Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 93 (2000)

Heft: 1

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DOI: https://doi.org/10.5169/seals-168808

0012-9402/00/010065-15 $1.50 + 0.20/0
Birkhäuser Verlag, Basel, 2000

Eclogae geol. Helv. 93 (2000) 65–79

The onset of the syn-orogenic sedimentation in the Flysch Basin of the Sicilian Maghrebids: state of the art and new biostratigraphic constraints

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Key words: Early Miocene, Biostratigraphy, Tectonics, Sicilide Units, Maghrebian Chain, Sicily, Southern Italy

ABSTRACT

The synorogenic deposits forming the uppermost part of the stratigraphic successions of the Sicilide Units have been studied in order to recognize the tectogenetic phases in the Sicilian sector of the Maghrebian Chain. The Sicilide Units deposits sedimented in the Maghrebian Flysch Basin, which represents the southernmost of the oceanic branches separating, from the Late Jurassic, the European and African plates and the microcontinents located between them.

The study, focused on the Troina-Tusa Unit, has shown that it consists of prevalently marly-clayey foreland deposits, from Cretaceous to early Miocene age. Within the uppermost part of these deposits arenaceous beds appear, which mark the transitional boundary with two heteropically lying turbiditic formations. The first one (Tusa Tuffite Fm.) is characterized by volcanoarenitic layers, whereas the second one (Troina Sandstone Fm.) consists of arkosic and lithic arkosic beds, interbedded with conglomerates and pelites. These two formations testify the onset of the foredeep stage in the Sicilide Basin evolution, occurring through the replacement of the marly-clayey sediments by syn-orogenic turbiditic deposits. Contemporaneously, an active andesitic magmatic arc supplies abundant epiclastic detritus to the internal areas of the basin.

In the uppermost levels of the marly-clayey sediments microfloras indicate an age not older than Aquitanian. Coccoliths and foraminifera in the overlying Tusa Tuffite and Troina Sandstone Fms. indicate an age not older than Burdigalian for the synorogenic turbiditic sediments. Therefore, these deposits are more recent than indicated up to now (upper Oligocene-middle Aquitanian). Consequently, the deformation of the Sicilide Basin, the consumption of the Maghrebian oceanic area and the following Africa-Europe continental collision must have occurred in late Burdigalian or during the Langhian.

Biostratigraphic and field data show that there is no evidence, in the Sicilian sector of the Maghrebian Flysch Basin, of the meso-Alpine, Eocene-early Oligocene, tectogenetic phases, which have been recently re-proposed by some authors. They rather agree with the Aquitanian deformation of the more internal Peloritanian Domain. Moreover, they question the deformation age of the Maghrebian External Domain contiguous to the Flysch Basin (Panormide and Imerese Zones). These latter must have been deformed not earlier than Langhian, or, more probably, during the Serravallian, later than what was thought up to now.

Finally, the new data indicate a synchronous deformation in the whole Maghrebian Flysch Basin from the Calabria-Peloritani Arc to the Rif and Betic Cordilleras.

RESUME

Les dépôts synorogéniques qui caractérisent le sommet des successions stratigraphiques des Unités Sicilides ont été étudiés afin de définir l'âge des premières phases tectogénétiques qui ont affecté le secteur sicilien de la Chaîne maghrébine. Les sédiments des Unités Sicilides ont été déposés dans le bassin des Flyschs maghrébins qui a représenté, à partir du Jurassique Supérieur, la plus méridionale des branches océaniques qui séparaient les plaques européenne et africaine et les microcontinents entre les deux.

L'étude est focalisée sur l'Unité de Troina-Tusa, caractérisée par une succession méso-cénozoïque dont les niveaux supérieurs ont été jusqu'à présent considérés comme étant compris entre l'Oligocène inférieur et l'Aquitanien. Cette unité est formée surtout de dépôts marno-argileux d'un âge compris entre le Crétacé et le Miocène inférieur. Au sommet, apparaissent des grès, qui marquent le passage graduel à deux formations turbiditiques hétéropiques: la Formation des *«Tufiti di Tusa»*, caractérisée par des couches volcano-gréseuses, et la Formation des *«Arenarie di Troina»*, composée par des arkoses et des arkoses lithiques, dans lesquelles sont intercalés des conglomérats et des pélites. Ces deux formations témoignent du début du stade d'avant-fosse dans le bassin sicilide, marqué par le remplacement de la sédimentation marno-argileuse par des dépôts turbiditiques synorogéniques. En même temps, un arc magmatique andésitique alimentait les zones internes du bassin avec un abondant détritus épiclastique.

Les niveaux les plus élevés des sédiments marno-argileux sont caractérisés par des microflores qui témoignent d'un âge qui ne peut pas être plus ancien que l'Aquitanien, tandis que les coccolithes et les foraminifères des *«Tufiti di Tusa»* et des *«Arenarie di Troina»* indiquent un âge pas plus ancien que le Burdigalien. Par conséquent, les dépôts synorogéniques de l'Unité de Troina-Tusa sont beaucoup plus récents que ce qu'on avait cru jusqu'à présent (Oligocène supérieur-Aquitanien moyen) et la déformation du bassin sicilide, la fermeture de l'Océan maghrébin et la collision continentale Europe-Afrique ont eu lieu à partir du Burdigalien supérieur ou pendant le Langhien.

Les données biostratigraphiques et de terrain démontrent que, dans le secteur sicilien du bassin des Flyschs maghrébins, il n'y a aucune évidence des phases tectogénétiques mésoalpines, d'âge Eocène-Oligocène inférieur, dont on a, encore récemment, supposé à nouveau l'existence. Ces données s'accordent bien également avec l'âge aquitanien de la déformation du plus interne domaine péloritain, et elles remettent en question l'âge de déformation des domaines externes maghrébins contigus au bassin des Flyschs (zones panormide et imérèse). La déformation de ces dernières ne peut pas être plus ancienne que le Langhien ou, plus probablement, elle s'est manifestée pendant le Serravallien, c'est-à-dire beaucoup plus récemment que ce que l'on avait admis jusqu'à présent.

Enfin, les nouvelles données indiquent que la déformation de tout le bassin des Flyschs est synchrone à partir de l'Arc Calabro-péloritain jusqu'au Rif et à la Cordillère Bétique.

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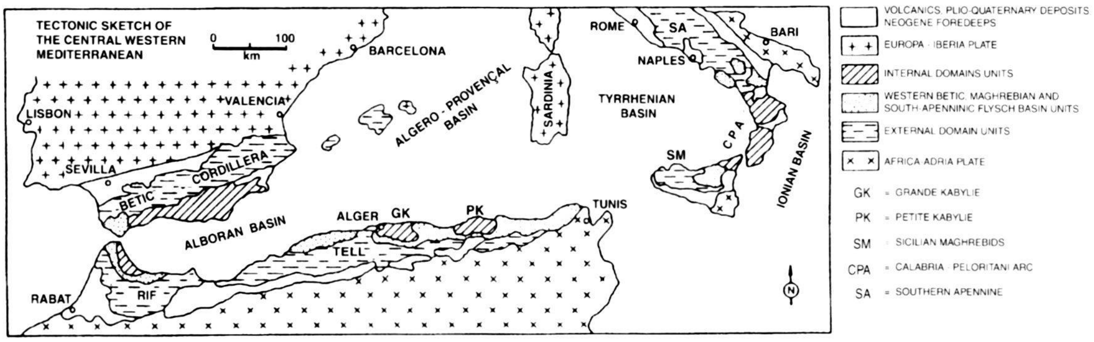

Fig. 1. Tectonic sketch of the Alpine Chains of the Central-Western Mediterranean (after Guerrera et al. 1993).

1. Introduction

The Maghrebian Chain, as defined by Aubouin & Durand Delga (1971), Durand Delga (1980) and Wildi (1983), is an Africa-vergent Alpine chain, extending from the Gibraltar Strait to the Catanzaro Graben in Central Calabria. The chain is made of a nappe pile resulting from the deformation of three main domains: the Internal, the Flysch Basin and the External Domains (Fig. 1).

From these domains, located from north to south respectively, nappes now stacked from the top to the bottom in the tectonic pile, originated. The Internal Domain nappes, preserved in the Rif, the Kabylies and the Calabria-Peloritani Arc, are characterized by pre-Alpine crystalline basement and only some of them show a Meso-Cenozoic cover (Fig. 1).

The Flysch Basin nappes are made up of pelagic and turbiditic successions, ranging in age from the Latest Jurassic to the early Miocene. They accumulated in a Meso-Cenozoic basin, extending from Gibraltar to Eastern Sicily, characterized by an oceanic crust (Wildi 1983; Guerrera et al. 1993), which is preserved in a few outcrops across the Kabylies (Durand Delga 1971) and the Rif (Olivier et al. 1996). This basin was the site of a prevailing turbiditic sedimentation: differences both in lithology and sedimentary evolution allowed to individuate internal (Mauretanian) and external (Massylian) successions, markedly continuous along the basin axis (Bouillin et al. 1970).

