows a regressive trend.

Dinosaur footprints at both of the Puntizela-Puntisella sites (outcrop I and outcrop II plus III) were impressed in sediments at the top of two intervals marked by beds which are generally thin and characterized by facies ascribable to tidal flat setting. The two footprint bearing layers show rather similar characteristics. They consist of mud supported facies with ostracods typical of a restricted setting and only differentiate owing to the presence or lack of Ophtalmidiidae and *Aeolisaccus*. The average thickness of the beds clearly increases above the footprint bearing surfaces. Moreover, the first capping layer is ascribed to an open lagoon setting. In both cases, footprint bearing layers occur in the proximity of a marked environmental change that marks a transgressive phase.

Some footprints forming part of the track at outcrop II have not been preserved due to a combination of factors including: (*i*) the rapid consolidation of the bedding surface prior to printing because of desiccation; (*ii*) the high degree of fluidity of the water clogged muds at the time of trampling; (*iii*) the high moisture content of the topmost surface during the following rising of the sea.

The microtopographic features of the surface, with low lying sectors lacking in footprints and relatively high zones characterized by small mud cracks, suggest different degrees of moisture of the substrate which would be determinant both for footprint impression and subsequent preservation. In such a way, the time required for exposure and burial of the footprints was very short, probably shorter than at outcrop II of Solaris, judging from the localized incomplete desiccation phenomena recognizable in different sectors of the topmost surface at Puntizela-Puntisella. Moreover, according to Cohen *et al.* (1991), shallow footprints are recognizable and may be referred to specific large animals for a few days only after imprinting; some weeks later the probability of footprints surviving has come to nought.

It is probable that a more prolonged subaerial exposure has involved the overlying layers (outcrop II), which were probably dinoturbated. Anyhow, trampling has occurred when sediments were not hardened, as one can evince from boudinage processes that have yielded soft clasts and from peculiar structures of deformation observable within the matrix. Amalgamation of sediments has also involved thin levels rich in organic material, thus giving origin to rare black pebbles, and equally thin interlayers of clayey marls. Both the very fine terrigenous material and the black pebbles suggest temporary isolation from the sea and probable terrestrial input.

The clay input is predominant in the marly horizons that record brackish-freshwater settings. The relatively sharp environmental change at the base of the clayey-marly levels is noteworthy, passing from limestones of an open lagoon setting (top of the underlying bed) to marls and conglomerates of a probable lacustrine setting. Taking into account the lower clayey-marly level, this passage seems to coincide with an emersion phase. At this time the probable dinoturbation and the crystal silt penetration in the underlying bed occurred. This regressive phase was unfavourable to the preservation of recognizable footprints. The noticeable thickness of the marls, small karstic features observed in the limestone lenses within the clayey marls, and lateral continuity in the stratal geometry of this horizon testify to a relatively wide and long lasting lacustrine

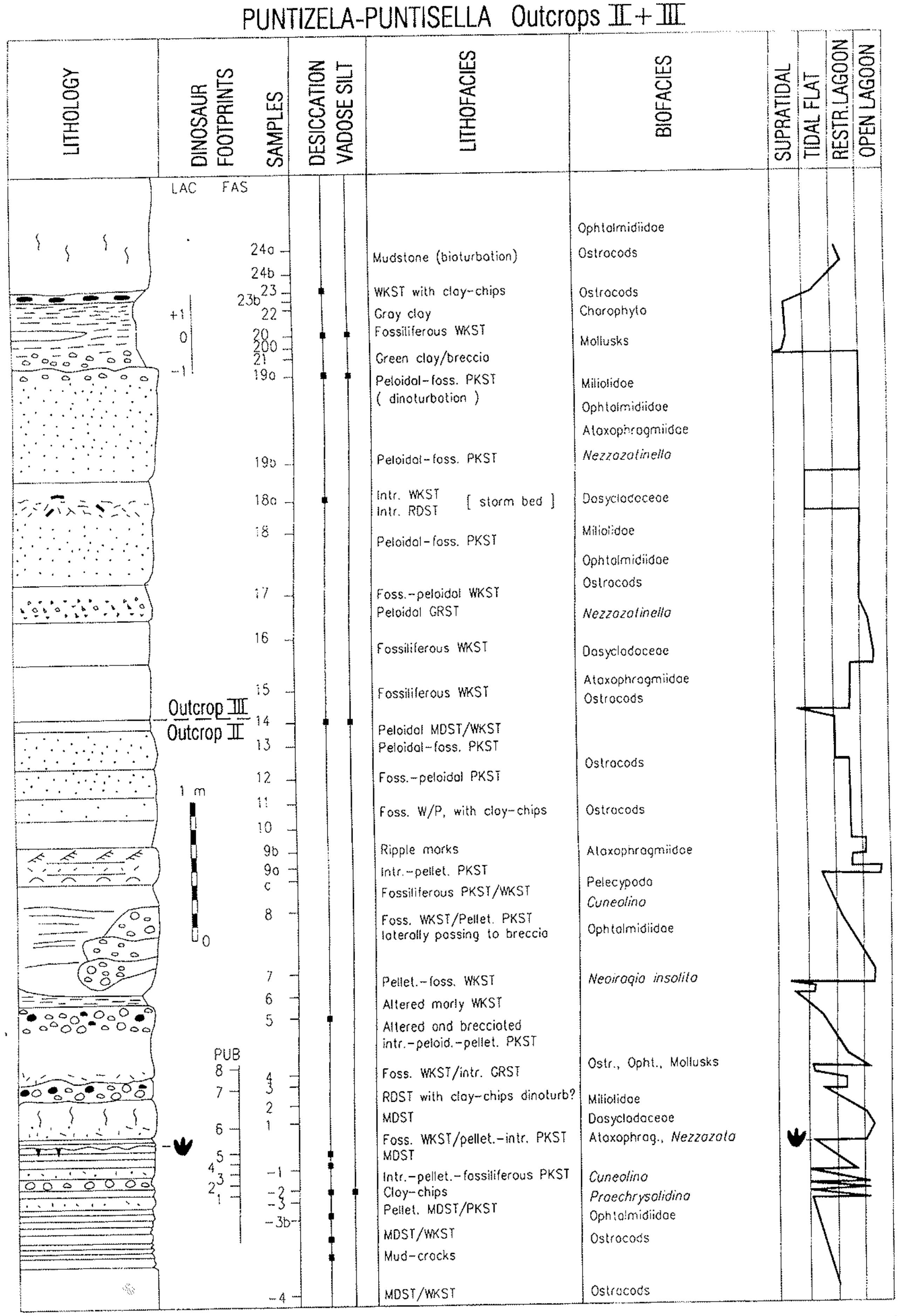
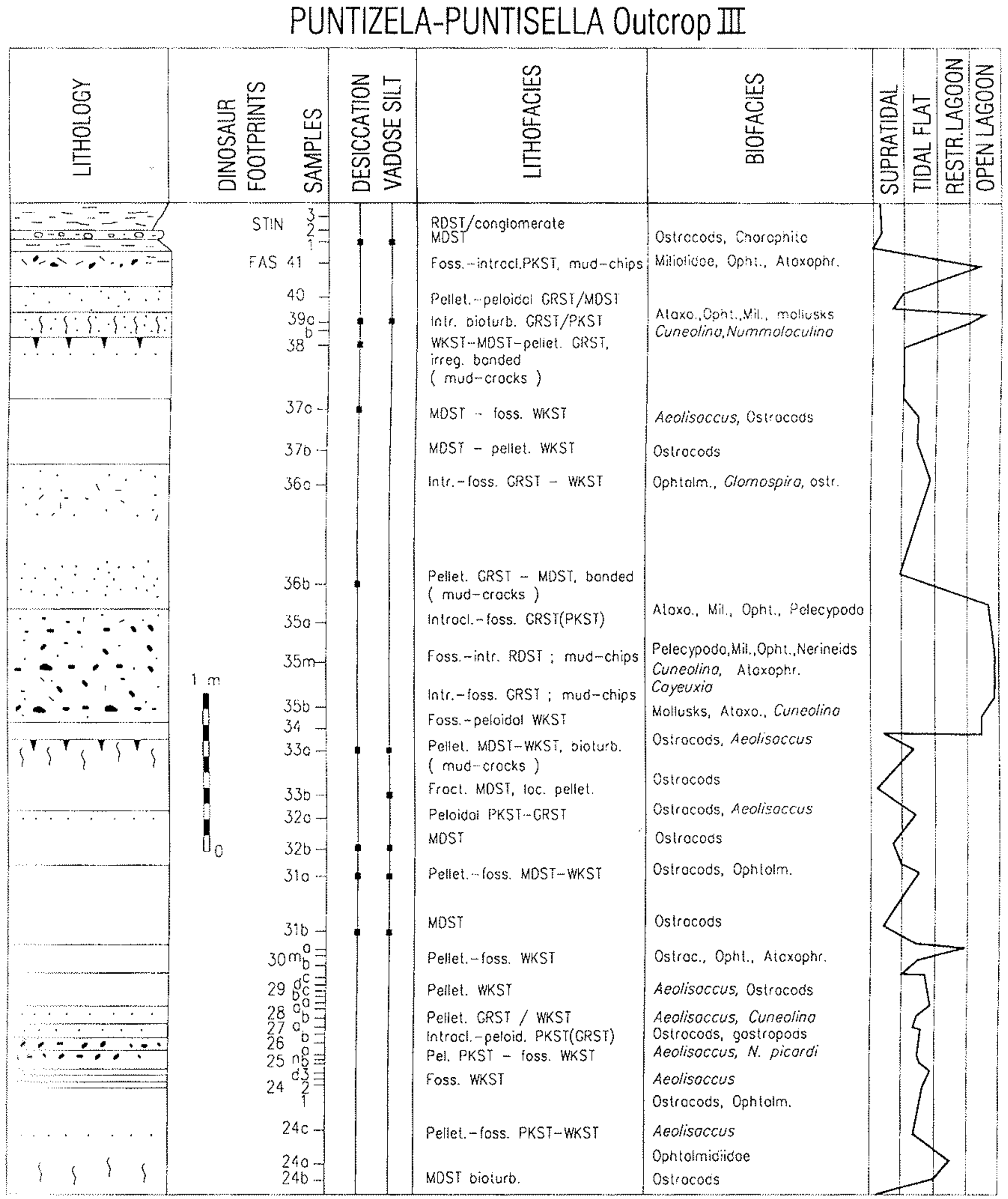


