| GEOL. CROAT. | 46/1 | 25 - 40 | 9 Figs. | | | ZAGREB 1993 |
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UDC 551.35:551.763(450)

Original Scientific Paper

# The Platform Carbonates of Monte Jouf, Maniago, and the Cretaceous Stratigraphy of the Italian Carnian Prealps

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**Key Words:** Upper Cretaceous, Biostratigraphy, Sr-isotope chronology, Paleoenvironments, Adriatic Carbonate Platform

### Abstract

The Late Cretaceous strata of Monte Jouf are reasonably pure, white limestones, and are part of the stratigraphic unit known as Calcari del Monte Cavallo. M. Jouf is the original locality of two genera of rudists *Joufia* and *Colveraia*, which are used as biostratigraphic markers for shallow water carbonate facies in central-western Tethys. The limestone sequence has been subdivided into 4 units on the basis of facies and these have been dated using Sr-isotope chronology. This technique gives an independent age for the units and of the fossils as they occur on M. Jouf, and thus provides an accurate and precise timescale to present the evolution of the palaeoenvironment in this part of the Adriatic Carbonate Platform. Unit 1 is Late Cenomanian, as dated by the caprinid rudist *Caprinula boissyi*. Unit 2 ranges from the earliest to middle/late of the Campanian according to the Sr-isotope results. Unit 3 is Late Campanian to Campanian/Maastrichtian boundary, as dated by Sr-isotopes. Unit 4 is of earliest Maastrichtian age (placing the Campanian/Maastrichtian boundary at the extinction of the planktonic foraminifer *Globotruncana calcarata*). Two main epochs of broad, shallow carbonate platforms, covered by a diverse rudist fauna with large individuals, including recumbent forms are noted. The first of these was in the Late Cenomanian and the second in the latest Campanian. The Late Cenomanian event was ended by downfaulting of the platform margin, possibly preceded by a regression. Sediment wedges then began to build out again over the Late Cenomanian deposits, though in the interval Turonian-Santonian sediment by-passed the M. Jouf area. In the latest Campanian platform carbonate deposition was ended by a regression and by subsequent downfaulting in the Maastrichtian and Palaeocene.

## 1. INTRODUCTION

In the foothills of the Alps, as they rise abruptly from beneath the cover of the Venetian plain in northern Italy, there are several outcrops of Cretaceous limestones. These limestones, now forming the Carnian Prealps, were deposited on the north-western edge of the carbonate platform which includes the rocks exposed today on the Croatian coast. The westernmost part of the outcrop makes up the Monte Cavallo-

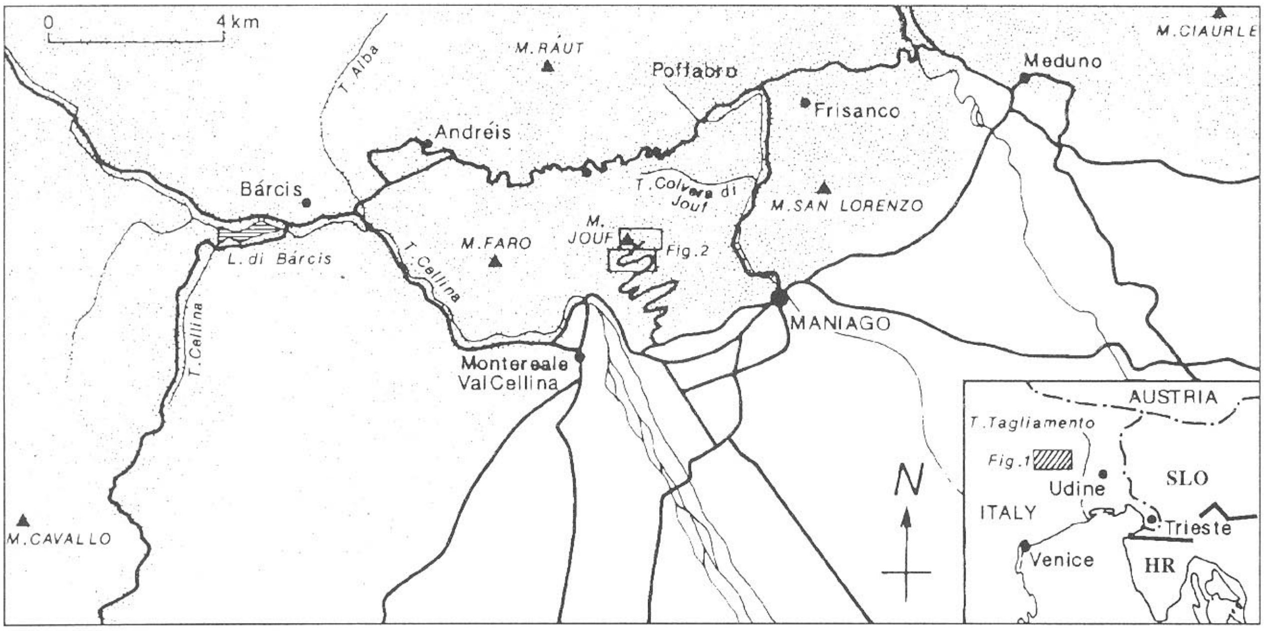


Fig. 1. Locality map of the M. Fara - M. Jouf - M. San Lorenzo massif with inset showing regional location.

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Cansiglio mountain range (Fig. 1). This is continuous with the M. Fara - M. Jouf - M. San Lorenzo massif which is the subject of this paper. To the east, and separated by an area of Tertiary rocks, is M. Ciaurlec as well as a few outcrops on M.Pala and M. Prat. East of these is the river Tagliamento which marks the boundary between the Carnian and Julian Alps.

The areas have much in common in structure and stratigraphy. The Cretaceous and Tertiary rocks are delimited to the north by the major Periadriatic overthrust (DAINELLI, 1921; ZENARI, 1929) which brings Jurassic and Triassic rocks southwards and marks the start of the Alps proper. The general form of the Cretaceous outcrops is exemplified by M. Jouf, which is an asymmetric, domal anticline with a gently sloping northern limb, folded sharply into a steeply-dipping, occasionally overturned, southern limb. The entire mass has also been thrust southwards (MARTINIS, 1979). To the north and east of M. Jouf, the structure closes in a synclinal basin. Here the Cretaceous limestones are overlain by Tertiary deposits, firstly red-grey marls, the so-called Scaglia Rossa, then dark-grey sandstones and siltstones, the Flysch, and finally by continental conglomerates (see column on Fig. 4).

The area is of particular interest because it was believed to be one one of the few places in Italy where the platform carbonates were still being deposited at the very end of the Cretaceous Period (PHILIP, 1985). Indeed, M. Jouf is known from the literature to be the type locality of two genera of rudist bivalves, *Joufia* and *Colveraia*, described at the turn of the century (BÖHM, 1898; KLINGHARDT, 1921), and conventionally regarded as Maastrichtian in age (SLADIĆ-TRIFUNOVIĆ, 1987).

This study is based on detailed logging of the Late Cretaceous carbonates exposed on the road sections on M. Jouf, a collection of the rudist faunas and dating of the sequence using strontium isotope chronology by N.H.M. Swinburne and mapping of the area at a scale of 1:5000 and broader study of the limestone stratigraphy and facies over the entire M. Fara - M. Jouf - M. San Lorenzo area by A. Noacco.

## 2. OUTCROP ON MONTE FARA, MONTE JOUF AND MONTE SAN LORENZO

The M. Fara - M. Jouf - M. San Lorenzo limestone massif has several sharply incised N/S valleys which potentially provide excellent exposure of the sequence, particularly of its lower parts (see Fig. 1 for location map). That of Val Cellina, to the west of M. Fara marks the western limit of this study. Val Cellina cuts a section roughly perpendicular to the SW-NE trending axis of the M. Fara part of the anticline. At the mouth of Val Cellina, on the road to Montereale Val Cellina, at Ravedis, there is an excellent view of the anticline structure with the tight folding in the anticline core and the assumption of the regular northerly dip of around

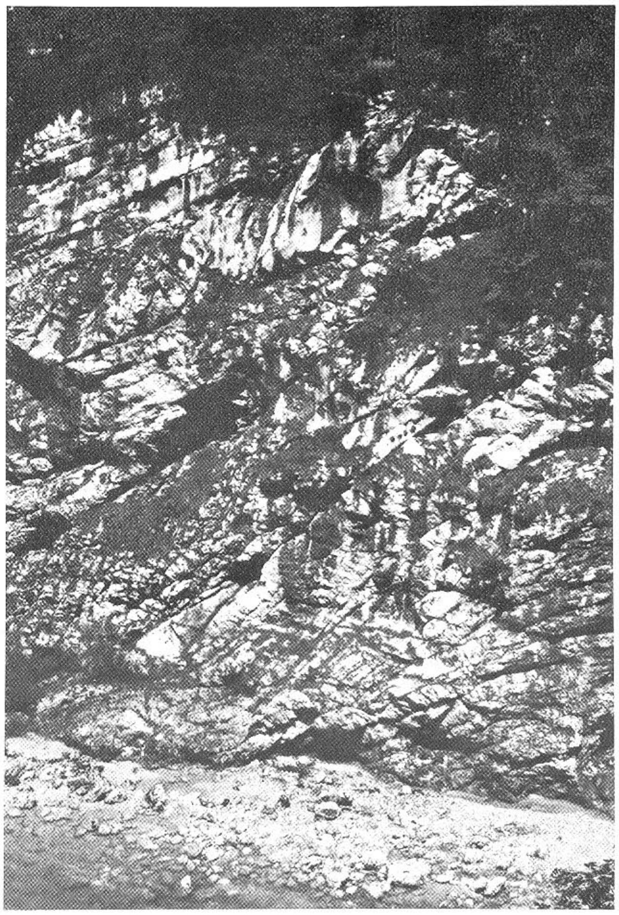


Fig. 2. Probable thrust complexes, or duplexes in southern Val Cellina.