The differences between Mauretanian and Massylian successions are particularly remarkable from the late Oligocene onwards, when in the Mauretanian Zone of the basin the sedimentation of immature sandstones occurs, while the very mature quartzarenitic Numidian Flysch Sequence, supplied by the African Craton, is deposited in the Massylian Zone. The two types of successions pass one into the other through typical alternances of lithic arkoses and quartzarenites (Mixed Successions; Didon & Hoyez 1978; Guerrera et al. 1986). Terrains of the Flysch Basin have been recognized in the Betic Cordillera (Flysch of the Campo de Gibraltar; Didon 1969; Martín-Algarra 1987) and recently in the Apenninic Chain (Bonardi et al. 1988, 1994; Guerrera et al. 1993; Fig. 1).

The External Domain nappes, finally, are mainly characterized by calcareous and marly successions, related to both neritic and pelagic environments.

Although the geometric setting and the major paleogeographic interpretations are unanimously accepted, many problems are still debated. Among these the following are the most controversial: 1) the origin of the Internal Domain nappes, for which a provenance from Africa (Amodio Morelli et al. 1976), Europe (Bouillin et al. 1986) or an intermediate microcontinent (Wildi 1983; Guerrera et al. 1993) has been suggested; and 2) the age of the onset of the deformation in the different domains, because ages ranging from the middle Eocene to the middle Miocene have been proposed (Duée 1969; Courme & Mascle 1988; Roure et al. 1990; Lentini et al. 1991, 1995; Cassola et al. 1992; Guerrera et al. 1993; La Manna et al. 1995).

This paper deals with some results of a research carried out on the Sicilian sector of the Maghrebian Chain and turns to the reconstruction of the tectogenetic history of this sector during the Paleogene-middle Miocene, that it is to say between the onset of the compressive deformation in the Western Mediterranean domains and the Africa-Europe collision. The research has involved a revision of the siliciclastic syn-orogenic formations, which characterize the units deriving from the Internal and Flysch Basin Domains, and of the late-orogenic formations, post-dating the stacking of the nappes resulting from the first deformative phase.

2. The eastern sector of the Maghrebian Chain

In the eastern sector of the Maghrebian Chain (Sicily and Southern Calabria; Aubouin & Durand Delga 1971) all the main domains are easily recognizable (Fig. 2).

The Internal Domain is represented by the nappes of the Peloritani Mountains and Southern Calabria, which are characterized by a metamorphic pre-Alpine basement. Only the lowest nappe (Longi-Taormina Nappe) shows a continuous Upper Triassic-Aquitanian sedimentary cover.

The age of deformation of the Internal Domain is well constrained by the Aquitanian age of the youngest sediments stacked in the nappe pile (de Capoa et al. 1997) and the Burdigalian age (Bonardi et al. 1980) of the oldest clastic deposits unconformably lying on all the Peloritanian Units (Stilo-Capo d'Orlando Formation).

The Flysch Domain units are arranged in three nappes: Monte Soro, Troina-Tusa and Nicosia, emplaced respectively

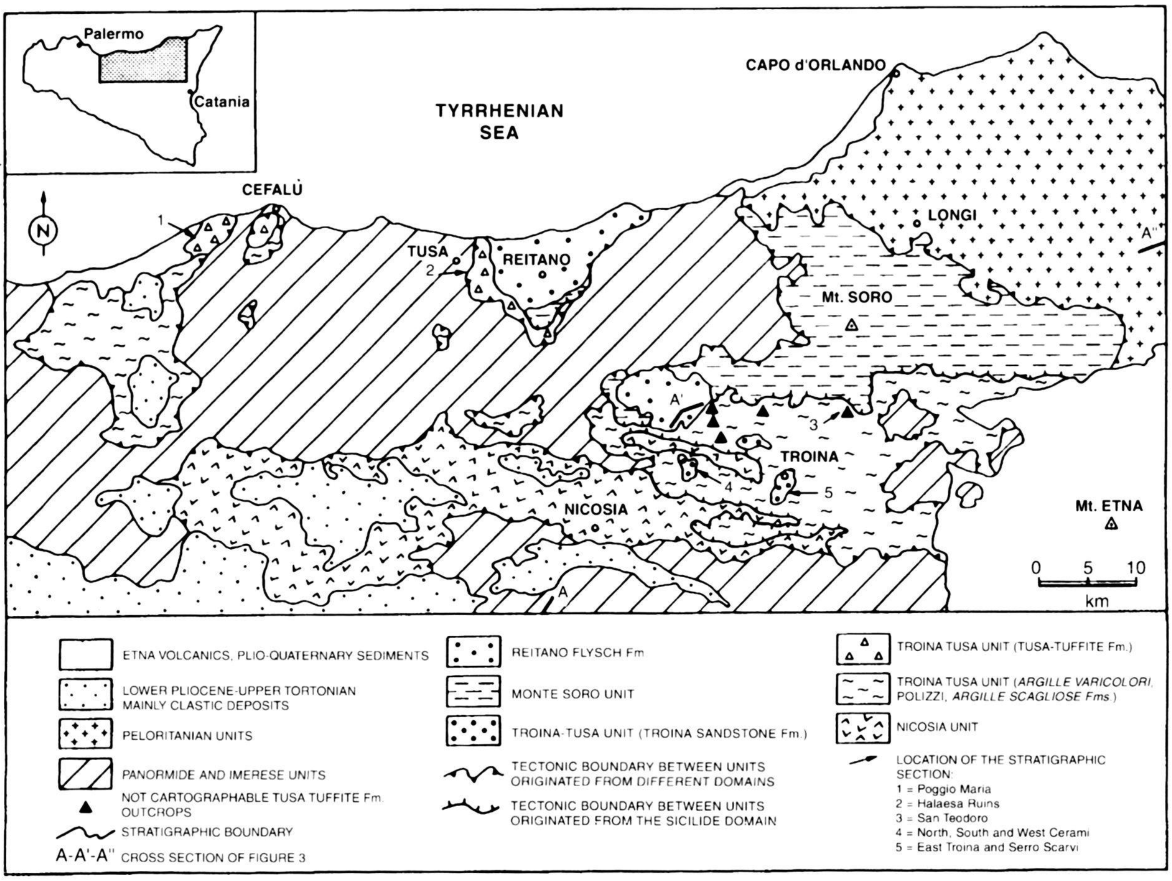

Fig. 2. Geologic sketch map of north-eastern Sicily.

from the top to the bottom of the stack. For the Sicilian sector of the Flysch Basin we propose to use the term Sicilide Basin (Ogniben 1960), in agreement with the Italian literature. Sicilide units have also been recognized in a more internal position, onto the Stilo-Capo d'Orlando Fm. or directly lying on the metamorphic basement of the Peloritanian units (Fig. 3). This supra-Peloritani arrangement has been interpreted as the result of a back-thrusting (Antisicilide Complex; Ogniben 1960), related with the closure of the Sicilide Flysch Basin and the consequent Africa-Europe collision (Bonardi et al. 1996).

The External Domain Units are recognizable in several thin-skinned thrust sheets, made up of deposits ranging in age from the Middle Triassic to the middle-late Miocene. They show prevailing Mesozoic carbonate platform or carbonate ramp successions and subordinate deep pelagic sediments.

In the early Miocene a wide deep basin extends from a part of the External Domain (Imerese and Panormide Zones) to the Mauretanian Zone. Within this basin, the pelitic and quartzarenitic sedimentation of the Numidian Flysch Sequence develops in the former Imerese, Panormide and Massylian Zones. Northward, the Numidian Sequence passes to the immature sediments of the Mauretanian Zone. Therefore, the uppermost levels of the Imerese, Panormide and Massylian Units are characterized by the same sediments of the Numidian Flysch Sequence.

3. The Maghrebian Flysch Basin in Sicily: previous papers and state of the art

Ogniben (1960) distinguishes a Sicilide Complex characterized by an upper nappe (Cesarò Nappe), constituted by Cretaceous sandy-pelitic sediments, and a lower nappe (Troina Nappe), made up of Cretaceous-Miocene deposits. The Eocene of the Troina Nappe includes some heteropic formations, capped by the mainly arenaceous Reitano Flysch, Oligocene-middle Miocene in age. According to Ogniben (1960) the Cesarò and Troina Nappes would derive from the same stratigraphic succession, whose upper part would have been overthrust by the lower one, detached in correspondence with Eocene variegated clay levels.