Fig. 21 (a e b) - Litho-biostratigraphic logs of outcrops II and III at Puntizela-Puntisella. The two successions are very close and in stratigraphic juxtaposition.

episode. The latter is associated with an emersion phase of the platform documented by related karstic features; in fact severe alteration of the relic clasts within the marl horizon would also indicate long lasting subaerial exposure of limestones in the neighbouring areas.

Lastly, a significant phenomenon affecting the carbonate sedimentation of the Puntizela-Puntisella succession is represented by the third breccia layer at outcrop II, above the footprint bearing layer. The breccia does not seem to be ascribable to pedogenic-rhizogenic processes, dinoturbation or the presence of tidal channels. The general face suggests that the genesis of this bed is to be attributed to peculiar deformation processes with probable dish structures, local breakage of laminated limestones and, sometimes, abrupt lateral passage to undisturbed limestones. A lagoon environment, due to very gentle morphology and a tranquil setting, does not seem proper for the aforementioned sedimentary features. Fluidization processes in partially hardened sediments may be perhaps due to earthquakes, also effective in this setting.



21 b

Fig. 22 - Two breccia levels (see small arrows) at outcrop II Puntizela-Puntisella (samples Fas 3 and Fas 5 of Fig. 21). The footprint bearing surface is shown by the long arrow on the left of the photo. The older level is sometimes markedly eroded due to the presence of a clayey muddy matrix. The intermediate (second) level shows breccia fabric only in the upper part.

CORRELATIONSHIPS AND COMPARISONS BETWEEN THE ISTRIAN ALBIAN LOCALITIES WITH FOOTPRINT BEARING LAYERS

Solaris, Mirna-Quieto river mouth (Fig. 2b), Veli Brijun-Brioni Maggiore (Fig. 19b) and Puntizela-Puntisella successions are set in the same biostratigraphic interval characterized by the presence of *Neoiraqia insolita*. Footprint bearing layers at outcrops I and II of Solaris and at the track site located in the Lanterna camp site - Mirna-Quieto river mouth (see Dalla Vecchia *et al.*, 1993) are very near both from geographic and stratigraphic points of view.

Going on from the Solaris camp site southern boundary to Cervar Porat-Cervera grande, which is situated about 1 km S-SE of Solaris camp site (Fig. 2b), a horizon of the early Aptian age with *Palorbitolina lenticularis* is recorded. In the absence of faults, not yet discovered, and following the strike of the beds, the difference in height inside the stratigraphic column may be calculated at about 20 metres between the early Aptian levels outcropping at Cervar Porat-Cervera grande and the late Albian levels at Solaris camp site. Therefore, the footprint bearing layers of Solaris may be set in the basal part of the upper Albian succession of the Istrian platform carbonates; incidentally, the thickness of the entire upper Albian interval is around 250 m (see Fig. 1) according to Tišliar *et al.* (1998).

Similar computations are not possible for the Puntizela-Puntisella section because the late Albian succession is extensively covered between Puntizela-Puntisella and the harbour of Fazana-Fasana. The only stratigraphic reference is represented by the Ploce-P. Lastra (Veli Brijun-Brioni Maggiore) section, where Velič and Tišliar (1987), Dalla Vecchia (1997) and Dalla Vecchia and Tarlao (1995) noticed two track sites at the base of the Albian succession, which are set, according to the Croatian authors, respectively 8 and 20 metres above the early Aptian deposits. Also the basal part of the Albian section of Veli Brijun-Brioni Maggiore, once attributed to the early Albian, has been ascribed to the late Albian (Velič *et al.*, 1995). This part of the Veli Brijun-Brioni Maggiore succession shows strong lithological and paleoenvironmental relationships with the Puntizela-Puntisella succession. In particular, marly and marly conglomeratic levels interpreted as lithofacies characteristic of subaerial exposure (Velič and Tišliar, 1987) seem to be correlable with the clayey-marly levels interbedded within the limestones at Puntizela-Puntisella outcrops II, III and IV and near to Prošlina-P. Cristo (Fig. 19b).

Like Puntizela-Puntisella and Ploce-P. Lastra, the base of the Albian section at Solaris and Mirna-Quieto river mouth localities (Figs 2b and 31) is also characterized by clayey-marly levels. With regard to these outcrops, the presence of micromolluscs, ostracods and charophytes within the marly horizon, both at Puntizela-Puntisella and Solaris localities, is worth mentioning.

Fig. 23 - The second breccia level at outcrop II Puntizela-Puntisella (sample Fas 5 of Fig. 21) with probable dinoturbated structure. Hammer for scale.

Lithologic, stratigraphic, floral and faunal affinities suggest co-eval lacustrine/brackish paleoenvironments with fine terrigenous inputs, isolated from the sea and, at times, perhaps interconnected. Connections between lacustrine settings may have permitted the migration of peculiar faunas and floras.

Tidal flat-restricted lagoon settings with rare episodes of relatively higher energy both at Solaris and Mirna-Quieto river mouth may be inferred by the study of marine biofacies.

Relatively more open-marine and more fossiliferous facies were found in the lower part of the Puntizela-Puntisella section, while a tidal flat setting may be assumed from an environmental interpretation of the lithofacies of the upper part.

Some lithofacies of the Albian age (Cape Ploce-P. Lastra, Veli Brijun-Brioni Maggiore, Fig. 19b), bearing well preserved footprints, document relatively open depositional setting. The samples collected by Posocco (1995) suggest an open lagoon with episodes of subaerial exposure: a few levels are rich in gastropods (Fig. 32). Close relationships may be established between this section and the Puntizela-Puntisella section (outcrop I) above the footprint bearing layer. The only marked difference is represented by the rich faunal assemblage with miliolids and *Nezzazatinella* found in the footprint bearing beds at Ploce-P. Lastra, but lacking at Puntizela-Puntisella. Both

