

## **Basin dynamics and sequence stratigraphy in the Calabrian Arc (Central Mediterranean); records and pathways of the Croton Basin**

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Received 29 June 1990; accepted in revised form 11 December 1990

*Key words:* Central Mediterranean, foreland basins, strike-slip, sequence stratigraphy, Neogene

### **Abstract**

The structural and tectonostratigraphical Late Neogene development of the Croton Basin is presented, a foreland basin in the accretionary wedge along the external side of the Calabrian Arc (Central Mediterranean). It demonstrates the role of local tectonic activity of the thrust wedge and that of regional relative sea level fluctuations on the formation of unconformity-bound depositional sequences.

The tectonostratigraphic development of the basin can be divided in 4 stages: 1. a Serravalian – early Messinian Stage, characterized by a progressive enlargement of the Basin, 2. a middle Messinian – Early Pliocene Stage, characterized by intense and complex fault movements that were overprinted by the Messinian salinity crisis, 3. an Upper Pliocene – Early Pleistocene Stage, characterized by a pulsating onlap, and 4. a Late Pleistocene – Recent Stage, characterized by strong vertical movements in conjunction with the uplift of the Sila basement Massif. At the end of Stage 2 regional compression during the Mid-Pliocene Phase inverted the basin and thrust its cover towards the margins. A kinematic model is proposed whereby the evolution of the Basin was controlled by oblique sinistral movements along two confining NW-SE trending convergent crustal shear zones. Within this concept, the Middle Miocene – Early Pliocene development (Stages 1 and 2) reflects a strike-slip cycle.

The sequence boundaries that belong to the Stages 1 and 3 are of remarkably similar tectonostratigraphic significance. They reflect a ‘composite tectonic event’ comprising an uplift/regression pulse, followed by a rapid subsidence/onlap. Each composite tectonic event is here considered to represent one growth pulse in the progressive evolution of the accretionary wedge system, while the middle Messinian – Early Pliocene phases of basin fill and tectonic inversion (Stage 2), and the Late Pleistocene – Recent uplift phase (Stage 4) reflect the increase of regional stress in the Central Mediterranean.

### **Introduction**

In the Central Mediterranean region the Calabrian Arc lies at the junction of three important orogenic systems: the western Mediterranean N. African-Betic Cordilleras system, the Apennine-Alpine

system and the eastern Mediterranean Aegean-Dinaride system (Fig. 1). Recently, Van Dijk & Okkes (in press) proposed a new evolutionary model for this area, which addresses aspects of the Late Neogene evolution of these three systems. In that model, the kinematic evolution of the Central

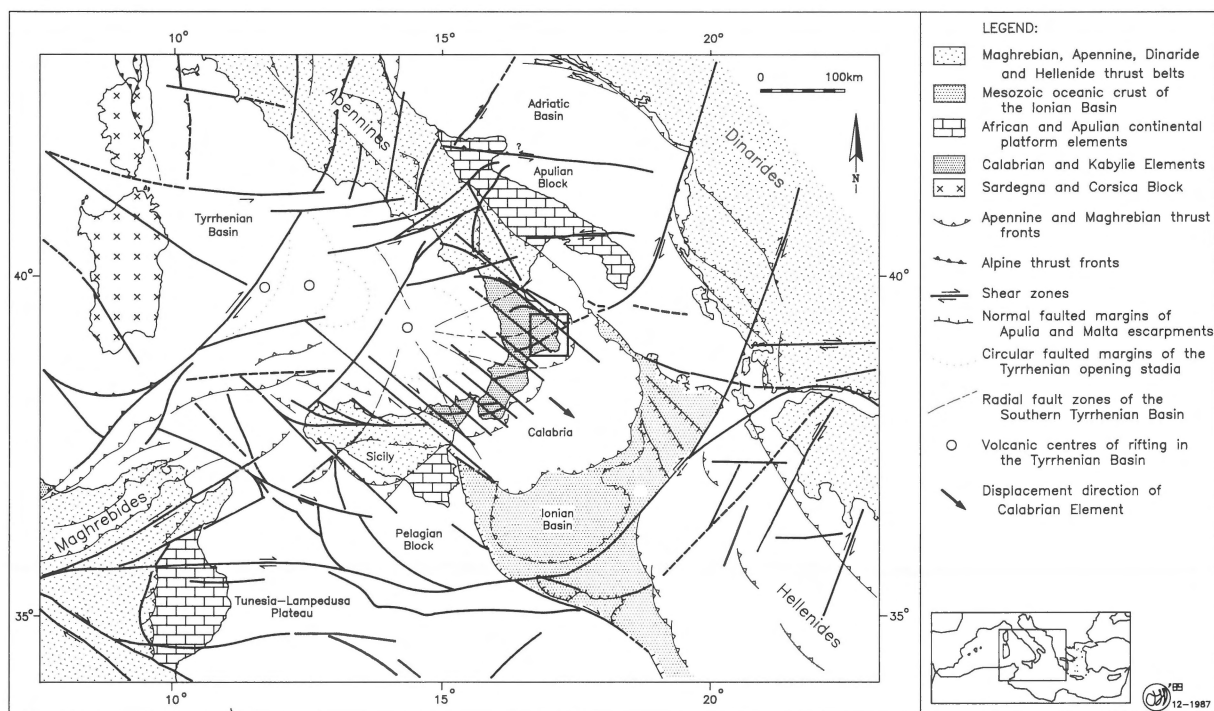


Fig. 1. Calabria in its Central Mediterranean setting after Van Dijk & Okkes (in press). The inset shows the location of the Croton Basin.

Mediterranean was characterized by two factors: 1. the sliding of the Calabrian Element\* to the SE along a basal mid-crustal detachment zone (due to gravitational instabilities created by slab-pull and asthenosphere doming in the back-arc region), and 2. lateral shear of the area by means of strike-slip movements along large E-W and NE-SW trending trans-Mediterranean shear zones with resulting NE-SW directed shortening. The latter movements were concentrated in distinct phases (L. Burdigalian, middle Pliocene and middle Pleistocene – Recent) in response to increasing regional stress induced by plate reorganizations. The Central Mediterranean appears to be highly interesting for the analysis of the interaction between sea level fluctuations, tectogenesis on various scales and formation of unconformity-bound depositional sequen-

es (see discussions in Vail et al. 1977, Burton et al. 1987, Haq et al. 1987, Sloss 1988, Cloetingh 1988). During the Messinian a drop in sea level and a subsequent sudden rise are thought to have been of global importance (Benson 1984, Müller 1986), and the large-scale tectonic activity of the area can easily be appreciated. This paper discusses these factors within a geokinematic and geodynamic model and describes some aspects of the Neogene evolution of the Croton Basin, which is situated at the northeastern, external side of the Calabrian Arc (Figs 1 and 2).

Previous studies of the Croton Basin described the stratigraphy but gave little information on the tectonic setting and development of the Basin (Ogniben 1955, Roda 1964, 1965, Burton 1971, Meulenkamp et al. 1986; for historical references see Ogniben 1973). Recently, some ideas have been expressed concerning the kinematic evolution of the Calabrian basins within the frame of regional models for the Arc: Ghisetti & Vezzani (1981) regarded them as being tensional triangular basins,

\* A microplate or amalgamated terrane following the terminology of Irwin 1972, Coney et al. 1980, Schermer et al. 1984, and adapted for the Calabrian Arc by Van Dijk & Okkes 1988, 1990.

