

SEQUENCE STRATIGRAPHY, KINEMATICS AND DYNAMIC GEOHISTORY OF THE CROTONE BASIN (CALABRIAN ARC, CENTRAL MEDITERRANEAN): AN INTEGRATED APPROACH

J.P. VAN DIJK (*)

ABSTRACT

A comprehensive study on the Late Neogene tectonostratigraphic development of the Crotone Basin is presented. The basin is situated on the accretionary wedge along the external side of the Calabrian Arc (Central Mediterranean). The results of our analysis provide a detailed insight into the relative role of local tectonic activity of the thrust wedge and regional relative sea level fluctuations in the creation of unconformity bound depositional sequences.

The tectonostratigraphic significances of the sequence boundaries of the Early-Late Miocene and Late Pliocene-middle Pleistocene sequences are remarkably similar. They reflect a «composite tectonic event» comprising an uplift/regression pulse, followed by a rapid subsidence/onlap. Each composite tectonic event, in turn, represents one pulse in the progressive evolution of the accretionary wedge system. We regard the middle Messinian-Early Pliocene phases of basin fill and tectonic inversion, and the Late Pleistocene-Recent uplift phase as reflections of the increase of regional stress in the Central Mediterranean

KEY WORDS: *Central Mediterranean, foreland basins, strike-slip, sequence stratigraphy, Neogene*

RIASSUNTO

Il presente lavoro riguarda l'evoluzione tettono-stratigrafica tardo Neogenica del Bacino di Crotone, situato al di sopra del prisma di accrezione del margine esterno dell'Arco Calabro (Mediterraneo Centrale). Esso comprende una dettagliata visione interpretativa del ruolo relativo dell'attività tettonica locale del prisma di sovrascorrimento, rispetto alle fluttuazioni regionali del livello marino, nella creazione di sequenze deposizionali limitate da superfici di discordanza. L'evoluzione tettono-stratigrafica può essere divisa in quattro stadi: 1) Stadio tardo Serravalliano/co-Messiniano, caratterizzato da una progressiva espansione del bacino; 2) stadio Messiniano medio/eo-Pliocene, caratterizzato da intenso fagliamento e sequenze complesse, sovrapposto alla crisi di salinità Messiniana; 3) stadio tardo

Pliocene/eo-Pleistocene, caratterizzato da un onlap pulsante; 4) stadio tardo Pleistocene/Recente, caratterizzato da forti movimenti verticali collegati al sollevamento del basamento della Sila. Alla fine dello stadio 2 la tettonica compressiva regionale della fase medio-Pleistocene è responsabile dell'inversione del bacino e del sovrascorrimento della copertura verso i margini. L'evoluzione del bacino è controllata da movimenti sinistrali lungo due zone di taglio crostali convergenti dirette NW-SE. Secondo questa visione l'evoluzione medio Miocenica/eo-Pliocenica (stadi 1 e 2) riflette un ciclo di strike-slip, nel senso di MITCHELL & READING (1978). Il significato tettono-stratigrafico dei limiti delle sequenze opposte negli stadi 1 e 3 è marcatamente simile: esso riflette un «evento tettonico composito» che comprende una pulsazione di sollevamento/regressione, seguita da rapida subsidenza/onlap. Ogni evento composito a sua volta rappresenta una pulsazione nell'evoluzione progressiva del sistema costituito dal prisma di accrezione. Le fasi di deposizione e inversione tettonica (stadio 2) medio-Messiniano/ eo-Plioceniche e la fase di sollevamento tardo Pliocenica ad Attuale (stadio 4) sono qui interpretate come un riflesso dell'aumento dello stress regionale nel Mediterraneo Centrale.

INTRODUCTION

The Calabrian Arc in the Central Mediterranean Area is situated in between three important orogenic belts: the Western Mediterranean E-W trending North African belt, the NW-SE trending Apennine belt and the Eastern Mediterranean NW-SE trending Hellenide-Dinaride belt (for general descriptions, we refer to MANTOVANI *et alii*, 1985; FINETTI & DEL BEN, 1986; PATACCA & SCANDONE, 1989). Related to its position in the central part of the young orogenic Mediterranean system, the Calabrian Arc appears to be highly interesting for the analyses of the interaction between sea level fluctuations and tectonics on various scales and the formation of unconformity-bound depositional sequences (see discussions in VAIL *et alii*, 1977; BURTON *et alii*, 1987; HAO *et alii*, 1987; SLOSS, 1988; CLOETINGH, 1988). Both have been proved to be important: during the

(*) Department of Geology, Institute of Earth Sciences, State University of Utrecht; Budapestlaan 4, 3508 TA Utrecht, The Netherlands.

Messinian a sea level-drop and the subsequent sudden rise are thought to be of global importance (BENSON, 1984; MÜLLER, 1986) while the large-scale tectonic activity of the area easily can be appreciated. In this paper we will focus on the tectonostratigraphic aspects of the Neogene evolution of the Crotona Basin, which is situated at the northeastern, external side of the Calabrian Arc (figs. 1 and 2).

Previous studies on the Crotona Basin mainly deal with the stratigraphy but gave little information as to the tectonic setting and development of the basin (OGNIBEN, 1955; RODA, 1964, 1965b; BURTON, 1971; MEULENKAMP *et alii*, 1986; see for historical references OGNIBEN, 1973). Basin models for the

Calabrian Arc are generally discussed within kinematic frameworks for the whole area (GHISETTI & VEZZANI, 1981; MOUSSAT, 1983; BOCCALETTI *et alii*, 1984). VAN DIJK & OKKES (1988, 1990 and in press.) and VAN DIJK (1991) reviewed the various existing models and proposed a new tectonic model for the Crotona Basin as an oblique (transpressive) piggy-back basin, locked between two intra-arc shear zones. The present contribution shows how the reconstruction of sequence stratigraphy from conventional stratigraphy provides insight into the evolution of the foreland basin. Some examples of geohistory analyses illustrate the phases in basin development as recognized.

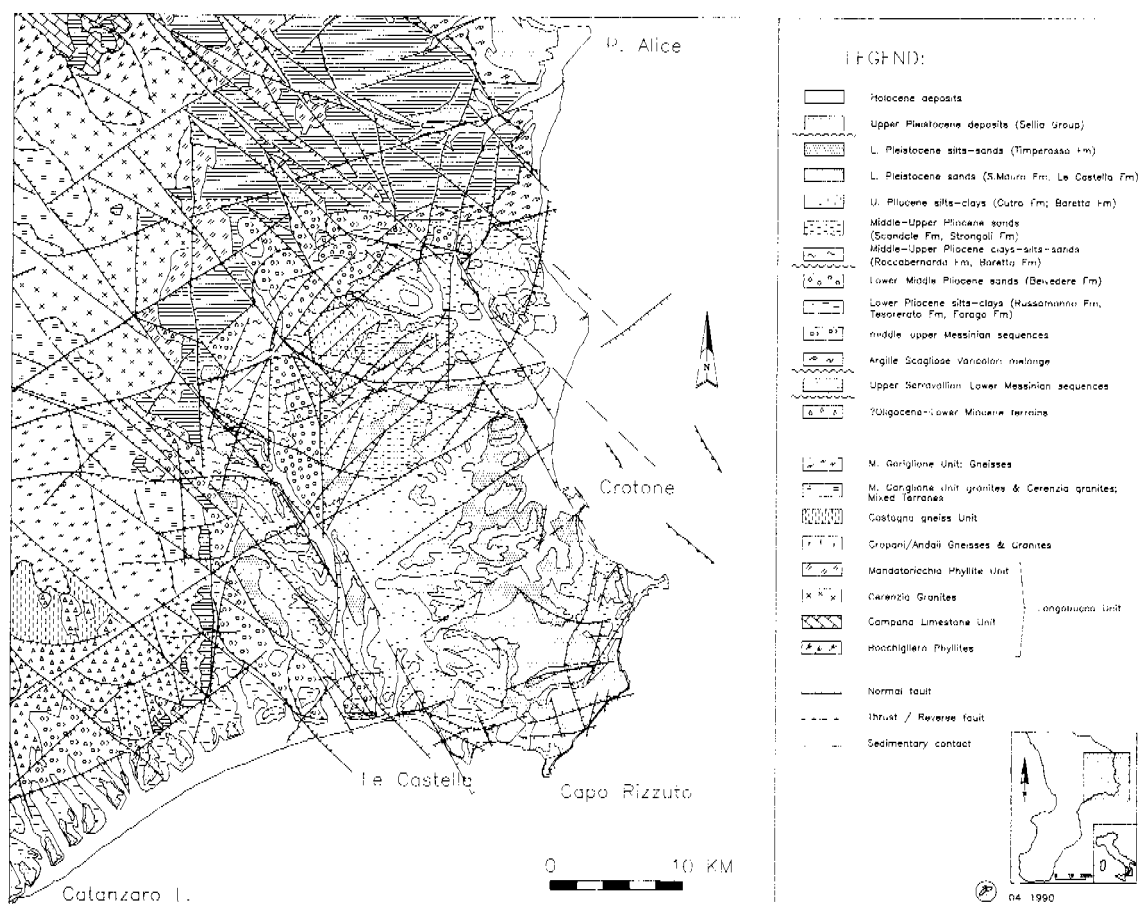


Fig. 1 - Geological map of the Crotona Basin. Basement structure was compiled and modified after BURTON (1971), DUBOIS (1976), AMODIO-MORELLI *et alii* (1976), ZANETTIN-LORENZONI (1982) and GUERRIERI *et alii* (1982). The basement structure clearly indicates the continuation and significance of the faults as recognized in the Neogene, and can also be used to detect Neogene overthrust tectonics.

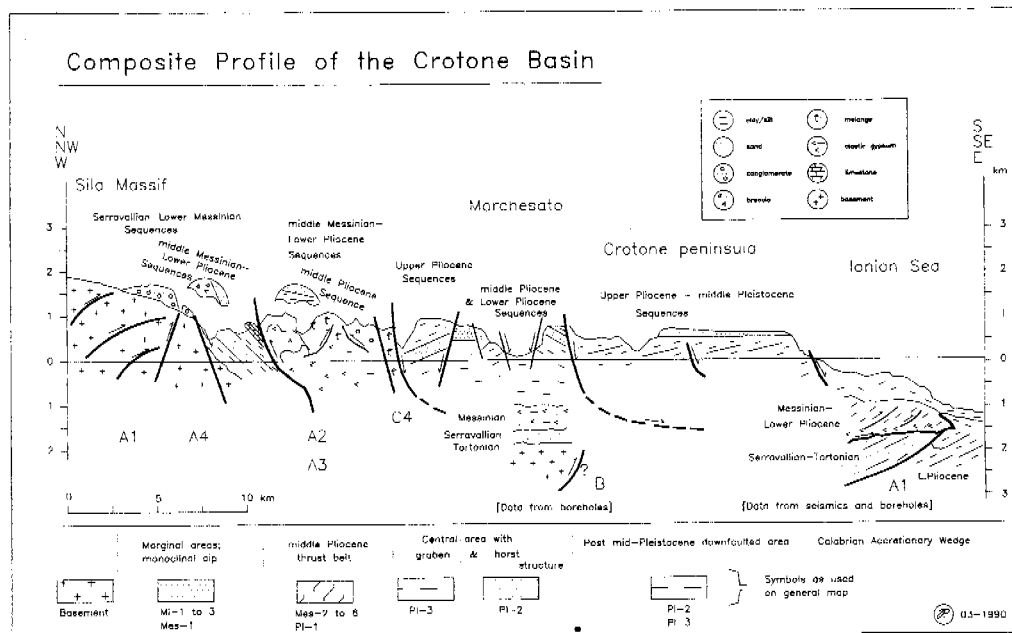
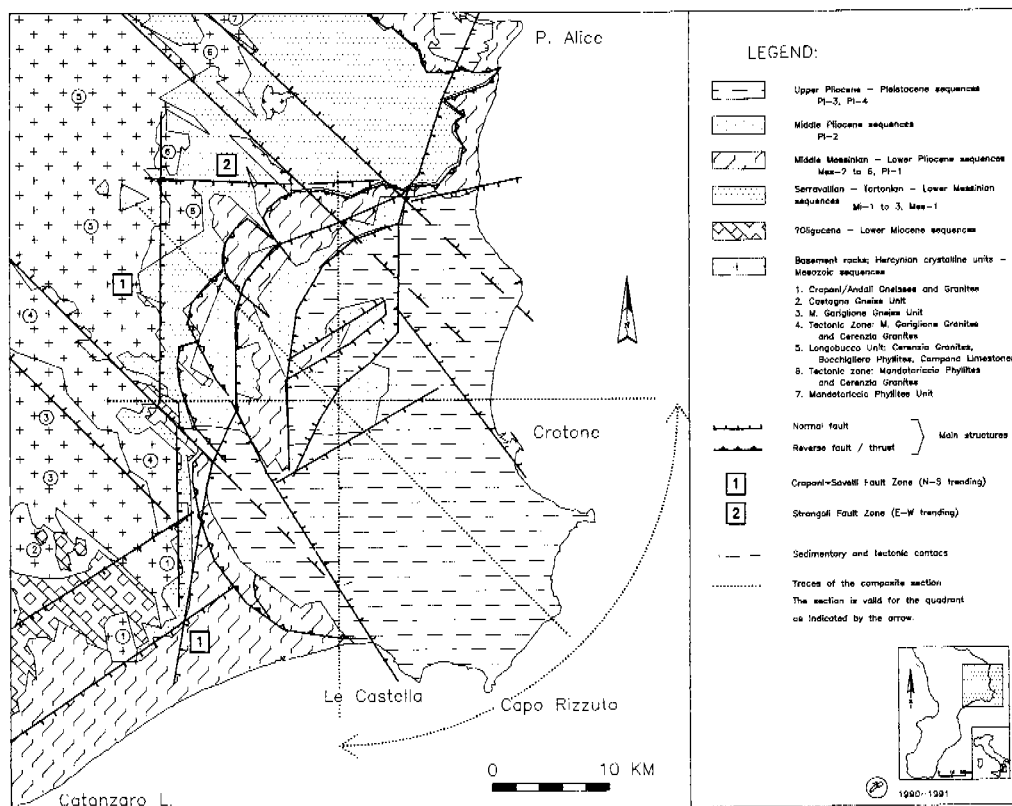


Fig. 2 - Geological structure of the Crotona Basin. a) Simplified geological sketch-map of the area. b) Composite cross-section of the Crotona Basin. Note that the section can be read in a N-S, as well as in an E-W or NW-SE sense. Modified from: VAN DIJK (1991). The letters A, B and C refer to fault patterns.