These ideas resulted in the geologic map of Vezzani et al. (1972). The stratigraphic succession of the Sicilide Complex, from which the Cesarò and Troina Nappes originated, starts with a Tithonian?-Lower Cretaceous formation made up of clays and limestones, and ends with three heteropic Eocene formations. The first two are constituted by clays, marls and,

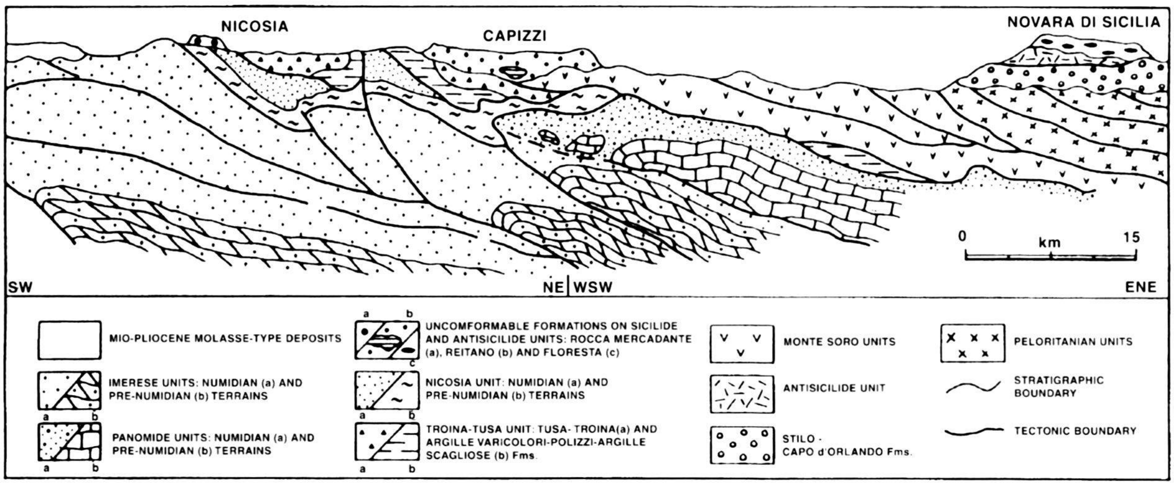

Fig. 3. Schematic cross section of north-eastern Sicily (after Bianchi et al. 1987; slightly modified), along the alignment Novara di Sicilia-Capizzi-Nicosia (A-A'-A'' in Fig. 2).

subordinately, limestones and sandstones; whereas the third is made up of tuffites, tuffitic sandstones and clays (*Tufiti di Tusa* Fm.). The arenaceous turbidites of the Reitano Flysch, latest Oligocene-early Miocene in age, unconformably lie on both Cesarò and Troina Nappes, post-dating their tectonic contacts.

However, according to Duée (1969) and Caire (1970) three main nappes (*Argille Scagliose*, Reitano and Monte Soro) originated from the Sicilide Basin. Starting from the Late Jurassic, the sediments of the Sicilide Basin would have been deposited all around the partially emerging crystalline Peloritanian Domain. In the Oligo-Miocene, the deformation of this domain would have directly influenced the sedimentation, causing an immature sandy-conglomeratic supply in the Reitano Nappe basin, located immediately north and west of the crystalline area. Contemporaneously the clayey and quartzarenitic sedimentation continued in the *Argille Scagliose* and Monte Soro Nappe basins, located north of the Reitano Basin and south of the crystalline domain, respectively. This paleogeographic reconstruction would explain the present arrangement of the Sicilide Nappes, which lie above and below the Peloritanian units (Fig. 3). Some unconformities, Cretaceous, Eocene and late Oligocene in age, would testify important tectonic events, but the present setting would be the result of Tortonian tectogenetic phases.

Later, Wezel & Guerrera (1973) and Guerrera & Wezel (1974) reached very different conclusions. The *Tufiti di Tusa* Fm., late Oligocene-middle Aquitanian in age, overlies in stratigraphic continuity varicoloured clays, it constitutes the highest part of the Troina-Tusa tectonic unit and is heteropic of the marly-litho-arkosic flysch successions, cropping out at Troina and Cerami. The Troina-Tusa Unit is unconformably topped by the neo-authochtonous Reitano-Capo d'Orlando Flysch, early Miocene in age. Moreover, the authors were the first to interpret the Tusa tuffites according to a plate tectonics model: this turbiditic formation was supplied from the erosion of a calc-alkaline volcanic arc, and may be correlated with other volcaniclastic deposits of the Central-Western Mediterranean region.

These interpretations are shared by Amodio Morelli et al. (1976), except for the correlation between the Capo d'Orlando and Reitano Fms., which, on the contrary, are considered to follow two different tectogenetic phases: the first is responsible for the deformation of the Peloritanian Domain, the second of the Sicilide one. Therefore, also the ages should be different: more ancient (Oligocene) for the Capo d'Orlando Fm., younger (early or middle Miocene) for the Reitano Flysch Fm.

Because of the occurrence of coeval levels in both the Troina and Cesarò Nappes, Lentini & Vezzani (1978) and Lentini (1982) question that there was only one stratigraphic succession, split up by the tectonics. According to these authors, two nappes originated from the Sicilide Basin: the internal Monte Soro Nappe and the external Troina-Tusa Nappe. In the late Oligocene-early Miocene a tectogenetic phase, post-dated by the Reitano-Capo d'Orlando Flysch, caused the overriding of the Peloritanian Units on the Monte Soro Unit and, later, the emplacement of the nappe pile on the Troina-Tusa deposits. In the still undeformed most external areas of the Sicilide Basin – around Cerami and Troina – the clastic sedimentation of the Reitano Flysch continued on the Oligocene sediments. Therefore, an internal Reitano Flysch, unconformably lying on deformed Sicilide Units, and an external Reitano Flysch, following still undeformed Sicilide terrains, are for the first time distinguished.

Puglisi (1979, 1987) points out marked differences in the petrography of the sandstones of the Internal and External Reitano Flysch. This latter is significantly rich of andesitic volcanic clasts, which represent an evident link with the Tusa Tuffite Fm.

Giunta et al. (1982) and Giunta (1985) describe a Nicosia Unit within the Sicilide Domain. This nappe is geometrically the lowest one, lying below the Troina-Tusa Nappe; its external paleogeographic origin is confirmed by the upper

Oligocene-lower Miocene Numidian Flysch, never recognized in the Troina-Tusa and Monte Soro Units.

Bianchi et al. (1987) describe the units, both exposed and buried, recognizable along a crustal profile Nebrodi-Iblei. In the northernmost part, the Sicilide units crop out beneath the Peloritanian units. From the top to the bottom they are: 1) the Monte Soro Unit, made up of only Thitonian-Cretaceous deposits; 2) the Sicilide s.s. Unit, which shows Cretaceous-Eocene pelitic and carbonate sediments and ends with a marly-arenaceous, somewhere tuffitic, turbiditic formation, early Miocene in age; 3) the Nicosia Unit, whose highest levels (Numidian Flysch) are early Burdigalian in age. The first two units are sutured by the unconformably lying Reitano Flysch, probably middle Miocene in age.

Later on, some papers re-propose a pre-late Oligocene age for the Reitano Flysch and for the tectogenetic phases responsible for the deformation of the Sicilide Basin. Courme & Mascle (1988) consider the External Reitano Flysch late Eocene-middle Oligocene in age, whereas Roure et al. (1990) recognize a major unconformity at the base of the Reitano Flysch, which is considered Oligocene in age, and propose again the pre-Oligocene deformation, already pointed out by Ogniben (1960).

Similarly, Cassola et al. (1992, 1995) and Puglisi (1992), on the base of further biostratigraphic data, propose an early Oligocene age for all the terrains previously ascribed to the Reitano Flysch. The authors distinguish an Internal Reitano Flysch, unconformably lying on the only Monte Soro Unit, and an External Reitano Flysch. This latter constitutes the uppermost levels of the Troina-Tusa succession and would be deposited in small pull-apart basins, located in the still undeformed area. Moreover, the early Oligocene age of the Internal Reitano Flysch would demonstrate the occurrence in the Sicilian sector of the Maghrebian Chain of a meso-Alpine tectogenetic phase. This is responsible for the deformation of both the Peloritanian Domain and the sector of the Sicilide Basin in which the Monte Soro succession deposited.

Interesting data are shown in the map of Carbone et al. (1990) and in Lentini et al. (1991, 1995). The Sicilide Units represent an accretionary wedge originated during the Paleogene. Particularly, in the Troina-Tusa and Nicosia Units, stratigraphic successions, starting from the Cretaceous and ending respectively in the early Miocene and in the early Burdigalian, are recognized. All the deposits previously ascribed both to the Internal and External Reitano Flysch, would lie unconformably on the Monte Soro and Troina-Tusa successions: moreover, they would be Burdigalian-Serravallian in age and would post-date the deformation of the Sicilide Basin, which, therefore, started in the late Oligocene and ceased during the early Burdigalian. Besides, according to Lentini et al. (1995), two other Sicilide units would be recognizable. The first one (*Argille Scagliose Superiori* Unit) would be a broken formation made up of exclusively Cretaceous varicoloured clays, marls and sandstones, tectonically sandwiched between the Peloritanian and the Monte Soro Units. The second one (Monte Salici Unit, formerly considered as an Imerese Unit; Bianchi et al. 1987) crops out below the Nicosia Unit and its upper levels would be made up of only lower-middle Miocene quartzarenites.

Finally, La Manna et al. (1995) propose a sketch of the tectono-sedimentary evolution of the Sicilide Basin. The deformation would take place between the late Oligocene (*i.e.* the age of the Tusa tuffites) and the Aquitanian (*i.e.* the age of the uppermost levels of the Nicosia Unit stratigraphic succession). The stacking of the Sicilide units was immediately followed by the deposition of the Reitano Flysch Fm., whose age ranges between the Burdigalian and a no better definable middle Miocene.

4. The Sicilide Basin units

As already pointed out, the units resulting from the deformation of the terrains deposited in the Sicilide Basin are, from the top to the bottom, the Monte Soro (Duée 1969), the Troina-Tusa (Wezel & Guerrera 1973) and Nicosia (Giunta et al. 1982) Units.

The stratigraphic succession of the Monte Soro Unit starts with clays, marls and fine-grained turbiditic limestones (clayey-calcareous member), followed by quartzarenites with a few beds of varicoloured clays (quartzarenitic member). In this succession only Cretaceous foraminifera and coccoliths have been found (Vezzani et al. 1972). Recently, Bouillin et al. (1995) recognized Upper Jurassic radiolarites (Contrada Lanzeri Formation), interpreted as the bottom of the succession. Only Giunta et al. (1982) believe that the Cretaceous succession of the Monte Soro Unit continues with Paleogene and perhaps lower Miocene terrains, but no biostratigraphic data supporting these ages have ever been presented (Tab. 1).