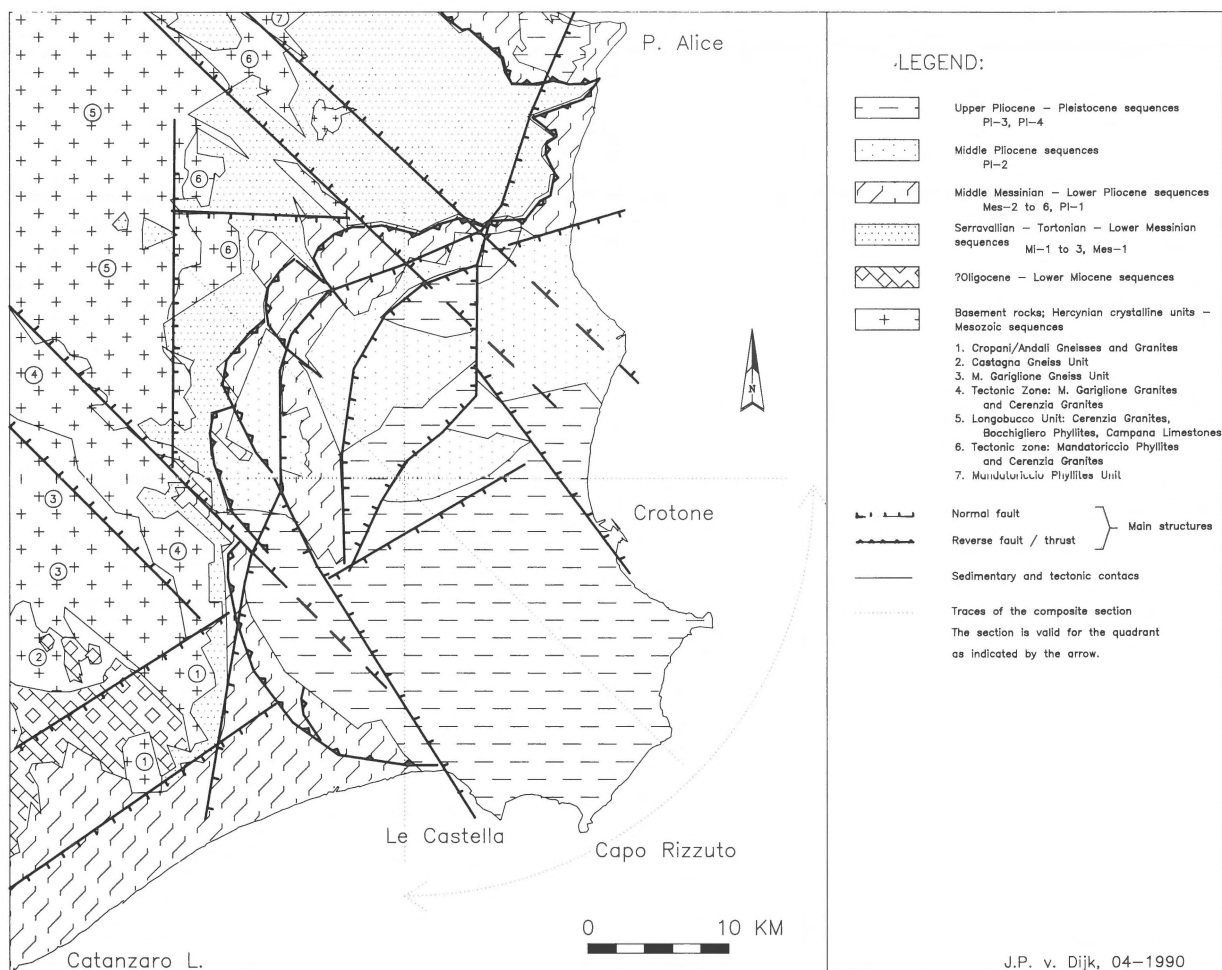


Fig. 2a. Geological sketch map of the Crotona Basin.

whereas Moussat (1983) and Boccaletti et al. (1984) considered them to be pull-apart basins between NE-SW trending shear zones. Van Dijk & Okkes (in press) proposed a different model in which these basins were regarded as oblique (transpressive) piggy-back basins. The present contribution aims to illustrate this last model.

## Methods

New data were gathered during a number of field campaigns between 1983 and 1989 in the internal area of the Crotona Basin. This resulted in 1:25.000 and 1:10.000 geological maps and stratigraphic schemes supported by biostratigraphic as-

signments to ca. 100 samples. The results were compared with previously published field studies (see references above and also Selli 1973, Dubois 1976, Gu er emy 1976, Gurrieri et al. 1982, Cosentini et al. 1989), seismic sections (Finetti & Morelli 1972, Finetti 1982, Rossi et al. 1982, Pacchiarotti 1984, Pieri & Mattavelli 1986), borehole data (Bronzini 1959, Roda 1965) and satellite photography studies (Biju-Duval et al. 1975). The composite tectonostratigraphic sequences were processed to construct geohistory diagrams using information on biostratigraphy and facies. The software is based on procedures described by Horowitz (1976) and Van Hinte (1978) and reviewed by Guidish et al. (1985). The backstripping algorithms are from Stam et al. (1987).

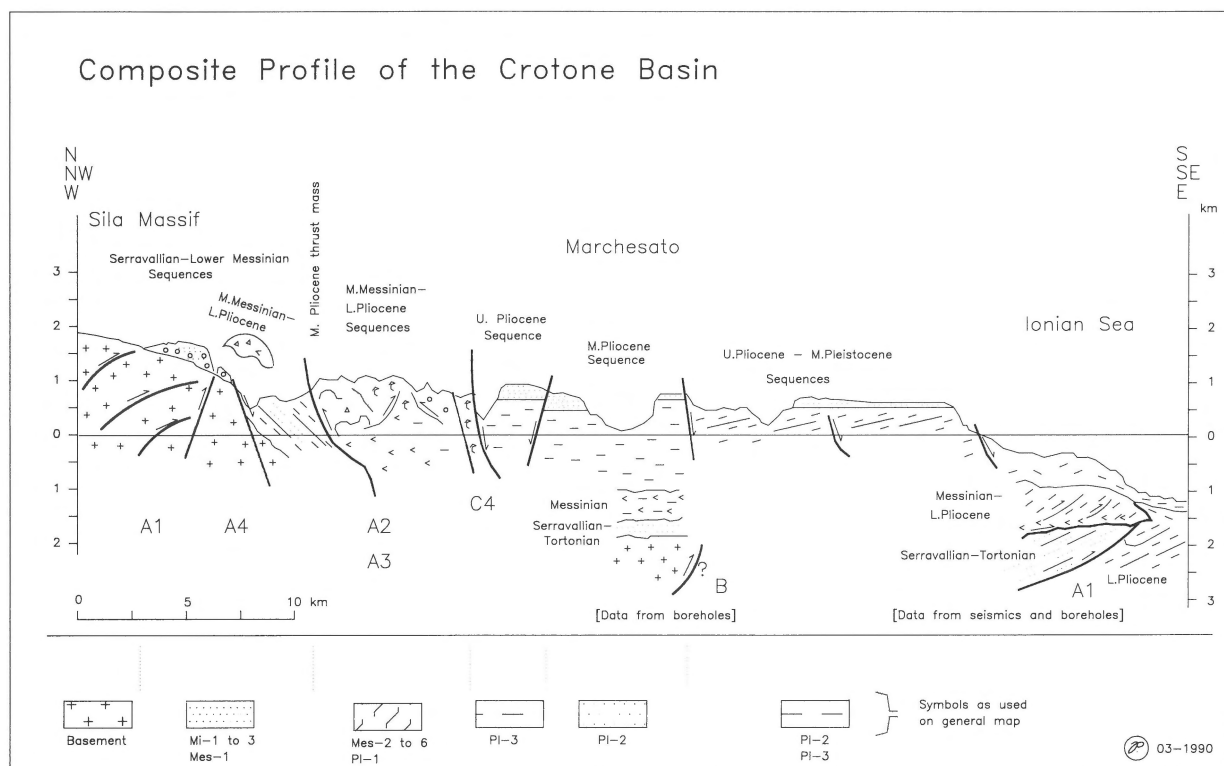


Fig. 2b. Composite cross-section of the Croton Basin. Fault patterns A1-C4 correspond with the notations of Fig. 3. Note that the section can be read in a N-S, as well as in a W-E or NW-SE sense.

### Records: tectonic structure

The recent configuration of the Croton Basin can be characterized as follows: In plan view (Fig. 2a), 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). The succession comprises three zones, which from inner to outer basin can be recognized both in a W-E as well as in a N-S direction: A. along the margins (N-S and E-W trending fault zones) Middle to Upper Miocene sequences cover the basement and display a monoclinical dip towards the centre of the Basin. B. The central part of the area (Marchesato) comprises Upper Miocene to Lower Pliocene folded and thrust terrains. C. the external area (Croton Peninsula) in the SE comprises relatively undisturbed Upper Pliocene-Pleistocene sediments.