25°, seen along the gorge to the north. However, the apparent simplicity is sometimes deceptive as there are undoubtedly several low-angled thrusts hidden amidst the seemingly homogeneous limestone sequence, noteably the duplexes visible in the southern part of the Val Cellina (Fig. 2). The Cretaceous limestones pass up into the Tertiary Scaglia Rossa and then Flysch in the core of the Barcis-Andreis syncline north of the junction between the Torrente Cellina and the Torrente Alba. The Cretaceous limestone then reoccurs in a thin fault slice, north of Lake Barcis.

M. Jouf is bordered to the east by Val Colvera which separates it from M. San Lorenzo. Parts of M. San Lorenzo are intensely fractured and these zones have been quarried to such an extent that the mountain summit has been partly removed. From the exposures in these quarries MARTINIS (1979) has shown that there may be a thrust fault at the base of the anticline on its southern side, located mainly along the junction between the Cretaceous limestones and the Scaglia Rossa.

The upper parts of the Cretaceous limestone sequence are best seen on M. Jouf itself (Figs. 3 & 4). Exposure is available along a track some 20 years old, which leads from Maniago to the summit, and a road which leads north from the summit down to the pass at Pala Barzana which was under construction at the time of this study and gave excellent fresh exposure. The

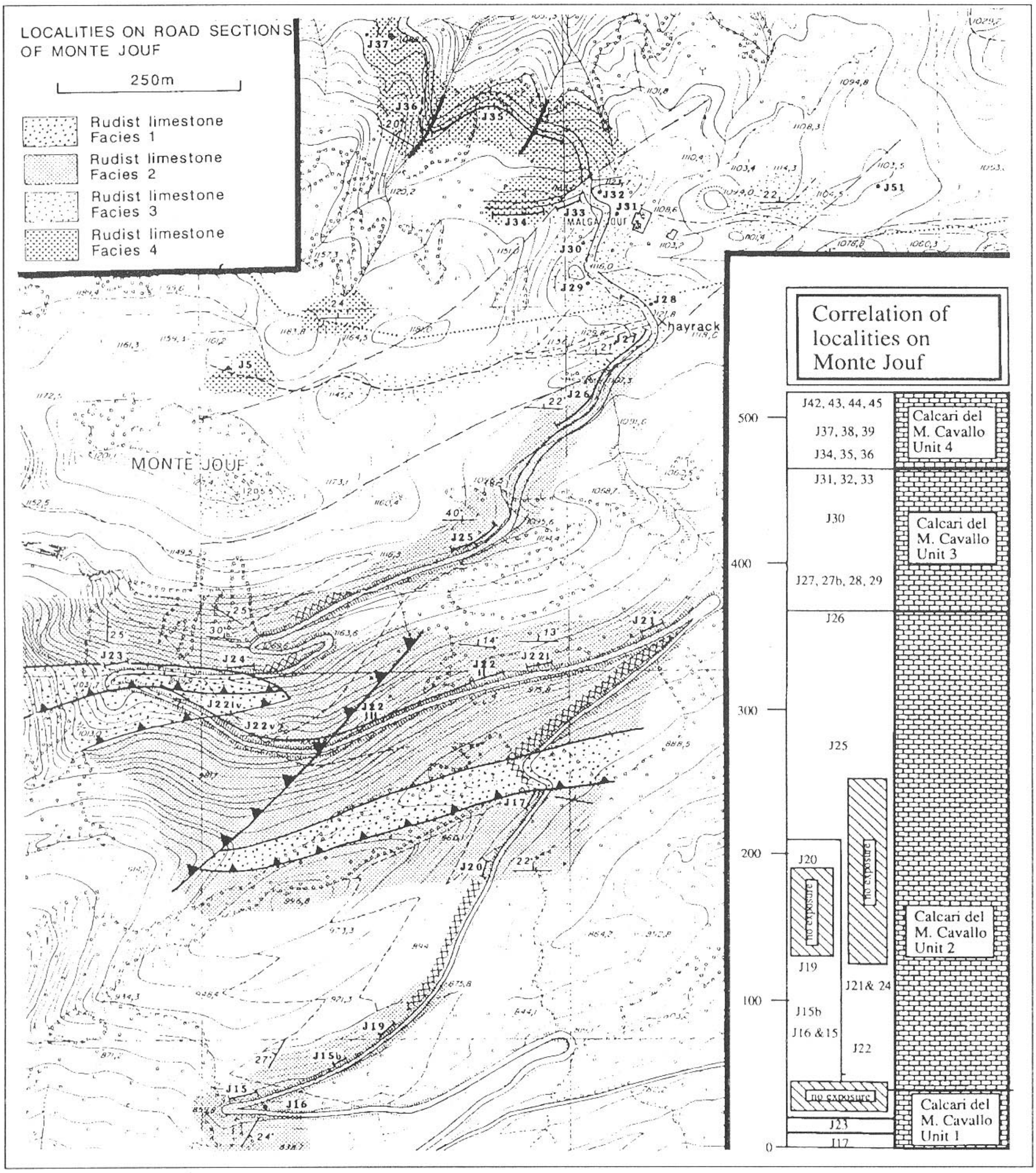



Fig. 3. Locality map of the road sections of M.Jouf showing the position of the unit boundaries and major faults and their proposed stratigraphic correlation.

southern side of the anticline is generally patchily exposed and outcrops are difficult to correlate. It is also more faulted that the northern side and two main trends can be detected: a N-S subvertical set and an E-W set with northerly dipping component. The northern part of the anticline, which begins about half way up the southern side of the mountain, is easier to study although there are still some areas of non-exposure and occasional tilted blocks. Outcrop along the northern road is extensive but as the road runs approximately parallel to bedding the oucrop is of limited stratigraphic extent. The northern limb is also cut by small N-S faults, probably of little throw.

## 2.1. PREVIOUS WORK

The sequence of Val Cellina has been the focus of previous attention to this limestone massif. Most important are the works of ZENARI (1929), who compiled the first major geological map of the Maniago area, FERASIN (1958), CUVILLIER et al. (1968), GNACCOLINI & MATTAVELLI (1969), SALVINI (1969),