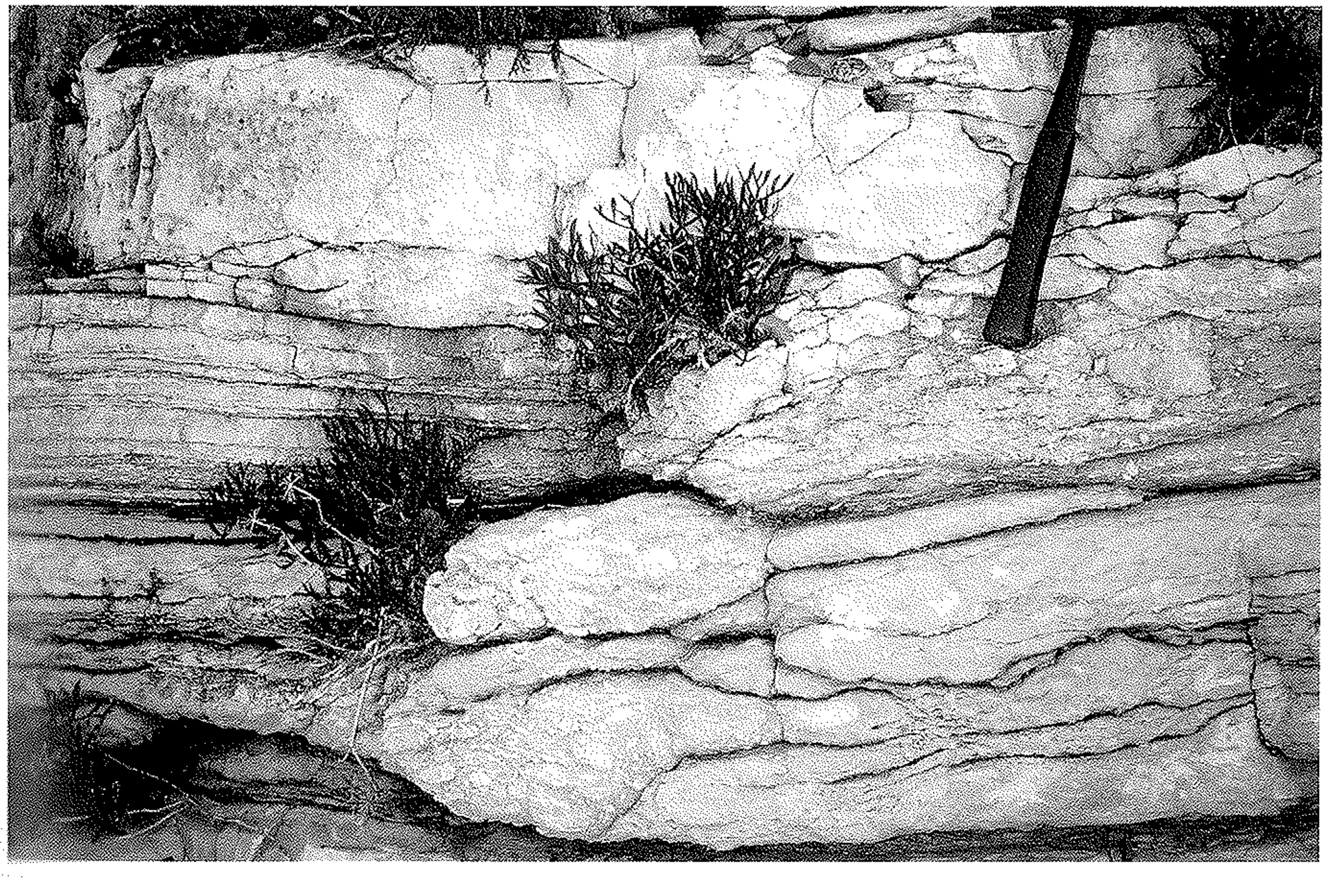


Fig. 24 - The third breccia level at outcrop II Puntizela-Puntisella and partial view of the succession (Fas 7 - Fas 12). At the base of this succession, the marly horizon (Fas 6) showing evidences of pedogenic rubefaction is overlied by limestones affected by synsedimentary deformation and by breccia beds. Note the abrupt lateral variation from breccia to laminated well bedded limestones.

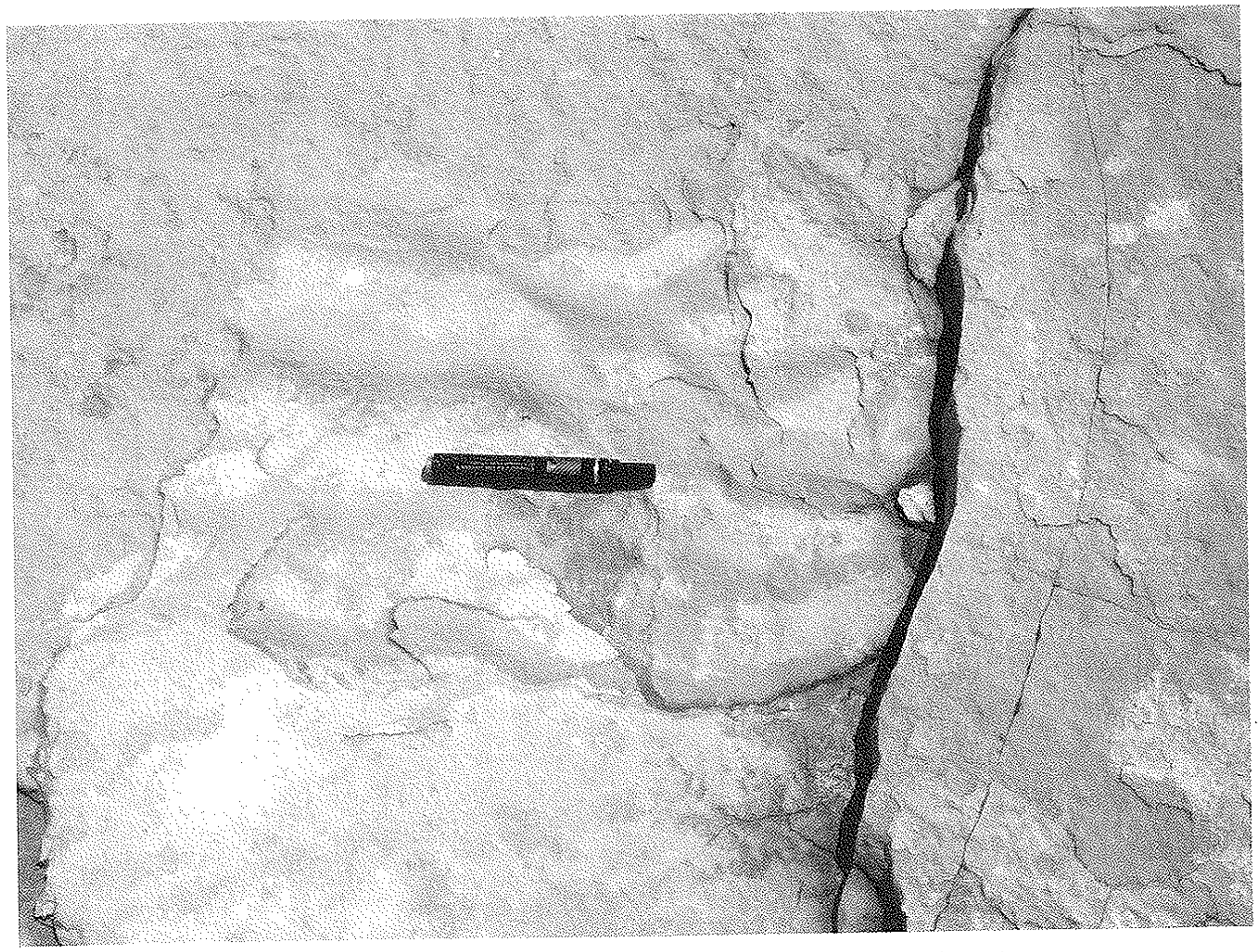


Fig. 25 - Ripple marks at outcrop II Puntizela-Puntisella (Fas 9b). Pen for scale.

the footprint bearing layers at outcrops I and II of this latter locality contain scarce specimens of ostracods, *Aeolisaccus* and Ophtalmidiidae.

The same taxa and rare *Microcodium,* associated with dessiccation structures, were observed in thin sections from footprint bearing surfaces at Solaris and Mirna-Quieto river mouth localities.

A second late Albian site on the Veli Brijun-Brioni Maggiore island is at present under study by Dalla Vecchia and Vlahovič (pers. commun.). The site is located on the narrow

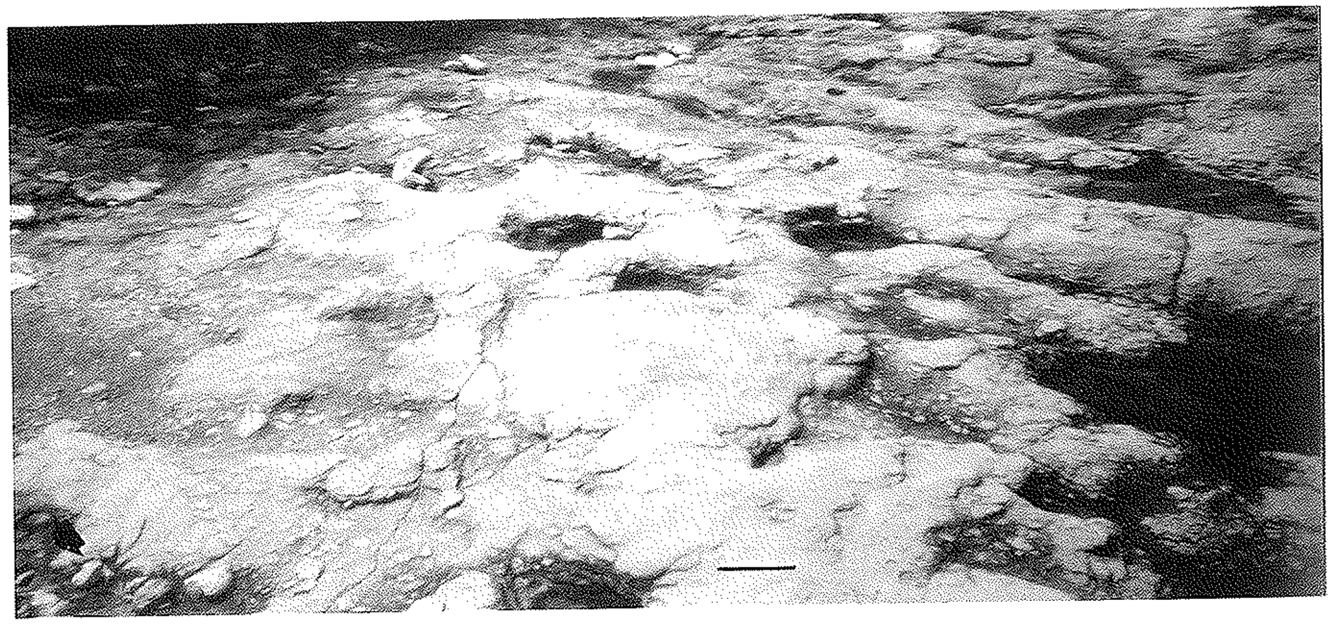


Fig. 26 - Bedding plane surface with partial breccia fabric at the lower boundary of the clayey marly horizon, outcrop IV Puntizela-Puntisella. Breccia fabric is clear near some small scale depressions but it is less evident on the sides of the holes. Bar = 10 cm.