A schematic cross-section through the Basin

(Fig. 2b) shows that the Messinian and Lower Pliocene is folded and thrust towards the N-S and E-W trending faulted basin margins ('pushed up and squeezed out of the basin'), movements which can be linked to a middle Pliocene tectonic phase. The thrust mass is confined along the external SE-side by normal faults with vertical displacements of several hundred metres. Along these faults, tectonic melanges of Messinian sediments with wedges of Lower Pliocene remnants are present. Externally, thrusts have been documented in seismic profiles (e.g. Pacchiarotti 1984), showing overthrusting of Upper Miocene sequences upon Lower Pliocene deposits and decollement of Tortonian and Messinian terrains.

The faults and fault zones present in the area are grouped in systems which in turn can be grouped in a number of patterns (Fig. 3; for terminology see Badgley 1965 and Visser 1980): 1. patterns A and B, a conjugate set of NW-SE and NE-SW trending oblique shear zones and related faults of the Rie-

SYSTEM	DIRECTION OF STRIKE	LOCATION	TYPE OF STRUCTURES	PATTERN	INTERPRETATION
1			N W T	A1	NW-SE trending crustal oblique convergent sinistral shear zone system with accompanied deformation of crustal blocks and overlying sedimentary cover
2			T F	A2	
3			W T N	A3	
4			W N		
5			N	A4	NE-SW trending crustal oblique convergent dextral thrust zone system with accompanied deformation of crustal blocks and overlying sedimentary cover
6			N	B	
7			N W T		
8			N W		
9			N	A/B	Fault systems due to interactions of shear zones of patterns
10			N		
11			N	A/B	<p>N: Normal Faults W: Wrench Faults T: Reverse Faults / Thrusts F: Folds</p> <p>Tensional fault pattern, genetically linked to the uplift of the Sila basement Massifs</p> <p>Radial and concentric tensional fault patterns, defining the dome-shaped uplift of the Sila Piccola basement Massif</p>
12			T	A/B	
13			N	C4	
14			N		
15			N	C3	
16			N		
17			N	C3	
18			N		

Fig. 3. Fault systems and patterns distinguished in the Crotone Basin.

del-shear and pull-apart basin type. 2. pattern C, tensional faults that are linked to the Late Pleistocene to Recent uplift of the Sila Massif. Pattern C partly coincides with fault systems of the older patterns A and B.

The interpretation of the patterns A and B as oblique crustal shear zones is based on the Riedel-shear fault patterns (terminology of Cloos 1928, Riedel 1929, Emmons 1969, Tchalenko 1970, Wilcox et al. 1973, Sanderson & Marchini 1984, Sylvester 1988), basement structure (Dubois 1976, Gurrieri et al. 1982) and seismic profiles (see references above). Two major NW-SE fault zones can be recognized (Fig. 2a): the Petilia-Sosti Zone in the SW, and the Rossano-San Nicola Zone in the NE. These NW-SE trending shear zones confine the

principle tectonostratigraphic suspect terranes of which the Calabrian Element is constituted.

### Records: sequence stratigraphy

The Upper Neogene tectonostratigraphy was reconstructed by mapping the internal parts of the Basin and by sampling key sections for biostratigraphic assignments. A general scheme has been constructed (Fig. 4), in which information from outside the studied area has been included (Catanzaro Area to the SW, Rossano-Cariati Area to the NE).

The tectonostratigraphy can be divided into a number of sequences that are bounded by uncon-

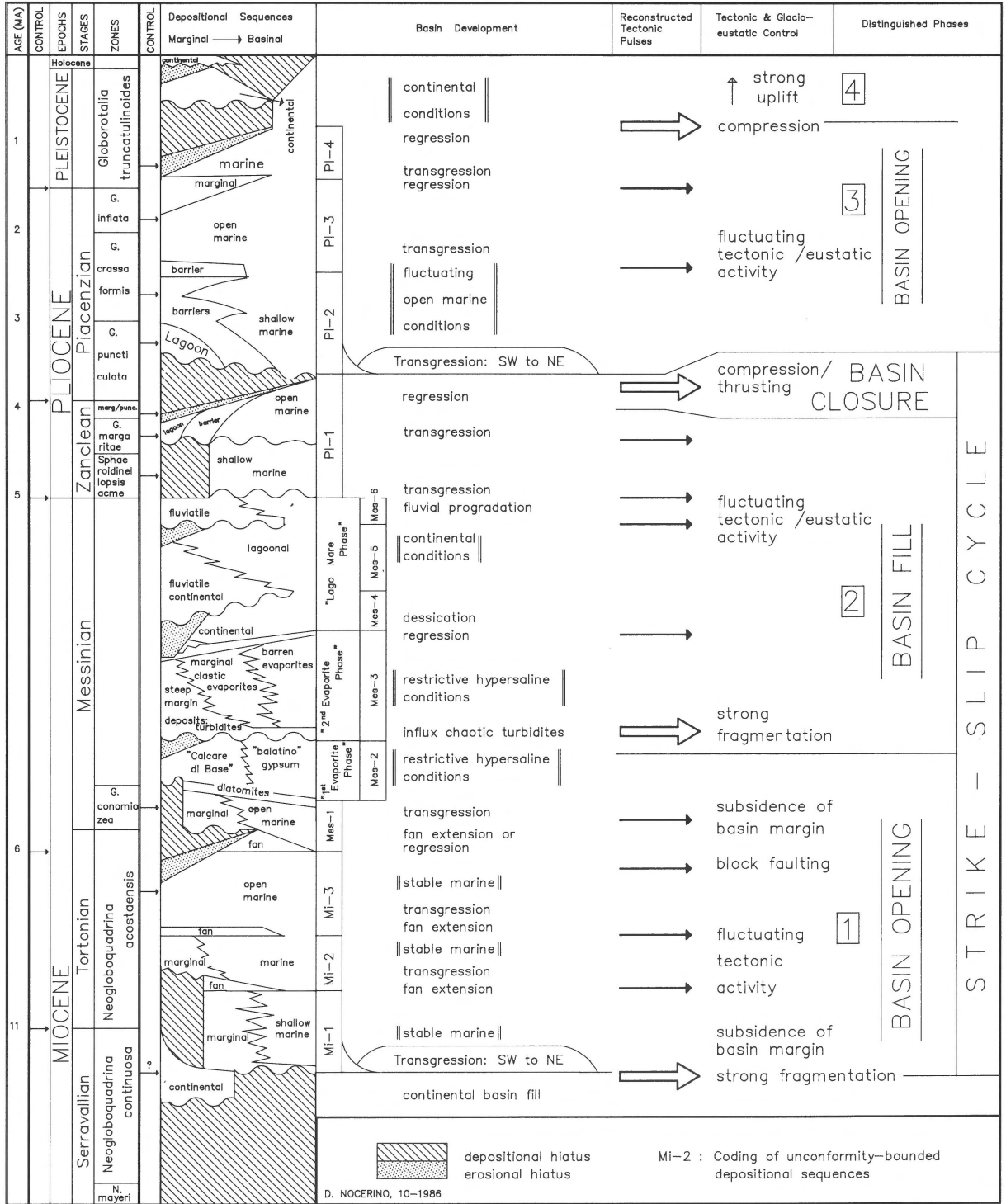


Fig. 4. Composite synthetic tectonostratigraphic scheme for the Central and Northern Calabrian basins. Stages 1, 2, 3 and 4 (see text) are marked.