The base of the succession of the Troina-Tusa Unit is made up of varicoloured clays. They somewhere are strongly deformed and contain blocks of jaspers, marls and whitish calcilutites, Cretaceous-Eocene in age (*Argille Scagliose* Formation; Lentini et al. 1991). It is followed by an alternance of calcareous and marly-calcareous turbidites, with abundant macroforaminifera of Eocene age (Polizzi Formation; Lentini et al. 1991). The stratigraphic succession continues with another varicoloured clayey formation of Oligocene age, characterized in the upper part by marly and marly-calcareous beds, some tens of metres thick (*Argille Varicolori* Formation; Lentini et al. 1991). This latter, near Cefalù, is capped by tuffitic sandstones, whereas in the region of Tusa, San Teodoro and Capizzi, it passes to a pelitic-tuffitic succession (Tusa Tuffite Fm.). Finally, between Cerami and Troina, the *Argille Varicolori* Fm. is followed by a sandy-pelitic turbiditic succession, with abundant volcaniclastic detritus at the bottom (Puglisi 1979). For these latter terrains we propose the denomination of Troina Sandstone Formation (Tab. 1).

The Nicosia Unit shows in the lower-middle part a stratigraphic succession similar to that constituting the Troina-Tusa Unit, characterized by the *Argille Scagliose*, Polizzi and *Argille Varicolori* Fms. In the uppermost part of the last formation

MAGHREBIAN FLYSCH BASIN OF SICILY									
MAURETANIAN DOMAIN							MASSYLIAN DOMAIN		
Reitano Flysch Fm. Serravallian ? – Upper Burdigalian ? (*La Manna et al., 1995)*					?	?	Rocca Mercadante Fm. Middle Miocene (*Fravega et al., 1995)*		
MONTE SORO UNIT	COZZO DI MANGANO - ALCARA LI FUSI SUCCESSIONS *(Giunta et al., 1982)*	Lower Miocene ? - Upper Cretaceous ? *(Giunta et al., 1982)*	TROINA TUSA UNIT	TUFITI di TUSA Fm. *(Wezel & Guerrera, 1973)*	ARENARIE di TROINA Fm. *(this Paper)*	Upper – Lower Burdigalian *(this Paper)*	NICOSIA UNIT	NUMIDIAN FLYSCH Fm. *(Giunta et al., 1982)*	Burdigalian *(Carbone et al. 1990; (La Manna et al., 1995)*
	MONTE SORO QUARTZARENITIC, SANDY-CLAYEY and CLAYEY-CALCAREOUS MEMBERS *(Vezzani et al., 1972)*	Upper Cretaceous ? - Tithonian ? *(Vezzani et al. 1972)*		ARGILLE VARICOLORI Fm. *(Carbone et al., 1990)*		Aquitanian – Oligocene *(this Paper)*		ARGILLE VARICOLORI Fm. *(Carbone et al.,1990)*	Lower Burdigalian - Oligocene *(Carbone et al. 1990)*
				POLIZZI Fm. *(Carbone et al., 1990)*		Eocene *(Carbone et al., 1990)*		POLIZZI Fm. *(Carbone et al.,1990)*	Eocene *(Carbone et al., 1990)*
	CONTRADA LANZERI Fm. *(Bouillin et al., 1995)*	Upper Jurassic *(Bouillin et al., 1995)*		ARGILLE SCAGLIOSE Fm. *(Carbone et al., 1990)*		Lower Eocene ? - Upper Cretaceous *(Carbone et al.,1990)*		ARGILLE SCAGLIOSE Fm. *(Carbone et al.,1990)*	Lower Eocene ? - Upper Cretaceous *(Carbone et al., 1990)*

Tab. 1. Schematic table of the Units of the Sicilide Domain. Stratigraphic successions and ages from our and previous Authors data.

thin quartzarenitic levels appear, which mark the passage to the Numidian Flysch, characterized by thick quartzarenitic layers interbedded with brown pelites. The Numidian Flysch ends with lower Miocene cherty marls (Carbone et al. 1990) and a typical Mixed Succession (Guerrera et al. 1986), in which lithic-arkosic and tuffaceous beds are interbedded with the quartzarenites (Tab. 1).

5. Field data

A study of the stratigraphic sections of the upper part of the Troina-Tusa Unit has been carried out in the region of Troina, San Teodoro, Cerami, Castel di Tusa and Cefalù, in order to provide a detailed picture of the stratigraphic successions, both volcaniclastic (Tusa tuffites) and arkosic (Troina sandstones), and to check their relationships with the pelagic sediments of the underlying *Argille Varicolori* Fm.

As far as the *Argille Varicolori*-Tusa Tuffites succession is concerned, four stratigraphic sections, located near Cefalù, within the Fiumara of Tusa and at San Teodoro, have been reviewed and sampled (Fig. 4). In the area of Cefalù, Lascari and Gibilmanna, terrains belonging to the Troina-Tusa Unit constitute two small klippen overlying the Panormide Numidian Flysch (Fig. 2). These klippen are made up of some tens of metres of the marly and marly-calcareous beds, corresponding with the uppermost portion of the *Argille Varicolori* Fm., followed by volcaniclastic sandstones, up to 200 m thick, well exposed in the Poggio Maria, Cozzo Sant'Elia and le Serre reliefs. These sandstones, up to now included in the Reitano Flysch Fm., are here for the first time identified as belonging to the Troina-Tusa Unit.

The transitional boundary between the marly and calcareous beds and the overlying volcaniclastic sandstones is well exposed in both klippes, particularly along the road from Cefalù to Gibilmanna and in the valley of the Rio Campella, in front of Lascari. In the uppermost 10 m of the marly-calcareous succession some thin sandstone beds appear above which the succession is exclusively made up of arenaceous turbidites. These show characteristic greenish strata, up to 30–40 cm thick, within which the Bouma sequence is generally difficult to recognize. Both the T_e interval and hemipelagic levels are missing as well as calcareous and marly beds: the succession, therefore, appears exclusively arenaceous and only in the uppermost portion in the area of Poggio Maria some thin silty-pelitic levels may be found (Fig. 4). The best section of the succession occurs on the southern slope of Poggio Maria, along the Rio Campella stream, where also the boundary between the pelitic and the arenaceous sediments is well exposed. Well preserved outcrops may be also observed, for about 2 km, along the coast east of Capo Plaia.

In the Fiumara of Tusa, close to the Halaesa ruins, the Troina-Tusa Unit terrains lie through a tectonic boundary on the brown marls and quartzarenites of the Numidian Flysch. The Tusa tuffites and the underlying *Argille Varicolori* have been recognized in two tectonic sheets (Wezel & Guerrera 1973). The lower sheet is 170 m thick (lower Halaesa sheet); the upper sheet is overturned and reaches a thickness of 600 m (upper Halaesa sheet). It is unconformably overlain by the sandy-pelitic turbidites of the Reitano Flysch Fm. The two sheets may be correlated by means of a 14 m thick volcaniclastic layer (Fig. 4).

In the upper Halaesa sheet the stratigraphic substratum of the volcaniclastic succession is well preserved. It is made up of varicoloured clays containing beds of fine-grained carbonate turbidites. The uppermost levels, below the first volcaniclastic bed, are strongly deformed and affected by slumpings. The varicoulored clays, however, clearly grade into the volcaniclastic succession.

In both sheets the tuffitic succession is different from that one cropping out in the Cefalù area, which is characterized by