Fig. 27 - The marl horizon with charophytes at outcrop IV Puntizela-Puntisella. Some lenses of breccias appear on the right side; the bedding plane surface at the base is probably dinoturbated. Hammer for scale.

promontory of Pljisevac-P. Cavarolla (Fig. 19b), known also as Kamnik, where two footprint bearing layers were found. The upper bed bears footprints of midsized biped sauropod, while the lower one bears a track with circular tracks, presumably imprinted by an ornithopod (Dalla Vecchia, 1997; Dalla Vecchia and Tarlao, 1995).

Both footprint bearing layers are made by bioturbated fossiliferous-pellettiferous wackestones with miliolids,

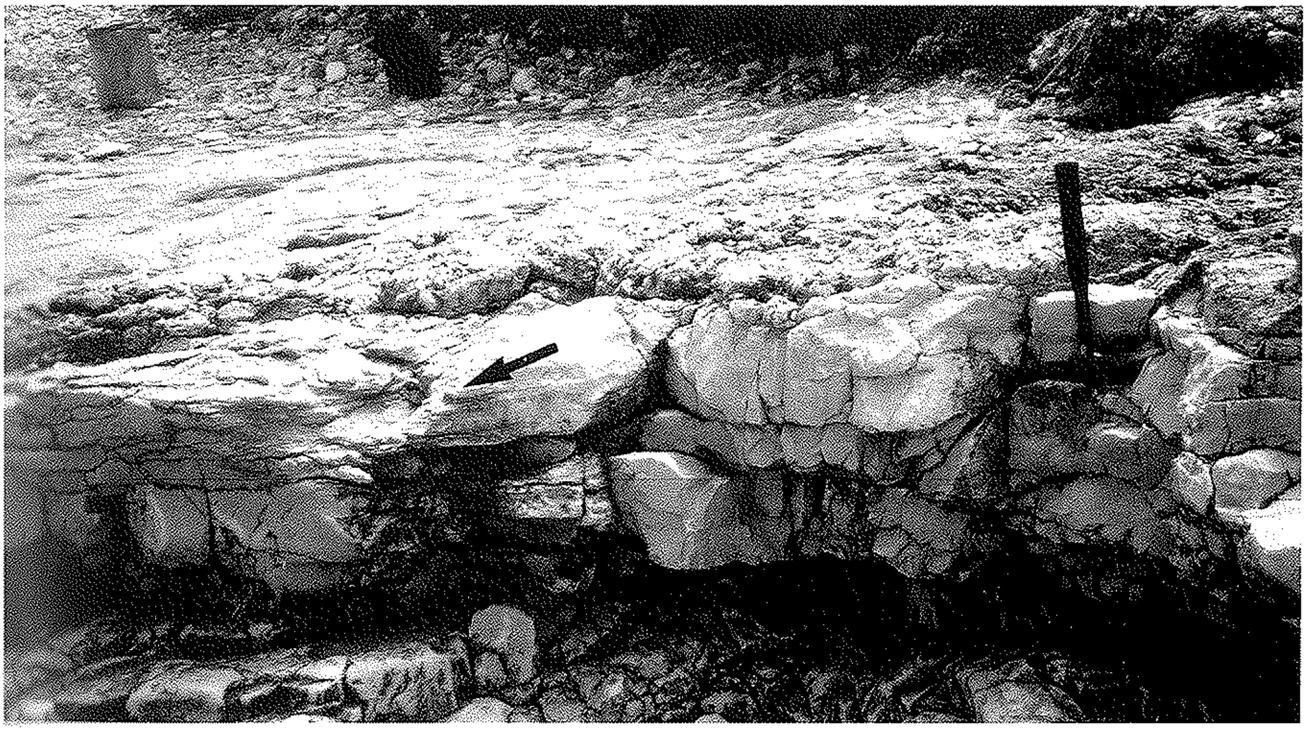


Fig. 28 - A breaking structure of the bedding plane surface at outcrop IV Puntizela-Puntisella (see Fig. 27) filled with a thin horizon of fine grained breccia (see arrow). This structure was probably caused by deep dinosaur prints that penetrate down to the layer. Note the marl horizon LAC (see Fig. 21) in the background.

Fig. 29 - Lateral lithological change from breccia to clayey marls. Outcrop IV Puntizela-Puntisella. Hammer for scale.

Ophtalmidiidae and *Nezzazata*, without evidence of subaerial exposure. The lagoon setting and the lack of desiccation structures are the cause of the bad preservation of the footprints, of ornithopod in particular, which are partly collapsed due to cohesiveness or a high degree of soaking of the sediments.

The footprint bearing surfaces of Solaris, Mirna-Quieto river mouth and Puntizela-Puntisella, on the basis of the microfacies, may be ascribed to tidal flat settings dominated by muddy sedimentation. The trampled bed of Ploce-P. Lastra contains faunas typical of an open lagoon, but localized zones with mud cracks observed on the upper footprint bearing surface (Dalla Vecchia, pers. comm.), provide evidence of subaerial exposure for a very limited time.

To sum up, the stratigraphic interval in which different track sites occur is nearly the same, at the base of the upper Albian. In particular, they were developed at the beginning of the late Albian transgressive phase upon the Aptian deposits. The environmental setting of each footprint bearing layer and the dinoturbated levels are attributed to tidal flat except for the ones at Ploce-P. Lastra that may be ascribed in part to a relatively open lagoon. However, desiccation structures and mud cracks prove that localized subaerial exposure and consequent induration of sediments occurred anyway.

SUBENVIRONMENTS AND THE EVOLUTION OF THE ISTRIAN SECTOR OF THE ADRIATIC-DINARIC CARBONATE PLATFORM DURING THE LATE ALBIAN

The long lasting late Aptian-early Albian emersion phase caused severe karstification of the platform top. This phase lasted probably long enough to allow dinosaur populations to grow. Unfortunately, the extensive pedogenic processes did not allow the preservation of dinosaur footprints. Instead, slow and oscillating transgressive phases during the late Albian turned out to be the main factor leading to the preservation of dinosaur footprints.

During this phase, dinosaur populations sporadically visited the sites in question, owing to the poor living conditions for big herbivores which probably necessitated a large freshwater and food supply. The presence of plant eater quadruped dinosaurs (sauropods) during the late Albian in Istria is well documented at the Solaris track site II (see Dalla Vecchia and Tarlao, this volume), whereas evidence of biped dinosaurs has been recognized in all the other sites. The filling sediments of the footprints of Solaris suggest the presence of meteoric water and, therefore, more favourable living conditions for dinosaurs, compared to the other sites. The substrate of the footprint bearing beds, however, does not show marked evidence of root mats that could provide unequivocal proof of vegetation cover. It is possible that, in analogy to the Pleistocene mangroves, the peats oxidized and the litter was washed out or eaten, so that peat and pollen did not fossilize (see Galli, 1991). More likely, one may assert that the quadruped plant-eater dinosaurs did not live *in loco* and have only left evidence of their movements, walking through tidal flats or supratidal settings between perennial vegetated lands.