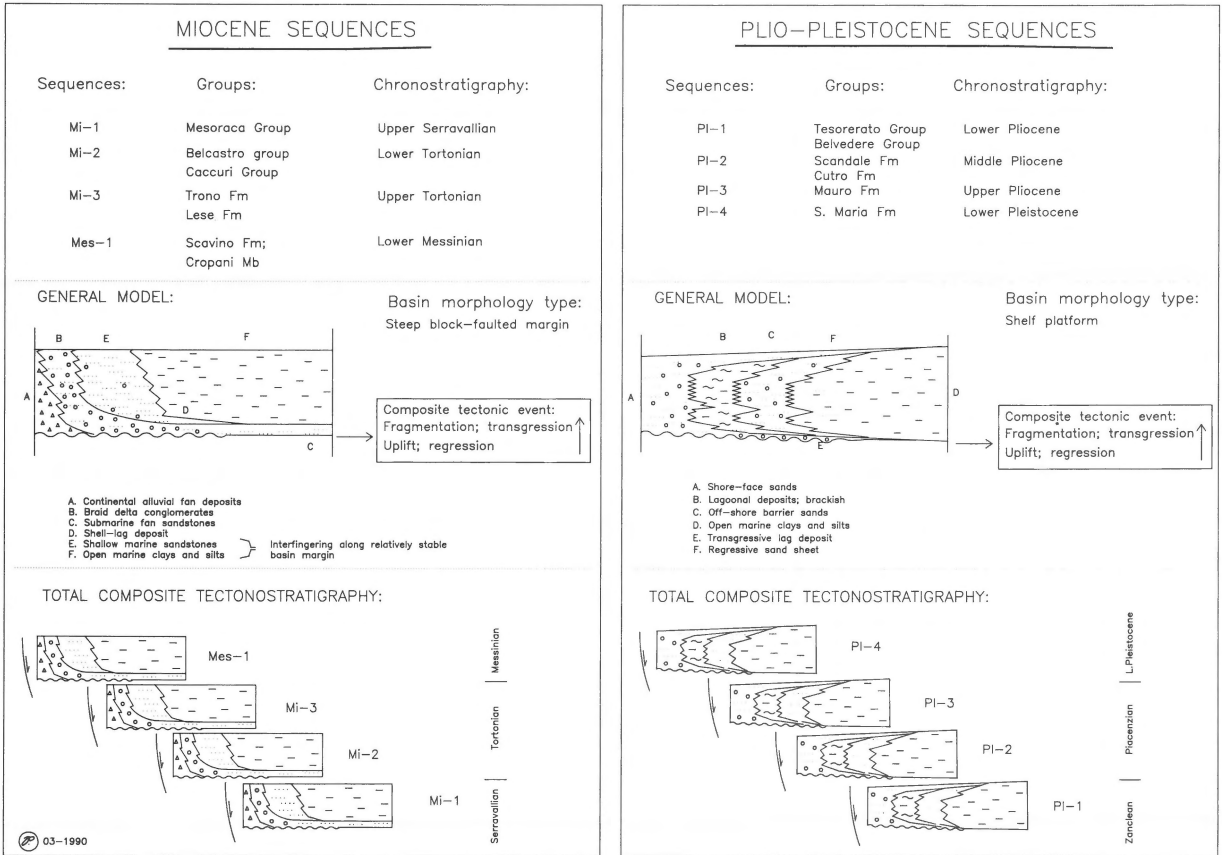


Fig. 5. Sequence models for the Miocene and Pliocene of the Crotona Basin.

formities. The unconformities which separate the Serravallian/Tortonian and Pliocene/Pleistocene sequences seem to record a standard tectonic signal (Fig. 5): the base of each sequence can be interpreted to reflect a small chain of tectonic events which we choose to collectively call a 'composite tectonic event', comprising 1. a phase of uplift and erosion of the basin margin, accompanied by the outgrowth of a submarine fan, and 2. a rapid subsidence and back stepping of the basin margin producing a regional onlap.

In order to be able to detect which sequence boundaries are accompanied by tectonic pulses, we set up a series of criteria which we used for this purpose (Fig. 6; see also Krumbein 1942, Shanmugam 1988 and Embry 1989 for this type of approach). Combining these criteria enabled us to establish the reliability with which sequence

boundaries can be linked to tectonic pulses or to relative sea level fluctuations. The latter may still be due to tectonic activity, but then on a larger scale than the studied basin, or to glacio-eustatic activity.

The evolution of the Basin can be divided into four stages (Fig. 4), which are separated by main tectonic phases:

1. a Serravallian – early Messinian Basin Opening Stage,
2. a middle Messinian – Early Pliocene Stage (2a) with high tectonic instability that is overprinted by the Messinian salinity crisis and ends with a middle Pliocene basin inversion Phase (2b),
3. a Late Pliocene – Early Pleistocene Basin Opening Stage, and
4. a Late Pleistocene – Recent Uplift Stage.

	Sequences:	1	2	3	4	5	6	7	Deduced signals:	Explanation of criteria:
QUATERNARY	(Sub-)Recent	*	*				*		MAIN TECTONIC PHASE relative + sea level ↓	1. The sequence boundary consists of an angular unconformity between two successive sequences.
	PI-4									
PLIOCENE	PI-3		*		*		*		Tectonics relative sea level ↑	2. The sequence boundary covers block faulting of the underlying sequence.
	PI-2					*				
	PI-1	*	*			*			MAIN TECTONIC PHASE relative + sea level ↑	3. Growth faulting is present in the successions along the sequence boundary.
				*	*	*				
MESSINIAN	Mes-6			*	*	*			Tectonics relative sea level ↓	4. Tapering is present in the successions along the sequence boundary.
	Mes-5			*	*	*				
	Mes-4			*					MAIN TECTONIC PHASE relative sea level ↓	5. Influxes of coarse clastics along the sequence base indicate rejuvenation of relief.
	Mes-3	*	*	*	*	*	*			
	Mes-2	*	*				*		Tectonics relative + sea level ↓	6. Distinct differences in tectonisation exist between the sequences underlying and overlying the sequence boundary.
	Mes-1	*	*				*			
	SERR.-TORTONIAN	Mi-3					*			Tectonics relative sea level ↑
Mi-2							*			
Mi-1			*	*			*		MAIN TECTONIC PHASE	
				*	*	*				

Conclusive arguments

Non-conclusive arguments

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Fig. 6. Scheme of criteria used in the relativistic analyses of tectonics and sea level fluctuations. The asterisks indicate criteria that have been used to establish which signal is represented by the sequence boundary.

### Pathways: kinematic basin evolution

We propose the following kinematic model for the evolution of the Croton Basin (Fig. 7): The Basin is situated at the intersection of the NW-SE trending 'thrust system A' (which is dominant in the area north of the Croton Basin) and the NE-SW trending 'thrust system B' (which is dominant in the area to the southwest of the Croton Basin). It is locked between two major NW-SE trending sinistral oblique crustal shear zones, which belong to the oblique thrust system A. The Middle Miocene to middle Pliocene development is characterized by a shearing of the area whereby an evolution from initial small strike-slip basins to a large pull-apart basin finally results in an inversion of the whole area in the middle Pliocene.

Analysis of in situ measurements on small scale deformation phenomena, previously presented for

the Calabrian area by Tortorici (1981), Ghisetti & Vezzani (1981) and Moussat (1983), all show a similar pattern of overall tension interrupted by two short periods of compressional deformation in the middle Pliocene and middle Pleistocene. The vectors of maximum shortening for both these periods were placed in the NE-SW quadrant. Although those data were almost exclusively gathered outside the Croton Basin, and are based on less detailed stratigraphic schemes, they can be used in combination with our tectonostratigraphic framework.

The two geohistory diagrams which we processed (Figs 8a and b), illustrate the vertical movements in respectively basin margin and basinal settings. The diagrams show a continuous subsidence from Serravallian to Early Pleistocene, interrupted by short phases of high tectonic activity. The characteristic pattern of accelerating subsidence as