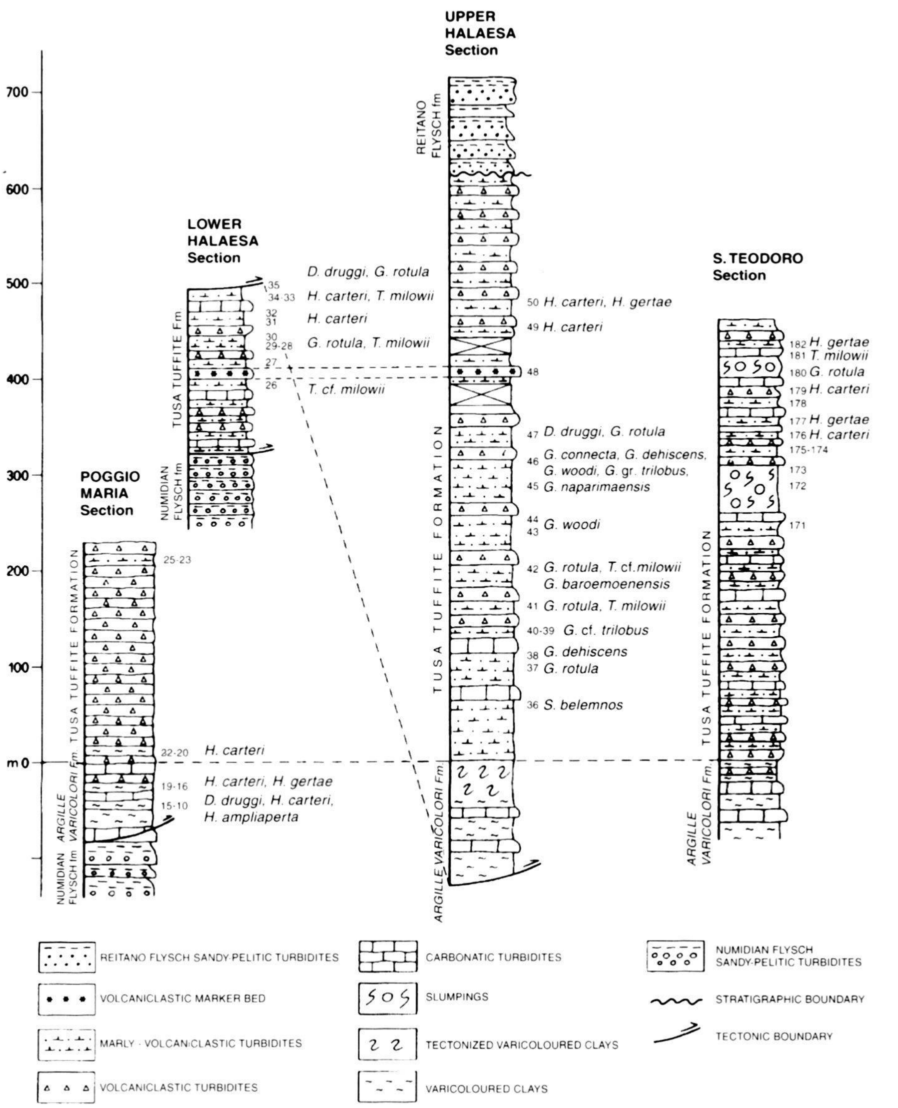

Fig. 4. Stratigraphic columns of the studied sections of the Tusa Tuffite Fm. The location of the samples and the occurrence of taxa starting from early Miocene are indicated.

only arenaceous beds. Here, it is made up of clearly re-sedimented volcaniclastic and marly-calcareous beds, and few and thin hemipelagic levels, formed by greenish pelites (Fig. 4). The volcaniclastic strata are mainly constituted by thin silty-marly turbidites, more or less rich in volcanic detritus, interbedded with coarse-grained arenaceous levels. These latter constitute about twenty layers of graded blue-greenish andesitic sandstones, gradually passing to arenaceous marls. The thickness of these sandstone beds, ranging between 20 cm and 14 m, is frequently 2–3 m. The petrographic composition is mainly characterized by volcanic clasts (40–90%; andesite fragments, glasses, crystals of plagioclase, magnetite, biotite, olivine, hyperstene, etc.) and to a lesser extent by plutonic and metamorphic detritus (10–40%; quartz, feldspars, muscovite, gneissic, granitic and phyllitic fragments). As regards the calcareous turbidites, some of them are coarse-grained and characterized by neritic bioclasts (macroforaminifera and algae), whereas others are fine-grained.

The fourth stratigraphic section has been sampled 2 km north of San Teodoro, along the road which from the village reaches the 289 State Road at Portella Buffali. Here, the Tusa Tuffite Fm. crops out with a thickness close to 450 m. Also in this section some volcaniclastic beds appear interbedded within the uppermost portion of the *Argille Varicolori* Fm. and abruptly increase upwards, becoming the markedly prevailing lithotypes. The stratigraphic succession, wholly turbiditic, is very similar to that of the Fiumara of Tusa area: silty-marly beds, rich in volcanic detritus, and blue-greenish tuffitic strata are interbedded with minor whitish limestones, some of them made up of re-sedimented neritic fragments. In the middle-upper portion of the succession two slumps occur (Fig. 4).

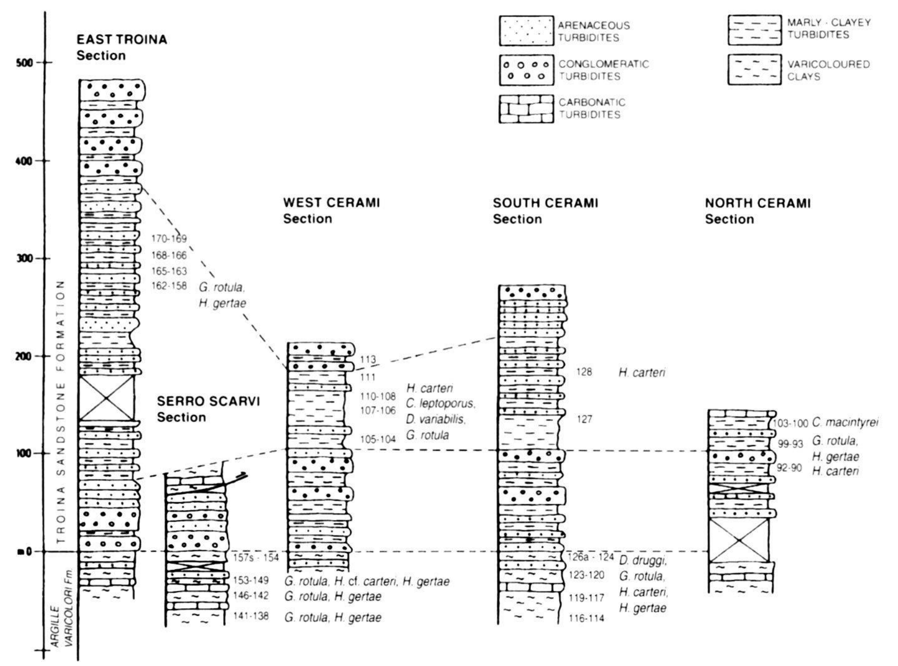

Fig. 5. Stratigraphic columns of the studied sections of the Troina Sandstone Fm. The location of the samples and the occurrence of taxa starting from early Miocene are indicated.

Other outcrops of the Tusa Tuffite Fm. are located in an almost continuous belt from Castel di Tusa to Mistretta and in the region north-west of Troina (Fig. 2). In all these outcrops the small extension and the strong deformation did not allow to define detailed stratigraphic successions.

As regards the successions characterized by the *Argille Varicolori* Fm. grading into the arkoses and lithic arkoses of the Troina Sandstone Fm., five stratigraphic sections have been examined in detail and sampled, in the region of Cerami and Troina (Fig. 5). In the most complete sections across the Troina Sandstone Fm. (East Troina; West Cerami and South Cerami), three different lithologic intervals, already pointed out by Cassola et al. (1992), may be observed. The lower interval, made up of thick and channelized beds of coarse-grained conglomerates and sandstones, is followed by a mainly pelitic interval, characterized by thin beds of fine-grained sandstones and, finally, by an upper interval, formed by thickening and coarsening upwards coarse-grained sandstones.

The East Troina section is a composite stratigraphic section, whose lower part crops out 1.5 km east of the town, along the 575 State Road. The Troina Sandstone Fm. starts with layers of coarse conglomerates, which abruptly but transitionally replace the clays, marls and fine-grained turbiditic limestones of the *Argille Varicolori* Fm. The conglomerates, 50 m thick, pass to graded sandstones, about 20 m thick, followed by 70 m of pelites containing some thin arenaceous beds. Nearly 1 km east of Troina, between Monte Ragone and Monte Eliseo, pelites and thin sandstones can be observed for further 175 m. In the following 35 m the sandstone layers become thicker and coarser and, finally, they are replaced by conglomerates forming the uppermost 100 m of the succession (Fig. 5).

In the Serro Scarvi area, nearly 4 km south-east of Troina, the transition from the *Argille Varicolori* to the Troina Sandstone Fms. may be examined in detail. Only some tens of metres of conglomerates and sandstones of the Troina Sandstone Fm. are exposed, because a minor thrust which allows the *Argille Varicolori* to override the Troina sandstones (Fig. 5). The upper fifty metres of the *Argille Varicolori* Fm., made up of marls and fine-grained turbiditic limestones, include some arenaceous beds, prefacing the appearence of thick sandy-conglomeratic layers, which abruptly replace the underlying mainly pelagic deposits.

In the West Cerami section, W of the village along the 120 State Road, the transition from the *Argille Varicolori* Fm. to the Troina Sandstone Fm. is well exposed (Fig. 6). This latter starts with 25 m of arenaceous turbidites followed by 65 m of coarse conglomerates, overlain by 90 m of pelites containing few arenaceous beds, which upwards become more frequent and thick. The succession is capped by 15 m of conglomerates and some arenaceous beds.

In the South Cerami section, located on the southern slope of Monte Grottelle, nearly 1 km south of the village, the transition from the *Argille Varicolori* to the Troina Sandstone Fm. is particularly evident. The uppermost marly-calcareous portion of the *Argille Varicolori* Fm. is characterized by numerous levels of allodapic limestones and by the appearence of thin arenaceous beds (Fig. 7). Here, the Troina sandstones show a succession similar to that observed in the West Cerami section. The lower portion is made up of 105 m of sandstones and channelized conglomerates. These latter are more frequent upwards, and are followed by a 95 m thick interval, characterized by arenaceous beds prevailing on the pelitic ones. The succes-

Fig. 6. South-western corner of the Cerami outcrop, between West and South Cerami sections. Conformable boundary between the marly calcareous uppermost part of the *Argille Varicolori* Fm. and the Troina Sandstone Fm.