METHODS

We gathered our data during a number of field campaigns between 1983 and 1989 in the internal area of the Crotona Basin (fig. 3). The results were compared and appended with previously published field studies, seismic sections, borehole data and satellite photography studies (fig. 3). This resulted in 1:25.000 and 1:10.000 geological maps and stratigraphic correlation charts which are supported by biostratigraphic assignments to about 100 sam-

ples taken from key locations. Fig. 4 illustrates the methods we used to reconstruct the unconformity-bound depositional sequences from the field sections. This exercise resulted in detailed «composite tectonostratigraphic schemes» (i.e. composite columns with indications of existing relations along unconformities; see fig. 6) which are each representative for one specific, tectonically defined area (fig. 5). This concept shows affinity with the concept of «suspect allochthonous tectonostratigraphic terranes» (terminology of IRWIN,

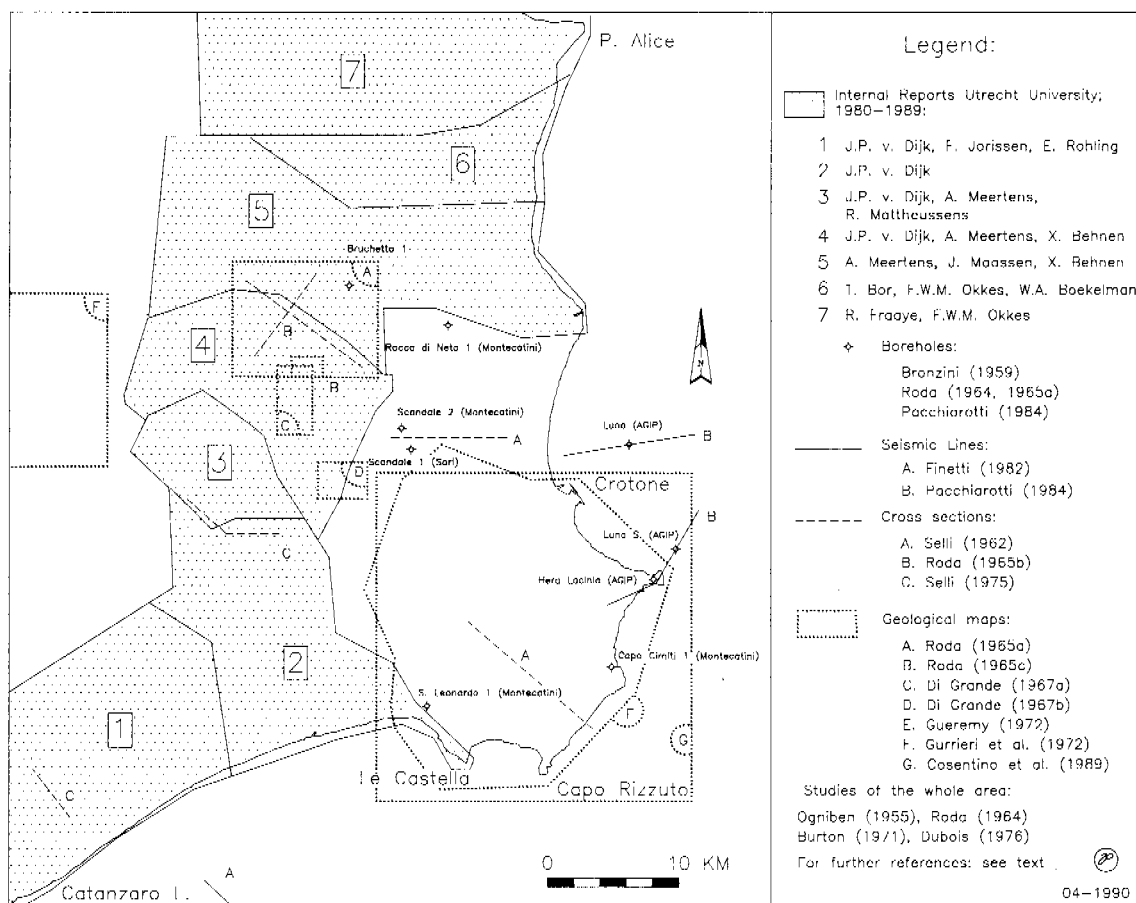
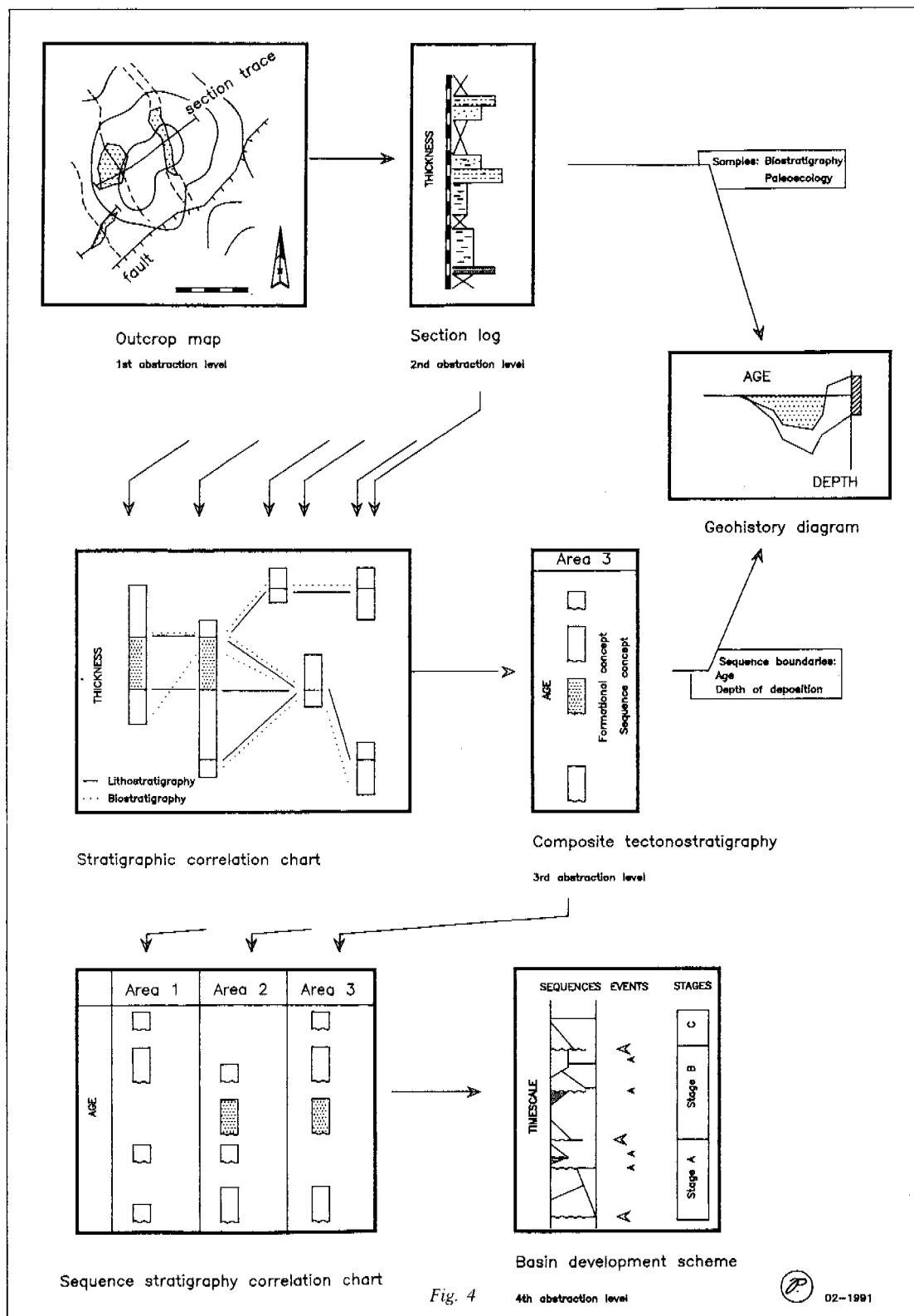


Fig. 3 - Locations of the areas which were mapped and the additional information from literature which was used in this study.

Fig. 4 - Flow chart illustrating the method of reconstructing unconformity-bound depositional sequences from field sections. Note that both from field sections as well as from composite stratigraphy geohistory diagrams can be processed. In this paper, the second approach was followed. The reason for this, is that separate field sections each display only a condensed part of the total tectonostratigraphic record. Processing the composite record results in an image which does not show the vertical movements of one specific point in the basin, but shows a subsidence/uplift path which is representative for a tectonically defined area. The elements presented in this paper are of the 3rd and 4th abstraction level.



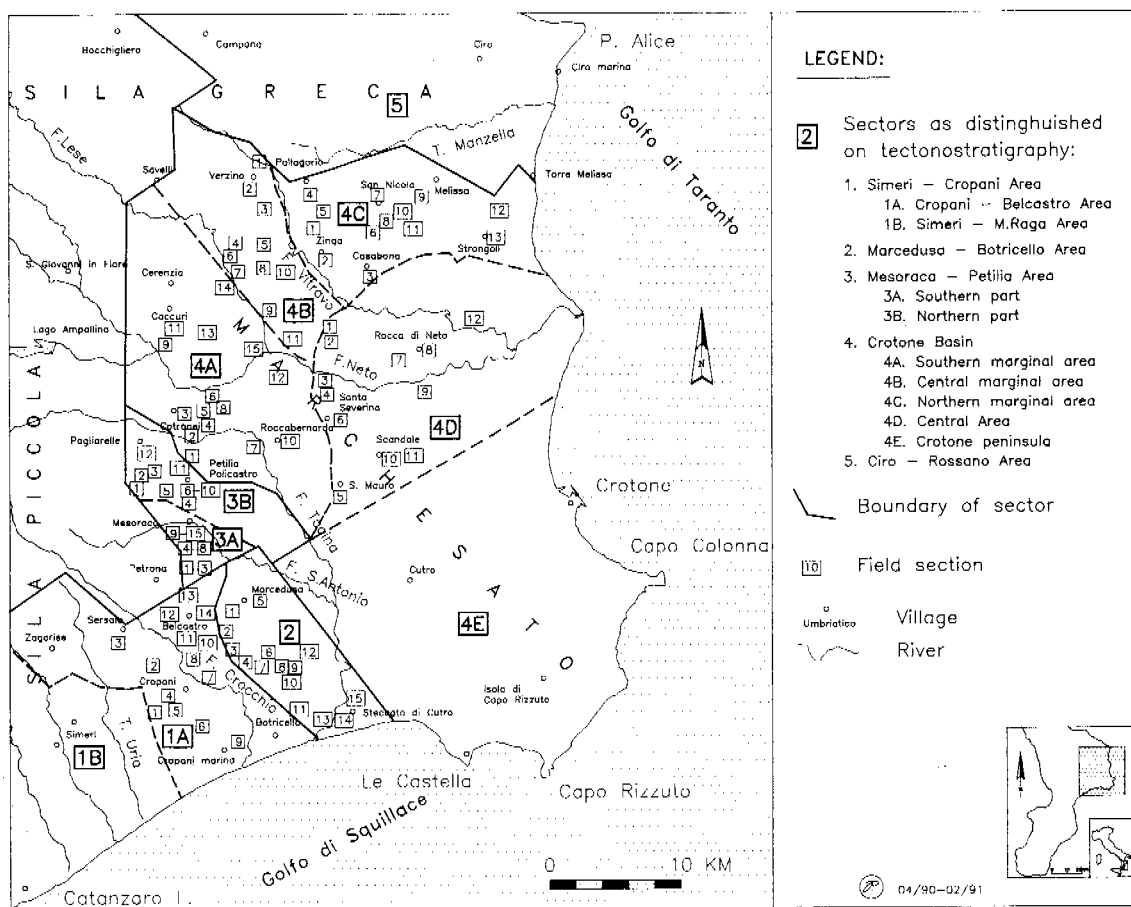


Fig. 5 - Subdivision of the Crotona Basin based on the tectonostratigraphic schemes of fig. 6. Separate land sections are indicated and numbered as in fig. 6.

1972; CONEY *et alii*, 1980; SCHERMER *et alii*, 1984; proposed to apply to the Calabrian Arc by VAN DIJK & OKKES, 1988, 1990). Finally a general basin development scheme has been constructed (fig. 8). The composite tectonostratigraphic schemes were processed to construct geohistory diagrams of different settings, using available information on biostratigraphy (age) and lithofacies (depth of deposition). Our software is based on the procedures for decompaction and loading correction as proposed and discussed by HOROWITZ (1976) and VAN HINTE (1978) and reviewed by GUIDISH *et alii* (1985). We used the algorithms as presented by STAM *et alii* (1987). Furthermore, the available data were combined and elaborated by means of newly designed methods (see for a full discussion VAN DIJK, in

press.) into three-dimensional representations of calculated topography, the so-called Time-Snapshot Plots, or «synthetic landscapes».

TECTONIC STRUCTURE OF THE BASIN

The present-day configuration of the Crotona Basin can be characterized as follows (figs. 2a and b; after VAN DIJK, 1991): The remnants of Miocene to recent terrains are present in a quadrangular area confined to the west by a N-S and to the north by an E-W trending normal fault zone (resp. Cropani-Savelli Fault Zone and Strongoli Fault Zone). Three zones or areas can be recognized from the internal to the external side, both in an E-W, as well as in a N-S direction: A) Along the fault-bound-

ded margins of the Sila Massif (N-S and E-W fault zones), Middle to Upper Miocene sequences are present which overlie basement and show a monoclinical dip towards the basin centre. B) The central zone (Marchesato area) comprises Upper Miocene to Lower Pliocene terrains, which are folded and thrustured towards the basin margins in the N and W. This tectonization can be linked to a middle Pliocene tectonic phase. C) The external area (Crotone Peninsula) in the SE comprises relatively undisturbed Upper Pliocene-Pleistocene sediments. Areas B and C are separated by post-Middle Pleistocene N-S, NNE-SSW and NE-SW trending normal faults with vertical displacements of several hundred metres which dominate the present geomorphology. Externally, thrusts have been documented in seismic profiles which show overthrusting and decollement of Upper Miocene and Lower Pliocene sequences.

SEQUENCE STRATIGRAPHY

The detailed tectonostratigraphic records of various areas (fig. 5) of the Crotone Basin are presented in fig. 6. These areas have primarily not been distinguished solely on the basis of jumps in stratigraphic successions (MEULENKAMP *et alii*, 1986), but have been defined following tectonic criteria using the structural elements as have been recognized in the area (VAN DIJK, 1991; see the above described terrane concept). Fig. 6 shows how sequences have been reconstructed through conventional lithostratigraphic correlation. Along unconformities, these lithostratigraphic correlations coincide with biostratigraphic/chronostratigraphic levels which evidences the existence of specific time-synchronous sequence boundaries. In that way, a number of unconformity-bound depositional sequences can be distinguished, which are comparable in magnitude with the third-order cycles of VAIL *et alii* (1977) and HAO *et alii* (1987) as used in seismostratigraphy. In order to be able to detect which sequence boundaries are associated with tectonic pulses, we set up a series of criteria for syn-sedimentary tectonic activity along the basin margin which we used for this purpose (fig. 10; see also KRUMBEIN, 1942; SHANMUGAM, 1988 and EMBRY, 1990 for this type of approach). These criteria are exclusively based on field observations, which will

not be discussed in detail; fig. 10 summarizes the total amount of data, indicating which phenomena can be observed. By means of combinations of these criteria, we could establish the amount of certainty with which the sequence boundaries can be linked to tectonic pulses or relative sea level fluctuations (or both). The latter can than still be due to tectonic activity, but on a larger scale than the studied basin, or to glacio-eustatic activity.

The unconformities which separate the Serravallian/Tortonian and Pliocene/Pleistocene sequences seem to record a standard tectonic signal (fig. 9): Each unconformity can be interpreted as the reflection of a small chain of tectonic events which we choose to call a «composite tectonic event», comprising a short phase of uplift and erosion of the basin margin, accompanied by the outgrowth of a submarine fan body (comparable to a Low Stand Systems Tract); this phase is followed by a rapid subsidence and back stepping of the basin margin resulting in a regional onlap (Transgressive Surface followed by a High Stand Systems Tract).