Relatively long phases of subaerial exposure can be recognized within the successions of Solaris, Puntizela-Puntisella and Mirna-Quieto river mouth. Here, dinoturbated beds, sometimes with pedogenic features, and moreover, clayey-marly levels with continental faunas and floras can be observed. It should be pointed out that some structures penetrating down into the underlying layer are evident at the base of the lower marl level of Puntizela (outcrop IV): these structures may represent strongly altered deep prints of large dinosaurs or casts

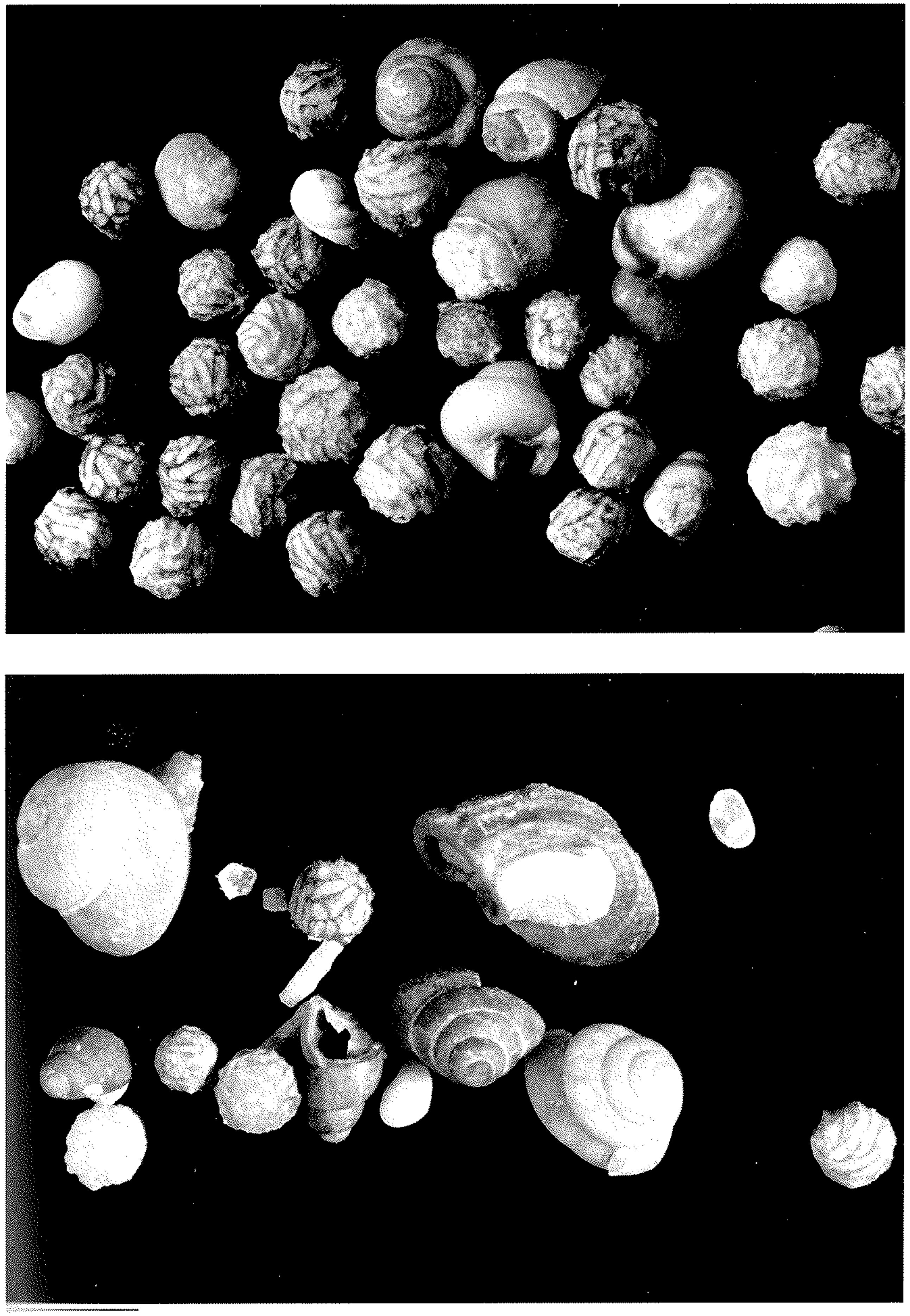


Fig. 30 - Faunal and floral assemblages of the lower clayey marly horizon of the Puntizela-Puntisella section. Above and below: *Atopochara trivolvis* Peck, charophyte stems, ostracods and gastropods. Scale bar = 1 mm.

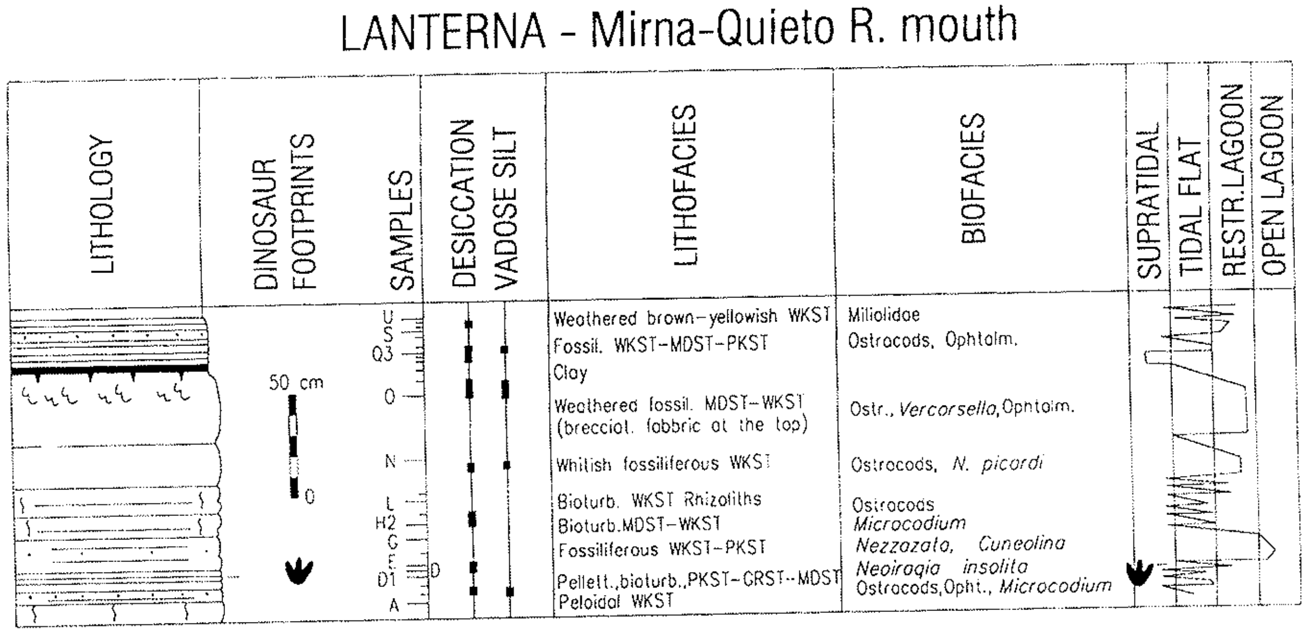


Fig. 31 - Litho-biostratigraphic log of the Lanterna-Mirna-Quieto river mouth track site.

of plant roots. Both these hypothesis are in agreement with the nature of the immediately overlying lacustrine-brackish deposits. At the same time, when lacustrine deposits developed, the surrounding areas were under the influx of meteoric water which washed away clays from karstified areas. Continental facies document isolation from the sea and temporary breaks of the carbonate sedimentation, that was replaced by terrigenous sedimentation.

It may be that part of the grainy facies and also some mud supported facies were not deposited in subtidal settings but perhaps they represent the product of episodic storms which have carried sands and muds in a supra-tidal setting. Vast emerged sectors of the coast of Florida have been recently covered by several centimeter thick sediments carried there by storms and surges (Shinn, 1983).

From a paleoenvironmental point of view, the examined sections resemble the Barremian succession of Barbariga, in southern Istria (Dini *et al.*, 1998), which exhibits an heterogeneous association of lagoons, marshes, brackish-lakes and swamps. All these paleoenvironmental variations show strong similarities with the coastal plain of Florida Everglades (see Platt and Wright, 1992) where strong seasonal precipitations alternate with relatively long, dry weather periods.