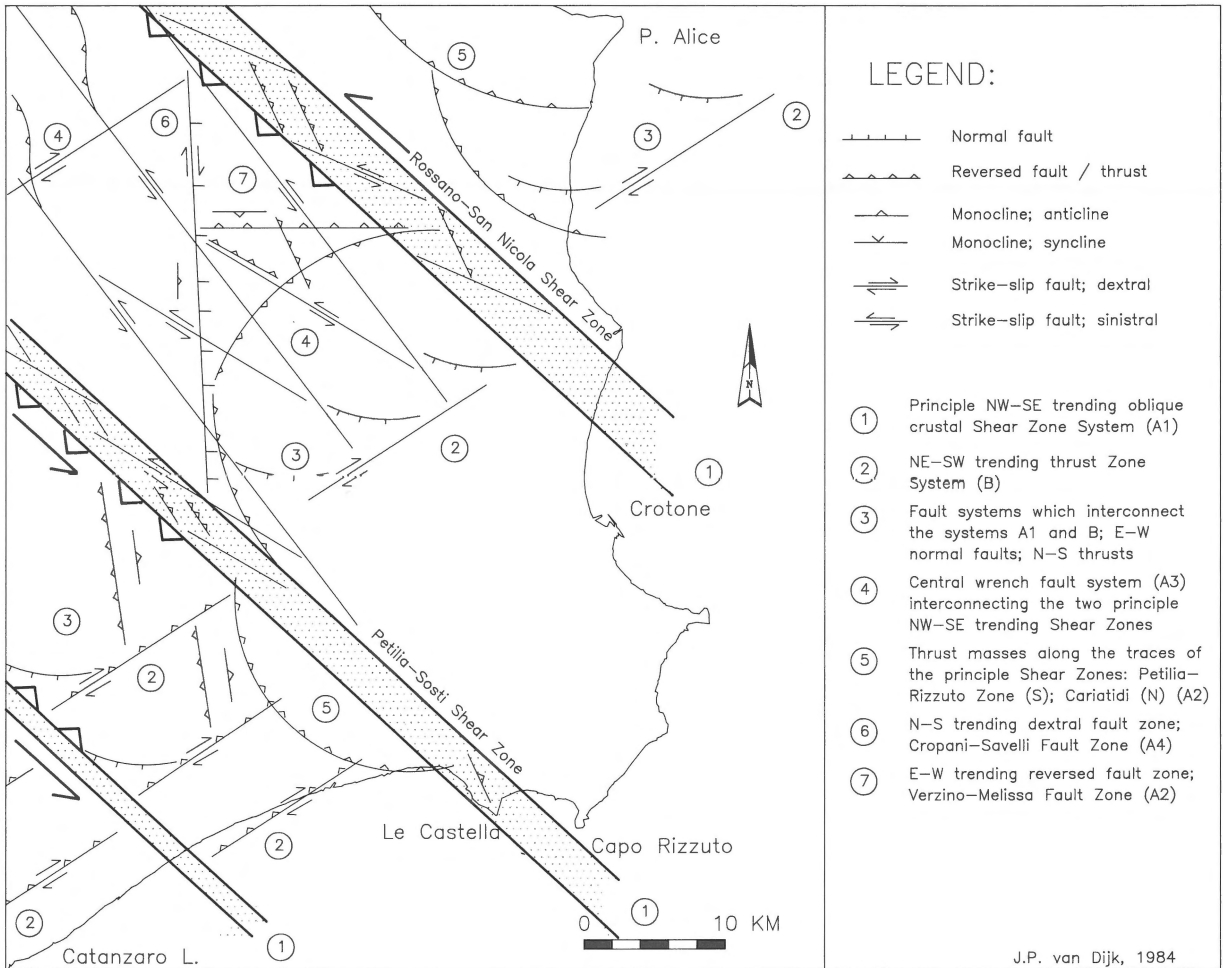


Fig. 7. Kinematic model for the Late Neogene evolution of the Croton Basin.

shown by the diagram for the basinal setting occurs frequently but not exclusively in foreland basins (compare with diagrams of Allen et al. 1986, Armagnac et al. 1988, Pieri & Mattavelli 1986). The difference in magnitude of vertical movements between the two settings is quite noticeable and supports the idea that tectonic mechanisms control the system (cf. a suggestion by Embry, 1989 for extensional basins).

Using the kinematic model as descriptive concept, the first two of the Stages in basin development as mentioned above can now be linked to the Strike Slip Cycle of Mitchell & Reading (1978) and the basin evolution can be characterized as follows:

### 1. the Serravallian – early Messinian basin opening stage

In this period, the area started to subside intermittently as a response to lateral movements along the bordering NW-SE trending shear zones. Thus a large sedimentation area was finally formed, limited by the N-S trending Cropani-Savelli Fault zone, which can be regarded as the 'pull-apart margin'. Local sedimentation patterns were determined by N090 trending tensional faults and N120 trending R-shears along this margin. This can be seen as the opening stage of the pull-apart basin.

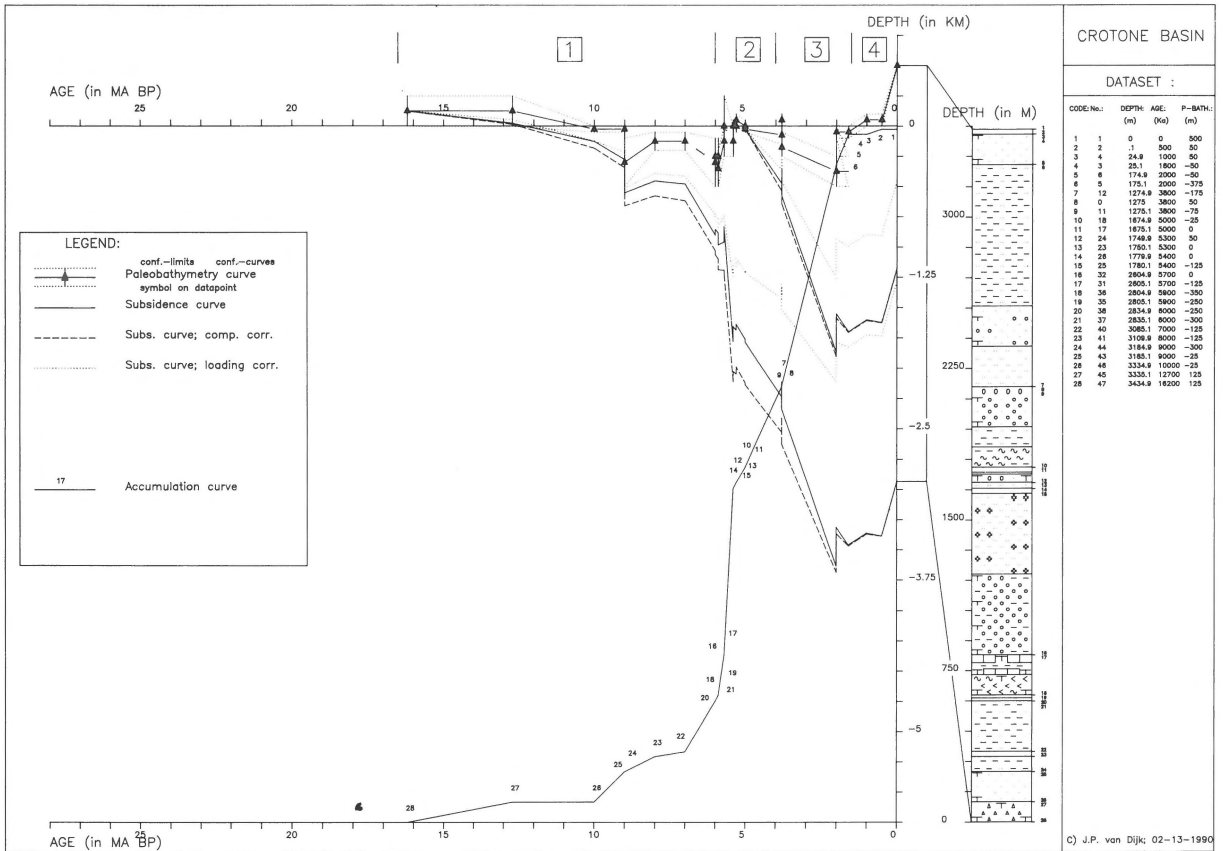


Fig. 8a. Geohistory diagram of the Croton Basin. Stages 1, 2, 3 and 4 (see text) have been marked.

2a. the middle Messinian – early Pliocene basin fill stage

For this period the subsidence curve (Fig. 8a) shows a dramatic acceleration. During the tectonic phase in the middle Messinian faulting along P-shears and tensional E-W faults in the Petilia-Sosti Shear Zone (basin margin during this period) was very intense. Furthermore, the complex upper Messinian tectonostratigraphic patterns probably also reflect the high tectonic activity along the bordering shear zones. Basin subsidence may partly be due to loading of overlying thick sedimentary sequences (Fig. 8) but after (maximum) correction for that effect a still considerable amount of subsidence remains. We propose to link the subsidence and tectonic activity to folding of the basin floor due to the thrusting along the NW-SE trending crustal shear zones in response to a NE-directed

component of regional stress. The regional relative sea level fluctuations of the Messinian salinity crisis, although bounded by tectonic phases, seem to overprint this tectonic evolution.