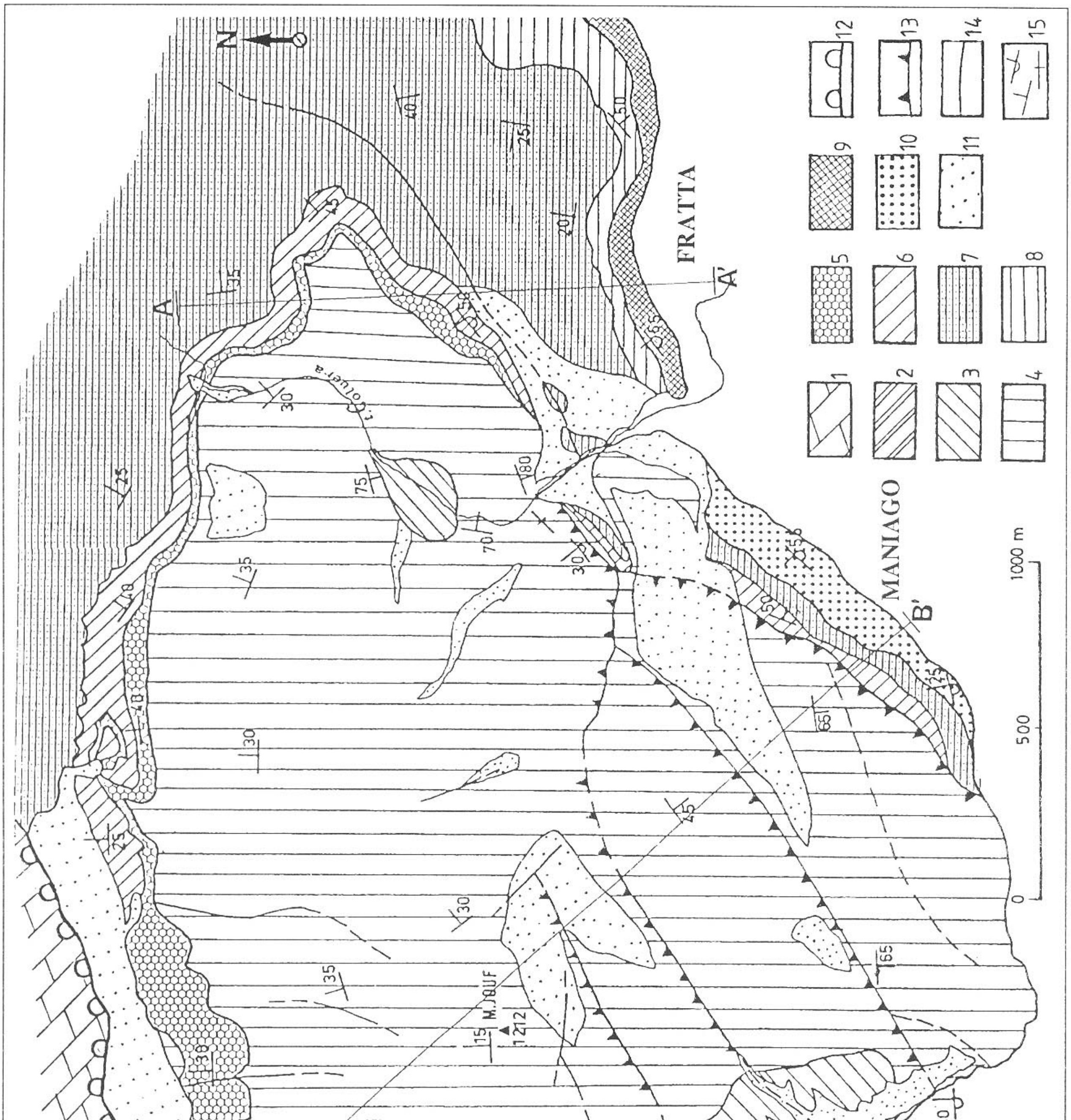
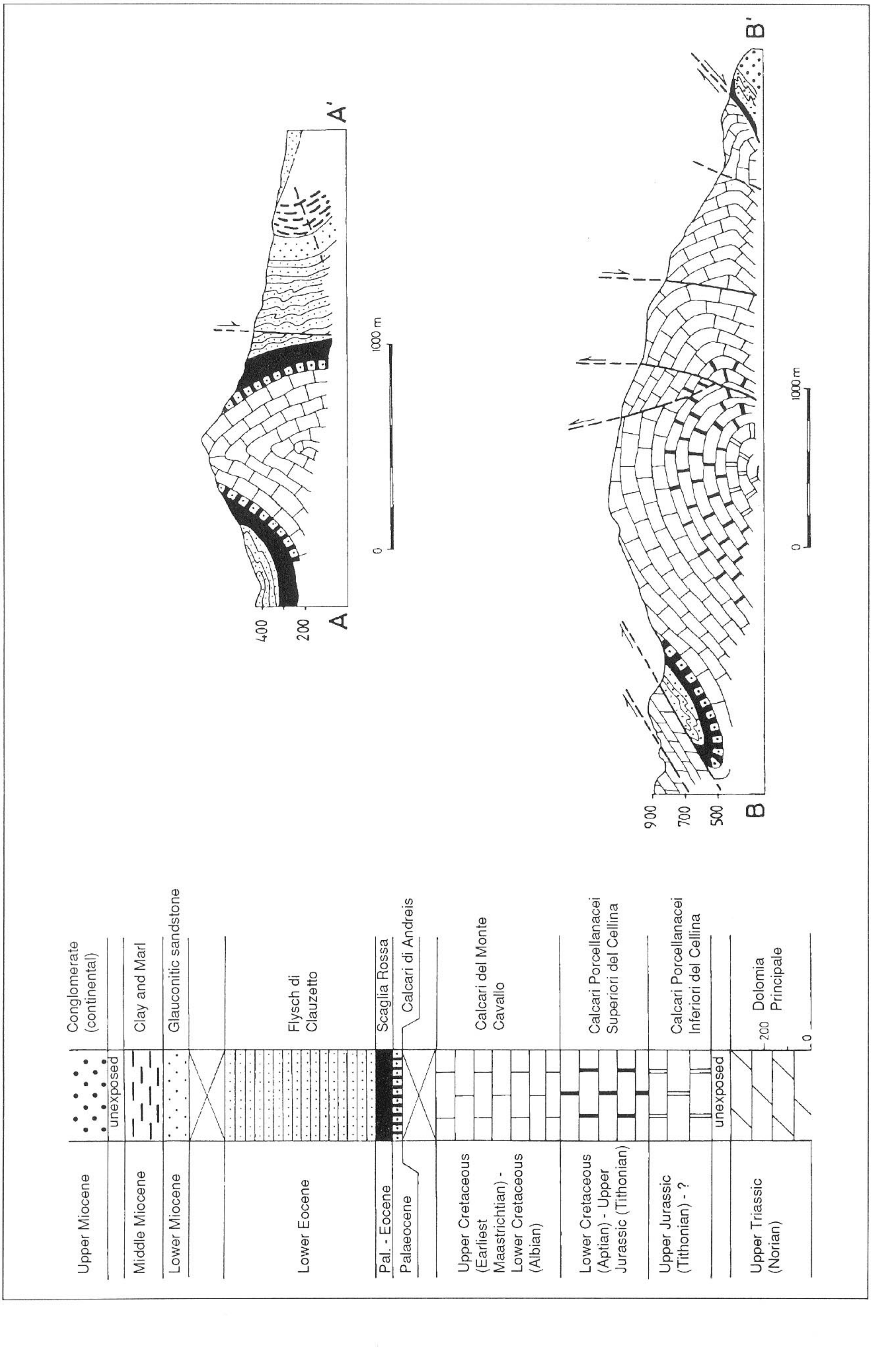



Fig. 4. Geological map, stratigraphic column and cross sections of the M. Jouf area..
1 - Dolomia Principale (Norian); 2 - Calcari Porcellanacei Inferiori del Cellina (Tithonian); 3 - Calcari Porcellanacei Superiori del Cellina (Tithonian - Aptian); 4 - Calcari del Monte Cavallo (Albian - Earliest Maastrichtian); 5 - Calcari di Andreis (Upper Palaeocene); 6 - Scaglia Rossa (Upper Palaeocene - Lower Eocene); 7 - Flysch di Clauzetto (Lower Eocene); 8 -Sand and glauconitic sandstone (Lower Miocene, Langhian); 9 - Marl and clay (Middle Miocene, Serravallian); 10 - Continental conglomerate (Upper Miocene, Messinian); 11 - Quaternary; 12 - Overthrust; 13 - Reverse fault; 14 - Fault or fracture; 15 - Strike and dip of strata.


Upper Miocene
Middle Miocene
Lower Miocene
Lower Eocene
Pal. - Eocene
Palaeocene
Upper Cretaceous (Earliest Maastrichtian) - Lower Cretaceous (Albian)
Lower Cretaceous (Aptian) - Upper Jurassic (Tithonian)
Upper Jurassic (Tithonian) - ?
Upper Triassic (Norian)
unexposed
unexposed
200
0
Conglomerate (continental)
Clay and Marl
Glauconitic sandstone
Flysch di Clauzetto
Scaglia Rossa
Calcari di Andreis
Calcari del Monte Cavallo
Calcari Porcellanacei Superiori del Cellina
Calcari Porcellanacei Inferiori del Cellina
Dolomia Principale
A
A'
400
200
0
1000 m
B
B'
900
700
500
0
1000 m

and more recently GHETTI,1986 and NOACCO,1987. Recent work on M. Jouf is restricted to the study of SAINT-MARC (1963) who recorded the sucession from Ravedis, via Val di San Antonio and finishing at Pala Barzana. NOACCO (1987) presents the first major published account of the Val Colvera sequence. There are also several papers concentrating on the tectonic structure of this zone such as DAINELLI (1921), MARTINIS (1966, 1979) and ZANFERRARI (1973, 1974). Previous descriptions of the Late Cretaceous rudist fauna of the Carnian Prealps can be found in PIRONA (1877, 1884), TELLINI (1892), BÖHM (1894, 1897, 1898), ZENARI (1920) and KLINGHARDT (1921).