Fig. 7. South Cerami section, southern slope of Monte Grottelle. Transitional boundary between the uppermost marly-calcareous part of the *Argille Varicolori* Fm. and the Troina Sandstone Fm. Note the first occurrence of thin arenaceous beds (arrow) within the *Argille Varicolori* Fm.

sion ends with nearly 55 m of alternating conglomerates and sandstones (Fig. 5).

The North Cerami section, located nearly 500 m north of the village, lacks of the lowermost portion, and consists only of 60 m of the lower sandy-conglomeratic interval and of nearly 30 m of the overlying pelitic interval (Fig. 5).

6. Biostratigraphic data

130 samples, collected in the previously described logs (Fig. 4 and 5) have been analyzed with respect to foraminifera and coccoliths. The latter have been studied after the taxa were concentrated owing to several centrifugations.

Taking into account the results of the biostratigraphic studies carried out on turbiditic formations of the southern Apennines, Calabria and Peloritani Mountains (Bonardi et al. 1980, 1988; Patacca et al. 1992; de Capoa et al. 1997), we have considered only the FAD (First Appearance Datum) of the taxa, because the LAD (Last Appearance Datum) is meaningless in turbiditic sediments, as well as the state of preservation of the taxa and the quantitative analysis. The above mentioned studies led to a general re-juvenation of formations formerly considered Cretaceous or Paleogene in age and demonstrated that the reworking of coccoliths and foraminifera in turbiditic successions is systematic and criteria useful to distinguish reworked and unreworked taxa do not exist. Conse-

Tab. 2. Coccolithid assemblages recognized in the samples collected in the Serro Scarvi section of the *Argille Varicolori* Fm.

Name of section:	SERRO SCARVI																	
Sample:	139	140	142	143	144	146	147	148	149	150	151	153	154	155	156	157	157 a	157 b
Braarudosphaera bigelowi	+											+						
Coccolithus miopelagicus	+	+	+	+		+	+			+		+	+	+	+	+	+	+
Coccolithus miopelagicus >20µ					+						+							
Coccolithus pelagicus	+		+	+	+			+	+		+	+	+	+		+	+	+
Coronocyclus nitescens	+																	
Cyclicargolithus abisectus	+	+	+	+	+		+		+	+	+	+		+	+	+	+	+
Cyclicargolithus floridanus	+	+			+	+	+			+	+	+	+	+	+	+	+	+
Discoaster adamanteus	+						+					+		+				
Discoaster calculosus	+																	
Discoaster deflandrei	+		+		+					+		+	+	+	+	+	+	
Discoaster aff. *formosus*	+																	
Discoaster spp.											+			+		+		
Ericsonia cava	+									+	+		+		+	+		
Ericsonia obruta	+		+	+		+	+		+		+	+	+	+	+	+	+	+
Geminilithella rotula					⊗							⊗		⊗	⊗			
Helicosphaera cf. *carteri*																	⊗	
Helicosphaera euphratis	+	+	+		+		+					+	+	+	+	+	+	
Helicosphaera gertae					⊗							⊗		⊗	⊗	⊗		
Helicosphaera truempyi					+										+	+		
Helicosphaera cf. *truempyi*																		+
Pedinocyclus larvalis	+																	
Pontosphaera spp.	+	+																
Pyrocyclus hermosus	+				+		+			+	+			+		+	+	
Reticulofenestra daviesi																		+
Reticulofenestra gartneri	+	+	+		+						+	+			+			
Reticulofenestra perplexa	+	+				+	+	+	+	+	+			+	+	+	+	+
Reticulofenestra sp.																	+	
Sphenolithus conicus																	+	
Sphenolithus aff. *dissimilis*																		+
Sphenolithus cf. *dissimilis*																		+
Sphenolithus moriformis	+				+		+		+		+	+		+	+	+	+	+
Sphenolithus sp.																		+
Thoracosphaera spp.	+				+								+				+	+
Triquetrorhabdulus carinatus												+					+	

+ occurrence; ⊗ marker

Tab. 3. Coccolithid assemblages recognized in the samples collected in the Poggio Maria and South Cerami sections of the *Argille Varicolori* Fm.

Name of Section:	POGGIO MARIA									SOUTH CERAMI														
Sample:	10	11	12	14	15	16	17	18	19	114	115	116	117	118	119	120	121	122	123	124	125	125 a	126	126 a
Braarudosphaera bigelowi							+							+							+			
Coccolithus miopelagicus				+			+			+	+	+	+	+	+	+	+		+	+		+	+	
Coccolithus pelagicus	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+			+	+	+	
Coronocyclus nitescens										+	+			+	+							+		
Cyclicargolithus abisectus	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	+
Cyclicargolithus floridanus	+			+	+		+	+	+	+	+	+	+	+	+	+	+	+			+	+		
Discoaster calculosus	+																							
Discoaster deflandrei										+	+		+	+	+	+						+	+	
Discoaster cf. *deflandrei*	+						+																	
Discoaster druggi			⊗																				⊗	
Discoaster cf. *druggi*																						⊗		
Discoaster spp.				+	+					+												+	+	
Ericsonia cava	+	+		+						+	+		+		+		+				+	+		
Ericsonia obruta										+	+			+	+	+					+	+	+	
Geminilithella rotula																						⊗	⊗	
Helicosphaera ampliaperta	⊗																							
Helicosphaera carteri	⊗			⊗					⊗													⊗		
Helicosphaera cf. *carteri*	⊗	⊗				⊗			⊗												⊗	⊗		
Helicosphaera euphratis				+							+		+	+	+						+	+	+	
Helicosphaera cf. *euphratis*	+																							
Helicosphaera gertae									⊗												⊗	⊗	⊗	
Helicosphaera cf. *truempyi*																							+	
Helicosphaera spp.																					+			
Pontosphaera ocellata											+													
Pontosphaera spp.						+					+												+	
Pyrocyclus hermosus										+	+		+	+	+	+				+	+	+		
Reticulofenestra daviesi							+	+													+	+		
Reticulofenestra gartneri										+	+			+	+					+		+	+	
Reticulofenestra perplexa	+			+	+		+				+	+		+							+	+	+	+
Reticulofenestra sp.							+																	
Sphenolithus conicus										+												+		
Sphenolithus cf. *conicus*							+																	
Sphenolithus moriformis	+	+		+	+	+	+	+	+		+			+	+	+			+		+	+	+	
Sphenolithus spp.	+		+																		+	+	+	
Thoracosphaera sp.																							+	
Triquetrorhabdulus carinatus		+		+		+			+					+								+		

+ occurrence; ⊗ marker

quently, only a minimum age could be proposed for the fossiliferous samples.

40 of the examined 130 samples resulted barren. The assemblages are generally poor and rests are often highly deformed; coccoliths are more or less overgrown or dissolved.

All the collected samples are characterized by the prevalence of reworked taxa (up to 90% and more). Among them Paleogene forms prevail, but also Cretaceous species are observable. Nevertheless, in all the studied formations (*Argille Varicolori*, Tusa Tuffite and Troina Sandstone) taxa whose first occurrence is early Miocene in age have been identified and they are indicated in the columns of figures 4 and 5.

Unreworked coccoliths recognized in the uppermost levels of the *Argille Varicolori* Fm. are shown in Tables 2 and 3. The occurrence of *Discoaster druggi*, *Geminilithella rotula*, *Helicosphaera ampliaperta*, *H. carteri* and *H. gertae* both in the Serro Scarvi and Poggio Maria sections (Fig. 4 and 5) testifies an age not older than Aquitanian (Zone NN1-NN2 of Martini 1971 = Zone CN1 of Okada & Bukry 1980). In the South Cerami section (Tab. 2) the samples 114–120 and 121–124 furnished taxa which start from the late Rupelian (*Sphenolithus distentus*, *Helicosphaera wilcoxoni*, *Chiasmolithus altus*) and the Chattian (*Sphenolithus ciperoensis*, *Triquetrorhabdulus carinatus*), respectively. Only in the uppermost samples (125–126) taxa which start from the Aquitanian (*Discoaster druggi*, *Geminilithella rotula*, *Helicosphaera carteri*, *H. gertae*) have been recognized, but, taking into account that all the studied samples have been collected across only 30 metres of the succession, we consider as the most probable an early Miocene age for all the levels of this section.