2b. the middle Pliocene tectonic phase

During this phase, a large-scale tectonic inversion of the basin occurred. The sedimentary cover was folded and thrust against its margins, probably as a result of on-going transpressional shear of the area between the large shear zones. The information based on the on-shore geology alone supplies no evidence for a regional character of the compressive phase. The amount of shortening in the seismic profiles (e.g. Rossi et al. 1982), the regional character of the inversion phenomena and the occurrence of small scale deformation features (see references

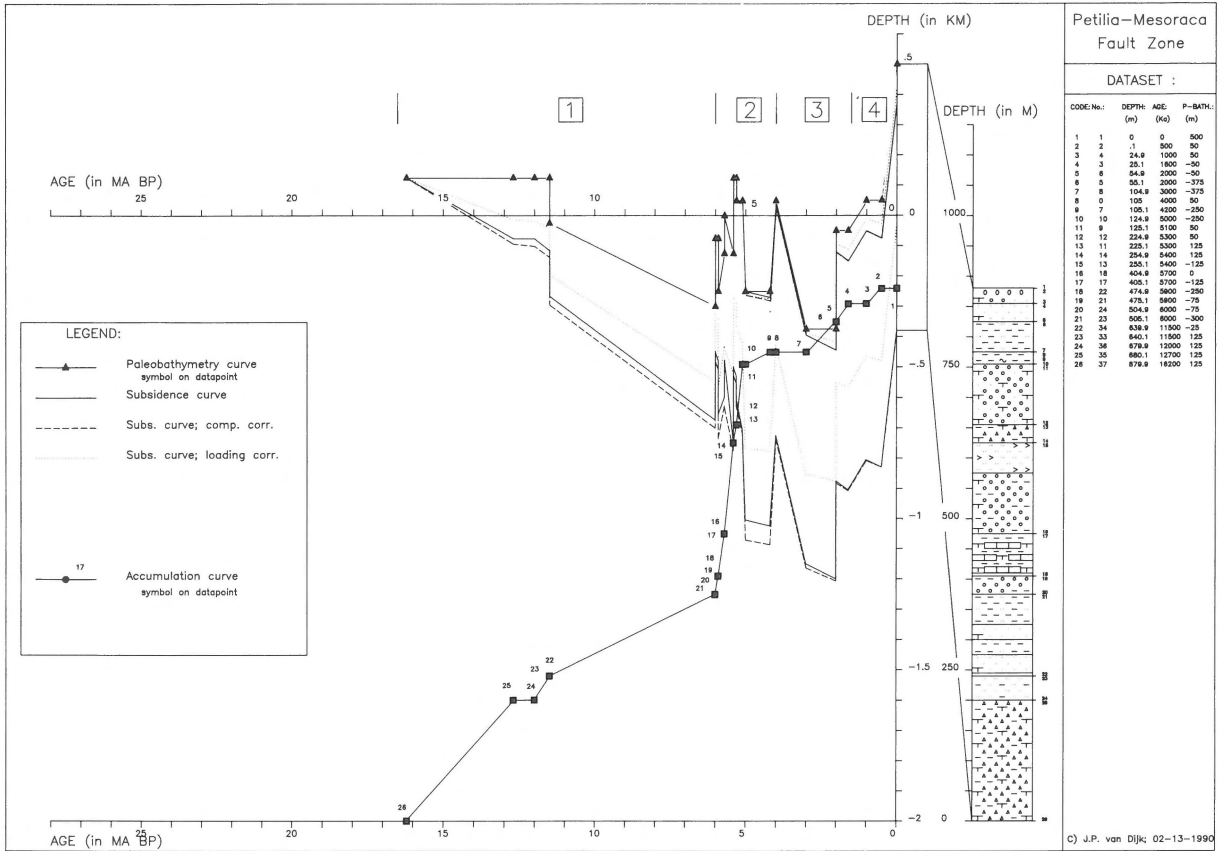


Fig. 8b. Geohistory diagram of the Petilia-Policastro – Mesoraca area, along the SW-margin of the Croton Basin. Stages 1, 2, 3 and 4 (see text) have been marked. Note the difference in scale between the two diagrams. The legend is based on Shell (1976).

above), however, strongly support the interpretation of a regional middle Pliocene compressive phase linked to NE-SW shortening, roughly perpendicular to the NW-SE trending oblique sinistral shear zones. The mid-Pliocene compressive phase has also been reconstructed from structural analyses elsewhere in the Calabrian Arc and in the southern Apennines. For a discussion and review, we refer to Auroux et al. (1985) and Bousquet & Philip (1986).

### 3. the late Pliocene to early Pleistocene basin opening stage

During this period, repetitive rapid shock-wise subsidence and onlap occurred which, although

more gradually, strongly resembles the Miocene evolution (Fig. 5).

### 4. the late Pleistocene – recent uplift stage

During this last stage, the whole area was rapidly uplifted. The fault systems of pattern C developed in response to rapid uplift of the Sila Massif. This Stage was also associated with a regional mid-Pleistocene compressive Phase (see references above).

## Discussion

The development of the Croton Basin can be described in the following way:

Stages 1 and 3 can be linked to southeastward

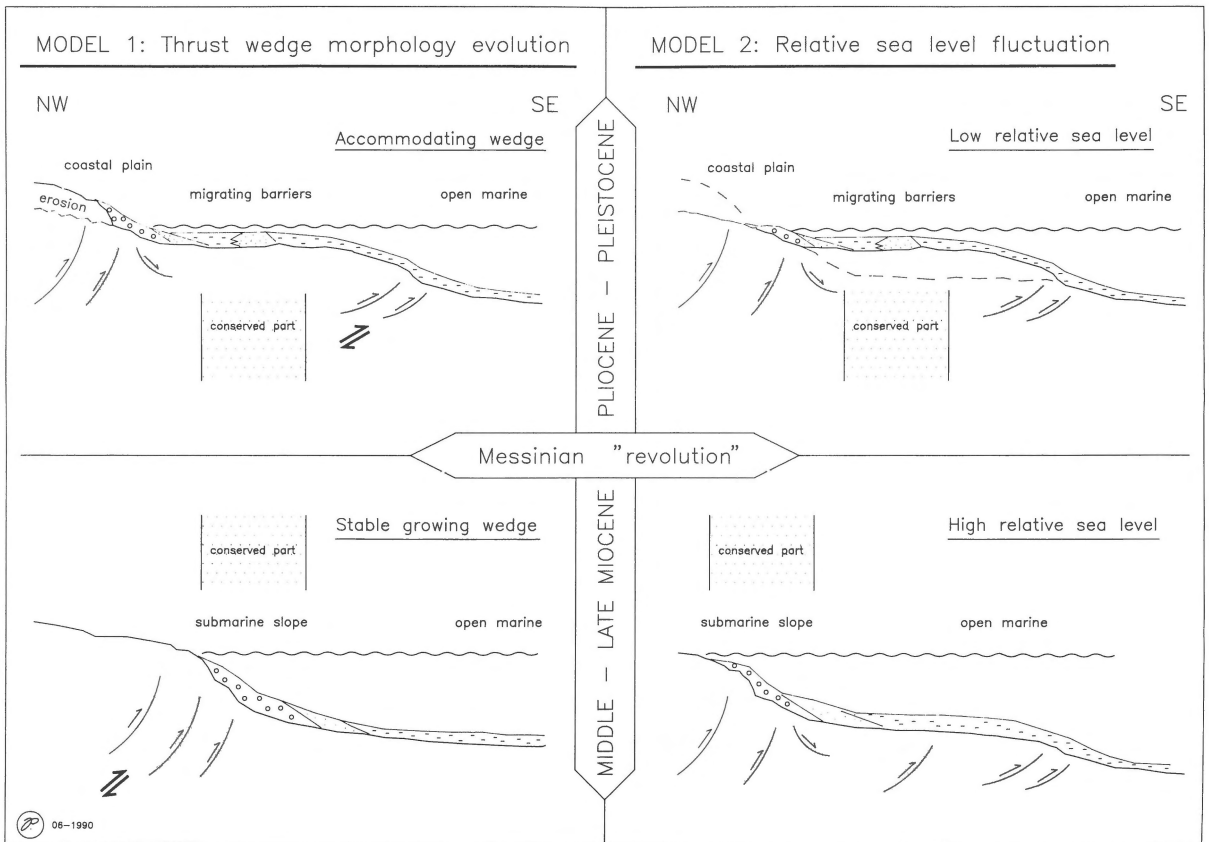


Fig. 9. Two possible models which can be used to explain the principle differences between Miocene and Pliocene development of depositional systems in the Croton Basin.

pulsating gravitational sliding of the Calabrian Element and accompanied growth of the frontal accretionary wedge. The composite tectonic events which control the sequence stratigraphy development during these Stages (Fig. 5) can be linked to phases of stagnation in Element migration. We believe that each of these events reflects a sudden compressive growth of the accretionary wedge followed by tensional accommodation through restabilization of its taper as was mathematically modelled in a series of papers by Davis et al. (1983), Dahlen et al. (1984) and Dahlen (1990).