We distinguish the following sequences:

?Oligocene – Lower Miocene deposits:

Remnants of ?Oligocene-Lower Miocene clastic deposits are present in the central area in small rhombic blocks delimited by N120 and N140 normal or reverse faults (Petilia-Policastro, Caccuri and San Nicola; see fig. 2), and in the south in the Sila Piccola area (SW-part of fig. 2; west of Cropani and Sersale). The deposits are strongly tectonized; they often show low angle thrust contacts with basement (Sersale, Zagarise) and are sometimes overthrustured by crystalline units (M. Raga and Pagliarelle; M.S. Barbara). We tentatively correlate the sequences in the Sila Piccola area and the remnants in the central area with the Paludi Fm (ZUFFA & DE ROSA, 1978) further north in the Ciro-Rossano Area, and with the Upper Oligocene-Lower Miocene Complex (sensu VAN DIJK & OKKES, 1988; 1990; Stilo-Capo d'Orlando Fm of BONARDI *et alii*, 1984; see also MEULENKAMP *et alii*, 1986) of southern Calabria. This correlation is based on similarities in lithofacies and tectofacies. Given the fact that biostratigraphic studies have up to date not resulted in any clear solutions these records can, alternatively, also be assigned to the Langhian-Serravallian (following the assignments of BURTON, 1971 and MEULENKAMP *et*

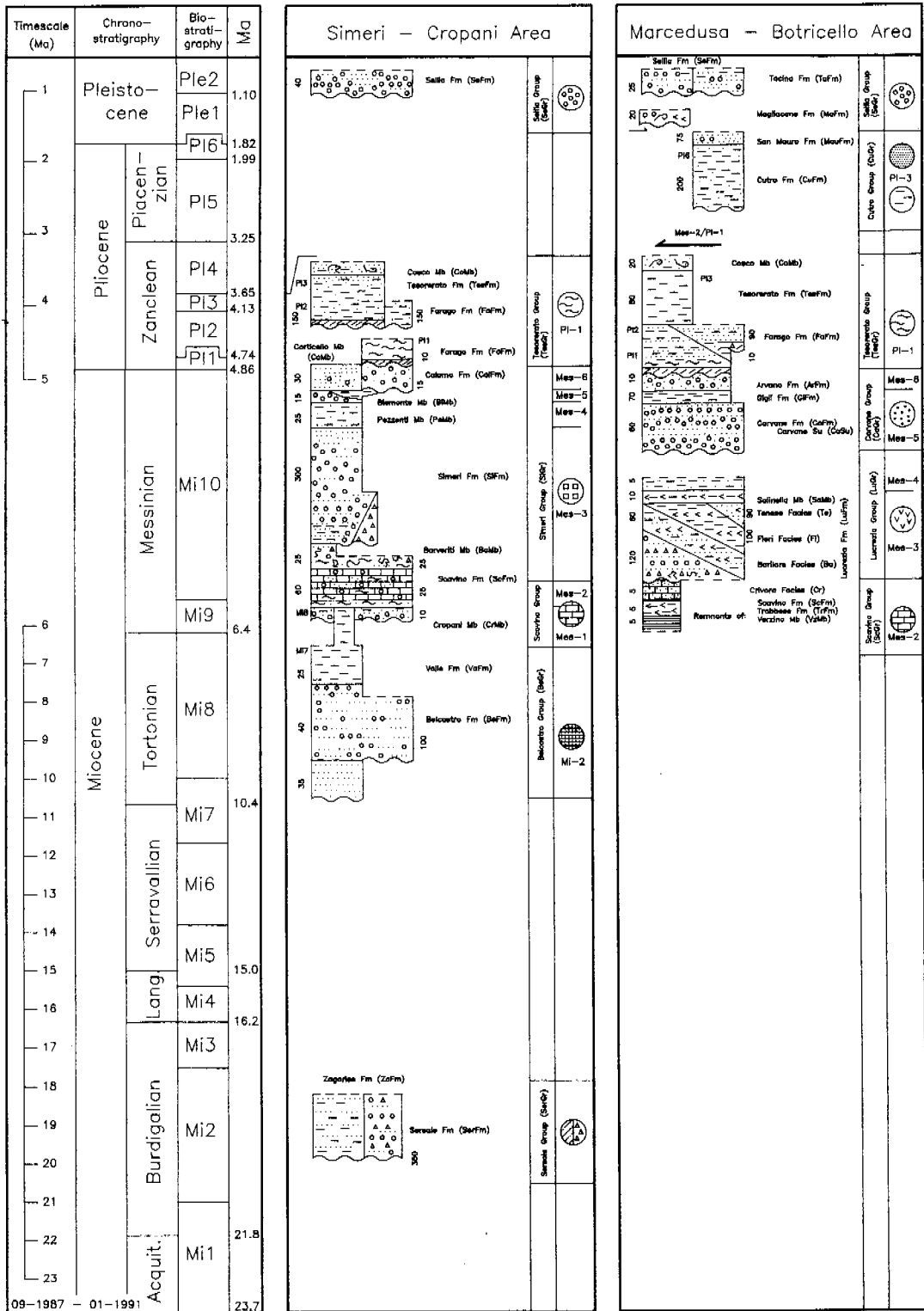
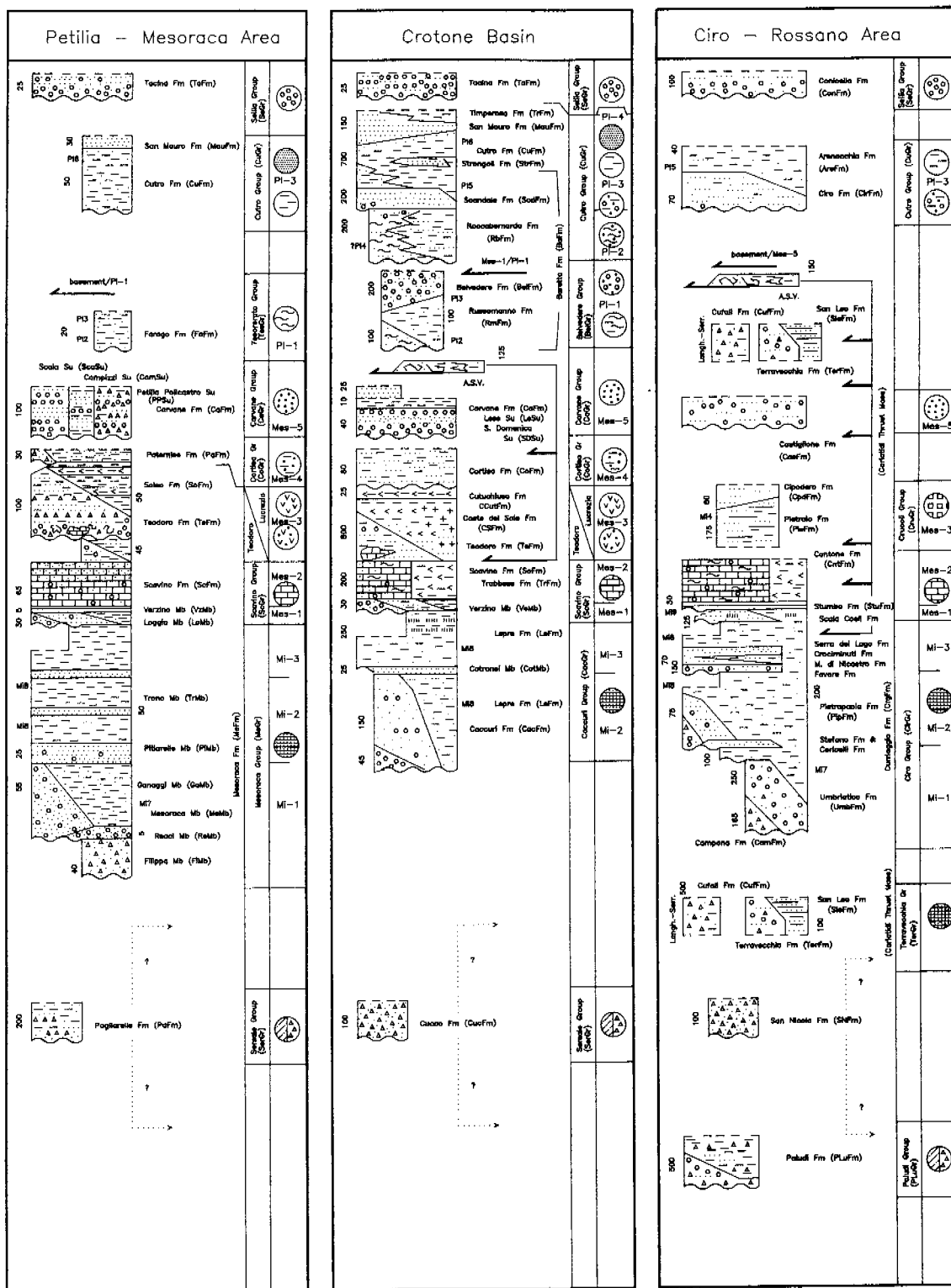


Fig. 6 - Tectonostratigraphic correlation charts and composite schemes. Note that the maximum thickness of the formation as indicated in the composite stratigraphic schemes does not always coincide with the thickness as indicated in the correlation charts. This is due to the fact that the final total thickness is obtained using cross sections and additional information from boreholes. For the location of the areas and the sections see fig. 5. a) Composite tectonostratigraphic scheme for the studied area. b) Correlation chart for the Cropani-Simeri Area.



c) Correlation chart for the Marcedusa-Bottricello Area. d) Correlation chart for the Mesoraca-Petilia Area; southern part. e) Correlation chart for the Mesoraca-Petilia Area; northern part. f) Correlation chart for the Croton Basin; southern marginal area. g) Correlation chart for the Croton Basin; central marginal area. h) Correlation chart for the Croton Basin; northern marginal area. i) Correlation chart for the Croton Basin: central area.

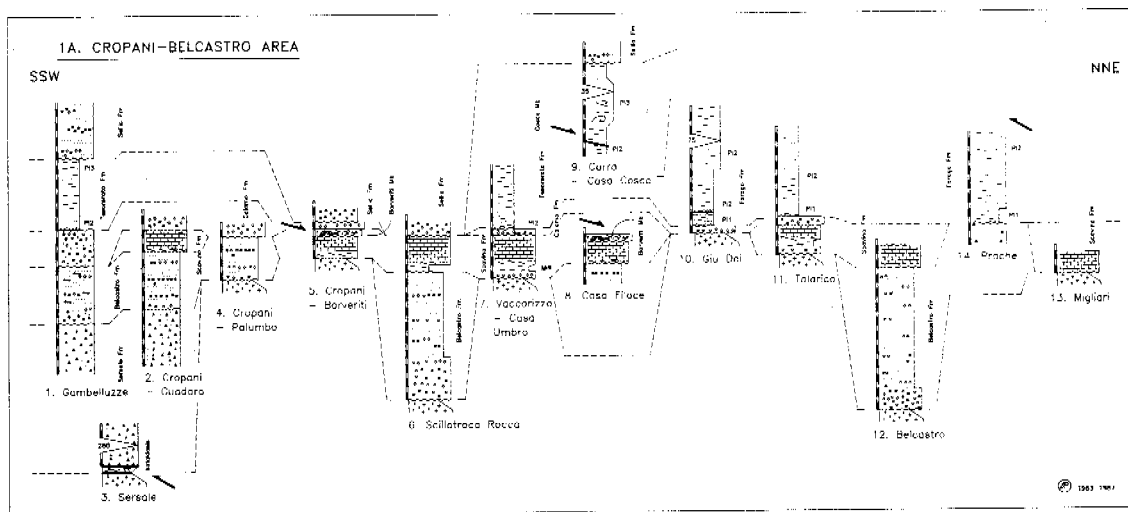


Fig. 6 b

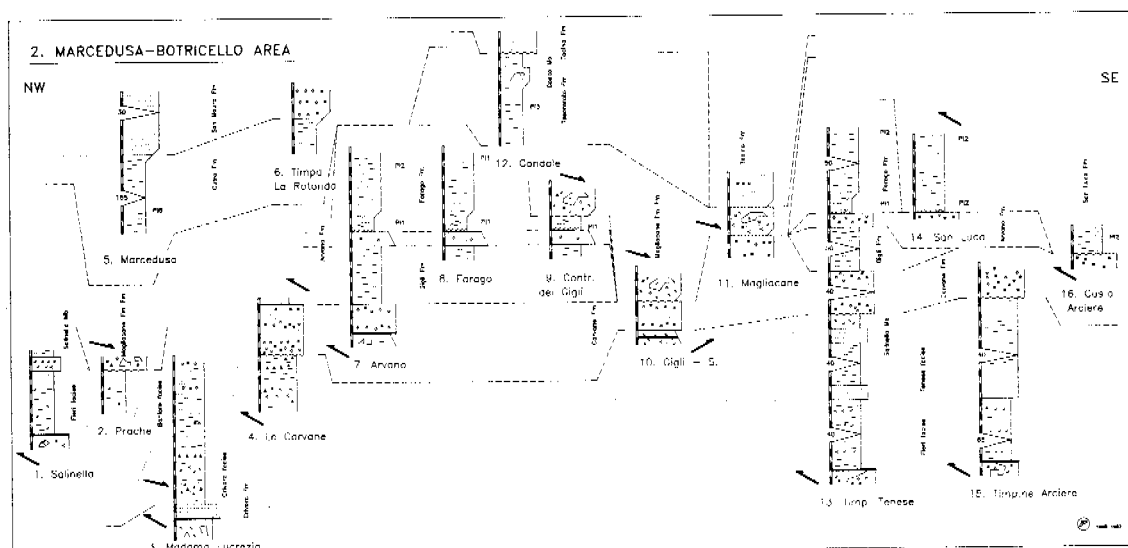


Fig. 6 c

alii, 1986 for the Sersale Fm and Zagarise Fm in the Sila Piccola). Both options have been indicated in fig. 6.

Upper Serravallian-Tortonian sequences (Mi-1 to Mi-3): This group of thick, shallow marine arkosic deposits can be subdivided into three depositional sequences, each of which apparently comprises a standard suc-

cession (fig. 9), and which are separated by unconformities of the standard type as described above. The total image reflects the continuous growth of the basin to the NW with a pulsating back stepping basin margin; each pulse comprises an initial uplift phase followed by rapid subsidence («composite tectonic event»). The N-S trending Cropani-Savelli fault zone constitutes the basin margin for the

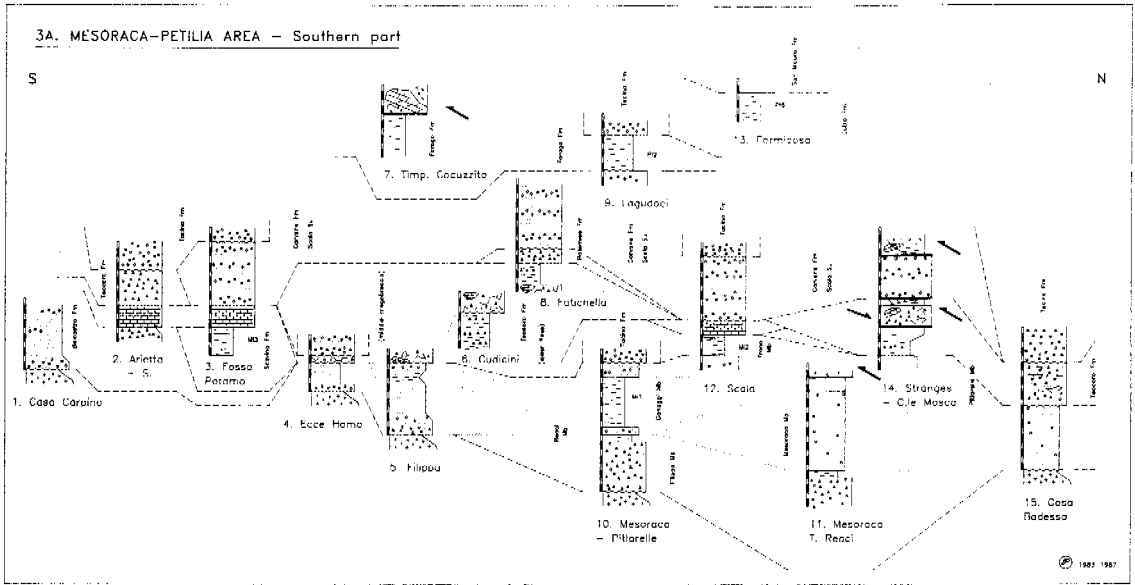


Fig. 6 d

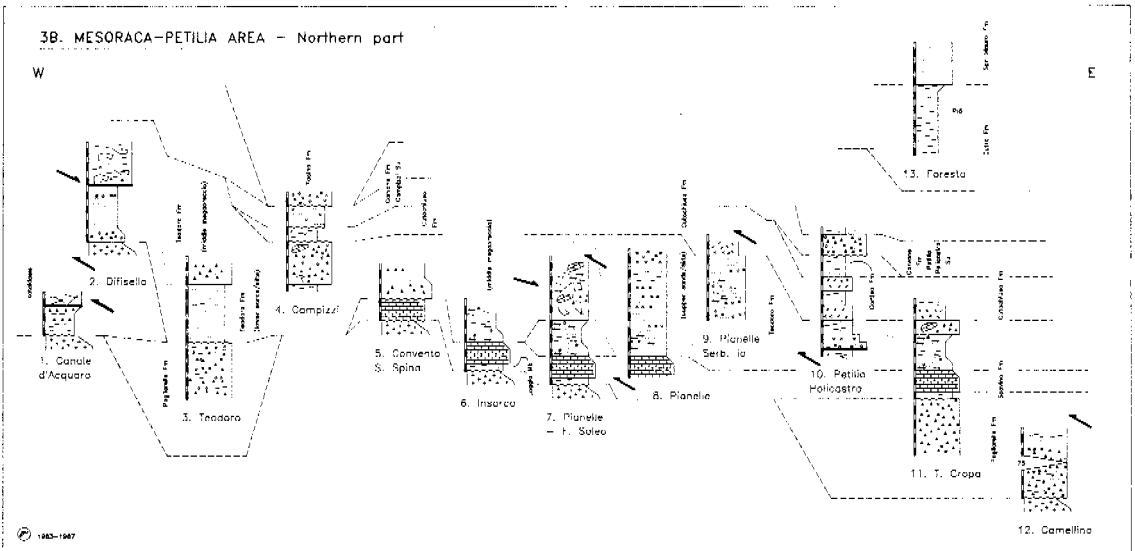


Fig. 6 e

Tortonian sequences. Subtle facies changes in the shallow marine deposits were confined by small parasitic faults trending E-W and N120. The sedimentation area was confined by two NW-SE trending fault zones (fig. 2a), as is suggested by: 1) the startling difference in overall

stratigraphy with the areas north and south of these fault zones (see fig. 6), and 2) the very rapid facies changes and unconformities along N120 trending fault-bounded blocks, as we documented in the Mesoraca-Petilia area (fig. 6).