Name of section:	POGGIO MARIA			UPPER HALAESA															LOWER HALAESA									SAN TEODORO						
Sample:	20	21	25	36	37	3	39	40	41	42	43	44	45	46	47	48	49	50	26	27	28	29	31	32	33	34	35	171	173	176	177	178	179	180
Braarudosphaera bigelowi				+		+	+			+				+			+			+	+	+				+			+					
Coccolithus miopelagicus	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+		+		+	+		+	+	
Coccolithus pelagicus				+	+	+			+	+		+	+		+	+	+		+	+	+	+	+	+	+	+		+	+	+	+		+	+
Coronocyclus nitescens									+	+	+				+		+	+				+							+	+			+	
Cyclicargolithus abisectus	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cyclicargolithus floridanus			+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Discoaster adamanteus						+	+	+		+			+																+					
Discoaster aff. adamanteus										+																			+					
Discoaster cf. adamanteus						+																		+										
Discoaster calculosus																						+												
Discoaster deflandrei				+	+		+			+				+		+	+		+	+		+							+		+	+	+	+
Discoaster cf. deflandrei													+																					
Discoaster druggi															⊗											⊗								
Discoaster spp.		+										+		+	+		+	+			+	+									+	+	+	+
Ericsonia cava	+		+	+	+	+	+	+	+		+				+		+	+		+	+	+	+	+	+						+			+
Ericsonia obruta				+	+	+	+	+	+	+	+		+		+	+	+	+	+	+		+			+	+		+	+	+			+	+
Geminilithella rotula					⊗				⊗	⊗					⊗							⊗			⊗							⊗		
Helicosphaera carteri		⊗	⊗														⊗	⊗					⊗		⊗					⊗		⊗		
Helicosphaera euphratis	+			+			+		+	+	+	+		+	+	+	+	+		+	+	+	+		+	+	+		+				+	+
Helicosphaera gertae																		⊗													⊗			⊗
Helicosphaera cf. gertae																																		⊗
Helicosphaera truempyi											+				+					+		+					+			+				+
Helicosphaera sp.																+																		
Pontosphaera discopora																									+									
Pyrocyclus hermosus				+	+	+		+		+	+							+	+	+		+			+			+	+					
Pyrocyclus sp.																	+																	
Reticulofenestra daviesi														+	+	+	+	+										+	+	+	+	+	+	+
Reticulofenestra gartneri					+					+												+		+	+	+								
Reticulofenestra perplexa				+	+	+	+	+	+	+	+		+						+	+	+	+	+	+	+	+		+	+					
Reticulofenestra spp.																														+		+	+	
Sphenolithus belemnos				⊗																														
Sphenolithus capricornutus																													+					
Sphenolithus conicus											+		+									+							+					
Sphenolithus aff. conicus																		+																
Sphenolithus dissimilis																	+																	
Sphenolithus moriformis			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+		+	+	+	+		+	+
Sphenolithus spp.										+								+		+													+	
Thoracosphaera spp.				+			+		+						+		+		+	+						+			+					
Triquetrorhabdulus carinatus						+	+			+				+	+	+	+	+					+					+	+	+	+	+	+	+
Triquetrorhabdulus milowii									⊗												⊗				⊗									⊗
Triquetrorhabdulus cf. milowii										⊗									⊗															

+ occurence; ⊗ marker

Tab. 4. Coccolithid assemblages recognized in the samples collected in the Tusa Tuffite Fm.

As regards the foraminifera, the following taxa have been identified in the lower part of the Serro Scarvi section (samples 138–153):

Globigerina galavisi
Globigerina tripartita
Globigerina venezuelana
Globigerina euapertura
Globigerina sellii
Globigerina ampliapertura
Globigerina increbescens
Globigerina eocaena
Globigerina corpulenta
Globigerina ciperoensis
Globigerina praebulloides
Neogloboquadrina nana
Globorotaloides suteri
Catapsydrax unicavus
Catapsydrax dissimilis
Pseudohastigerina micra
Pseudohastigerina naguewichiensis
Chiloguembelina cubensis
«*Globorotalia gemma*»

In the uppermost portion of the section (samples 154–157) only a poor and badly preserved microfauna, made up of lower

Oligocene Globigerinidae and small Upper Cretaceous Heterohelicidae, has been recognized. Owing to the co-existence of *Pseudohastigerina micra*, *P. naguewichiensis*, *Chiloguembelina cubensis*, *Globigerina ampliapertura*, *G. increbescens* and *G. sellii*, the reported assemblage would be representative of the Zone P19 (Blow 1969) and should be attributed to the early Oligocene. The nannoplankton assemblages, recognized in the same samples, however, demonstrate that all the taxa must be considered reworked, except *Globigerina praebulloides*, *Globorotaloides suteri*, *Catapsydrax unicavus* and *C. dissimilis*.

In the Tusa Tuffite Fm. several coccolith taxa occur, which start from the early Miocene (*Discoaster druggi*, *Geminilithella rotula*, *Helicosphaera carteri* and *Triquetrorhabdulus milowii*) occur (Tab. 4; Fig. 4). The most significant datum, however, is the finding (Fig. 4), in the lower part of the succession of the upper Halaesa sheet section (sample 36), of *Sphenolithus belemnos*, whose first occurrence is reported in the upper part of the Zone NN2 of Martini (1971) = Zone CN2 of Okada & Bukry (1980). Consequently, the age of the Tusa Tuffite Fm. is from the bottom not older than the early Burdigalian.

The Tusa Tuffite Fm. is very poor in foraminifera. Very scarce planktonic and benthonic (mainly agglutinant) foraminifers and radiolaria are present, in just a few samples. In the lower Halaesa sheet section the planktonic foraminifera are almost completely lacking and mainly reworked Upper Cretaceous (Globotruncanidae) and Paleocene-Eocene (*Morozovella aequa*) taxa have been identified. It is probable that *Catapsydrax unicavus* and *C. dissimilis* are the only unreworked taxa. In the upper Halaesa sheet section (Fig. 4) rather more planktonic microfauna is contained and the following taxa have been identified:

Acarinina sp.
Globigerina galavisi
Globigerina venezuelana
Globigerina praebulloides
Globigerina woodi
Globigerina connecta
Globigerinoides gr. *trilobus*
Globigerinita naparimaensis
Globigerinita baroemoenensis
Globoquadrina dehiscens
Globoquadrina cf. *dehiscens*
Globorotaloides suteri
Catapsydrax unicavus
Catapsydrax dissimilis
Turborotalia gr. *cerroazulensis*

This assemblage confirms the results obtained through the coccolith analysis, because taxa, whose first occurrence is early Miocene in age (*Globigerina woodi*, *G. connecta*, *Globigerinita naparimaensis*, *G. baroemoenensis*, primitive forms of *Globoquadrina dehiscens*) have been recognized. Specimens have also been found that present *Globigerinoides trilobus* morphology, but the existence of supplementary openings cannot be warrented, due to the poor state of preservation. Particularly, the recognition of *Globigerina woodi*, *Globigerinita naparimaensis* and *Globigerinoides* gr. *trilobus* testifies the existence of taxa which occurred as from the Burdigalian (Zones N5-N6; Blow 1969).

As far as the Troina Sandstone Fm. is concerned, the only significant taxa of this formation are coccoliths (Tab. 5) and, also in this case, taxa which start from the early Miocene (*Geminilithella rotula*, *Helicosphaera carteri* and *H. gertae*) have been recognized (Fig. 5). The most significant datum is the occurrence in the middle part of the succession of *Calcidiscus macintyrei* (sample C 101), *C. leptoporus* (sample C 107) and *Discoaster variabilis* (sample C 107) in the North Cerami and West Cerami sections, respectively (Fig. 5). These taxa, whose first occurrence is recognized in the Zone NN4 of Martini (1971) = Zone CN3 of Okada & Bukry (1980), therefore, testify that the Troina Sandstone Fm. reaches an age not older than the late Burdigalian. As regards the foraminifera, a microfauna made up mainly of agglutinant species (Astrorhicidae, *Reophax* sp., *Ammodiscus* sp., *Glomospira* sp., *Cyclammina* sp.) has been recognized. Few radiolaria, benthonic calcareous (mainly *Nodosaria* sp.) and planktonic foraminifera are also present. The latter are characterized by the following assemblage:

Globigerina galavisi
Globigerina tripartita
Globigerina venezuelana
Globigerina euapertura
Globigerina sellii
Globigerina cf. *ampliapertura*
Globigerina increbescens
Globigerina eocaena
Globigerina corpulenta
Globigerina praebulloides
Neogloboquadrina nana
Globorotaloides suteri
Catapsydrax unicavus
Catapsydrax dissimilis

Also this assemblage, because of the occurrence of specimens of the groups *Globigerina eocaena-corpulenta* and *G. ampliapertura-increbescens*, would be early Oligocene in age, but the coccolith assemblages of the same samples suggest an early Miocene age.

In conclusion, the above data indicate an age not older than the Burdigalian for the syn-orogenic, volcaniclastic and siliciclastic, deposits of the Troina-Tusa Unit, and this age agrees with that of the uppermost levels of the underlying *Argille Varicolori* Fm., in which taxa showing an age not older than the Aquitanian have been found.

7. Discussion and conclusions

The Tusa Tuffite and Troina Sandstone Formations conformably lie on the succession *Argille Scagliose*-Polizzi-*Argille Varicolori* Fms., and constitute the uppermost, heteropic, deposits of the stratigraphic successions characterizing the Troina-Tusa Unit. The transition is marked by the sudden ap-

Tab. 5. Coccolithid assemblages recognized in the samples collected in the Troina Sandstone Fm.