This evolution is overprinted by phases of increasing regional compressive stress, of which the middle Messinian – middle Pliocene and the middle Pleistocene – Recent phases are examples. These phases account for the NE-SW compression and inversion of the foreland basins. Furthermore

these phases are accompanied by periods of excessive vertical fault movements such as in the Late Pleistocene – Recent, which overprinted all previous formed structures. These taphrogenetic movements were induced by the detachment of subducted lithosphere remnants and subsequent rapid regional isostatic adjustments (see for discussion Van Dijk & Okkes, in press). Externally along the Arc, thrusting activity can be observed in seismic profile MS-25 (Finetti & Morelli 1972) which can be regarded as gravitational spreading (Ogniben 1973) linked to an extensional collapse of the accretionary wedge in response to the rapid uplift of the Arc.

The fundamental difference between the Miocene and Pliocene basin morphology can be explained in one or the other of two ways (Fig. 9). The first model accepts the dominant role of the

tectonic thrust wedge morphology evolution. During the Miocene, the basin was situated on a normal growing accretionary wedge. In the Pliocene and Pleistocene, the basin was situated on a large crustal slab with a back-stepping tensional margin, which slid to the SE to restabilize the externally growing accretionary wedge (Van Bemmelen 1976, Platt 1986). The second model assigns a dominant role to erosion/deposition and relative sea level fluctuation in the shaping of the basin morphology. In that case, the tectonic thrust wedge morphology did not necessarily change fundamentally in the latest Miocene.

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 phenomena may both be controlled by regional tectonic mechanisms. Likewise, regional tectonic activity may have controlled the growth pulses of the accretionary wedge by temporarily blocking the subduction process and/or by triggering wedge restabilization. This provides an explanation for the synchronous sequence boundaries in various Mediterranean systems (see also suggestions by Meulenkamp & Hilgen 1986, Cloetingh 1988), despite differences in tectonic setting.

## Conclusions

The evolution of the Croton Basin can be divided in four stages: 1. a Serravallian – early Messinian Tension Stage, 2. a middle Messinian – Early Pliocene Basin Fill Stage, which ended with a middle Pliocene Compression Phase with basin inversion, 3. a Late Pliocene – Early Pleistocene Tension Stage and 4. a Late Pleistocene – Recent uplift Stage with uplift of the Sila Massif and intense tensional faulting. The Late Miocene – Early Pliocene evolution reflects the Strike-Slip Cycle of Mitchell & Reading (1978).

The development of depositional sequences was controlled by the local tectonic activity of the accretionary wedge system, overprinted by the increase in regional stress in the middle Messinian – middle Pliocene and in the middle Pleistocene – Recent

Phases. Both local tectonic activity and regional relative sea level fluctuations are probably controlled by regional tectonic mechanisms.

## Acknowledgements

I greatly appreciate the collaboration of X. Behnen, W.A. Boekelman, T. Bor, F. Jorissen, R.P.A. Kievits, J. Maassen, R. Matheussens, A. Meerstens, F.W.M. Okkes, H. Schmied and B. Westerop in the field and I thank them for sharing their field data. The assistance and valuable suggestions of J.B. Broekman, F.J. Hilgen, J.E. Meulenkamp, W.J. Zachariasse and G.J. van der Zwaan concerning the fieldwork, sample analyses and corrections of the manuscript have been of great importance. Prof. S. Cloetingh is thanked for his constructive criticism which improved the manuscript. Dr. W.J.M. van der Linden is greatly acknowledged for his critical revision of the present text. 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 T. van Hinte, D. Nocerino and W.A. den Hartog for the assistance in the preparation of the drawings. G.C. Ittman and G.J. van 't Veld skillfully prepared the samples.

## References

- Allen, P., P. Homewood & G.D. Williams 1986 Foreland basins: an introduction. In: P. Allen & P. Homewood (eds): *Foreland Basins – Int. Ass. Sedim., Spec. Publ. 8*, Blackwell (New York): 3–12
- Armagnac, C., J. Bucci, C.G.St.C. Kendall & I. Lerche 1988 Estimating the thickness of sediment removed at an unconformity using vitrinite reflectance data. In: N.D. Naeser & T. McCulloh (eds): *Thermal history of sedimentary basins. Methods and case histories – Springer* (New York): 217–238
- Auroux, C., J. Mascle, R. Campedron, R. Mascle & S. Rossi 1985 Etude néotectonique du Golfe de Tarente (Italie). *Rapports des données de la téledétection et de l'analyse microtectoniques – Soc. Geol. France Bull.* 8: 621–628
- Badgley, P.C. 1965 *Structural and tectonic principles* – Harper & Row (New York): 520 pp
- Benson, R.H. 1984 The Phanerozoic 'crisis' as viewed from the Miocene. In: W.A. Berggren & J.A. Van Couvering (eds):