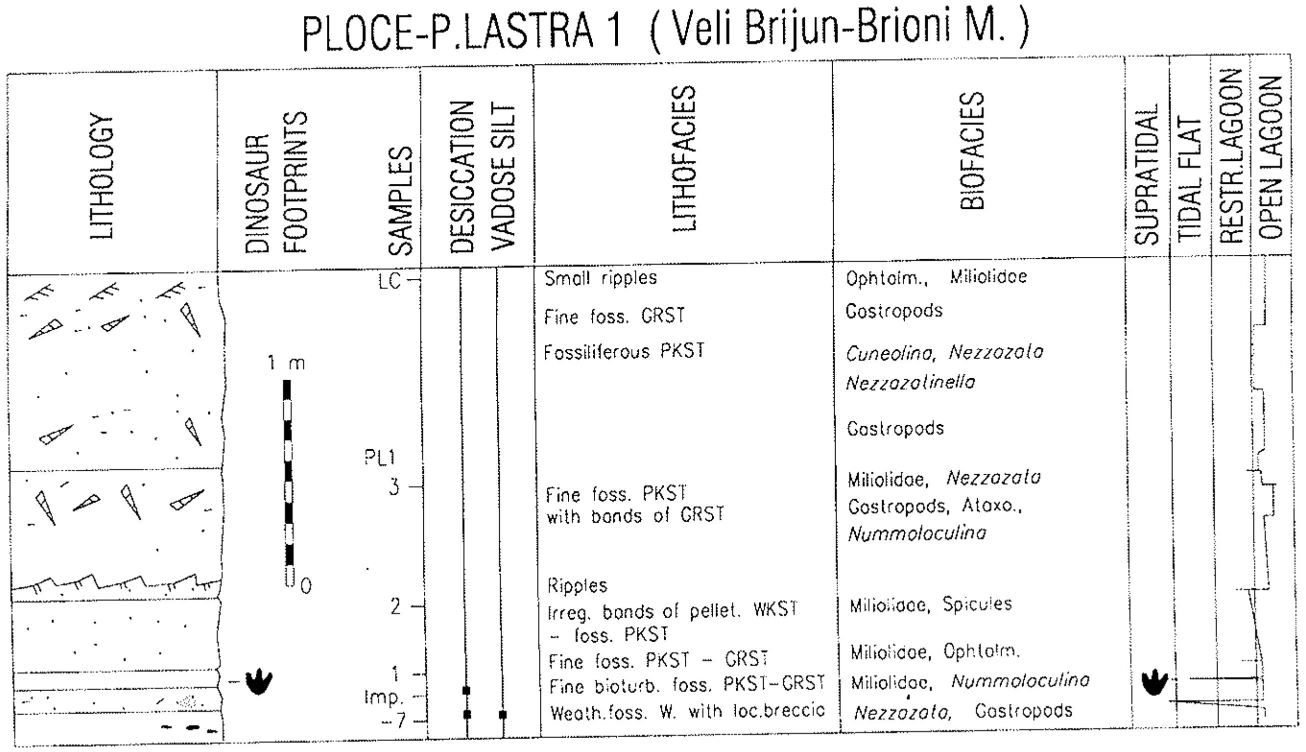


Fig. 32 - Litho-biostratigraphic log of the Ploce-P. Lastra track site (Veli Brijun-Brioni Maggiore island).

ACCUMULATION RATES AND THE CYCLICITY OF SEDIMENTATION: RELATIONSHIPS WITH THE TAPHONOMY OF FOOTPRINTS

A detailed analysis of the stratigraphic successions of Solaris and Puntizela-Puntisella was carried out, with the aim to define the nature of the sediments and the environment in which the trampling took place, the mode of footprint infill and the factors conductive to footprint preservation.

The detailed lithofacies and biostratigraphic analysis has been extended to the intervals comprising the footprinted horizons with the twofold purpose of framing them into the late Albian depositional theme, and to investigate the effect of possible sea level oscillations driven by eustatic-climatic cycles (see also De Boer and Smith, 1994).

Studies carried out on modern and Quaternary track sites (Cohen *et al.*, 1991; Laporte and Behrensmeyer, 1980) drew attention to important aspects of the footprint preservation of large terrestrial vertebrates and their potential for fossilization. These footprints can be commonly observed on soils in zones free of vegetation, periodically moist enough to be easily deformed under load. Grain sizes commonly range between very fine sand and mud. The shallowest footprints, such as those left on partly dewatered soils, rapidly deteriorate and their characteristics vanish. Only the deepest footprints are recognizable after a few weeks, mainly if in combination with trackways. In the case of water-saturated soft sediment, especially if it is mud carbonate, morphologic characteristics of the individual footprints are not recognizable. Besides the deterioration caused by meteoric waters, a prolonged exposure often causes the reworking of substrate due to both the trampling of large vertebrates and the bioturbation by invertebrate infauna. Those footprints, that were sun-baked and developed a superficial crust with high salinity interstitial water that inhibited the bioturbation, are the ones that had the chance of survival.

A rapid burial may be necessary to avoid a mechanical and biological reworking of sediments.

On the basis of these arguments, one may infer that a very narrow space-time window allowed the moulding and the preservation of footprints with well recognizable taxonomic characteristics.

As far as the Albian of Istria is concerned, this constraint seems to have been important for some of the well preserved tridactyl footprints at Solaris, Puntizela-Puntisella and Mirna-Quieto river mouth sites. The time lapse between the trampling episode and the beginning of sedimentation may be estimated in some weeks, exceptionally in a few months. The desiccation of the superficial imprinted crust, with local mud cracks as well, partially inhibited the meteoric alteration and subacqueous erosion before the burial.

If we assign a rate of deposition of 1 mm/month for the sediments which draped the depressions (we hypothesize this as a *minimum* rate allowing a good preservation of the footprints), we obtain an average sediment accumulation rate of 12 mm/year, that is 12 m/ka. In general, the overall average rate of sedimentation during the late Albian in Istria may be estimated around 6-3 cm/ka and this value also approximately represents long term subsidence. The above mentioned rates of sediment accumulation show a striking difference: the former, that supported the preservation of the footprints, exceeds the latter by two orders of magnitude, that is the average sedimentation rate on the geological time-scale. Furthermore, indication of sediment fluidity observed at Solaris outcrops I and II, at a depth of 10 cm below the footprint bearing surface, points out the lack of cementation and a higher degree of water saturation. If we assume the average sedimentation rate of the Albian, an approximate age of 2-4 ka would be attributed to these muds, implying several problems as far as the carbonate diagenesis (see also Dravis 1995, Friedman, 1998) and bioturbation rate are concerned. In this way, it is probable that the deposition of the footprint bearing layer at Solaris also happened in a much shorter interval of time. Differences between the rate of the sedimentation of individual beds and of the whole Albian deposits come from more or less prolonged breaks of sedimentation; these episodes occurred when forming pedogenic horizons and probably during tectonic phases affecting the platform. As mentioned above, the tectonic movements were accompanied by the formation of lacustrine settings, probably not of short duration.

On the basis of the microstratigraphic study of early Cretaceous carbonate platform deposits of the southern Apennines, the high frequency cyclic nature of the shallow water sedimentation has been recognized by D'Argenio *et al.*, 1992a, 1992b, 1994, 1997, in press, Buonacunto *et al.*, 1994, Longo *et al.*, 1994, etc. These authors have correlated lithofacies thickness periodicities with the orbital perturbation periodicities of the Earth (precession, axial obliquity and orbital eccentricity). For instance, the time interval of 18-22 ka (*i.e.* precession) corresponds to a stratigraphic periodicity of 40-70 cm, which represents an elementary cycle and, approximately, the thickness of a single bed of the successions examined by the aforementioned authors. In this way, the average rate of sediment accumulation may be calculated between 20-40 mm/ka. The average rate of sediment accumulation during the late Albian in Istria is around this range; nevertheless it is clear that similar values are not consistent with the taphonomic processes needed for the fossilization of the dinosaur footprints.

The study of the Istrian sites with dinosaur footprints was also initially aimed at documenting high frequency cyclicity, with the purpose of verifying a possible eustatic control of the episodes of trampling and fossil footprint preservation. Except for the lower part of the Puntizela-Puntisella section (outcrop II), where some 1-m-thick "regressive" sequences were found, the data collected elsewhere does not display either cyclic nature, therefore suggesting the interplay of multiple factors.

Among these factors, the sedimentological ones are noteworthy. In fact, (*i*) sharp lateral variations in stratal thickness and geometry at the outcrop scale, caused by the forming of bars or by the abrupt presence of breccia, (*ii*) lateral changes of lithofacies at a single bed scale, (*iii*) storm layers, (*iv*) bioturbation and (*v*) rare dolomitization processes could have obscured the recognition of cyclicity. Also tectonics could have cut or modified many cycles.

PROBLEMS CONNECTED WITH THE DINOSAUR POPULATION ON THE PERIADRIATIC PLATFORMS: CLIMAX AND HYPOTHESIS

Biogeographical and paleoenvironmental problems raised due to the discovery of dinosaur presence on the Periadriatic Platforms are very far from being understood and resolved. The regional palinspastic reconstructions alone (for instance see Dercourt *et al.*, 1985, 1993) and the distribution maps of dinosaur presence based on the finding of rare, fragmentary and not easily recognizable bones are not sufficient for the tracing of a coherent scenario, as far as continental connections between Africa, the Middle East and Europe are concerned. Studies on the settlement and duration of emerged areas within the Adriatic-Dinaric carbonate platforms are just starting. Information from foraminiferal and algal assemblages of the Early Cretaceous suggests a probable paleogeographic contiguity up to the Aptian between the Adriatic-Dinaric areas, the Middle East and Africa, while a probable separation of these land and platform masses beginning from the Cenomanian may be inferred owing to the presence of vast and deep marine areas (Cherchi, 1989, Fleury *et al.*, 1985, Moullade *et al.*, 1980, Schindler and Conrad, 1994).

In view of this, possible migrations of large vertebrates from southern land masses and the colonization of the Adriatic-Dinaric Platform following the most important transgressive phases (for istance the *Palorbitolina* event) may be assumed, at least from the beginning of the Cretaceous up to the Aptian.