Name of Section:	NORTH CERAMI												WEST CERAMI			SOUTH CERAMI		EAST TROINA				
Samples:	90	91	92	93	94	95	96	98	99	100	101	102	106	107	110	127	128	158	159	164	167	168
Braarudosphaera bigelowi																		+				
Calcidiscus leptoporus														⊗								
Calcidiscus macintyrei											⊗											
Coccolithus miopelagicus		+	+		+	+	+			+	+	+	+		+	+	+	+	+	+	+	
Coccolithus pelagicus	+		+	+	+	+	+		+		+	+	+		+	+					+	+
Coronocyclus nitescens	+							+				+										
Cyclicargolithus abisectus	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+		+	+
Cyclicargolithus floridanus	+		+	+		+	+	+	+	+			+	+	+	+				+	+	+
Discoaster variabilis														⊗								
Discoaster spp.														+								
Ericsonia cava	+														+							
Geminilithella rotula				⊗										⊗				⊗				
Helicosphaera carteri	⊗													⊗			⊗					
Helicosphaera euphratis				+					+					+								
Helicosphaera gertae				⊗				⊗											⊗			
Pontosphaera sp.																				+		+
Pyrocyclus hermosus	+		+	+				+	+	+	+						+					
Reticulofenestra gartneri	+		+	+			+		+		+			+	+							
Reticulofenestra perplexa				+		+	+				+	+		+								
Sphenolithus dissimilis				+																		
Sphenolithus moriformis				+										+					+		+	
Thoracosphaera sp.			+	+	+																	
Triquetrorhabdulus carinatus												+		+							+	

+ occurrence; ⊗ marker

pearance of sandstone beds in the uppermost portion of the *Argille Varicolori* Fm. The age of both formations is not older than early Burdigalian. Particularly, the lower tuffitic levels of the Tusa Tuffite Fm. are of early Burdigalian age (occurrence of *Sphenolithus belemnos*), whereas the upper levels of the Troina Sandstone Fm. are of late Burdigalian age (occurrence of *Calcidiscus macintyrei*, *C. leptoporus* and *Discoaster variabilis*). The taxa observed in the uppermost levels of the underlying *Argille Varicolori* Fm. confirm these ages through the presence of nannofloras not older than Aquitanian in the Poggio Maria and Serro Scarvi sections and not older than Chattian in the South Cerami section. A Burdigalian age of the Tusa Tuffite Fm. is confirmed also by foraminifera (*Globigerina woodi*, *Globigerinita naparimaensis*, *Globigerinoides* gr. *trilobus*), whereas in the Troina Sandstone and *Argille Varicolori* Fms. only lower Oligocene, or older, clearly reworked foraminifera have been recognized. We emphasize that an early Miocene age of the uppermost levels of the *Argille Varicolori* Fm. has already been pointed out by Carbone et al. (1990) in the Troina-Tusa Unit and also in the more external Nicosia Unit, immediately before the beginning of the siliciclastic sedimentation of the Troina sandstones and Numidian Flysch, respectively.

The biostratigraphic data do not allow to ascertain the existence of a possible diachronism as regards the beginning of the volcaniclastic and siliciclastic sedimentation, and, more in general, of the onset of the foredeep stage in the evolution of the Troina-Tusa basin. The described stratigraphic successions, however, show strong differences in thickness, lithology, volcaniclastic content, petrography and sedimentary facies, which may be related to a complex paleogegraphic setting, strongly influenced by the tectonics and by the location of the areas which supplied the volcaniclastic and siliciclastic sediments.

The Tusa Tuffite and Troina Sandstone Fms. testify the onset of the foredeep stage of the Sicilide Basin, when siliciclastic sediments replace the mainly pelagic deposits, immediately before the tectogenesis. The deformation will originate an accretionary wedge and the stacking of the Sicilide units in the arising chain. The Tusa tuffites and the Troina sandstones have been deposited in two different areas of the Sicilide foredeep, whose main difference was represented by the amount of the volcaniclastic detritus, deriving from the erosion of a calc-alkaline magmatic arc. Such a detritus was added to the plutonic and metamorphic one, supplied by the erosion of the crystalline basement of the Peloritanian units.

On the base of these data the Paleogene ages assigned to the mentioned formations, also recently re-proposed (Courme & Mascle 1988; Cassola et al. 1992), must be definitevely neglected. Similarly, paleotectonic reconstructions, involving meso-Alpine tectogenetic phases for the stacking of the Sicilide nappes, cannot be considered (Roure et al. 1990; Cassola et al. 1992). In fact, if the uppermost siliciclastic formations of the Sicilide units must be considered Burdigalian in age, no biostratigraphic or field data exist in the Sicilian sector of the Maghrebian Flysch Basin demonstrating that tectogenetic phases occurred during the Paleogene. This conclusion agrees well with the recent data of de Capoa et al. (1997), showing that the deformation of the external zones of the more internal Peloritanian Domain, which were paleogeographically contiguous to the northern boundary of the Sicilide Basin, occurred during the Aquitanian.

Taking into account that also the uppermost stratigraphic levels of the Nicosia Unit – i.e. the most external of the Sicilide Basin – are early Miocene in age (Carbone et al. 1990; La Manna et al. 1995), the formation of an accretionary wedge and the stacking of all the terrains deposited in the Sicilide Basin occurred not earlier than Burdigalian. From that time on, the consumption of the Maghrebian oceanic area begins to be accomplished and will be followed by the continental collision between the African Margin and the Peloritanian units, which constituted the front of the Maghrebian paleo-chain, still leaned against the European Margin.

The early Miocene deformation of both the external Peloritanian (de Capoa et al. 1997) and the Troina-Tusa Zones allows to believe that also the deformation of the Monte Soro Unit terrains, which unanimously are considered as sedimented between the Peloritanian Domain and the Troina-Tusa Zone, is early Miocene in age, even if within the Monte Soro Unit only Upper Jurassic-Lower Cretaceous terrains have been recognized.

The interpretation, which considers a Burdigalian-Langhian age for the piling up of the Sicilide Basin units, the consumption of the Maghrebian Ocean, the Africa-Europe continental collision and the back-thrusting of Sicilide terrains onto the more internal Peloritanian units (*i.e.* the Antisicilide Complex), may be confirmed only by attributing a definitive age to the base of the formations (Floresta Calcarenites, Reitano Flysch and Rocca Mercadante Calcarenites; Fig. 3) unconformably lying both on all the Sicilide and Antisicilide Units and post-dating the nappe stacking. The base of the first two formations has been considered as Burdigalian in age (Lentini et al. 1990, 1995; La Manna et al. 1995), whereas for the last a middle Miocene, probably Langhian, age has been proposed (Fravega et al. 1993). Although a Burdigalian age for both Floresta Calcarenite and Reitano Flysch Fms. could be admitted also considering the biostratigraphic results of this study, we believe more probable a Langhian age for the basal levels of the Floresta calcarenites, already recognized by Bonardi et al. (1980) in the Novara di Sicilia area (Monte Ritagli di Lecca section). In any case, our biostratigraphic data definitively allow to exclude ages older than late Burdigalian for all the deposits which have been up to now comprised in the Reitano Flysch Fm.

Taking into account the data exposed in this paper, the Burdigalian-Serravallian age proposed by Carbone et al. (1990) for the Troina sandstones, still remains an open problem. Such an age agrees with the reconstruction advanced by those authors who consider the Troina sandstones resting unconformably on the *Argille Varicolori* Fm. and, therefore, ascribe them to the Reitano Flysch Fm. This interpretation undoubtedly would solve many problems, but it is not supported by our field observations. In fact, all the outcrops (Cerami; Troina; Ancipa Lake; Serro Scarvi) show a transitional, even if abrupt, boundary between the pelagic terrains of the *Argille Varicolori* Fm. and the lower conglomerates of the Troina Sandstone Fm. Petrographic analyses, moreover, have pointed out close resemblances between the sandstones constituting the Troina and Tusa Fms. On the contrary, the sandstones of the Troina and Reitano Fms. are characterized by marked compositional differences (Puglisi 1979). Up to now, our research did not allow to recognize in the Troina Sandstone Fm. taxa whose first occurrence is younger than Burdigalian, but if the data of Carbone et al. (1990) will be confirmed by further studies, a more recent deformation, if not of the whole Sicilide Basin at least of its less internal portion, will have to be admitted.

We agree with the paleotectonic evolution proposed by La Manna et al. (1995), but we do not accept a late Oligocene-Aquitanian age for the deformation of the Sicilide Basin. We believe that the Sicilide accretionary wedge formed more recently and more rapidly, in the time-span late Burdigalian-middle Langhian, constrained by the age of the uppermost levels of the Sicilide Units successions and that of the terrains unconformably sedimented on all of them.

The above reported data, moreover, question also the paleotectonic evolution so far indicated for the external units of the Maghrebian Chain. In fact, it seems very difficult to admit the starting of the Numidian sedimentation as from the Oligocene in the Panormide and Imerese Zones, and the stacking of the nappes originated from the same zones before the Langhian or, more probably, the Serravallian.

Finally, the biostratigraphic data constraining the deformation age of the Sicilide Basin have important implications for the whole orogenic system of the Central-Western Mediterranean. The beginning of the foredeep stage and the first tectogenetic phase in the Sicilide basin result really to be coheval with the ones already recognized in the Flysch Domain of the Betic and Rifian sectors (Martín-Algarra 1987; Guerrera et al. 1993, and references therein).

In other words, the building up of the accretionary wedge, the closure of the oceanic area and the consequent continental collision, are synchronous at the eastern and western extremities of the Maghrebian Chain, which at present are about 1.700 km afar. In this framework it is very difficult to admit the older, either Eocene or Oligocene, deformation age for the Tellian sector of the Maghrebian Chain, pointed out by several authors. The synchronous deformation from the Gibraltar Arc to the Calabria-Peloritani Arc allows us to admit a same event as responsible for the neo-Alpine tectonics, which involved the Maghrebian Flysch Domain and later the continental margins of the Iberia and Africa plates. Taking into account the age of the deformation, this event may be easily indicated as the opening of the the Algero-Provençal Basin.

Acknowledgements

This study was supported by the following grants: MURST 40%-Urbino University 1998 (resp. V. Perrone).

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Manuscript received February 11, 1999
Revision accepted January 18, 2000