## 3. STRATIGRAPHIC UNITS

The limestone has traditionally been divided into three formations called the Calcari del Cellina (Oxfordian - Aptian), Calcari del Monte Cavallo (?Albian - Campanian/Maastrichtian) and the Calcari di Andreis (U. Palaeocene). These names were never formally defined but were used in the geological surveys of the area by AGIP (AGIP, 1959) and have been adopted by subsequent authors. In this paper we divide the Calcari del Monte Cavallo, as it outcrops on M. Jouf, into 4 subunits: Unit 1, Late Cenomanian; Unit 2, early-middle Campanian; Unit 3, middle Campanian-uppermost Campanian; Unit 4, uppermost Campanian. The units have been dated using both the available biostratigraphic indicators of benthic foraminifera and rudist bivalves and also the Sr-isotopes preserved in the rudist shells (for details, see Fig. 5). Figure 3 shows the location of the unit boundaries on the road sections of M. Jouf and the locality numbers referred to in the text. Figure 4 is a geological map of the M. Jouf and its surroundings.

### 3.1. CALCARI DEL CELLINA

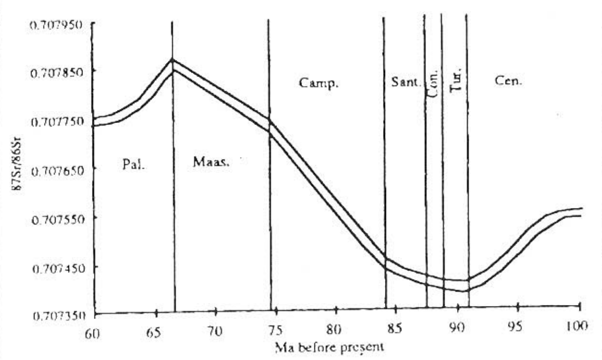
The Calcari del Cellina, which ranges only into the early Cretaceous is beyond the scope of this discussion and the reader is referred to the works of CUVILLIER et al. (1968) and MASSE & SENTENAC (1987). In general these sediments are characteristic of extremely shallow water and have numerous palaeosol horizons indicating emergence. They also differ from those of the overlying formation in being poorer in macrofossils, notably rudist bivalves.

### 3.2. CALCARI DEL MONTE CAVALLO

The base of the Calcari del M. Cavallo is not visible on M. Jouf, where the earliest rocks belong to the Late Cenomanian. In Val Cellina, the lowest subdivision of this unit was considered Albian-Cenomanian by CUVILLIER et al. (1968) and by SAINT-MARC (1963). However, studies on M. Cavallo-Cansiglio revealed a major lacuna between deposits of Albian age and those of Late Cenomanian (SARTORIO, 1987) and from Albian to Early Campanian (MASSE & SENTENAC, 1987).

The outcrop of the base of the Calcari del Monte Cavallo in Val Colvera (near to the 2.2 km sign) is

A




B

| 87/86 Sr | Terms used in this paper | Boreal belemnite stratigraphy | Tethyan planktonic foraminiferal stratigraphy |
|---|---|---|---|
| | lower Maastrichtian | Lower Maastrichtian | lower Maastrichtian |
| 0.7077 | upper Campanian | Upper Campanian | Campanian |
| 0.7076 | middle Campanian | | |
| 0.7075 | lower Campanian | Lower Campanian | Santonian ? |
| | Santonian | | |

C

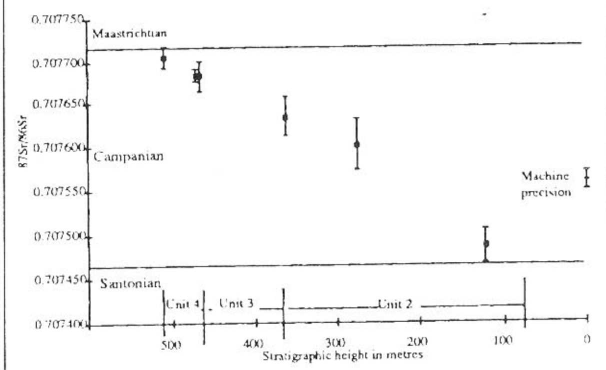



Fig. 5. Dating of certain rudist horizons using Sr-isotope chronology. This relies on a comparison of the $^{87}Sr/^{86}Sr$ ratio preserved in a shell of unknown age to a standard graph of $^{87/86}Sr$ change for this period. Figure 5a shows the general pattern of change in $^{87/86}Sr$ against time for the Late Cretaceous (data from KOEPNICK et al., 1985 (plotted in BURKE et al., 1982; HESS et al., 1986; SWINBURNE, 1990). In compiling this "standard graph" it became clear that the Campanian/Maastrichtian boundary in most common useage for Tethyan studies was the extinction of *G. calcarata* but that was a level lower than that at the base of the Boreal type sequences defined by the first appearance of *B. lanceolata*. This study uses the boundaries of the zones as defined using the planktonic foraminiferal biostratigraphy and subdivides the Campanian stage into an early, middle and late zone (Figure 5b) of equal durations. Figure 5c shows the variation in $^{87}Sr/^{86}Sr$ with stratigraphic height for the M. Jouf sequence. Error bars on the points show the twice the standard error on analyses of different samples from that stratigraphic level. Value for the NBS-987 standard over the course of this study (used for comparison of different datasets) = 0.710230 (1 std. dev.).

described by NOACCO (1987). There are abundant small, pipe-like, bouquet-forming radiolitids in bioherms orientated at a either slight angle to bedding, or lying horizontally. These are interbedded with white limestones containing caprinid debris, palaeosols and intraformational conglomerates some 70 cm thick, particularly concentrated near the top of this interval. The rudist beds are overlain by some 12 m of grey and pink non-fossiliferous dolomitised micrites and followed by the conglomerates.

### 3.2.1. Unit 1: Late Cenomanian

The top of the unit described from Val Colvera has a small exposure on M. Jouf in the anticline core, where it was studied in greater detail. At 930 m (J17) there are many small thin-walled, dark brown reqieniids as well as radiolitids. The sediments are pel- and forambiomicrites or sparites mostly packstones-grainstones containing textulariids and miliolines in varying proportions. There is also some wackestone with rotalines and sponge spicules. Sometimes the sediment is a gravel