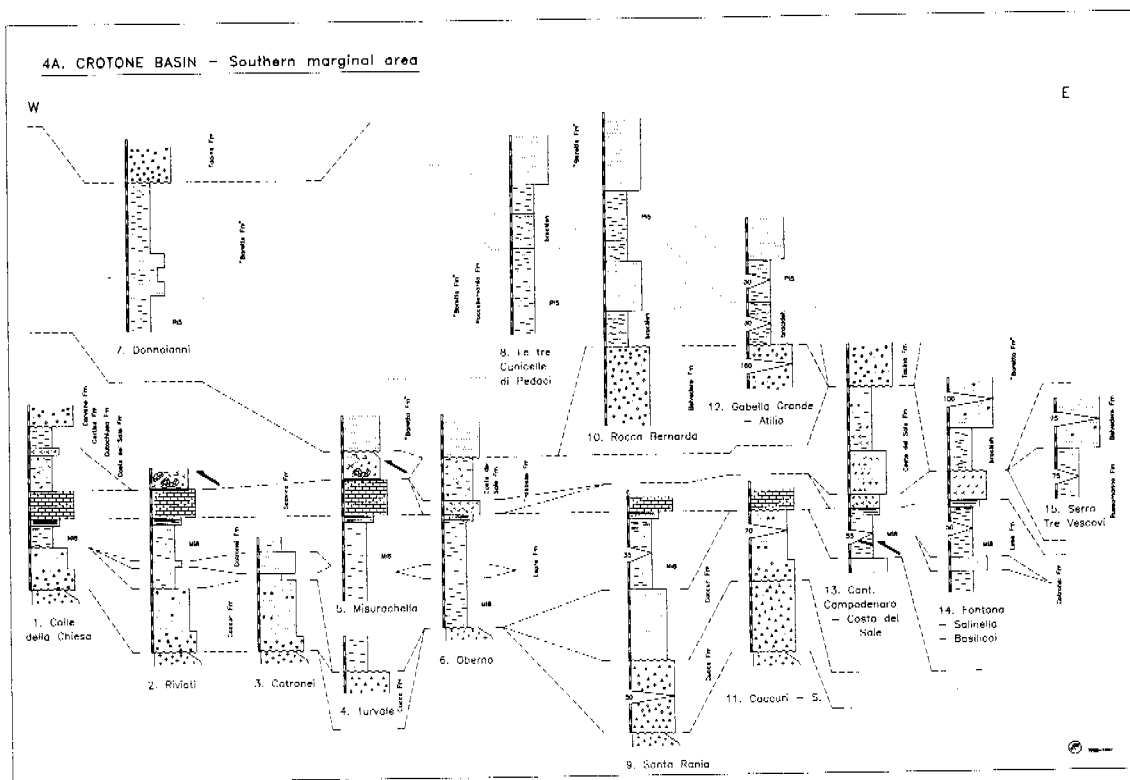


Fig. 6 f

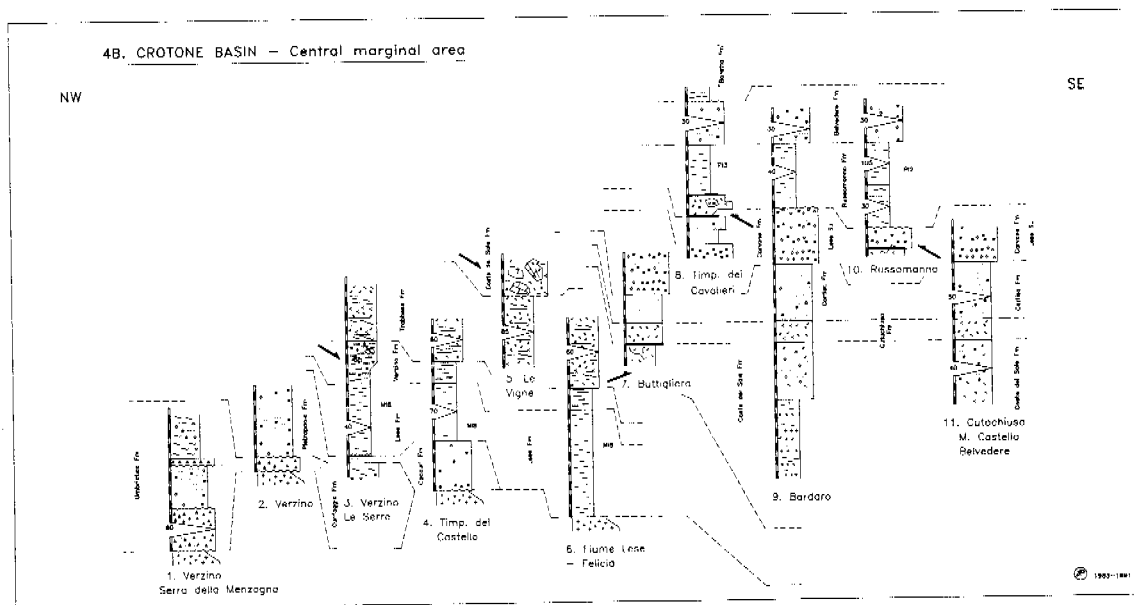


Fig. 6 g

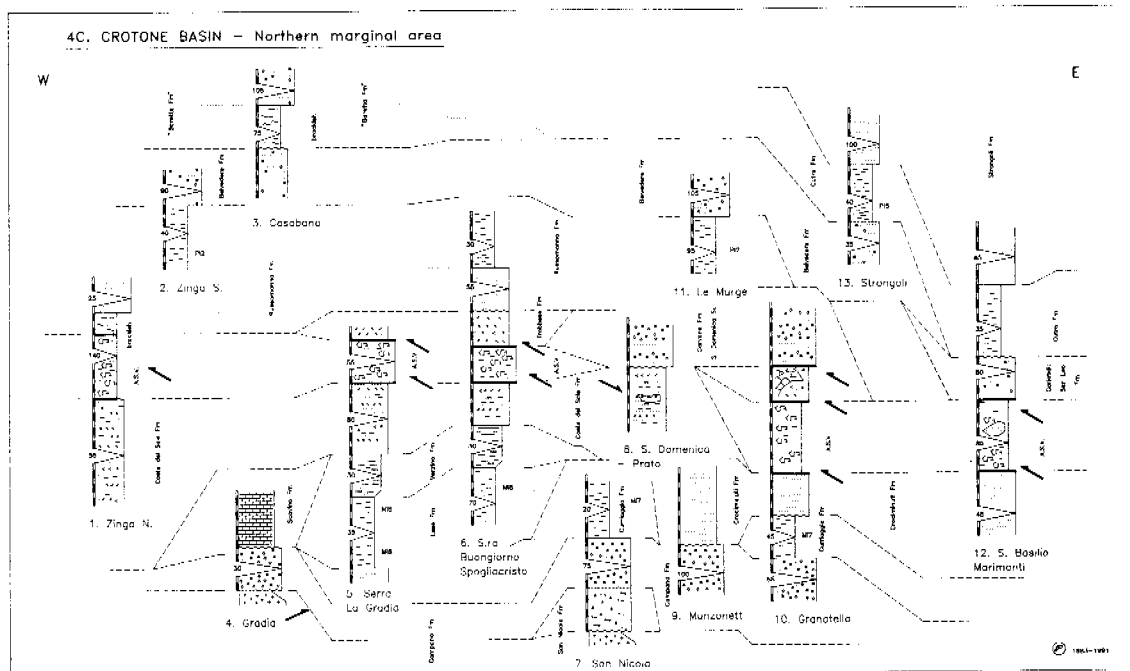


Fig. 6 h

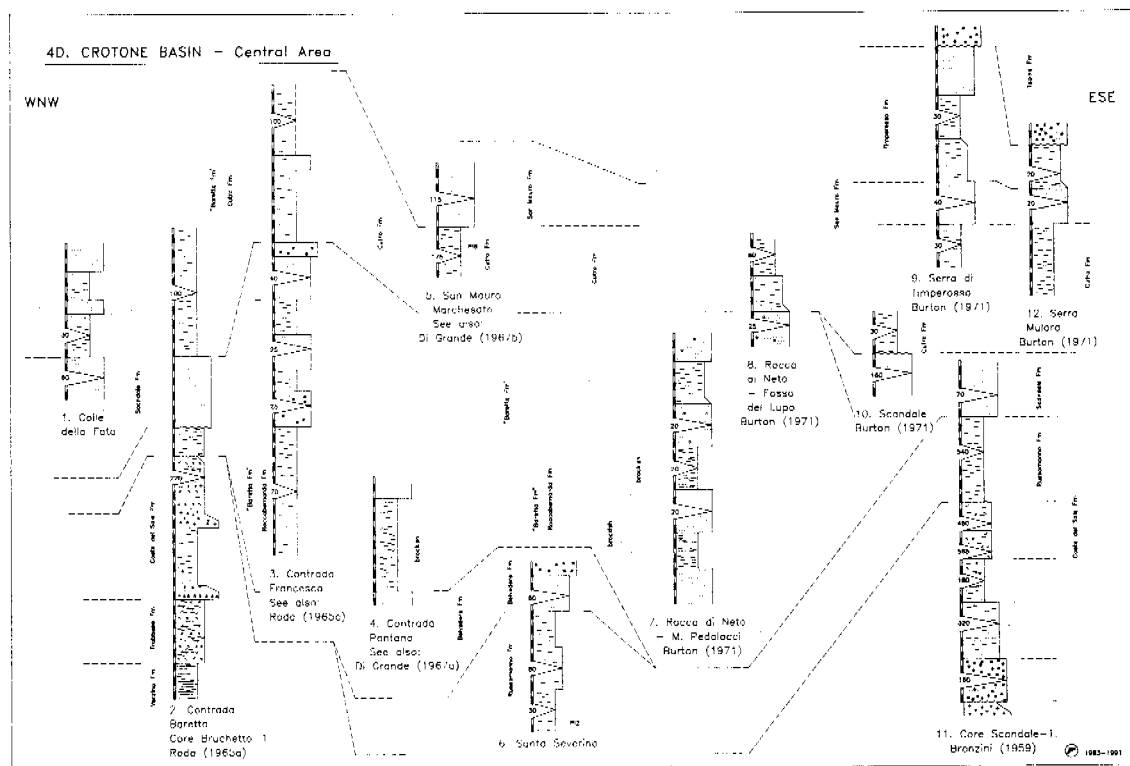


Fig. 6 i

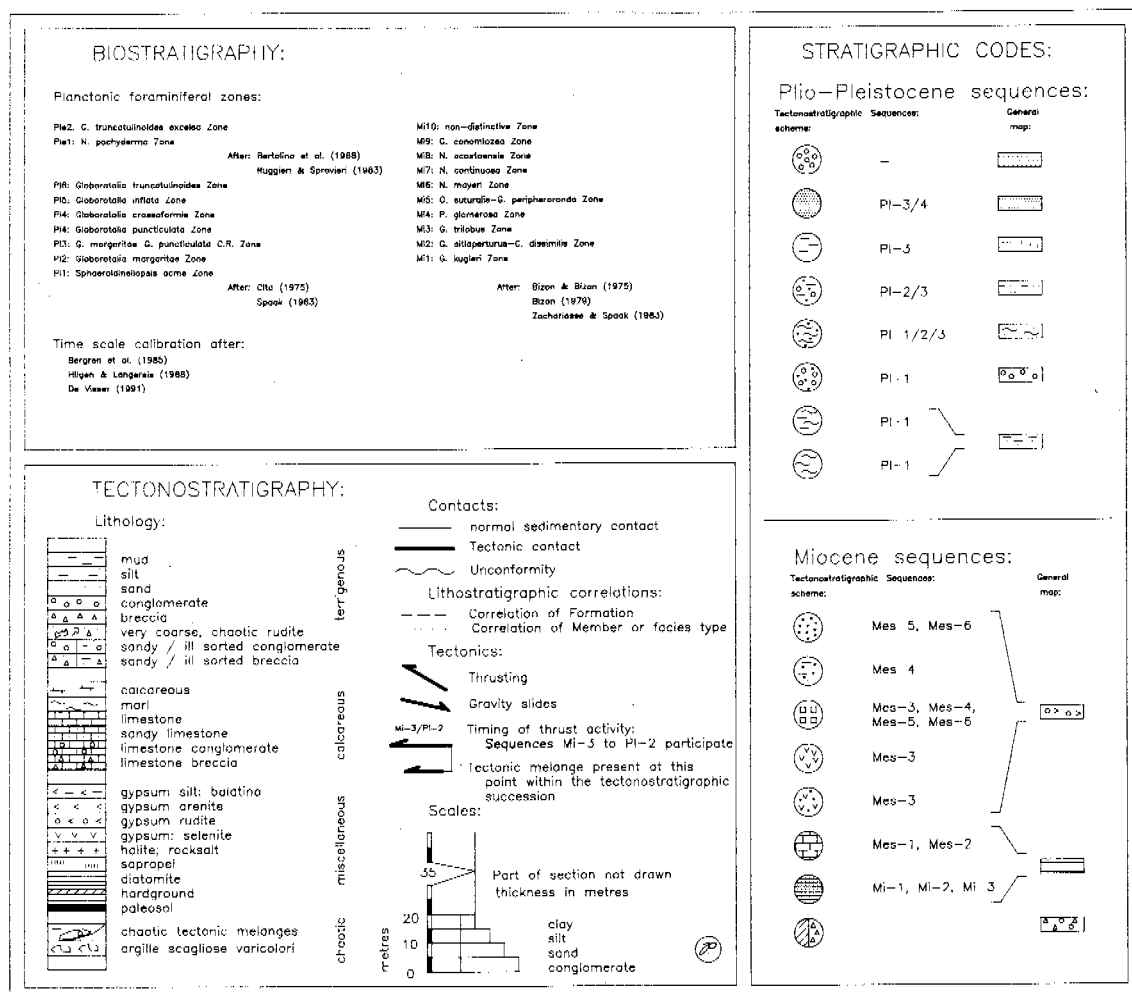


Fig. 7 - Legend for the tectonostratigraphic schemes of fig. 6.