After the Aptian, the survival of dinosaurs is not readily acceptable, if we do not suppose the existence of wide perennially emerged areas within the Adriatic-Dinaric platform. We may speculate that those wide continental lands were located in the inner Dinarids which were successively involved in the compressive Alpine phases. However, it is difficult to accept that so many traces of dinosaurs were left during hundreds of kilometers of transit across uninhabitable lands. A more logical conclusion is that dinosaurs frequented and dwelt more or less regularly in the Istrian area.

According to Matičec *et al.* (1996) some areas of Western Istria were emerged for most of the Cretaceous, since Paleogenic deposits locally transgress over Neocomian carbonates. Nevertheless, the extent of these supposed insular areas is very modest and probably inadequate to sustain large populations of dinosaurs, even if endemic and of small size (Dalla Vecchia and Tarlao, 1995; this volume). Moreover, the existence of Cretaceous horsts in the middle of the Istria platform, postulated by Matičec *et al.* (1996), is in conflict with the general subsidence of the area and, in general, of the Periadriatic Platforms, too (Cati *et al.*, 1987).

For these reasons we postulate that emerged lands were not perennial, but we argue that continental settings formed continually, although within a marked space and time variability.

From several hundred thousands to a few million-year long-lasting exposures in shallow water carbonate sequences of the Cretaceous age have been documented at several stratigraphic intervals in Eastern Friuli (Fig. 2a), (Sartorio *et al.*, 1997), in the Karst region (Tentor *et al.*, 1994) and in Istria (Velič *et al.*, 1987b, Matičec *et* al., 1996, Dini *et al.*, 1998), although not co-eval. They were attributed to a more or less important tectonic control at a regional scale.

Location of the footprint bearing layers above the important *biatus* of the Aptian *p.p.*-Albian *p.p.* age and at the base of the late Albian transgressive phase is in accordance with our hypothesis of temporary emerged islands, since the continental area had to be relatively near. Carbonate sedimentation in the marginal zones of the Friuli Platform (Eastern Friuli) showed a condensed character during the late Albian and is marked by hiatuses as shown by an interval of limited thickness made by a breccia bed (Sartorio *et al.*, 1997).

The Albian-Cenomanian boundary in the Karst area (Fig. 2a) is marked by important paleokarstic processes which prove to be an emersion phase; reddened breccias with intercalated limestones are typical of the lower-middle Cenomanian strata in the area in question. Normal marine sedimentation, interrupted by several breaks which document further subaerial exposure episodes, began again in the late Cenomanian.

On the basis of the arguments exposed above, the existence of vast emerged areas between Istria and Friuli, at least during the Aptian *p.p.*, Albian and lower-middle Cenomanian may be inferred.

Moreover, the emersion connected to a tectonic phase that occurred at the Hauterivian-Barremian boundary is noteworthy. This phase is well documented at Kolone-P.to Colonne, Southwestern Istria (Fig. 19b), where a rich deposit of dinosaur bones has been discovered recently (Boscarolli *et al.*, 1993). The levels containing bones belonging to large plant eating quadrupedal dinosaurs (Dalla Vecchia and Tarlao, 1995; Dalla Vecchia, 1998, 1999b) are preserved in a large erosional depression. The depression, carved in marine shallow water limestones of the late Hauterivian age, was caused by karstification, as a consequence of a tectonic phase, and is filled with laminated limestones, algal boundstones and oncolitic rudstones representing a few typical lacustrine facies (Tunis *et al.*, 1994). The great amount of the fossil bones of sauropods recovered so far shows that these dinosaurs came regularly to the margins of the lake that evidently supplied them with freshwater and supported vegetation cover: there are in fact probable remains of Equisetales within the lacustrine laminated limestones. Practically at the same time, large theropods and sauropods roved not far from the western margin of the Friuli Platform (Dalla Vecchia and Venturini, 1995; Dalla Vecchia, 1999a). Some probable dinosaur footprints of Barremian age have been found recently near the eastern edge (Iudrio valley, eastern Friuli) of this platform (research in progress).

So, there is evidence that wide emergent sectors of the platform by no means represented uninhabitable areas for dinosaurs.

Brackish and probably freshwater facies are also known from the upper part of the early Aptian succession on the northwestern margin of the Friuli Platform: some possible footprints impressed in marls with charophytes are found in the Bernadia Mountains (Fig. 2a, point 2) (Venturini 1995, Dalla Vecchia and Venturini 1996). Also in this case the footprints are co-eval to a long lasting phase of emersion documented by an Aptian *p.p.*-Albian *p.p.* hiatus as previously discussed.

Some studies on Istrian deposits of the late Cenomanian age, where the presence of footprint bearing layers has been documented (Lovrecica-S. Lorenzo di Daila, Karigador-Carigador, Grakalovac/Premantura-Promontore, Fenoliga-Sc. Felonega, see Figs 2b, 19a), are being in progress; other investigations on the Cenomanian emersion phases are being carried out at Mt. Sabotino, near Gorizia (NE Italy). The most puzzling problem to solve at the moment is represented by dinosaur survivors on the Adriatic-Dinaric Platform subsequently to the important transgressive phase at the Cenomanian-Turonian boundary (Gušič and Jelaska, 1993; see also Tentor *et al.*, 1994). Remains of *Hadrosaurus* (Tarlao, personal observation, and Dalla Vecchia, 1997) have been found close to the Villaggio del Pescatore (Fig. 2a, point 1) in a very localized intraplatform basin of the Santonian age (Tarlao *et al.*, 1994), and the finding of large dinosaur bones (Rimoli and Tarlao, personal communication; Debeljak *et al.*, 1999) within liburnian beds of the Maastrichtian age near Kozina (Fig. 2a, point 4), a few km east of Trieste, have been reported. A viable hypothesis is that land areas persisted at a noticeable distance from the Karst region and dinosaurs progressively recolonized this region during the 8 Ma time span between the early Turonian and the early Santonian.

Repeated subaerial exposures of the platform, sometimes marked by caliches and rhizoliths, have been recognized in the lower Senonian succession of the Karst area. An example of continentalization, which allowed the preservation of bones within brackish/freshwater deposits at the Villaggio del Pescatore site, is represented by a breccia bed on the exposed sides of the restricted basin; this breccia wedges out in a few tens of meters, passing laterally to a stylolitic surface. This stylolite suggests that locally it is very difficult to identify even very important continental phases.

Tectonic phases which gave rise to important hiatuses within the upper Cretaceous shallow water deposits and prevented the sedimentation of transgressive Turonian deposits, are well known in the Periadriatic platforms.

Bauxites encompass the whole Turonian time interval in the Murge region (Southern Italy) (Luperto Sinni and Reina, 1996). The *Calcare di Altamura* unit, where recently hundreds of dinosaur footprints were found (Sarti and Claps, personal communication), disconformably rests on the bauxites. As far as the Apulian Platform is concerned, the majority of authors agree that it has been separated from Africa since the middle Jurassic. Indeed, the more limited dimension of Apulia in comparison with the Adriatic-Dinaric platform generated true conditions of insularity, a paleogeographic feature confirmed by the small size of sauropod and theropod footprints.

The discovery of dinosaurs during the late Cretaceous on the Apulian Platform allows an interesting comparison with the Adriatic-Dinaric Platform and poses fundamental questions concerning paleogeography and dinosaur ecology.

The Hauterivian footprints of Sarone, Western Friuli (Fig. 2a, point 3), and those with large sauropod and theropod traces of the same age from the Istrian coast south of Rovinj (Fig. 19b, Cape Gustinja-Gustigna, Dalla Vecchia *et al.*, 2000), the Hauterivian-Barremian lacustrine deposits of Kolone, with bones of large sauropods and the dinosaur footprints of the Barremian age of Veli Brijun-Brioni Maggiore island (Pogledalo-Capo Salsa, Fig. 19b) represented by large tridactyl footprints would not indicate an insular domain for the different pre-Aptian settings, but rather a true continental area.

Under such circumstances, the search for footprint bearing layers of the early Cretaceous age would be promising on the Apulian Platform: integrated studies on faunal and floral continental assemblages would strongly improve our knowledge of paleogeography of the Tethyan realm during the Mesozoic.

We postulate that tectonics exerted a control on platform evolution and, consequently, on the time-space distribution of the dinosaurs. Relative movements of tectonic blocks and long lasting phases of emersion at a local or regional scale could be a controlling factor on vertebrate paleobiogeography; however we suggest the coexistence of eustatic cycles of Milankovich frequency to enhance or contrast the trends. Both these types of factors could be important for dinosaur distribution, in particular after the Aptian, when vertebrate faunas show "insular" characters (Dalla Vecchia and Tarlao, this volume). In an insular scenario, zones with differential subsidence could have generated islands distributed variously in time and space, thus permitting both the development of dinosaur populations and the deposition of a noticeable thickness of platform carbonates.

As far as eustasy is concerned, if we consider an average rate of platform subsidence around 3-6 cm/ka, the periodic oscillations of small amplitude (a few meters) of the sea level corresponding to the precession periodicity of the Earth (about 20 ka) may have caused the exposure of the platform at least through half of the time interval of the period: *i.e.* about 10 ka. Besides, the high accumulation rate of carbonates, especially if they are storm layers, rapidly took up most of the accomodation space.