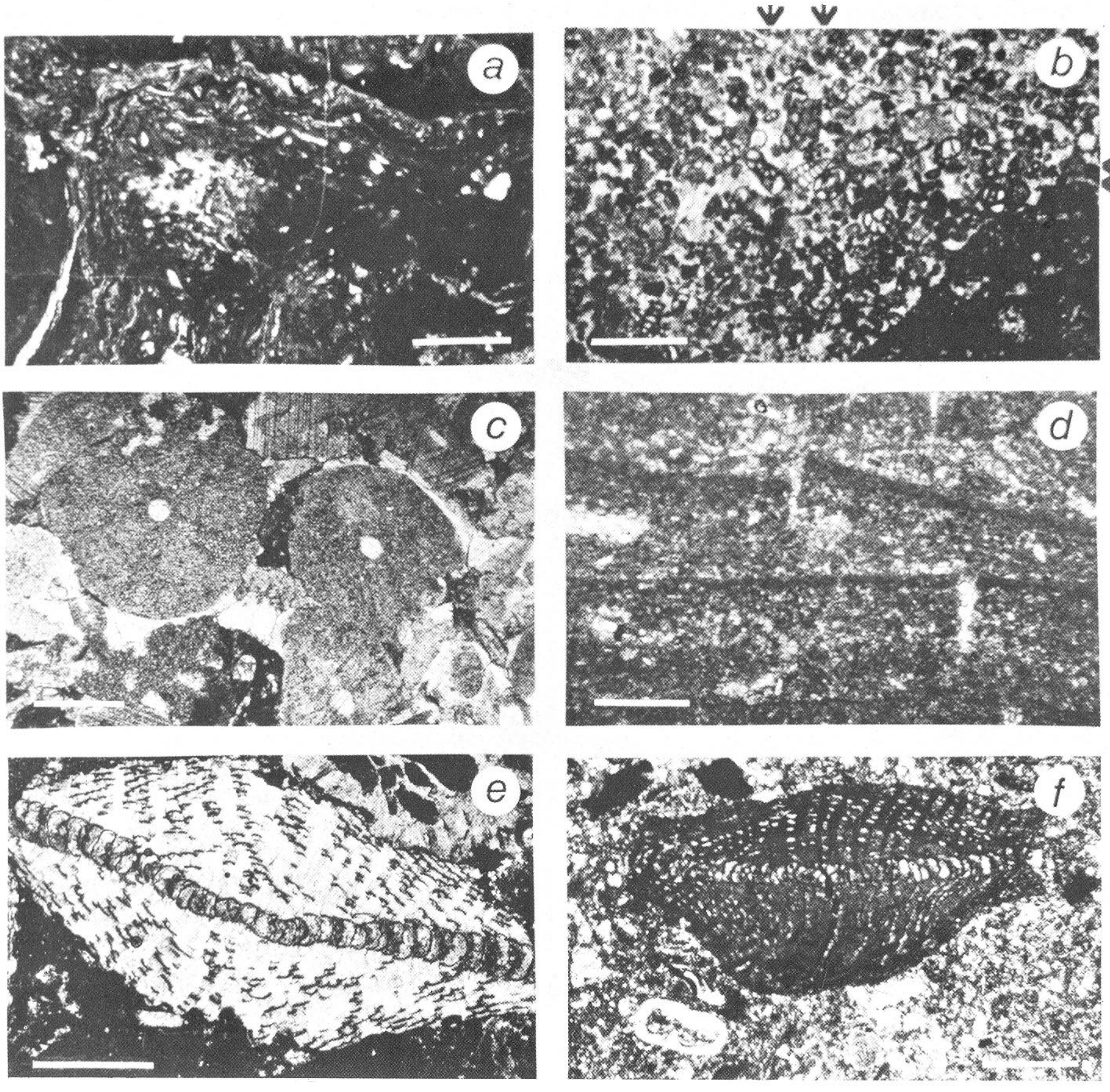



Fig. 6. Photos of microfacies. Scale bar = 1mm.
a) J 22iv, base unit 2: Swirling clayey texture of palaeosol.
b) J15, unit 2: Foraminiferal (textulariid) grainstone with sparitic matrix (possibly a result of neomorphism). Two examples of *Montcharmontia apenninica* as indicated by arrows in upper middle of picture, either side of biserial form.
c) J 35B, unit 4: Grainstone made almost entirely of echinoderm plates.
d) J 39, unit 4: Algal mat with desiccation cracks (cross polars).
e) J 55, unit 4 (Monte San Lorenzo): Specimen of *Orbitoides* along with spine of the rudist *Pseudopolyconites*.
f) J 40C, Top of Calcari di Andreis: Bed of reworked Cretaceous foraminifera such as this specimen of *Orbitoides* sp. together with Tertiary forms.

made of intraclasts of different varieties of these facies. The environment represented seems to be of a frequently disturbed inner shelf where reworking is common in shallow water.

The age of this outcrop is well constrained from the foraminifera. The following genera and species were noted: ?*Nezzazata simplex* OMARA, *Trochospira avnimelechi* HAMAOUI & SAINT-MARC, *Pseudolituonella* aff. *reicheli* MARIE, *Rotalia* aff. *mesogeensis* TRONCHETTI, *Nezzazatinella* sp. and *Cuneolina* sp., which strongly suggest a Cenomanian age, and probably Late Cenomanian (SCHROEDER & NEUMANN, 1985; BILOTTE, 1984a, 1984b, 1985) for the unit as exposed on M. Jouf.

An isolated outcrop slightly higher on the mountain, at 1020-1035 m, (J22iv & 23) is thought to be the same age, though it is of different facies. The outcrop is discordant to general bedding, and is probably a thrust slice from near the core of the anticline. At J23 the limestone is chalky-white and contains a large caprinid, *Caprinula boissyi* d'ORBIGNY and a radiolitid, probably *Radiolites*. Specimens of the caprinid lie with their growth axes parallel to bedding in a sediment probably similar to that in which they lived. This is an intraclastal gravel of forambiomicrite wackestones and packstones, rich in miliolines and also containing dasycladacean algae and gastropods. The immediately overlying beds contain caprinid debris and palaesol horizons. At the adjacent outcrop of J22 iv there are a few very well developed palaeosol horizons about 20 cm in thickness and irregularly discordant to the general bedding direction. These contain variegated clayey intraclasts in a white clayey matrix. In section the clasts show laminoid fenestrae with geopetal fills, fragments of dasycladacean algae, coated echinoderm plates and ostracods with fringing cements (Fig. 6 a). The matrix is sometimes rich in ostracod shells. All indications are of a very shallow water shoal environment of the middle platform, which periodically emerged.

*C. boissyi* was recorded by KLINGHARDT (1921) from M. Jouf. The same species is also known from other places in Yugoslavia and Italy (see illustration in IANNONE & LAVIANO, 1980, and references therein) from strata assigned ages ranging from Cenomanian to Middle Turonian although the Turonian dates are now considered less reliable (MASSE & PHILIP, 1986).

### 3.2.2. Unit 2: Earliest Campanian - Middle/Late Campanian

This unit includes rocks exposed south of the anticline core at heights 850-890 m (J16, 15, 15b and 19) as well as the beds on the northern side of the core, from 970-1110 m (J22i, ii, iii, v, 24, 25 & J26). South of the anticline core the limestone is well-bedded (0.5-1 m thick). The beds are mainly biostromes and debris beds and more rarely, bioherms, of small pipe-like radiolitids, probably *Bournonia* and *Medeella* and rarer *Katzeria*. The rudists, which can not easily be separated from the limestone sediment are best observed on weathered blocks where they may be iron-stained (as are the larger milioline foraminifers) and stand out from the sediment. The sediments have varying proportions of rudist debris and are forampelmicrite, packstones-grainstones (with prominent miliolines), and biosparite grainstones (with well preserved textulariids, Fig. 6 b). Rarely there are horizons with fenestrae or large dolomite-filled vugs and these beds may also contain planktonic forams. This shows that even parts of the platform under such shallow water still received sporadic pelagic sedimentation. The radiolitids must have been growing in small thickets of the low energy inner platform and have merely been knocked over and scarcely transported.

North of the anticline core, the corresponding beds are slightly different in lithology and represent shallower conditions. The lowest unit is whitish in colour and an intraclastal gravel of pelsparite and pelmicrite grainstone-packstone (the peloids are probably mostly micritised foraminifers). It contains gastropods and various bivalves, long lamellar rudist fragments as well as some entire specimens of *Durania* sp. and a small and a large species of hippuritid.

There then follow beds similar to those at J15, 16, with biostromes and debris beds (J22iii) and from there on (J22ii, 22i, 21, 24, 25, 26) the sequence shows progressively fewer rudist-rich beds and the beds thin to an average of 0.5 m or less. The most abundant sediment is a forambiomicrite packstone-grainstone with textularids and prominent miliolines. Algal laminites made of an interlamination of pelbiosparite grainstone and wackstone, which includes some planktonic foraminifera, become more common. The beds are frequently divided by stylolites. At the top of this unit (J25) there are also very flat beds with birdseyes and pink dolomitised horizons. These facies are cyclical in nature and

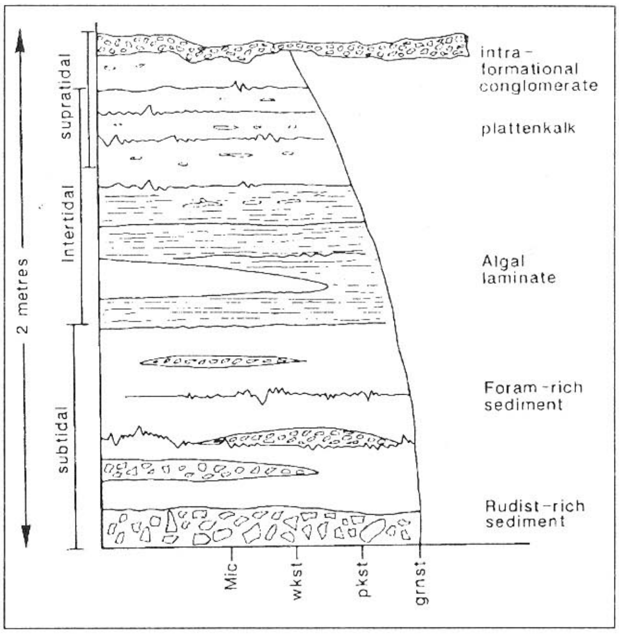



Fig. 7. A typical transgression-regression cycle from the top of unit 2.

finish with intraformational conglomerate which marks the completion of a minor marine regression (Fig. 7). A small radiolitid appears at the top of unit 4. It has several irregular projections, a relatively thin wall, no ligamentary invagination and therefore was either a species of *Bournonia*, or of *Biradiolites* .

The age of this unit is not well constrained from the biostratigraphy. The hippuritid, from J22v gives the best evidence for the age of the base of the unit. Sections of the two specimens are undoubtedly similar to that figured by Pleničar as *Vaccinites* aff.*giganteus* d'HOMBRES-FIRMAS from the Coniacian-Santonian of M. Nanos, Slovenia (PLENIČAR, 1975), although that figure does not resemble the original description. Incidently another specimen *V.* aff. *giganteus* was found on the south shore of Lake Barcis on the new road to Cansiglio (Val Caltea). Several other large hippuritids have also been noted from this locality (SAINT-MARC, 1963; GHETTI, 1986). The specimens of *Katzeria* are also of some help in biostratigraphy. This genus is known from the Karst of the Dinarides, mostly from beds of Senonian (i.e. Coniacian-Maastrichtian) age (PLENIČAR, 1973, 1974).