- Catastrophes and Earth history. The New Uniformitarianism – Princeton Univ. Press (Princeton, New Jersey): 437–446
- Biju-Duval, B., E. Deveaux, R. Gonnard, C. Lata arche, J.-C. Rivereau, C. Lamparein & N. Lopez 1975 Apports de l'étude des images du satellite Landsat-1 a la reconnaissance de la structure du domaine Méditerranéen – *Inst. Franc. Petr. Rev.* 30: 841–853
- Boccaletti, M., R. Nicolich & L. Tortorici 1984 The Calabrian Arc and the Ionian Sea in the dynamic evolution of the Central Mediterranean – *Mar. Geol.* 55: 219–245
- Bousquet, J.C. & H. Philip 1986 Neotectonics of the Calabrian Arc and Apennines (Italy): An example of Plio-Quaternary evolution from island arcs to collision stages. In: F.-C. Wezel (ed.): *The origin of arcs – Developments in Geotectonics 21*, Elsevier (Amsterdam): 305–326
- Bronzini, S. 1959 Note sulle ricerche di gas in alcune zone del litorale jonico. In: *Accademia Nazionale dei Lincei: I giacimenti gassiferi dell'Europa occidentale I*: 399–405
- Burton, A.N. 1971 Carta Geologica della Calabria alla scala di 1 : 25.000, Relazione generale – Cassa per il Mezzogiorno, Serv. Bonif. (Roma): 120 pp
- Burton, R., C.G.St.C. Kendall & I. Lerche 1987 Out of depth: on the impossibility of fathoming eustasy from the stratigraphic record – *Earth Sci. Rev.* 24: 237–277
- Cloetingh, S. 1988 Intraplate stresses: a new element in basin analysis. In: K.L. Kleinspehn & C. Paola (eds): *New perspectives in basin analysis*, Pettijohn Volume – Springer (New York): 205–230
- Cloos, H. 1928 Experimente zur inneren Tektonik – *Centralbl. Min. Paleont. B*: 609–621
- Coney, P.J., D.L. Jones & J.W.H. Monger 1980 Cordilleran suspect terranes – *Nature* 288: 329–333
- Cosentini D., E. Gliozzi & F. Salvini 1989 Brittle deformations in the Upper Pleistocene deposits of the Crotone Peninsula, Calabria, southern Italy. In: N.-A. Mörner & J. Adams (eds): *Paleoseismicity and neotectonics – Tectonophysics* 163: 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
- Dahlen, F.A., J. Suppe & D. Davis 1984 Mechanics of fold-and-thrust belts and accretionary wedges: Cohesive coulomb theory – *J. Geoph. Res.* 89(B12): 10087–10101
- Davis, D. 1983 Mechanics of fold-and-thrust belts and accretionary wedges – *J. Geoph. Res.* 88(B2): 1153–1172
- Dubois, R. 1976 La suture calabro-apenninique Cretacée-Eocene et l'ouverture Tyrrhénienne néogène: étude pétrographique et structurale de la Calabre centrale – These, Univ. Paris: 567 pp
- Embry, A.F. 1989 A tectonic origin for third-order depositional sequences in extensional basins-implications for basin modeling. In: T.A. Cross (ed.): *Quantitative stratigraphy – Prentice Hall* (London): 491–501
- Emmons, R.C. 1969 Strike-slip rupture patterns in sand models – *Tectonophysics* 7: 71–87
- Finetti, I. & C. Morelli 1972 Wide scale digital seismic exploration of the Mediterranean sea – *Boll. Geof. Teor. Appl.* 14: 291–342
- Finetti, I. 1982 Structure, stratigraphy and evolution of Central Mediterranean – *Boll. Geof. Teor. Appl.* 24: 247–312
- Ghisetti, F. & L. Vezzani 1981 Contribution of structural analysis to understanding the geodynamic evolution of the Calabrian Arc (Southern Italy) – *J. Struct. Geol.* 3: 371–381
- Guérémy, P. 1976 La Calabre centrale et septentrionale. Guide d'excursion géomorphologique – *Inst. Géogr. Reims Trav.* 10: 128 pp
- Guidish, T.M., C.G.St.C. Kendall, I. Lerche, D.J. Toth & R.F. Yazab 1985 Basin evaluation using burial history calculations: an overview – *Amer. Ass. Petr. Geol. Bull.* 69: 92–105
- Gurrieri, S., S. Lorenzoni, F. Stagno & E. Zanettin Lorenzoni 1982 Le magmatiti dell'Unita di Monte Gariglione (Sila, Calabria) – *Soc. Geol. Padova Mem.* 35: 69–90
- Haq, B.U., J. Hardebol & P.R. Vail 1987 Chronology of fluctuating sea levels since the Triassic – *Science* 235: 1156–1167
- Horowitz, D.H. 1976 Mathematical modelling of sediment accumulation in prograding deltaic systems. In: D.F. Merriam (ed.): *Quantitative techniques for the analysis of sediments – Pergamon* (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
- Krumbein, W.C. 1942 Criteria for subsurface recognition of unconformities – *Amer. Ass. Petr. Geol. Bull.* 26: 36–62
- Meulenkamp, J.E. & F.J. Hilgen 1986 Event stratigraphy, basin evolution and tectonics of the Hellenic and Calabro-Sicilian Arcs. In: F.-C. Wezel (ed.): *The origin of Arcs – Developments in Geotectonics 21*, Elseviers (Amsterdam): 327–350
- Meulenkamp, J.E., F. Hilgen & E. Voogt 1986 Late Cenozoic sedimentary – tectonic history of the Calabrian Arc. In: M. Boccaletti, R. Gelati & F. Ricci-Lucchi (eds): *Paleogeography and geodynamics of the Perityrrhenian Area – Giorn. Geol.* 3a, 48: 345–359
- Mitchell, A.H.G. & H.G. Reading 1978 Sedimentation & tectonics. In: H.G. Reading (ed.): *Sedimentary environments and facies – Blackwell* (London): 439–476
- Moussat, E. 1983 Evolution de la mer Tyrrhénienne centrale et de ses marges septentrionales en relation avec la néotectonique dans l'Arc calabrais – These, Univ. Paris: 125 pp
- Müller, D.W. 1986 Die Salinitätskrise im Messiniän (spates Miozän) der Becken von Fortuna und Sorbas (Südost-Spanien) – Sonderdruck der gleichnamigen Dissertation (Nr. 8056), Abt. Naturwissensch. ETH, Zürich (Schweiz): 183 pp
- Ogniben, L. 1955 Le Argile Scagliose del Crotonese – *Ist. Geol. Appl. Napoli Mem. e Note* 6: 1–72
- Ogniben, L. 1973 Schema geologico della Calabria in base ai dati odierni – *Geol. Romana* 12: 243–585
- Pacchiarotti, E. 1984 Attivita' di ricerca di idrocarburi nei mari italiani – *Soc. Geol. Ital. Mem.* 27: 287–301
- Pieri, M. & L. Mattavelli 1986 Geologic framework of Italian petroleum resources – *Amer. Ass. Petrol. Geol. Bull.* 70: 103–130

- Platt, J.P. 1986 Dynamics of orogenic wedges and the uplift of high-pressure metamorphic rocks – *Geol. Soc. Amer. Bull.* 97: 1037–1053
- Riedel, W. 1929 Zur mechanik geologischer Brucherscheinungen – *Centralblatt Miner. Paleont.* 1929, B: 354–368
- Roda, C. 1964 Distribuzione e facies dei sedimenti neogenici nel bacino Crotonese – *Geol. Romana* 3: 319–366
- Roda, C. 1965 Geologia della tavoletta Belvedere di Spinello (Prov. Catanzaro, F. 237, I-SE) – *Soc. Geol. Ital. Boll.* 84: 159–285
- Rossi, S., C. Auroux & J. Mascle 1982 The Gulf of Taranto (Southern Italy): Seismic stratigraphy and shallow structure – *Mar. Geol.* 51: 327–346
- Sanderson, D.J. & W.R.D. Marchini 1984 Transpression – *J. Struct. Geol.* 6: 449–458
- Schermer, E.R., D.G. Howell & D.L. Jones 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: C. Drooger (ed.): *Messinian events in the Mediterranean* – North Holland (Amsterdam): 150–171
- Shanmugam, G. 1988 Origin, recognition, and importance of erosional unconformities in sedimentary basins. In: K.L. Kleinspehn & C. Paola (eds): *New perspectives in basin analysis, Pettijohn Volume* – Springer (New York): 84–108
- Shell International Petroleum Company 1976 *Standard legend* – Shell Int. Petr. Comp., SIPM, The Hague
- Sloss, L.L. 1988 Forty years of sequence stratigraphy – *Geol. Soc. Amer. Bull.* 100: 1661–1665
- Stam, B., F.M. Gradstein, P. Lloyd & D. Gillis 1987 Algorithms for porosity and subsidence history – *Computers & Geosciences* 13: 317–349
- Sylvester, A.G. 1988 Strike-slip faults – *Geol. Soc. Amer. Bull.* 100: 1666–1703
- Tchalenko, J.S. 1970 Similarities between shear zones of different magnitudes – *Geol. Soc. Amer. Bull.* 81: 1625–1640
- Tortorici, L. 1981 Analisi delle deformazioni fragili dei sedimenti postorogeni della Calabria settentrionale – *Soc. Geol. It. Boll.* 100: 291–308
- Vail, P.R., R.G. Mitchum Jr., R.G. Todd, J.M. Widmier, S. Thompson 3rd, J.B. Sangree, J.N. Bubb & W.G. Hatlelid 1977 Seismic stratigraphy and global changes of sea level. In: C.E. Payton (ed.): *Seismic stratigraphy; Applications to hydrocarbon exploration* – *Amer. Ass. Petr. Geol. Mem.* 26: 49–212
- Van Bemmelen, R.W. 1976 Plate Tectonics and the Undation Model: a comparison – *Tectonophysics* 32: 145–182
- Van Dijk, J.P. & F.W.M. Okkes 1988 The analysis of shear zones in Calabria; implications for the geodynamics of the Central Mediterranean – *La Ric. Scient. Suppl.*, 68: 24–27
- Van Dijk, J.P. & F.W.M. Okkes 1990 The analysis of shear zones in Calabria; implications for the geodynamics of the Central Mediterranean – *Riv. Ital. Strat. Pal.* 3/4: 000–000
- Van Dijk, J.P. & F.W.M. Okkes (in press) Neogene tectonostratigraphy and kinematics of Calabrian basins; implications for the geodynamics of the Central Mediterranean – *Tectonophysics*
- Van Hinte, J.E. 1978 Geohistory analysis, application of micropaleontology in exploration geology – *Amer. Assoc. Petr. Geol. Bull.* 62: 201–227
- Visser, W.A. 1980 Geological nomenclature – *Roy. Geol. Min. Soc. Neth., Scheltema & Holkema (Utrecht)*: 550 pp
- Wilcox, R.E., T.P. Harding & D.R. Seely 1973 Basic wrench tectonics – *Amer. Ass. Petr. Geol. Bull.* 57: 74–96