In this way, it is possible that the Adriatic-Dinaric Platform was a terrestrial area for a large part of its evolution, thus creating the indispensable physiographic conditions for the survival of dinosaurs. However, climatic conditions were equally important, as large vertebrates could not live in arid and barren lands: a favourable humid climate was necessary to supply abundant freshwater and plants as food for the dinosaurs. If we take into account that the dinosaurs, the sauropods at least, were cold blooded animals and consequently of low trophic necessities, the constant and abundant supply of water was more important than food for them to survive.

Footprint bearing layers observed at the different late Albian sites imply that well vegetated, freshwater rich environments like those existing on modern oasis were not far away. Marls with charophytes both at Solaris and Puntizela-Puntisella document such settings, along with rhizolith layers associated with altered clasts at the same localities. This picturesque landscape of barren lands dotted with oasis is a bit immaginative because the common recognition of lacustrine-palustrine and brackish water facies, the scarcity of early diagenetic dolomites, the lack of evaporites and also the presence of bauxitic deposits of the Albian age in the southern Apennines would rather point to a relatively warm and humid climate (D'Argenio *et al.*, 1997). Humid-subhumid climate, even if seasonal or monsonic, may be also indicated by the presence of *Microcodium*, which is probably associated with rhizogenic structures of small-medium size. Some of the desiccation features, bioturbations and the reddened laminar micrites of Puntizela-Puntisella (outcrop II) are probably generated by root mats and therefore interpreted as paleosols (see also Galli, 1991). Unfortunately, information about vegetation on the Adriatic Dinaric Platform during the Cretaceous is really scanty (see Jungwirth, 1997). One of the most important and best preserved floral assemblages in the periadriatic Cretaceous platforms was discovered in the Julian Prealps, near Vernasso (Bozzi, 1891); in this site Senonian limestone contains conifers (among *which Sequoja, Frenelopsis, Araucaria*) and angiosperms (among which *Arundo, Rhus, Myrica*). This flora testifies that this platform, at least during the Senonian, had a local, but surprisingly rich, vegetation.

Periodic or episodic phases of relative sea level rise could have limited the living space for the terrestrial vertebrates allowing, at the same time, the best conditions for the fossilization of footprints. In these periods, dinosaurs walked either at the edge of vegetated areas or through the neighbouring wide tidal flats. A relatively large number of dinosaurs in humid palustrine environments gave rise to dinoturbated layers, whereas these large vertebrates (notwithstanding their durable and substantial presence) did not leave tracks during the long lasting exposures of the platform. Paradoxically, the probabilities of footprint fossilization were *minima* during the true long lasting exposures (those which had a duration from several hundred thousands to some millions of years); only eventual freshwater/brackish environments aided the preservation of dinosaur bones as the Hauterivian deposits at Kolone-P.to Colonne and the Santonian deposits at the Villaggio del Pescatore demonstrate. From a sedimentological point of view, one may expect the maximum probability of finding footprint bearing layers at the base of the transgressive phases (see also Dalla Vecchia and Venturini, 1996; Avanzini *et al.*, 1997), both of local or regional extent, driven by tectonics or by eustatic oscillations.

These assumptions seem to be confirmed by the study of the Puntizela-Puntisella and the Mirna-Quieto river mouth sections with the exception of the Solaris section.

Lastly, we propose a general model of fossil print preservation for all the track sites of Istria, including those of the Cenomanian age, that is based on the whole data set and on the knowledge of recent taphonomic processes. This model envisions a series of paleoenvironments from tidal to supratidal, with episodes of a very high sedimentation rate, interrupted by rapid subaerial exposures that occurred only for a limited time span. An ancient monsoon-like climate has been the best modern analogue that fulfils the requirements of sedimentological constraints and paleoecology. The hypothesis of a monsoon climate should be confirmed by the common finding of continental (lacustrine, brackish/palustrine) carbonate facies within the upper Jurassic-Cretaceous sequences of Istria and Friuli.

If our conclusions are correct, then the discovery of large vertebrate traces within the Tithonian succession of Istria, above the Kimmeridgian clayey bauxite horizon, should be possible, owing to the recurrent presence of tidal-flat facies and of freshwater floral assemblages. Also the Campanian-Maastrichtian succession of the Karst area is characterized by lacustrine, palustrine and brackish deposits, but, due to frequent long-lasting exposures, this stratigraphic interval seems more favourable for the finding of bones in paleokarst depressions than for the preservation of recognizable footprints.

CONCLUSIONS

Research on trampling episodes and on the taphonomy of dinosaur footprints is of great importance for the understanding of the evolution of the Periadriatic Carbonate Platforms and can provide useful links for paleoenvironmental, sedimentological and cyclostratigraphic analysis.

Frequently, tidal flats represent the ancient setting in which the dinosaur footprints were impressed. This environment, at first glance adverse to the survival of large vertebrates, turned out to be probably the most favourable one for the fossilization of footprints. Dinosaurs did not dwell permanently in such settings but only walked through the tidal flats along linear pathways (see Dalla Vecchia and Tarlao, this volume). During short, even local, subaerial exposures of the tidal flat, suitable moisture and the fine grain-size of sediments allowed the forming of footprints. Lack of footprints in a lagoon setting may be due both to the high degree of water saturation of the sediment and to severe bioturbation typical of a normal marine environment. Conversely, the dessication and cementation of sediments in sectors of the platform characterized by prolonged subaerial exposure prevented the recording of the presence of dinosaurs. The most favourable conditions for dinoturbation did occur in intermediate zones between terrestrial areas and tidal flats.

The formation of tracks at Puntizela-Puntisella and Lanterna came shortly before a transgressive phase marked by the transition from tidal flat to open lagoon. The sediments immediately overlying the footprint bearing layer at the Solaris site are ascribable to a schyzohaline lagoon. However, a precise correlation between printing episodes and transgressive phases does not appear; only in the Lanterna track site is the environmental change abrupt and can be traced immediately above the trampled surface.

By comparison with recent taphonomic processes, the rapid desiccation of the surface, very short subaerial exposure and very high accumulation rate of the capping sediments seem to be the most important factors for the quality of footprint preservation.

The morphological and sedimentological characters of the footprints indicate that these escaped erosion or further trampling by rapid burial, soon after their formation. This fact also confirms the postulated very high sedimentation rate of the carbonates at the scale of the single bed. A relatively prolonged subaerial exposure can cause the destruction of the footprints by physical reworking and by further dinosaur trampling, if the suitable moisture of substrate lasts.

The very high instantaneous sedimentation rate at the surface, if compared to the average rate of sediment accumulation during the late Albian in Istria, suggests that the time of actual carbonate deposition was much lower than the duration of the hiatuses.

Last but not least, the presence of dinosaurs themselves is an unequivocal proof of the significant subaerial exposures of vast areas of the platform, otherwise not recognizable by sedimentological studies alone. The presence of more or less significant hiatuses within the examined successions suggests the existence of tectonic movements, coexisting with short term sea level oscillations.

Tectonic phases favoured the formation of small intraplatform basins filled with fine terrigenous sediments and characterized by brackish freshwater faunal and floral assemblages. These assemblages consist, in particular, of stems and gyrogonites of Charophyta, micromolluscs and ostracods which are noticed for the first time in the Albian succession of Istria. Furthermore, these fossils prove the existence of freshwater sources, which was very important for dinosaur survival, on the Adriatic-Dinaric Platform.

Both the narrow suitable environmental zones and the delicate balance of factors needed for footprint fossilization make the finding of several sites with well preserved footprint bearing surfaces rather extraordinary. In terms of purely statistical speculation, this means that dinosaur populations were really substantial.

The insular character of the late Albian dinosaur population (see Dalla Vecchia and Tarlao, this volume) and the persistence of dinosaurs during the late Cretaceous both in Istria and Karst suggest that the examined tidal flats represented, for long time spans, the borders of vast lands inside the platform area. These "islands" were provided with enough fresh water and vegetation to substain a population of medium-size plant eaters. Conversely, evidences of large-sized sauropods and theropods in the Hauterivian, Barremian and Aptian of Istria and Friuli suggest that the Dinaric-Adriatic Platform and Africa were probably connected by a land bridge during the Early Cretaceous up to the Aptian, with the possibility therefore of repeated dinosaur colonizations.

In the case of both insular dinosaur populations and continental connections between the Adriatic-Dinaric Platform and Africa (or Europe) and the Middle East, it is necessary to reconsider, in the light of recent findings, current paleogeographic and palinspastic maps (see for example Dercourt *et al.*, 1993) that show the separation of the Apulian Platform from Africa occurred in the middle Jurassic. These maps show deep basins around the Periadriatic Platforms, and a wide marine domain on the platforms themselves; both these assumptions are inconsistent with recent vertebrate discoveries.

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