Beds south of the anticline core also yielded the foraminifera: *Montcharmontia apenninica* (DE CASTRO) and *Cuneolina* aff. *pavonia* d'ORBIGNY which suggest an age Santonian-Campanian. The dates from the foraminifera at J22iii, near the base of this unit, but north of the core, are vaguer with aff. *Stensiöina surrentina* TORRE, and aff. *Abrardia mosae* (HOFKER), suggesting Campanian - Maastrichtian.

The Sr-isotope measurement on the *Vaccinites* at 22v gave an ill-defined age of earliest Campanian (Fig. 5), though specimens from Val Caltea, which were better preserved, gave well constrained dates in the middle of the Campanian. *Katzeria* made suitable material for Sr-isotope dating and gave an age of early Campanian. The numerous measurements on samples at J25 & J26 give a precise age for the top of the unit in the middle/late Campanian.

### 3.2.3. Unit 3: middle/late Campanian - Campanian/Maastrichtian boundary

The change in facies at 1110 m (between J26 & J27) is marked by the reappearance of densely-packed rudist biostromes, which are more thickly bedded (1-3 m). In these, one species predominates, the small radiolitid with two prominent wings *Bournonia excavata* d'ORBIGNY. *B. excavata* replaces a very similar radiolitid present at the top of the previous unit. The boundary between the two units is marked by a small fault on the road.

*B. excavata* occurs in biostromes and debris beds and fragments constitute a major proportion of the sediment. In some beds it is accompanied by a small species of the genus *Pseudopolyconites*, mostly broken and sometimes only represented by numerous spines. The sediment is a pelbiosparite or forambiosparite grainstone with well preserved textulariids and miliolines, though when the pellets have been pressed together and degraded the sediment may resemble a biomicrite wackestone. Dasycladacean algae are fairly common in this facies. There are irregular calcite-filled vugs and dolomitization is extensive. This all indicates a shallow environment, generally subtidal and well oxygenerated, in shoals such as might exist in moderate energy environments of the middle platform.

*B. excavata* is of mild biostratigraphic use as it is recorded from the Santonian - Maastrichtian of Croatia (POLŠAK & MAMUŽIĆ, 1969). Most species of *Pseudopolyconites* are regarded as Maastrichtian in the Dinarides but one species may extend down into the Coniacian (PEJOVIĆ & SLADIĆ-TRIFUNOVIĆ, 1977). The foraminifera are again less diagnostic with *Cuneolina* sp. (?*C. pavonia-parva* HENSON), aff. *Stensiöina surrentina*, *Tetraminouxia* aff. *gibbosa* GENDROT and *Moncharmontia apenninica* which collectively indicate Coniacian-Campanian.

### 3.2.4. Unit 4: Campanian/Maastrichtian boundary - earliest Maastrichtian

The junction of units 3 and 4 is marked by an intraformational conglomerate and about a metre of deposits which record a rapid deepening of the water (Fig. 7). Unit 4 is widely exposed on the northern side of M. Jouf and contains a numerous and diverse fauna of large radiolitids: *Joufia reticulata* BÖHM, *Colveraia variabilis* KLINGHARDT, *Pseudolpolyconites* sp. 2, the smaller radiolitids *Sauvagesia* sp. and *Katzeria* (which is almost certainly a radiolitid, despite its acellular appearance); hippuritids: *Pironaea polystyla* PIRONA and *Hippurites lapeirousei* GOLDFUSS; as well as the enigmatic canaliculate recumbent rudist *"Sabinia" aniensis* PARONA (spelt *anienis* by Parona, though mis-spelt by subsequent authors as *aniensis*), the Plagioptychid (sensu SKELTON, 1978) *Plagioptychus* sp. and requieniid *Apricardia* sp. Where the rock is not intensively fractured it breaks into cobbles or boulders, the bedding is difficult to see but the fauna is readily collectable. The sediments are grainstones with some packstones and are generally coarser than previous unit, sometimes reaching rudite grade. They are made of rudist fragments, echinoderm plates, micritised orbitoids with rare planktonic foraminifera. The environment represented must have been one in fairly turbulent waters at the shelf edge.

There is some noticeable variation inside the unit which is lateral as much as vertical, although this is difficult to assess given the nature of the outcrop. A unit of coarse grainstone made almost entirely from echinoderm plates overlies the lowest beds of rudist limestone (Fig. 6 c). The bed, which probably wedges out laterally, and is not more than 5-10m thick, represents a shallow shoal. The middle of the unit is also barren of macrofauna; bedding is well developed and the sediments are predominantly intertidal laminated pelmicrite packstones-wackstones with some desiccation cracks

(Fig. 6 d). The friable appearance of some outcrops also suggests some carbonate dissolution, probably penecontemporaneous. After this interval the rudist limestones reappear and these are cut by several horizons of laminated greeny clay. These are also probably penecontemporaneous as in section the lamination can be seen to follow original lithological changes.

Exposures at the top of the sequence as the road nears the pass of Pala Barzana contain some noteworthy biostromes. There is a large thicket of the small bouquet-forming hippuritid, *H. lapeirousei,* embedded in a muddy sediment. Adjacent to the hippuritids were found several individuals of a large species of *Pseudopolyconites*, in life position, and surrounded by halos of spines which nearly interlocked. Each spine is about 1mm in external diameter and curves downwards after exiting the shell (Fig. 6 e). The same bed also had specimens of *Sabinia anienis* lying flat, parallel to the bedding, and some disarticulated and sometimes broken valves of *Joufia*. The co-occurrence of *Pseudopolyconites* with its hairy spines which best served to baffle sediment, together with the stable shape of the recumbent *Sabinia* is significant. It confirms suggestions of SKELTON & GILI (in press) that both had adopted strategies for maximum stability which allowed them to live in shoal areas washed by currents.

The exposures on northern M. Jouf near Pala Barzana are, as already indicated, quite new and the rudists described by other authors come from other localities. Böhm first described the genus *Joufia* from the top part of two free valves which he collected after a walk across the top of M. Jouf (BÖHM, 1898). KLINGHARDT (1921) collected a much larger amount of material (13 large chests to be precise!) and from these specimens amended and added to Böhm's description of *Joufia* and named the genus *Colveraia*. We located Klinghardt's original locality which is a disused quarry, on the Torrente Colvera di Jouf (see Fig. 1). Beds dip steeply downwards at this location and the quarry is filled with loose blocks from all horizons in units 3 and 4.

As regards the age of the uppermost unit of the platform carbonates, it contains many genera of rudists (*Joufia, Colveraia, Sabinia, Pironaea, Pseudopolyconites*), which have traditionally been regarded as Maastrichtian. This age assignment is traced ultimately to the work of MILOVANOVIĆ (1934, 1960) from eastern Serbia where the uppermost beds of platform carbonate, which also contained *Pironaea* were collectively termed Maastrichtian. They were then subdivided into three zones of purported early, middle and late Maastrichtian according to the supposed evolutionary development of *Pironaea*. Thus *Pironaea*, and the cooccuring rudist genera, gained a reputation as Maastrichtian (SLADIĆ-TRIFUNOVIĆ, 1972, 1980, 1981, 1983, 1987). The *Pironaea* from M. Jouf, called *P. polystyla forojuliensis* by Klinghardt, under that scheme would be Middle Maastrichtian in age. The scheme has now been shown to be invalid outside the eastern Serbian-Bulgarian area (SWINBURNE et al., 1992). *Pironaea* and the co-occuring fauna of *Joufia - Colveraia - Sabinia - Pseudopolyconites* have been shown to have a total age range of early Campanian-middle Maastrichtian.

There were a few recognisable foraminifera from this unit on M. Jouf: aff. *Reticulinella* cf. *reicheli* (CUVILLIER et al.), *Moncharmontia apennica*, but most usefully, *Siderolites* cf. *vidali* according to WANNIER (1983) and NEUMANN (1985), a Campanian species. However, recognisable orbitoids are more abundant and better preserved in this unit as it outcrops on M. San Lorenzo. The unit there contains the same rudists, albeit in smaller numbers, and is probably of slightly more open marine facies. Species of *Orbitoides* (?*O. tissoti* SCHLUMBERGER), *Siderolites, Lepitorbitoides* and the smaller benthic *Goupillaudina* were present and these indicate a Campanian-Maastrichtian age, probably Campanian. SAINT-MARC (1963) cites *Orbitoides media* (d'ARCHIAC), *Siplorbites* sp., *Lepidorbitoides* sp. and *Siderolites calcitrapoides* LAMARCK from this unit on M. Jouf, the latter generally regarded as Maastrichtian in age (WANNIER, 1983; BILOTTE, 1984a).

There was an abundance of suitable material for Sr-dating (Fig. 5). The bottom of the facies thus gave a date at the planktonic foraminiferal Campanian/Maastrichtian boundary and the top in the earliest Maastrichtian. The top of a unit with very similar assemblage from M. Nanos, Slovenia, was also dated in the earliest Maastrichtian.