Lower-middle Messinian «Lower Evaporites» sequence (Mes-1 and Mes-2): The base of the first sequence resembles the base of the previously described sequences; the outgrowth of a fan-body in the basin (Scala Coeli Fm in the Ciro-Rossano Area in the north), transgressive sands and marine clays along the margin (Cropani and Loggia Mbs in the central and southern areas). The top of the sequence, however, shows a deviating picture: Along the basin margin, the deposits grade into diatomites followed by dolomitic limestone-rudites («Calcare di Base»; Scavino Fm), whereas in the centre intercalations of sapropelites and diatomites are followed by clastic

gypsum, varying from fine-grained balatino-type to coarse grained gypsum arenites (Trabese Fm). The evaporites locally directly overlie basement, representing the base of the second Messinian sequence. This development reflects the local onset of the Messinian salinity crisis (see for a discussion of comparable facies in Sicily OGNIBEN, 1957 and DECIMA *et alii*, 1988). The top of the second sequence shows an upwards fining into carbonate-margin turbidites or carbonate sands with increasing influx of debris-flow material along the margins («lower fines facies» of the Theodore Fm in the Petilia-Mesoraca area; see for facies models McILREATH & JAMES, 1979). Upwards

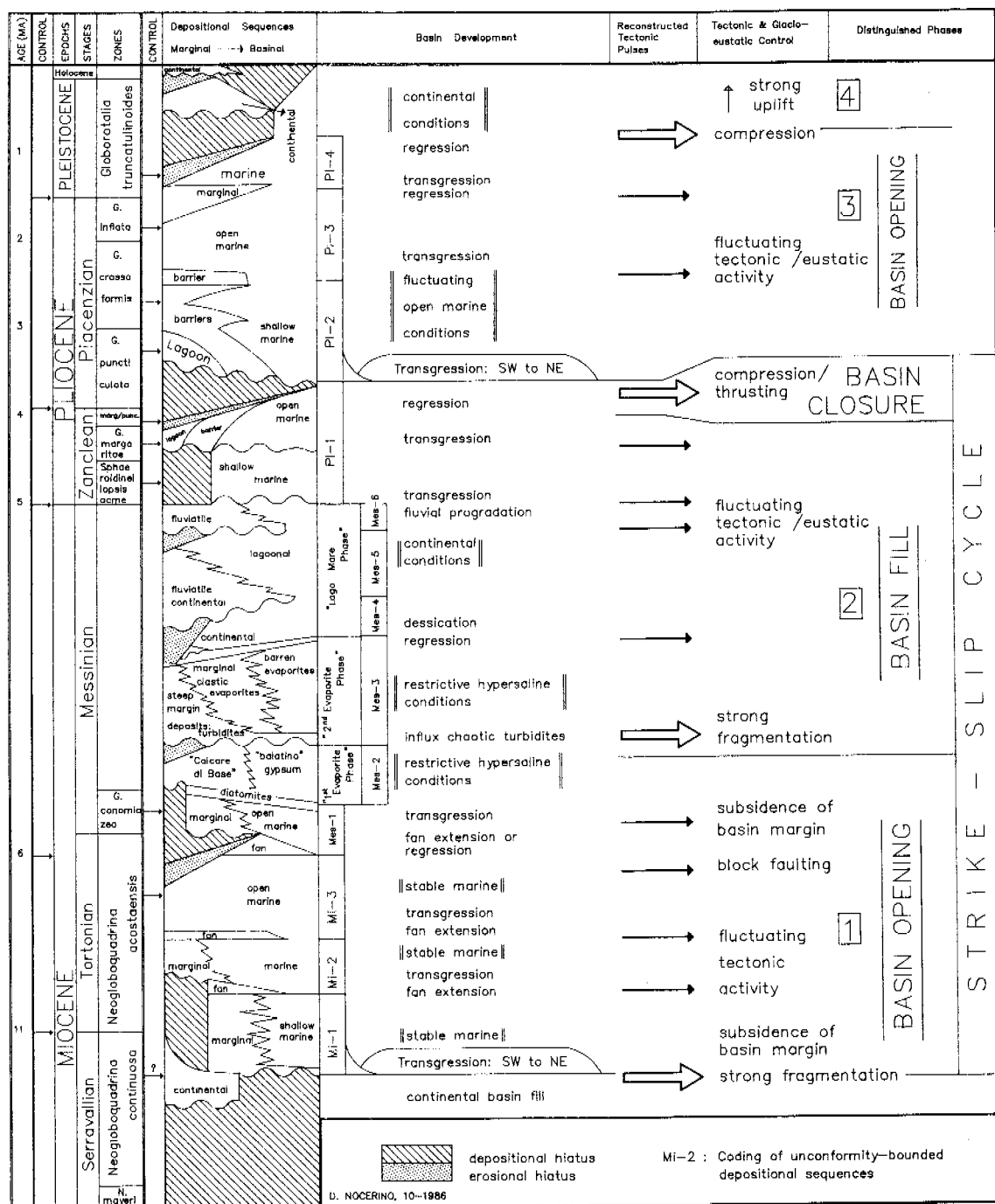


Fig. 8 - Composite synthetic tectonostratigraphic scheme for the basin development of Central and Northern Calabria. Modified from VAN DIJK & OKKES (1988, 1990 and in press.) and VAN DIJK (1991).

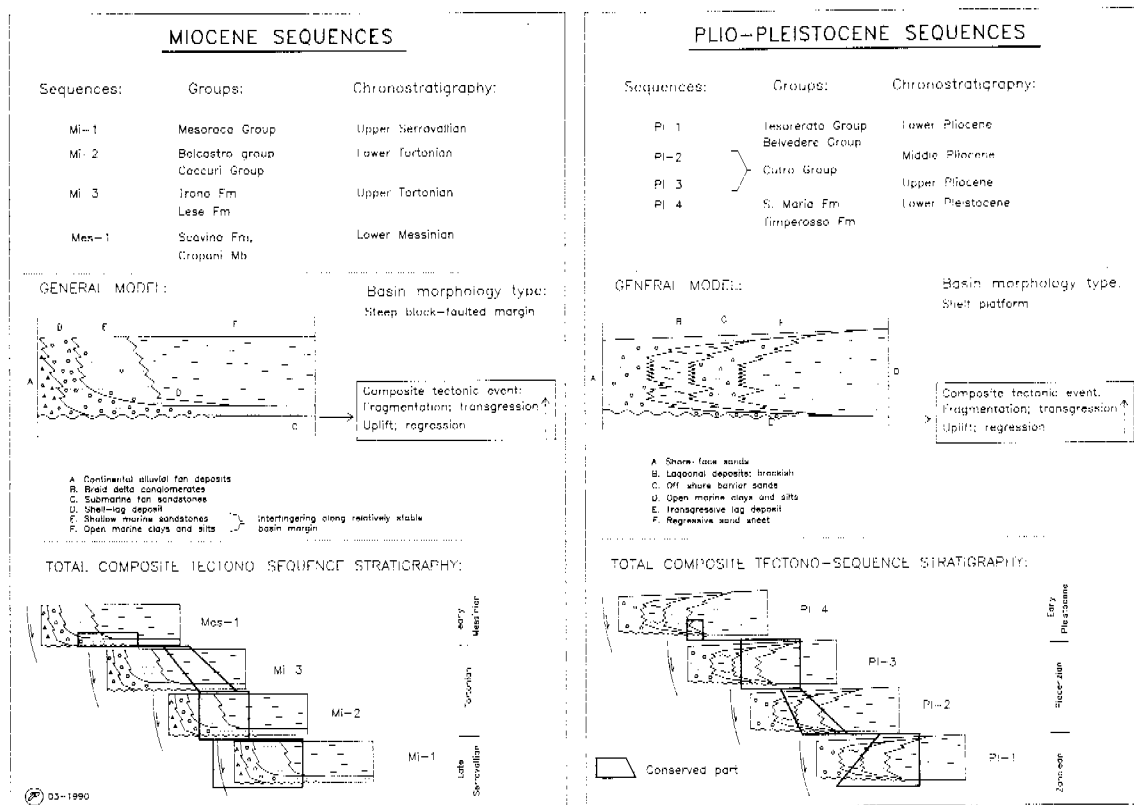


Fig. 9 - Sequence models for the Miocene and Pliocene of the Croton Basin.

grading into silts and clays with intercalated gypsum turbidite layers occurs in the central area (Coste del Sale Fm).

Middle-upper Messinian «Upper Evaporites» sequence (Mes-3): The base of this sequence locally shows growth faults with a N140 and N090 trend and slide blocks containing lower Messinian deposits, associated with very coarse clastics comprising olistostromes and alluvial fan deposits («middle megabreccia facies» of the Teodoro Fm in the Petilia-Mesoraca area). These deposits are followed by silts and sands with thin limestone-sand intercalations («upper sands/silts facies»), resembling the Colombacci-type lacustrine deposits of the Northern Apennines (SELLI, 1973). In the central area, a thick sequence of clastic gypsum and salts was formed (Coste del Sale Fm; see for facies models the review of basinal evaporites of KENDALL, 1979). In the area north of the Croton Basin,

this sequence is represented by a turbidite succession, resembling the Upper Messinian sequences of the Central Apennines such as the Laga Flysch Fm (SELLI, 1973). This can (also) in the Calabrian case be interpreted as the representation of a depositional system along the active margin of the evaporite basin. The top part of the sequence shows a shallowing with increasing influx of sandy material, followed by a distinct level of gypsum siltstones (Salinella Mb and Cutuchiusa Fm) which is recognizable over a large area (from Belvedere di Spinello in the central area up to Catanzaro in the south). These gypsum silts probably reflect the erosion of older gypsum deposits due to a regional relative sea level lowering, precluding the «Lago Mare» stage.

Upper Messinian «Lago-Mare» sequence (Mes-4 to Mes-6): In the upper Messinian continental deposits we distinguish the following three sequences:

«Lago-Mare sequence 1» (Mes-4): These deposits consist of fluvatile sandstones and hyposaline/brackish laminated fines with desiccation cracks (Cortisa Fm; Paternise Fm), directly overlying the uppermost gypsum deposits. Locally continental breccias are present with an unconformity at the base. Of this sequence, we found only remnants with a thickness of at most 15 metres.

«Lago-Mare sequence 2» (Mes-5): This sequence consists of large sheets of conglomerates and sandstones (Carvane Fm) which once probably covered the whole area from Strongoli in the north up to Cropani in the south, although now only remnants are present along major NW-SE trending fault zones. The base shows channel structures which cut into older Messinian sequences down to the lower Messinian «Calcare di Base». We interpret the deposits as braid plain to braid delta deposits (*sensu* McPHERSON *et alii*, 1987) reflecting a strong lowering of the base level of erosion and a (partly) dessicated basin.

The material, in literature referred to as «Sicilide» (e.g. OGNIBEN, 1973) is polymictic with a high abundance of pebbles of Mesozoic rock provenance. Some authors concluded that its origin is more external (S, SE or NE) in a formerly uplifted area (OGNIBEN, 1973). This conclusion was based on 1) Source rocks do not outcrop in the Sila, 2) The upper Messinian conglomerates show a sequence of polymict to crystalline material (BURTON, 1971) reflecting a switch from external to internal source-area (Messinian-Early Pliocene), 3) The Cariatidi thrust mass (BONFIGLIO, 1964; RODA, 1965 a) in the North which comprises Messinian terrains, is transported from NE to SW; if gravitational sliding is the operative emplacement mechanism, the external area is consequently the uplifted section. We do not support any of the listed arguments; 1) Our data indicate a much more complicated stratigraphy of the upper Messinian coarse clastics than the one proposed by the mentioned authors and we even place the clastics with crystalline material, used by BURTON (1971) to support his idea, in a position below and not above the Carvane conglomerates, 2) Mesozoic sequences do outcrop in the Sila and furthermore the rest of the source-area may simply be present in subsided terranes in the Tyrrhenian Basin, and 3. We presented a different tectonic model for the transportation of the thrust masses (VAN DIJK & OKKES, 1988, 1990) implying that they are back-thrusts to the SW, and were furthermore not displaced in the Messinian but in middle Pliocene times.

Discussions related to this issue regard the intercalations of Argille Scagliose in the Messinian deposits in the central and northern marginal areas which were interpreted by OGNIBEN (1955), RODA (1964) and MEULENKAMP *et alii* (1986) as being sedimentary in origin (Late Tortonian-Early Pliocene olistostromes). We have established that the phenomena related to these chaotic units can be separated into middle Messinian gravitational slides (Costa del Sale Fm; comparable to the

middle megabreccia facies of the Teodoro Fm in the southern marginal area) and middle Pliocene thrusts which cut upwards through the stratigraphy (fig. 6).

The top of the sequence shows upward grading into lagoonal fines (Gigli Fm). We interpret this as the reflection of a decrease in the supply of clastic material (by a flattening of the relief). «Lago-Mare sequence 3» (Mes-6): The top of the Messinian comprises a distinct level of fluvatile sandstones and conglomerates (Arvano Fm). In the studied area, the sequence reaches a maximum thickness of 10 metres. To the south of the area, however, much greater thicknesses (up to 50 metres) have been documented, e.g. in the Soverato area in Central Calabria. Along the basin margin (e.g. near Cropani) the deposits overlie basement rocks (Calamo Fm). We concluded that this level reflects a tectonic pulse responsible for the uplift of the source area and increase in supply of clastic material. This tectonic pulse is followed by the regional transgression at the beginning of the Pliocene, which indicates that the events at the Miocene-Pliocene boundary show a picture which is similar to the composite tectonic event described above. Following this concept, the Mes-6 and the Pli-1 sequences can be taken together as one.

Lower Pliocene sequence (P1-1): The Lower Pliocene sequence consists of fine grained clastics unconformably overlying older deposits (Russomanno Fm, Farago Fm, Tesorato Fm). It comprises both brackish, lagoonal fines, as well as shallow marine clays («Cavaliere Fm» of RODA, 1964), silts and sandstones. The lowermost (marine) Pliocene (Farago Fm) is only locally present along the southern margin in upthrust blocks. It must be stressed that the Pliocene clastic deposits which overlie older terrains along the margin in the central area cannot always be placed with certainty at their correct stratigraphic position. The reconstruction is strongly hampered by tectonic complications and by the fact that biostratigraphic assignments cannot always be performed. We named the total package «Baretta Fm»; only in cases of clear stratigraphic position (large sand bodies, biostratigraphic assignments, clear facies relations), specific formation names have been used. The top of the sequence consists of a thick series of sandstones and conglomerates

(Belvedere Fm). The sequence as a whole fits in a general model which we constructed for the successions of the Pliocene-Pleistocene sequences (fig. 9; see below). It reflects a migrating regressive lagoonal-barrier-open marine depositional system.

Upper Pliocene-Lower Pleistocene sequences (Pl-2 to Pl-4): These three open marine sequences (Cutro Group) show, like the Miocene sequences, a standard succession (fig. 9). Each sequence comprises lagoonal, brackish fines («Spartizzo Fm» of RODA, 1964), barrier-island sands (e.g. the Strongoli Fm) and open marine fines (Cutro Fm), showing complex interfingering relations. Differences between the sequences include relative thickness of the various facies and in some cases absence of certain parts due to erosion. The base of each sequence shows fines and sands overlying previous successions (Tortonian, Messinian, Lower Pliocene) and indicating rapid onlap. The top of the sequences consist of relatively thick, littoral sandstones showing a rapid regressive trend (Scandale Fm, San Mauro Fm).