### 3.3. CALCARI DI ANDREIS: LATE PALAEOCENE

This unit is of interest to the present discussion in consideration of the extent of the stratigraphic gap between the last beds of platform carbonate, and the overlying sediments. This lacuna is significant in the information it yields about the evolution of the environment in this area between the Mesozoic and Cainozoic eras. On the road section of M. Jouf, the uppermost unit of Cretaceous limestone ends with a shattered zone which is one of the well-marked N-S faults, and is followed by around 100 m of the breccia of the Calcari di Andreis. This megabreccia is made of beds of limestone blocks, sometimes graded. The blocks may be quite well rounded and vary in size in different beds from boulders of over a metre in diameter to small pebbles. The lithologies are representative of all the limestone facies exposed on M. Jouf with those of unit 4 predominating at the base of the unit. Matrix, when present, is a greeny clay. There are also prominent palaeokarst horizons irregularly dissecting the beds and blocks.

The unit has yielded fragments of foraminifera of both Cretaceous and Tertiary age. Some of the Tertiary forms, such as *Miscellanea miscella* D'ARCHIAC and *Discocyclina* were found at the very base of the unit and this constrains the start of limestone deposition in the Calcari di Andreis to the Palaeocene (and according to CUVILLIER et al., 1968, to the Late Palaeocene). The occurence of one of the Cretaceous forms *Hellenocyclina beotica* REICHEL is particularly significant. *H. beotica* is indicative of the end of the Maastrichtian in the Pyrenees (BILOTTE, 1984a; BIGNOT & NEUMANN, 1991) and suggests the deposition of a younger unit, not encountered on M. Jouf.

At the top of the breccia at Pala Barzana in the transition to the Scaglia Rossa is a bed of excellently preserved foraminiferal grainstone composed both of Tertiary forms (*Nummulites, Miscellanea miscella*) and reworked Cretaceous examples (*Orbitoides* sp., *Lepidorbitoides*) with clearly eroded margins (Fig. 6 f). The nummulitids and *Discocylina* indicate an minimum age of Late Palaeocene for the Calcari di Andreis at Pala Barzana.

The Calcari di Andreis varies greatly in thickness and in lithology between localities. Whilst there is around 100 m of breccia at Pala Barzana, in Val Colvera, at the exit of the tunnel on the new road to Frisanco (locality Fornasatte), there is only about 10 m of breccia interbedded with calcarenites. The underlying limestones are well bedded, without the rudist bioherms and contain numerous thin dissolution surfaces - all features indicating a shallower water environment in this area. On the southern side of Lake Barcis, the Calcari di Andreis is made of shallow water limestones, rather than megabreccia. Fragments of nummulitids and alveolinids were also found showing that some of this is Late Palaeocene. Around M. San Lorenzo, in the quarry on the eastern side, the Calcari di Andreis is exposed in a hillside consisting of a single, steeply-dipping bedding plane. It is made almost exclusively of blocks containing *Sabinia*, encrusted with pyrite cubes. It was almost certainly the lateral equivalent of this surface which SAINT-MARC (1963, p. 806-807) referred to as a hardground. In the related deposits of southern Italy, BORGOMANO & PHILIP (1987) claim to have detected an ecological preference for *Sabinia* clusters to grow on the upper parts of the slope area which is why they were therefore common amongst blocks of talus.

The Calcari di Andreis debris flows are classic deposits of a bye-pass margin. The platform edge has been downfaulted with some exposure of the tilted blocks and talus collected in an apron around the platform edge. The onset of faulting was probably sometime in the early Maastrichtian.

## 4. STRATIGRAPHICAL COMPARISONS WITH OTHER WORKS

The biostratigraphical subdivisions of the Late Cretaceous limestones of the Carnian Prealps and their index fossils, as defined by previous authors, have been tabulated in Fig. 8. We have attempted to correlate these schemes both to each other and to that used in this study. The schemes reveal two possible lacunae of Turonian - Santonian and Maastrichtian strata.

### 4.1. TURONIAN-SANTONIAN

One inconsistency between this and previous studies is in the apparent absence on Monte Jouf of strata belonging to the Turonian to Santonian interval. However, because of the lack of exposure and the strong possibility of emplacement of slices in the anticline core by thrust faulting, we can not prove conclusively that such strata were not deposited. Certainly the core of the anticline is made of Late Cenomanian beds (as dated by foraminiferal biostratigraphy) and this outcrop is accompanied by a fault slice slightly higher on the mountain containing caprinid rudists of probable Late Cenomanian age. The next exposure above this is of rocks with the large hippuritids, dated by Sr-isotopes as earliest Campanian.

The same caprinid beds are noted in all three of the tabulated biostratigraphic studies from M. Jouf, Val Cellina and M. Ciaulec. They are also noted as the uppermost unit exposed on M. Cavallo by SARTORIO (1986, 1987). None of the studies presents conclusive evidence that the overlying strata represent Turonian or Coniacian deposits. However, without further research in those regions the suggestion of a stratigraphic gap in this interval remains speculative.

### 4.2. MAASTRICHTIAN

The evidence for this second lacuna on Monte Jouf is much less ambiguous. The top of the rudist beds on Monte Jouf gave a well-constrained Sr-isotope date in the earliest Maastrichtian. As the same beds containing rudists and orbitoids, are recorded in all the biostratigraphic schemes, it seems probable that the sequence of platform carbonates terminates at approximately the same level over the entire area. Overlying the limestone, at least on the northern side of the M. Jouf anticline, is a megabreccia of eroded limestone blocks deposited in Late Palaeocene times. This seems to be roughly contemporaneous to the earliest beds of Scaglia Rossa judging from the foraminifera and the inter-fingering of breccia and Scaglia Rossa at localities on M. San Lorenzo. Yet the amount of time which goes unrecorded in the interval between the top of the Cretaceous limestone and bottom of the Tertiary Calcari di Andreis and Scaglia Rossa depends also on the thickness of limestone eroded away, and this varies locally. Somewhere near M. Jouf foraminiferal limestones were being deposited in the Maastrichtian which were the source for some of the blocks in the breccia.

East of M. Jouf on M. Ciaurlec the sequence (as described in COUSIN, 1963a) seems very similar to that observed on M. Jouf. However, at some isolated, thrust-bounded outcrops which now lie to the south of M. Ciaurlec at Paveon, and on M. Covria (outcrops mentioned in COUSIN, 1963b) the lowest beds of Scaglia Rossa contain such planktonic foraminifera as *Globotruncana arca* (CUSHMAN), *G. contusa* (CUSHMAN) - *caliciformis* VOGLER, *G. cf. stuarti*

<table>
<tr><th>This work<br>M. Jouf</th><th>Saint-Marc, 1963<br>Val di San Antonio & M. Jouf</th><th colspan="2">Cuvillier et al., 1968<br>Val Cellina</th><th>Cousin, 1963a<br>M. Ciaulec</th></tr>
<tr><td>CALCARI DI ANDREIS<br>Palaeocene</td><td>SCAGLIA ROSSA</td><td colspan="2">CALCARI DI ANDREIS<br>Upper Palaeocene</td><td>FLYSCH ?<br>U. Pal.<br>SCAGLIA ROSSA<br>Maas.?</td></tr>
<tr><td>UNIT 4<br>C/M boundary-uppermost Campanian</td><td>Orbitoid and rudist limestone<br>Maas.-Camp.</td><td rowspan="5">Zone of Cuneolina pavonia parva- Dicyclina schlumbergeri</td><td>Subzone of Orbitoides ss.<br>Maas.-Camp.</td><td>Orbitoid limestone<br>Maas.</td></tr>
<tr><td>UNIT 3<br>uppermost Campanian-middle Camp.</td><td rowspan="2">Hippuritid limestone<br>Camp.-Sant.</td><td rowspan="3">Santonian-<br>Upper Turonian</td><td rowspan="2">Hippuritid and Caprinid limestone<br>Senonian</td></tr>
<tr><td>UNIT 2<br>middle Campanian-lowermost Campanian</td></tr>
<tr><td></td><td>Radiolitid limestone<br>Con.-Tur.</td><td>Radiolitid and Hippuritid limestone<br>Turonian</td></tr>
<tr><td>UNIT 1<br>Upper Cenomanian</td><td>Caprinid limestone<br>Cenomanian</td><td>Subzone of Nezzazata simplex<br>Lower Turonian</td><td>Caprinid and Radiolitid limestone<br>Cenomanian</td></tr>
</table>

Fig. 8. Correlation of biostratigraphic zonal schemes used by previous authors to that of this study and revision of previous age assignments.

(De LAPPARENT) - *stuartiformis* DALBIEZ, which are Early Maastrichtian forms. At the southwestern end of Lake Barcis, at the junction of Val Caltea, Saint-Marc recorded Early Palaeocene foraminifera from the lowest part of the Scaglia (however, the contact with the Cretaceous limestones at this locality is probably tectonic). These outcrops were probably deposited on areas of the platform which were already submerged due to faulting sooner than M. Jouf.

At other places, which presumably represent more internal parts of the platform, limestone deposition continued for longer. These localities include M. Pedroc, (COUSIN, 1963a) where orbitoid limestones (with *Lepidorbitoides minor* SCHLUMBERGER, *L. socialis* (LEYMERIE), *Siderolites calcitrapoides* as well as the purportedly Late Maastrichtian form *Hellenocyclina beotica*) are overlain by Early Palaeocene limestones.

## 5. PALAEOENVIRONMENT OF THE M. JOUF DEPOSITS

The geological evolution of the M. Jouf area is described in Fig. 9. In Late Cenomanian times broad shelves were covered by shallow water but periodically emerged. At the end of the Cenomanian the M. Jouf area was drowned, perhaps by downfaulting of the platform margin. Sediments began to build out over Late Cenomanian deposits although strata representing the interval Turonian - Santonian are absent from the M. Jouf area because of by-passing. The first sediments are of earliest Campanian age and are representative of a relatively protected, low energy subtidal environment dominated by peloids, small benthic forams and some micrite. As the platform prograded seawards, by middle-late Campanian times the deposits acquired more characteristics of the intertidal zone. In the earliest Maastrichtian there was a slight deepening of water and

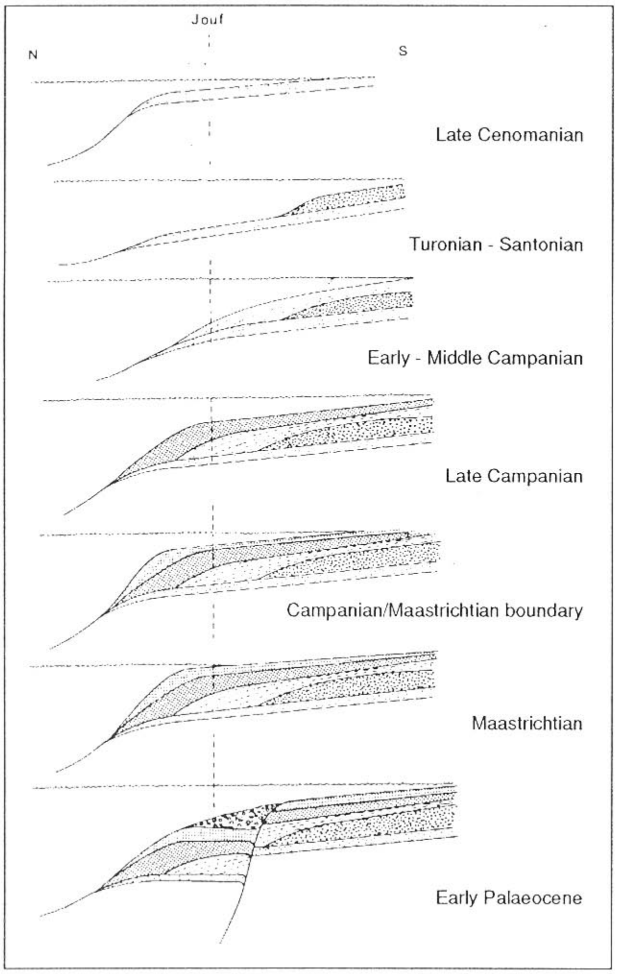



Fig. 9. Palaeoenvironmental evolution of the area during Late Cretaceous and Early Tertiary times.

a return to well washed shoal-type environments of the platform margin, dominated by bioherms of large radiolitids or banks of orbitoids.

Deposition of the rudist limestones came to an end when the sea regressed and withdrew completely from the platform edge leading to non-deposition, and some limestone dissolution during the Maastrichtian stage. On more inner part of the platform very shallow water carbonates contined to be deposited during the later in the middle-late Maastrichtian and Early Palaeocene. In Late Palaeocene the platform margin was broken into fault blocks, the scarps were eroded and talus deposited in the depressions together with pelagic sediment.

## 6. A REGIONAL PERSPECTIVE

Due to alpine tectonics, the M. Jouf area has been compressed in a N-S direction. Thus the transition in facies from platform to slope to basin is difficult to see because the area has been fragmented and telescoped. The Late Cretaceous deposits found south of the Periadriatic overthust, such as those exposed on M. Jouf, are *in situ* platform carbonates. North of the Periadriatic overthrust, such as Val Cellina north of Lake Barcis (COUSIN, 1963b), the Late Cretaceous consists exclusively of pelagic deposits. Slope deposits of Late Cretaceous age are not exposed in this area. This facies transition can however be seen in the Early Cretaceous deposits of the adjacent M. Cavallo-Cansiglio area (COUSIN, 1963a and MASSE & SENTENAC, 1987), and to the east in the Late Cretaceous of the Julian prealps (PIRINI RADRIZZANI et al., 1986).

On a regional scale the rocks of the Carnian Prealps are part of a facies belt that curves round to the SE to join the Internal Karst (Postojna mountains). To the south-west of this internal parts of the platform outcrop in the zone of External Karst (Karst mountains). Carbonate platform deposition continued here until the Late Eocene. The Internal Karst is bordered to the north-east by the area of Pre-Karst which was the slope area. This marked the zone of transition between the platform carbonates and the basin facies of the Tolmin trough (CARON & COUSIN, 1972). The general development of the Adriatic Carbonate Platform is outside the scope of this work and the reader is referred to the reviews of COUSIN & FOURCADE (1982) and CAVALLIN & PIRINI RADRIZZANI (1983).

## 7. CONCLUSIONS

The Late Cretaceous strata of M. Jouf are reasonably pure, white limestones and are part of the stratigraphic unit known as the Calcari del Monte Cavallo. On M. Jouf we subdivide this into 4 units.

**Unit 1** is Late Cenomanian, as dated by the caprinid rudist *Caprinula boissyi* and the small benthic foraminifera *Trochospira avnimelechi*. The sediment is generally an intraclastal gravel of packstones and wackestones and indicative of high energy conditions on a shallow, broad shelf. There is a major unconformity between units 1 and 2.

**Unit 2** ranges from the earliest to middle/late of the Campanian according to the Sr-isotope results. It contains several rudists and benthic foraminifera generally regarded as Senonian (Coniacian-Campanian with or without the Maastrichtian), notably the rudists *Katzeria* and *Vaccinites* aff. *giganteus*, and the foraminifera aff. *Stensiöina surrentina* and aff. *Abrardia mosae*. The facies grades from rudist biostromes of probably subtidal origin to a cyclical sub-supratidal plattenkalk.

**Unit 3** is late Campanian to Campanian/Maastrichtian boundary as dated by Sr-isotopes. The Senonian rudists *Bournonia excavata* and a species of *Pseudopolyconites* are of latest Campanian age at this locality. The sediments are rudist biostromes in a mainly grainstone sediment with other indications of very shallow, but fast-moving water in the middle platform.

**Unit 4** is of earliest Maastrichtian age (placing the Campanian/Maastrichtian boundary at the extinction of the planktonic foraminifer *Globotruncana calcarata*). Thus the assemblages of larger foraminifera -

*Orbitoides media, Siderolites calcitrapoides, Lepidorbitoides socialis*, and rudists - *Joufia, Colveraia, Pironaea, Pseudopolyconites*, are here of earliest Maastrichtian age. The facies is coarser than previous units with an abundance of large rudist and demonstrates turbulent conditions near to the shelf edge.

An unconformity separates the *in situ* rudist limestones from a megabreccia of the Calcari di Andreis and pelagic Scaglia Rossa of Tertiary age. Limestone deposition probably ended due to a regression in the earliest Maastrichtian. In Late Palaeocene times the platform margin of the M. Jouf area was extensively down-faulted with erosion of faults scarps and deposition of talus and pelagic deposits on top of the limestones.

### Acknowledgments

The M. Jouf work is part of a study by Nicola Swinburne into the extinction of the rudist bivalves at the end of the Cretaceous Period, for a PhD in the years 1987-90, at The Open University, Milton Keynes. This work was supervised by Peter Skelton at the Open University and funded by N.E.R.C. For the other author, Adriano Noacco, the work was for a doctoral thesis at the University of Trieste, 1986-88, supervised by Giorgio Longo Salvador, Giorgio Tunis and Camilla Pirini-Radrizzani. We would also particularly like to thank Michel Bilotte for his identification of the foraminifera from M. Jouf, field assistants Jane Brown and Katherine Medlow for their noble efforts, Peter van Calsteren and Mabs Kunka for help with the Sr-isotope analyses.

Finally, we wish to sincerely thank Giorgio Tunis of the University of Trieste for his help and precious advice.

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Manuscript received May 20, 1992.
Revised manuscript accepted March 5, 1993.