Like in the Miocene sequences, the total repetitive patterns in the Pliocene and Lower Pleistocene seem to reflect the continuing enlargement of the basin with a pulsating onlap. We therefore propose a comparable model as for the Miocene sequences (fig. 9) i.e. the sequences are separated by a composite tectonic event comprising an uplift phase followed by rapid subsidence, although in the Pliocene case the basin evolution seems to be more gradual.

Upper Pleistocene deposits: Along the southern coast (Botricello), masses of debris-flow material comprising Messinian and Pliocene deposits and slide blocks are present, associated with rotational antithetic faulting (Magliacane Fm). We can only tentatively place these phenomena in the middle Pleistocene, as they are overlain by Upper Pleistocene clastics. The Upper Pleistocene continental (braid-plain/lacustrine) and shallow marine (shoreline) deposits (Scellia Fm, Tacina Fm) are present as various terraces and have been well described in the literature (see for a review OGNIBEN, 1973).

The variations in height above sea level been linked to relative sea level fluctuations as well as to small-scale faulting (see also COSEN-

TINO *et alii*, 1989). Near Le Castella, we observed synsedimentary monoclinal folding (also reported by BRONZINI, 1959 in seismic studies nearby) and tapering indicating opening to the NE along NNW-SSE trending faults.

Sub-) Recent deposits: These are recent deposits in river braid-plains, along the sandy coast and as cones and landslides along the margins of the Sila Massif.

BASIN EVOLUTION AND KINEMATICS

Combining the available information on sequence stratigraphy and tectonics, a general basin development scheme can be constructed (fig. 8). The evolution of the basin can be divided into four stages, which are separated by the main tectonic phases. These phases are distinguished on the basis of the occurrence of features which indicate compressional tectonics and/or the occurrence of angular unconformities. 1) Serravallian-early Messinian stage, 2) middle Messinian-Early Pliocene stage with a late Early («middle») Pliocene Basin inversion phase, 3) Late Pliocene-Early Pleistocene opening stage, and 4) Late Pleistocene-Recent uplift stage.

VAN DIJK (1991) proposed the following kinematic model for the evolution of the Croton Basin (fig. 11): The basin is situated at the intersection of the NW-SE trending thrust system «A» (which is dominant in the area N of the Croton Basin) and the NE-SW trending thrust system «B» (which is dominant in the area SW of the Croton Basin). It is bordered in the NE and SW by two major NW-SE trending sinistral oblique crustal shear zones. The Middle Miocene to middle Pliocene development is characterized by a shearing of the area resulting in an evolution from the initial development of small strike-slip basins along wrench-faults to the final inversion of the whole area in the middle Pliocene. Following this kinematic model the first two stages can be linked to the Strike Slip Cycle of MITCHELL & READING (1978): 1) Late Serravallian-early Messinian «Basin Opening Stage», and 2) middle Messinian-Early Pliocene «Basin Fill Stage» with a late Early Pliocene «Basin Closure Stage».

The geohistory diagrams which we processed (figs. 12a and 12b), illustrate the patterns of vertical movements in respectively basin

		Sequences:	1	2	3	4	5	6	7	Deduced signals:	Explanation of criteria:
QUATERNARY	(Sub)Recent		*	*	*					MAIN TECTONIC PHASE relative + sea level ↑	Conclusive criteria
	Pi-4		*	*	*					Tectonics	
PLIOCENE	Pi-3			*	*	*				relative sea level ↑	
	Pi-2						*			MAIN TECTONIC PHASE	Conclusive criteria
	Pi-1		*	*			*			relative + sea level ↑	
								*		Tectonics	
MESSINIAN	Mes-6				*	*	*			relative sea level ↓	Conclusive/non-conclusive criteria
	Mes-5				X	X	X			Tectonics	
	Mes-4				X					relative sea level ↓	
	Mes-3						X			MAIN TECTONIC PHASE	Conclusive/non-conclusive criteria
	Mes-2		*	*	*	X	X	X		relative + sea level ↓	
			*	*						Tectonics	
	Mes-1		X	X			*			relative sea level ↑	Non-conclusive criteria
	Mi-3						X			Tectonics	
SERRAVALLIAN-TORTONIAN	Mi-2		*	*	*			*		MAIN TECTONIC PHASE	
	Mi-1			*	*		*	*		* Conclusive * Non conclusive	
				*	*		*	*			

Fig. 10 - Table indicating criteria used in the relativistic analyses of tectonics and sea level fluctuations. The asterix indicate criteria as have been used for recognition of tectonic activity in relation with the sequence boundary. The indication «+ relative sea level» refers to consensus in literature (see text) with respect to the occurrence of sea level fluctuations (Messinian salinity crisis, Pleistocene glaciations). The indication «relative sea level» in based on the absence of clear conclusive arguments of tectonic activity (negative proof).

margin and basinal settings. The diagrams show a continuous subsidence from the Serravallian to the Early Pleistocene, interrupted by short phases of high tectonic activity. The characteristic pattern of accelerating subsidence as shown by the diagram of the basin inward setting occurs frequently but not exclusively in foreland basins (compare with diagrams of ALLEN *et alii*, 1986; ARMAGNAC *et alii*, 1988; PIERI & MATTAVELLI, 1986). Notable is the difference in magnitude of vertical movements between the two settings, which illustrates how tectonic mechanisms control the system.

We furthermore present two examples of so-called Time-Snapshot Plots (fig. 13) which display the calculated topography for resp. 10.0 and 3.0 Ma. The two time moments which we choose are interesting because they show two distinct characteristic moments in the evolution of the basin: the first initial

development of small strike-slip basins along the Petilia-Sosti fault zone in the south (Late Serravallian-Early Tortonian), and the final stage just after the mid-Pliocene compression phase, when, in the same area, tectonic inversion can be seen, which represents the thrusting of the Miocene-Lower Pliocene deposits towards the southwestern basin margin.

The Messinian regional relative sea level fluctuations seem to overprint the general tectonic evolution. Both the onset as well as the end of the salinity crisis and dessication stages however display the same composite tectonic event as is present in the rest of the tectono-stratigraphic record. This argues for a regional control of this composite tectonic event (see further).

The middle Pliocene tectonic phase is reflected by a large-scale tectonic inversion of the basin. The sedimentary cover was folded and thrust against its margins, which can

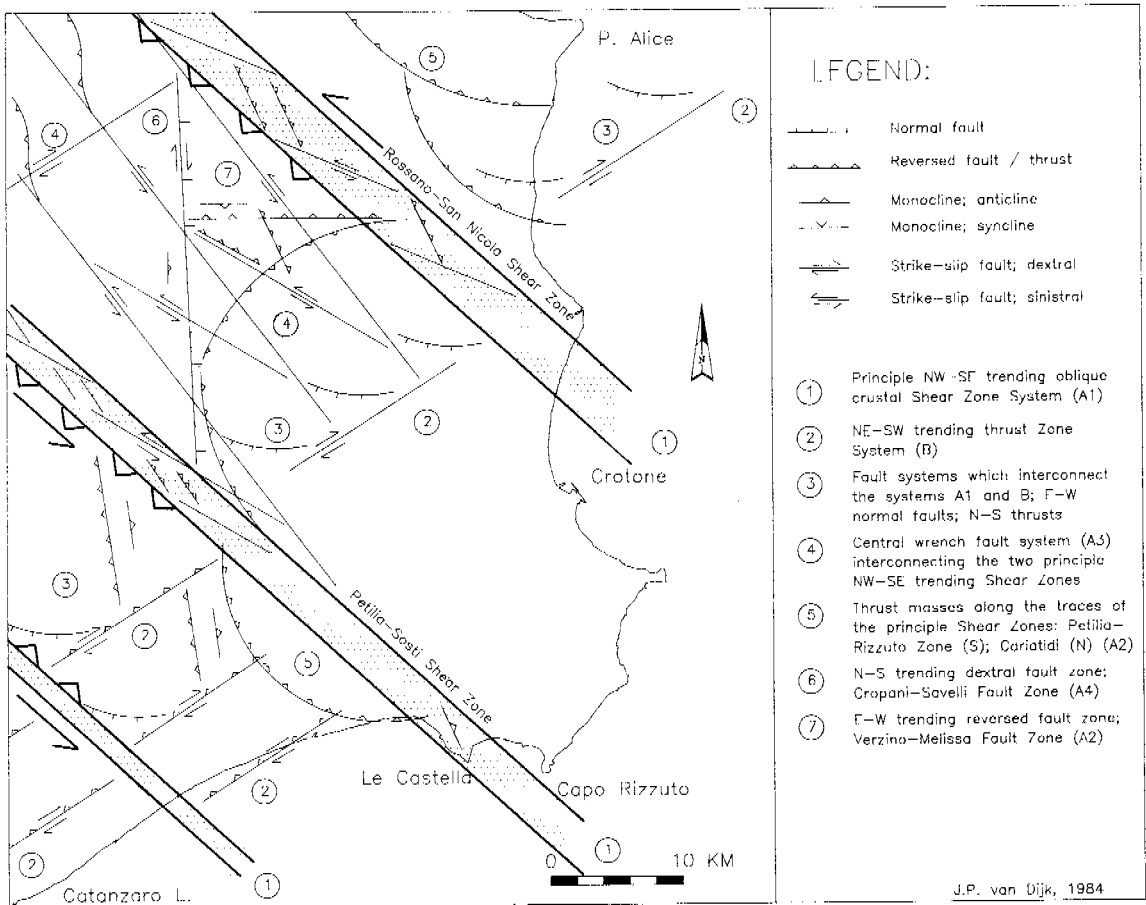
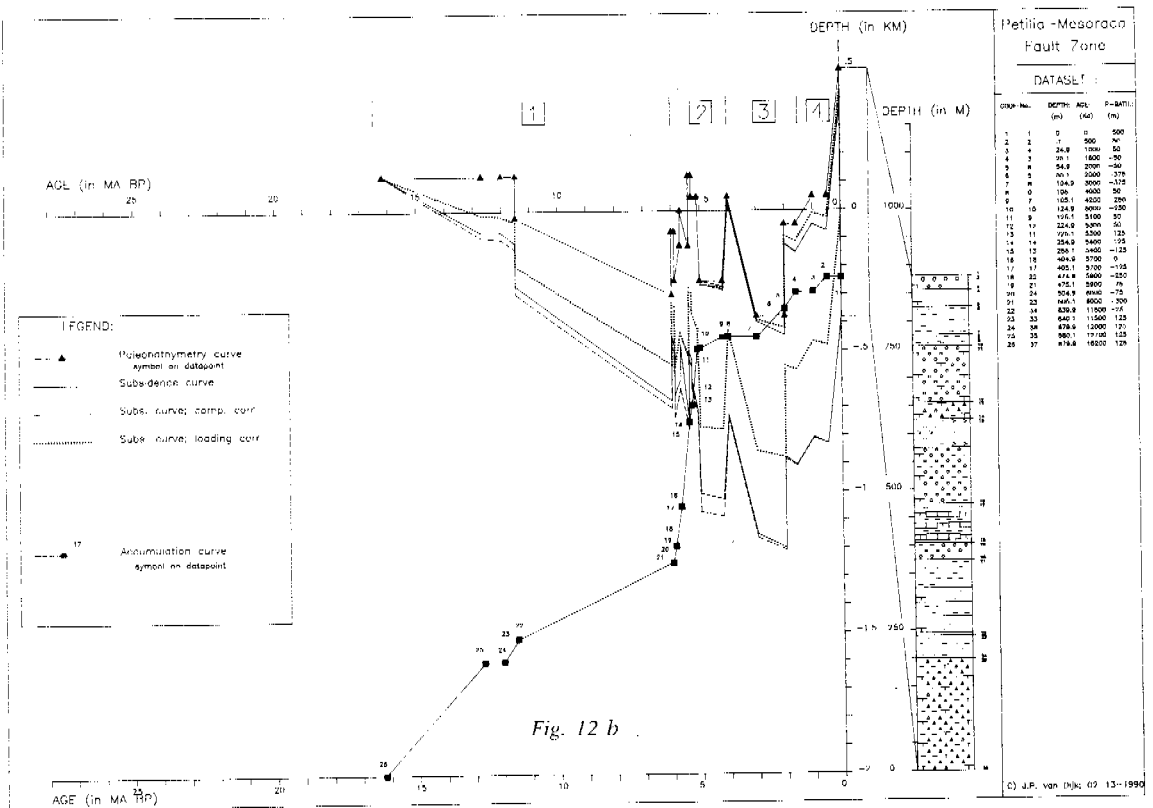
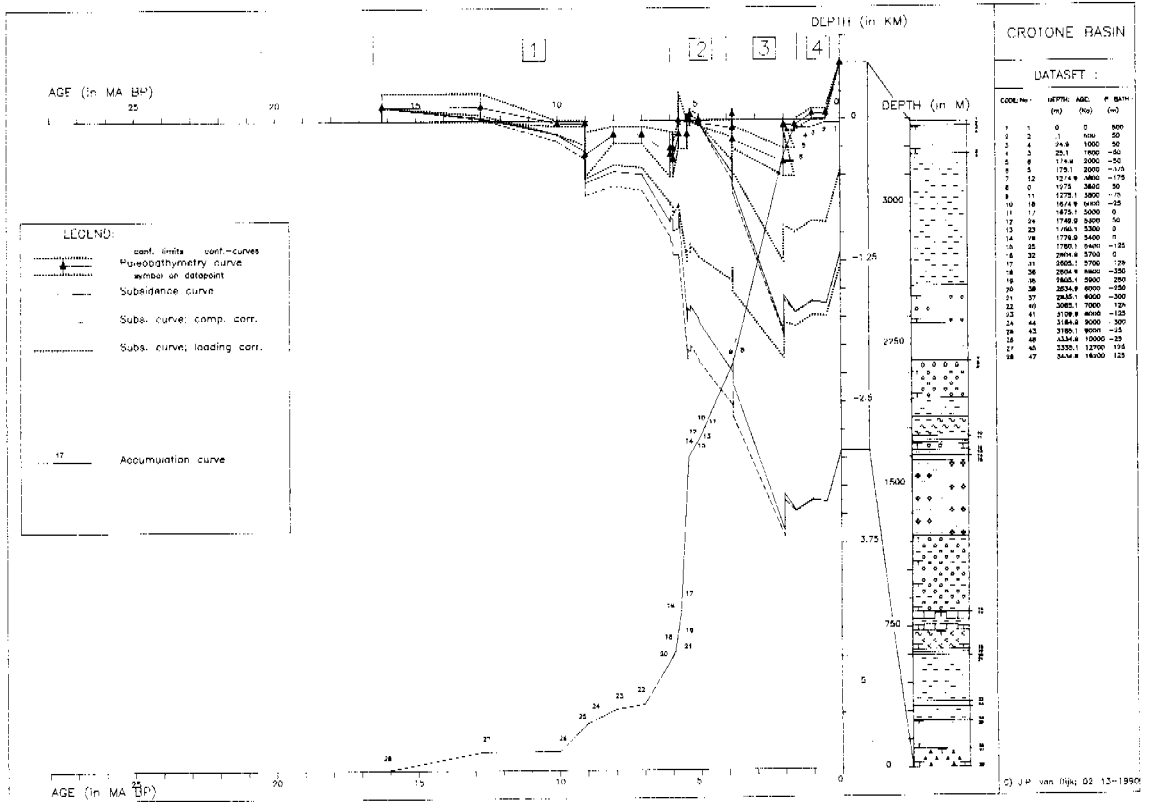


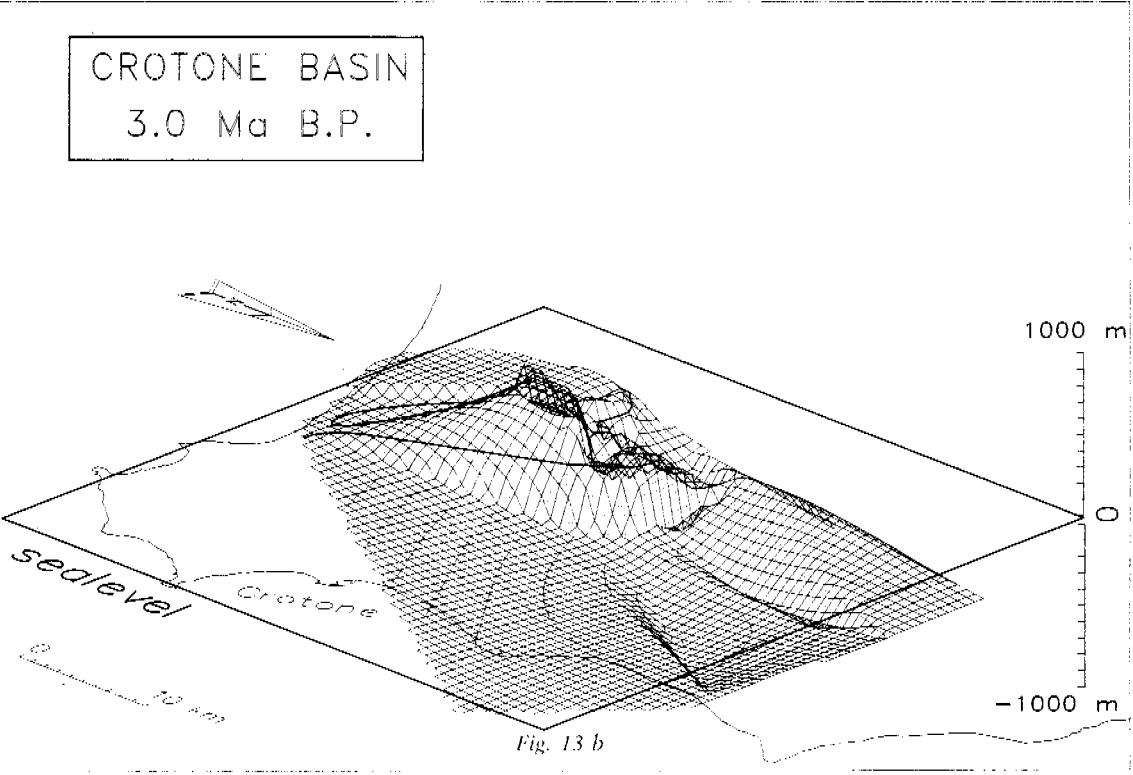
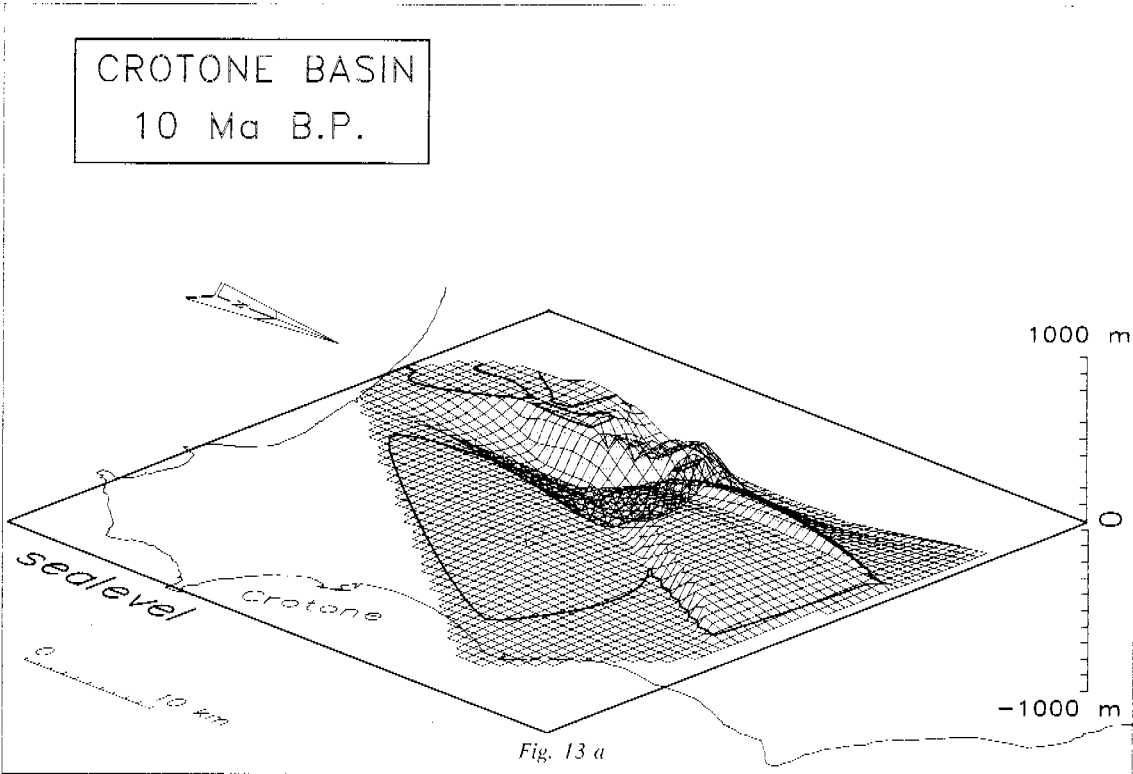
Fig. 11 - Kinematic model for the Late Neogene evolution of the Croton Basin. From VAN DIJK (1991). For a discussion of the structural data which were used to construct this model, and a differential analyses with existing basin models for the Calabrian Arc, we refer to VAN DIJK & OKKES (1990) and VAN DIJK (1991).

be interpreted as a result of on-going shearing of the area between the large shear zones. VAN DIJK (1991) compared the data from the Croton Basin with regional data from structural analyses (see for reviews AUROUX *et alii*, 1985;

BOUSQUET & PHILIP, 1986) and seismic profiles (ROSSI *et alii*, 1982), which support a regional character of this compression phase, linked to NE-SW shortening, roughly perpendicular to the NW-SE trending oblique sinistral shear zones.

Fig. 12 - Geohistory diagrams of the Croton Basin. Note the differences in scale between the two diagrams. The diagrams were processed from the composite tectonostratigraphic schemes (maximum thicknesses of formations) of fig. 4. This means that they must be regarded as representative for a whole area, and not, as in the case of a bore hole or land section, for one specific point. The paleobathymetry data are obtained by calibrating the depositional systems as discussed in the text (from lithofacies analyses) to depth zones as available in literature (referred in the text) for these depositional systems. The isostatic loading as has been applied, although it is probably not valid for foreland basins, gives an indication of the maximum influence of the sedimentary loading effect on the tectonic subsidence. The legend (based on Shell, 1976) can be compared to fig. 7b. a) Diagram of the central part of the Croton Basin. Note that in the diagram the basal coarse clastic deposits have been placed in the Langhian-Serravalian, following the second option (see text). b) Diagram of the Petilia-Policastro-Mesoraca area, along the southwestern margin of the Croton Basin.





During the Upper Pliocene-Lower Pleistocene stage, repetitive rapid shock-wise subsidence and on-lap occurred, which strongly resembles the Miocene evolution, though it seems to be more gradual (fig. 9). In combination with the large amount of sediment deposited this reflects an ongoing pulsating subsidence (fig. 12a). From middle Pleistocene onwards, the whole area was rapidly uplifted (ca. 0.1-0.5 cm/yr; see fig. 12 and also BIROT, 1980). Tensional fault systems developed as a response to rapid uplift of the Sila Massif.

DISCUSSION

The evolution of the Crotone Basin is closely related to its setting upon the Calabrian accretionary wedge system, developed as a response to the migration to the southeast of the Calabrian Arc (see references in the introduction). VAN DIJK (1991) discussed its development using the mechanism of DAHLEN (1990) and general suggestions of CLOETINGH (1988): The composite tectonic event can be linked to the progressive pulsating growth of the accretionary wedge during stages of migration of the Calabrian Arc to the SE. One such event represents a phase of active thrusting, followed by a phase of restabilization of the wedge morphology by means of progradation of the thrusting. The association of regional sea level fluctuations with local tectonic signals (early Messinian relative lowering, sudden rise at the Miocene/Pliocene boundary) suggests that these fluctuations may be controlled by regional tectonic mechanisms. An important argument in favour of this hypothesis is the fact that the tectonic events, as have they been recognized (fig. 8) can be calibrated with tectonic phases as described for the entire Central Mediterranean system (MEULENKAMP, 1982; PATACCA & SCANDONE, 1989; see for also VAN DIJK & OKKES, in press. and VAN DIJK, 1991). As such, regional tectonics may have triggered the growth pulses of the accretionary wedge system by temporarily

blocking the subduction process or by triggering wedge restabilization.

This development was overprinted by the increase in regional NE-SW stress in the middle Messinian-middle Pliocene and in the middle Pleistocene-Recent phases, which led to resp. basin inversion (middle Pliocene) and rapid uplift of the area (Late Pleistocene-Recent). This last phenomena may have resulted from a process of restabilization of isostatic equilibrium after the rupture of the subducted lithosphere slab in the middle Pleistocene-Recent phase of regional stress (see VAN DIJK & OKKES, 1988, 1990 and in press. VAN DIJK, 1990 and references therein).

As a final exercise, we compared the basin development scheme for the Crotone Basin, extended with information from the rest of the Calabrian realm (fig. 14) with the cycle-cart for global sea level fluctuations (HAQ *et alii*, 1987). From this (preliminary) comparison it can be concluded that the sequences as reconstructed in the Calabrian Arc compare pretty well in both magnitude and timing with third order «eustatic» cycles. This strongly argues for a global tectonic control through fluctuations of intraplate stresses, on both regional tectonics as well as global sea level fluctuations, as put forward by CLOETINGH (1988 and references therein). Also, major alternating phases of basin inversion and fragmentation (middle Oligocene, late Burdigalian, late Scrvallian) separate periods with each a unique general trend of rising or falling sea level (building up or gradual release of intraplate stress in terms of the «Cloetingh model») and coincide with periods of high frequency and large amplitudes of sea level fluctuations. The basin development stages delimited by these phases are comparable in size with the second order cycles.

CONCLUSIONS

The Neogene tectonostratigraphy of the Crotone Basin can be subdivided in a number

Fig. 13 - Preliminary Time-Snapshot Plots «synthetic landscapes» for the Crotone Basin with emphasis on its southern margin. The plots show calculated topography for the indicated moment in time. The thick line represents the coast line. The view-direction is SW. The plots have been processed using the available stratigraphic, lithofacial and biostratigraphic information within the concept of the geometrical and kinematic model for the basin we developed. They were calculated by means of extrapolation in space and time and related surface-fitting between various geohistory diagrams of the composite tectonostratigraphic columns which each represent the development of a part of the basin (see for methodology Van Dijk, in press.). a) Time-Snapshot Plot for 10.0 Ma. b) Time-Snapshot Plot for 3.0 Ma.

of unconformity-bound depositional sequences. The Late Serravallian-Tortonian and the Pliocene-Early Pleistocene sequences are separated from one another by a composite tectonic event, comprising a phase of uplift and increase of supply of clastic material, shortly afterwards followed by a phase of rapid subsidence and onlap. Both phases are related to tectonic activity along the basin margin.

The evolution of the Croton Basin can be divided in four stages: 1) Late Serravallian-early Messinian basin opening stage, 2) middle Messinian-Early Pliocene basin fill stage, which ended with a middle Pliocene compression phase with a tectonic inversion of the basin, 3) Late Pliocene-Early Pleistocene opening stage and 4) Late Pleistocene - Recent uplift stage with uplift of the Sila Massif and intense tensional faulting. The first two stages (Late Miocene-Early Pliocene) together reflect the Strike-Slip Cycle of MITCHELL & READING (1978).

The development of the basin was controlled by the local tectonic activity of the accretionary wedge system, overprinted by fluctuations in regional stress. Both local tectonic activity as well as regional relative sea level fluctuations are probably also controlled by regional tectonic mechanisms.

ACKNOWLEDGEMENTS

I greatly appreciate the collaboration of X. Behne, W.A. Boeckman, T. Bor, F. Jorissen, R.P.A. Kievits, H. Maassen, R. Matheussens, A. Meertens, F.W.M. Okkes, E. Rohling, H. Schmied and B.J.H. Westerop in the fieldwork and I thank them for sharing their field data. The assistance and valuable suggestions of J.A. Broekman, S. Cloetingh, F.J. Hilgen, J.E. Meulenkamp, W.J. Zachariasse and G.J. v.d. Zwaan concerning fieldwork, sample analyses and corrections of the manuscript have been of great importance. Thanks are due to R. ten Dam, F.W.M. Okkes and P. Sjoerdsma for the assistance in the development of the software for the geohistory analyses management system. I thank W.A. den Hartog, T. van Hinte and A. Nocerino for the assistance in the preparation of the drawings, and G.C. Ittman and G.J. van 't Veld for the preparations of the samples.

*Manoscritto pervenuto il 9 ottobre 1990.
Testo approvato per la stampa il 2 maggio 1991.
Ultime bozze restituite il 9 settembre 1991.*

REFERENCES

- ALLEN P., HOMEWOOD P. & WILLIAMS G.D. (1986) - *Foreland basins: an introduction*. In: Foreland basins., ALLEN P. & HOMEWOOD P. (eds.), Int. Ass. Sedim., Spec. Publ. no. 8, Blackwell Science Publ., 3-12.
- AMODIO-MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., PERRONE V., PICCARETTA G., RUSSO M., SCANDONE P., ZANETTIN-LORENZONI E. & ZUPPETTA A. (1976) - *L'Arco calabro-peloritano nell'orogene appenninico maghrebide*. Mem. Soc. Geol. Ital., **17**, 1-60.
- ARMAGNAC C., BUCCI J., KENDALL C.G. ST. & LERCHE I. (1988) - *Estimating the thickness of sediment removed at an unconformity using vitrinite reflectance data*. In: Thermal history of sedimentary basin, NAESER N.D. & McCULLOCH T. (eds), Methods and case histories, Springer-Verlag, New York, Ch., **13**, 217-238.
- AROUX C., MASCLE J., CAMPEDRON R., MASCLE G. & ROSSI S. (1985) - *Cadre géodynamique et évolution récente de la Dorsale Apulienne et de ses bordures*. Giorn. Geol., **3a**, **47**(1/2), 101-127.
- BENSON R.H. (1984) - *The Phanerozoic «crisis» as viewed from the Miocene*. In: Catastrophes in Earth history. The new uniformitarianism. BERGGREN W.A. & VAN COUVERING J.A. (eds), Princeton Univ. Press, Princeton, New Jersey, Ch., **17**, 437-446.
- BERGGREN W.A., KENT D.V. & VAN COUVERING J.A. (1985) - *The Neogene: Part 2*. In: The chronology of the geological record, SNELLING N.J. (ed), Mem. Geol. Soc. London, **10**, 211-260.
- BERTOLINO V. et alii (1968) - *Proposal for a biostratigraphy of the Neogene in Italy based on planktonic Foraminifera*. Proc. IVth session Comm. Mediterr. Neogene Strat., Bologna, 1967. Giorn. Geol., **35**, 23-30.
- BIROT P. (1980) - *La néotectonique Quaternaire dans l'Italie du Sud*. Rev. Géol. Dyn. Géogr. Phys., **23**(1), 1-72.
- BIZON G. (1979) - *Planctonic foraminifera*. In: BIZON, G. et alii (1979), Report of the Working Group on Micropaleontology. Ann. Geol. Hellen., 7th Int. Congress Medit. Neogene, Athens, 1340/3.
- BIZON G. & BIZON J.J. (1972) - *Atlas des principaux foraminifères planctoniques du bassin méditerranéen: Oligocène à Quaternaire*. Editions Technip., Paris, 1-316.
- BOCCALETTI M., NICOLICH R. & TORTORICI L. (1984) - *The Calabrian Arc and the Ionian Sea in the dynamic evolution of the Central Mediterranean*. Marine Geol., **55**, 219-245.
- BONARDI G., GIUNTA G., PERRONE V., RUSSO M., ZUPPETTA A. & CIAMPO G. (1980) - *Osservazioni sull'evoluzione dell'arco calabro-peloritano nel Miocene inferiore: la formazione di Stilo-Capo d'Orlando*. Boll. Soc. Geol. It., **99** (4), 365-392.
- BONFIGLIO L. (1964) - *La coltre alloctona di Cariati*. Atti Soc. Toscana Sc. Nat., S.A., **71**, 200-256.
- BOUSQUET J.C. & PHILIP H. (1986) - *Neotectonics of the Calabrian Arc and Apennines (Italy): An example of Plio-Quaternary evolution from island arcs to collision stages*. In: The origin of arcs, WEZEL F.-C. (ed), Developments in geotectonics, **21**, Elsevier, Amsterdam, 305-326.
- BRONZINI S. (1959) - *Note sulle ricerche di gas in alcune zone del litorale jonico*. In: I giacimenti gassiferi dell'Europa occidentale, Accademia Nazionale dei Lincei (ed), **1**, 399-405.

- BURTON A.N. (1971) - *Carta Geologica della Calabria alla scala di 1:25.000*, Relazione generale. Cassa per il Mezzogiorno, Servizio Bonifiche, Roma, 1-120.
- BURTON R., KENDALL C.G.St.C. & LERCHE E. (1987) - *Out of depth: on the impossibility of fanthoming eustasy from the stratigraphic record*. *Earth. Sci. Rev.*, **24**, 237-277.
- CITA M.B. (1975) - *Planktonic foraminiferal biozonation of the Mediterranean Pliocene deep sea record. A revision*. *Riv. Ital. Paleont.*, **81**, 527-544.
- CLOETINGH S. (1988) - *Intraplate stresses: a new element in basin analysis*; In: *New perspectives in basin analysis*, Pettijohn Volume, KLEISPEHN K.L. & PAOLA C. (eds), Springer Verlag, New York, Ch., **10**, 205-230.
- CONEY P.J., JONES D.L. & MONGER J.W.H. (1980) - *Cor-dilleran suspect terranes*. *Nature*, **288**, 329-333.
- COSENTINO D., GLIOZZI F. & SALVINI F. (1989) - *Brittle deformations in the Upper Pleistocene deposits of the Crotona Peninsula, Calabria, southern Italy*. In: *Paleoseismicity and neotectonics*, MÖRNER N.-A. & ADAMS J. (eds), *Tectonophysics*, **163**(3/4), 205-217.
- DAHLEN F.A. (1990) - *Critical taper model of fold-and-thrust belts and accretionary wedges*. - *Ann. Rev. Earth Planet. Sci.*, **18**, 55-99.
- DECIMA A., MCKENZIE J.A. & SCHREIBER B.C. (1988) - *The origin of «evaporative» limestones: An example from the Messinian of Sicily (Italy)*. *J. Sedim. Petrol.*, **58**(2), 256-272.
- DE VISSER J.P. (1991) - *Clay mineral stratigraphy of Mio-cene to recent marine sediments in the Central Mediterranean*. *Geol. Ultraieci.*, **75**, 1-243.
- DI GRANDE A. (1967a) - *La microfauna mediopliocenica di Contrada Pantano (Catanzaro) nell'Argilla mar-nosa di Spartizzo*. *Atti Acad. Gionia Sci. Natur. in Catania*, **19**, 66-92.
- DI GRANDE (1967b) - *Sezione-tipo della Molassa di S. Mauro (Calabrian) nel Bacino Crotonese*. *Riv. Ital. Palcont. Strat., Mem.*, **13**, 195-260.
- DUBOIS R. (1976) - *La suture calabro-apenninique Cre-tacée-Eocène et l'ouverture Tyrrhenienne neogene: étude pétrographique et structurale de la Calabre centrale*. These, Univ. de Paris, 1976, 1-567.
- EMBRY A.F. (1990) - *A tectonic origin for third-order depositional sequences in extensional basins - implications for basin modeling*. In: CROSS T.A. (ed.): *Quantitative e stratigraphy*-Prentice Hall (London), 491-501.
- FINETTI I. (1982) - *Structure, stratigraphy and evolution of the Central Mediterranean*. *Boll. Geof. Teor. Appl.*, **24**, 247-312.
- FINETTI I. & DEL BEN A. (1986) - *Geophysical study of the Tyrrhenian opening*. *Boll. Geof. Teor. Appl.*, **28**, 75-155.
- GHISETTI F. & VEZZANI L. (1981) - *Contribution of struc-tural analysis to understanding the geodynamic evo-lution of the Calabrian Arc (Southern Italy)*. *Journ. Struct. Geol.*, **3**, 371-381.
- GUÉREMY P. (1972) - *La Calabre centrale et septentrionale. Guide d'excursion géomorphologique*. *Trav. Inst. Géogr. Reims*, **10**, 1-128.
- GURRIERI S., LORENZONI S., STAGNO, F. & ZANETTIN LO-RENZONI E. (1982) - *Le magmatiti dell'Unità di Mon-te Gariglione (Sila, Calabria)*. *Mem. Sc. Geol. Pa-dova*, **35**, 69-90.
- GUIDISH T.M., KENDALL C.G.St.C., LERCHE I., TOTH D.J. & YARZAB R.F. (1985) - *Basin evaluation using burial history calculations: an overview*. *Bull. Am. Ass. Petr. Geol.*, **69**(1), 92-105.
- HAO B.U., HARDEBOL J. & VAIL P.R. (1987) - *Chronology of fluctuating sea levels since the Triassic*. *Science*, **235**, 1156-1167.
- HILGEN F.J. & LANGEREIS C.G. (1988) - *The age of the Miocene-Pliocene boundary in the Capo Rossello area (Sicily)*. *Earth Planet. Sc. Lett.*, **91**, 214-222.
- HOROWITZ D.H. (1976) - *Mathematical modelling of sedi-ment accumulation in prograding deltaic systems*. In: *Quantitative techniques for the analysis of sedi-ments*, MERRIAM D.F. (ed), Pergamon Press, Oxford, 105-119.
- IRWIN W.P. (1972) - *Terranes of the western Paleozoic and Triassic belt in the southern Klamath Mountains, California*. *U.S. Geol. Surv. Pap.*, **800-C**, 103-111.
- KENDALL A.C. (1979) - *Subaqueous evaporites*. In: *Facies Models*, WALKER R.G. (ed) - *Geoscience Canada*, Reprint Series no. 1, Ch. 14, 159-174.
- KRUMBEIN W.C. (1942) - *Criteria for subsurface recogni-tion of unconformities*. - *Bull. Amer. Ass. Petr. Geol.*, **26**, 36-62.
- MANTOVANI A., BABBUCCI D. & FARSI F. (1985) - *Tertiary evolution of the Mediterranean region; major out-standing problems*. *Boll. Geof. Teor. Appl.*, **27**(105), 67-90.
- MCLIREATH I.A. & JAMES N.P. (1979) - *Carbonate slopes*. In *Facies Models*, Walker R.G. (ed) - *Geoscience Canada*, Reprint Series no. 1, Ch. 12, 133-143.
- MCPHERSON J.G., SHANMUGAM C. & MOIOLA R.J. (1987) - *Fan-deltas and braid deltas: Varieties of coarse-grained deltas*. *Bull. Geol. Soc. Amer.* **99**, 331-340.
- MEULENKAMP J.E. (1982) - *On the pulsating evolution of the Mediterranean*. *Episodes*, **1**, 13-16.
- MEULENKAMP J.E. & HILGEN F.J. (1986) - *Event strati-graphy, basin evolution and tectonics of the Hellenic and Calabro-Sicilian Arcs*. In: *The origin of Arcs*, WEZEL F.-C. (ed) - *Developments in Geotectonics* no. **21**, Elseviers Publ. Comp., Amsterdam, 327-350.
- MEULENKAMP J.E., HILGEN F. & VOOGT E. (1986) - *Late Cenozoic sedimentary - tectonic history of the Cala-brian Arc*. In: *Paleogeography and geodynamics of the Perityrrhenian Area*, BOCCALETTI M., GELATI R. & RICCI-LUCCHI F. (eds), *Giorn. Geol.*, **3a**, 48(1/2), 345-359.
- MITCHELL A.H.G. & READING H.G. (1978) - *Sedimenta-tion & Tectonics*. In: *Sedimentary environments and facies*, READING H.G. (ed), Blackwell Scientific publications, London, 439-476.
- MÜLLER D.W. (1986) - *Die Salinitätskrise im Messinian (spates Miozän) der Becken von Fortuna und Sor-bas (Südost-Spanien)*. Sonderdruck der gleichna-migen Dissertation (Nr. 8056), Abteilung für Naturwissenschaften der ETH in Zurich (Schweiz), 1-183.

- MOUSSAT E. (1983) - *Evolution de la mer Tyrrhenienne centrale et ses marges septentrionales en relation avec la néotectonique dans l'Arc calabrais*. Thèse 3ème cycle, Univ. Pierre et M. Curie, Paris, 1-125.
- OGNIBEN L. (1955) - *Le Argille Scagliose del Crotonese*. Mem. e Note Ist. Geol. Appl. Napoli, **6**, 1-72.
- OGNIBEN L. (1957) - *Petrografia della Serie Solfifera siciliana e considerazioni geologiche relative*. Mem. descr. Carta Geol. d'Italia, **33**, 275 pp.
- OGNIBEN L. (1973) - *Schema geologico della Calabria in base ai dati odierni*. Geol. Romana, **12**, 243-585.
- PACCHIAROTTI E. (1984) - *Attività di ricerca di idrocarburi nei mari italiani*. Mem. Soc. Geol. Ital., **27**, 287-301.
- PATTACA E. & SCANDONE P. (1989) - *Post-Tortonian mountain building in the Apennines. The role of the passive sinking of a relic lithospheric slab*. In: The lithosphere in Italy; Advances in Earth Science Research. BORIANI A., BONAFEDE, M. PICCARDO G.B. & VAI G.B. (eds). Acc. Naz. Lincei, **80**, 157-176.
- PIERI M. & MATTAVELLI L. (1986) - *Geological framework of Italian petroleum resources*. Bull. Amer. Ass. Petrol. Geol., **70**(2), 103-130.
- PLATT J.P. (1986) - *Dynamics of orogenic wedges and the uplift of high-pressure metamorphic rocks*. Bull. Geol. Soc. Amer., **97**, 1037-1053.
- RODA C. (1964) - *Distribuzione e facies dei sedimenti neogenici nel Bacino Crotonese*. Geol. Romana, **3**, 319-366.
- RODA C. (1965 a) - *I sedimenti Neogenici autoctoni ed alloctoni della zona di Cirò-Cariati (Catanzaro e Cosenza)*. Mem. Soc. Geol. Ital., **6**, 137-149.
- RODA C. (1965 b) - *Geologia della tavoletta Belvedere di Spinello (Prov. Catanzaro, F. 237, I-SE)*. Boll. Soc. Geol. Ital., **84**(2), 159-285.
- RODA C. (1965 c) - *La sezione Pliocenica di Baretta (Bacino Crotonese-Calabria)*. Riv. Ital. Palcont., **71**, 605-660.
- ROSSI S., AUROUX C. & MASCLE J. (1982) - *The Gulf of Taranto (Southern Italy): Seismic stratigraphy and shallow structure*. Mar. Geol., **51**, 327-346.
- RUGGIERI G. & SPROVIERI R. (1983) - *Recenti progressi nella stratigrafia del Pleistocene inferiore*. Boll. Soc. Paleont. Ital., **22**, 315-321.
- SCHIRMER E.R., HOWELL D.G. & JONES D.L. (1984) - *The origin of allochthonous terranes: Perspectives on the growth and shaping of continents*. Ann. Rev. Earth. Planet., Sci., **12**, 107-131.
- SELLI R. (1973) - *An outline of the Italian Messinian*. In: Messinian Events in the Mediterranean, Drooger C. (ed), North Holland Publishing Company, Amsterdam, 150-171.
- SELLI R. (1975) - *Le Quaternaire marin du versant Adriatique-Ionien de la péninsule italienne*. Quaternaria, **6**, 391-413.
- SHANMUGAN G. (1988) - *Origin, recognition, and importance of erosional unconformities in sedimentary basins*. In: New perspectives in basin analysis. Petroleum Volume, KLEINSPEHN K.L. & PAOLA C. (eds), Springer Verlag, New York, Ch. 5, 84-108.
- SHELL INTERNATIONAL PETROLEUM COMPANY (1976) - *Standard legend*. Shell Int. Petr. Comp., SIPM, The Hague, 1976.
- SLOSS L.L. (1988) - *Forty years of sequence stratigraphy*. Bull. Geol. Soc. Amer., **100**, 1661-1665.
- SPAAR P. (1983) - *Accuracy in correlation and ecological aspects of the planktonic foraminiferal zonation of the Mediterranean Pliocene*. Utrecht Micropal. Bull., **28**, 1-160.
- STAM B., GRADSTEIN F.M., LLOYD P. & GILLIS D. (1987) - *Algorithms for porosity and subsidence history*. Comp. Geosc., **13**(4), 317-349.
- VAIL P.R., MITCHUM R.G. JR., TODD R.G., WIDMIER J.M., THOMPSON S. 3RD, SANGREE J.B., BUBB J.N. & HATLELID W.G. (1977) - *Seismic stratigraphy and global changes of sea level*. In: Seismic stratigraphy- Applications to hydrocarbon exploration, PAYTON C.E. (ed), Mem. Am. Ass. Petr. Geol., **26**, 49-212.
- VAN BEMMELEN R.W. (1976) - *Plate Tectonics and the Undation Model: a comparison* - Tectonophysics, **32**, 145-182.
- VAN DIJK J.P. (1991) - *Basin dynamics and sequence stratigraphy in the Calabrian Arc (Central Mediterranean); records and pathways of the Croton Basin*. Geol. Mijnb., **70**, 187-201.
- VAN DIJK J.P. (in press.) - *Four-dimensional restoration of sedimentary basins; the dynamic geohistory approach*. Submitted.
- VAN DIJK J.P. & OKKES F.W.M. (1988) - *The analysis of shear zones in Calabria; implications for the geodynamics of the Central Mediterranean*. La Ricerca Scient., Suppl., **68**, 24-27.
- VAN DIJK J.P. & OKKES F.W.M. (1990) - *The analysis of shear zones in Calabria; implications for the geodynamics of the Central Mediterranean*. Riv. Ital. Strat. Pal., **96**(2/3), Special Issue, 241-270.
- VAN DIJK J.P. & OKKES F.W.M. (in press.) - *Neogene tectonostratigraphy and kinematics of Calabrian Basins; implications for the geodynamics of the Central Mediterranean*. Tectonophysics, 196.
- VAN HINTE J.E. (1978) - *Geohistory analysis, application of micropaleontology in exploration geology*. Bull. Am. Assoc. Petr. Geol., **62**(2), 201-227.
- ZACHARIASSE W.J. & SPAAR P. (1983) - *Middle Miocene to Pliocene paleoenvironmental reconstruction of the Mediterranean and adjacent Atlantic Ocean: Planktonic foraminiferal record of Southern Italy*. In: Reconstruction of marine paleoenvironments, MEULENKAMP J.E. (ed), Utrecht Micropal. Bull., **30**, 91-110.
- ZANETTIN-LORENZONI E. (1982) - *Relationships of main structural elements of Calabria*. N. Jb. Geol. Paleont., Mh., **7**, 403-418.
- ZUFFA G.G. & DE ROSA R. (1978) - *Petrologia delle successioni torbiditiche Eoceniche della Sila Nord-orientale (Calabria)*. Mem. Soc. Geol. Ital., **18**, 31-55.