R.E. JONES(*) & M. GRASSO(**)

PALAEOTECTONICS AND SEDIMENT DISPERSAL PATHWAYS IN NORTH-CENTRAL SICILY DURING THE LATE TORTONIAN

CONTENTS

ABSTRACT

An integrated study utilising a combination of facies distributions and sequence stratigraphic analysis, has provided an insight into the palaeotectonic and palaeodrainage evolution of north-central Sicily during the late Tortonian. Regional studies have established a sequence stratigraphic framework and allowed alluvial/fluvial sections to be linked through correlation of sequence boundaries. Analysis of these deposits allows the timing of deformation to be bracketed and drainage patterns characterised for this part of the Maghrebian-Apennine collisional belt on Sicily.

RIASSUNTO

Il bordo settentrionale del "Bacino di Caltanissetta" (Sicilia centro-settentrionale) è caratterizzato da discontinui affioramenti di sedimenti silicoclastici grossolani di età alto-tortoniana, di ambiente fluviale e deltizio, alimentati da aree settentrionali oggi largamente sommerse nel Tirreno meridionale. Questi sedimenti passano verso sud ad argille di prodelta di ambiente marino via via piú profondo. Uno studio integrato della distribuzione areale delle facies basato su analisi stratigrafico-sequenziali ha permesso di correlare i vari depositi e di ricostruire il reticolo di drenaggio e i vettori di trasporto dei sedimenti fluviali, durante un periodo caratterizzato da un basso livello di base. I depositi fluviali forniscono inoltre utili indicazioni per la ricostruzione paleogeografica e paleotettonica dell'area. Le brusche variazioni registrate nelle direzioni di trasporto di tali sedimenti sono infatti da collegare alla presenza di "alti" costituiti essenzialmente da Flysch Numidico, già in gran parte strutturati nella parte settentrionale del Bacino di Caltanissetta, nel Tortoniano superiore.

(*)Department of Earth Sciences - University of Leeds (U.K.).
(**)Istituto di Geologia e Geofisica - Università di Catania.

KEY WORDS: Palaeodrainage pattern, Sequence stratigraphy, Palaeogeography, Tectonics, Late Tortonian, Central-north Sicily.

PAROLE CHIAVE: Reticolo di drenaggio, Paleogeografia, Tettonica, Tortoniano superiore, Sicilia centro-settentrionale.

INTRODUCTION AND GEOLOGICAL SETTING

Ahead of the Nebrodi and Madonie Mountains, the "Caltanissetta Basin" occupies the major part of central Sicily. It is superimposed on the frontal zone of the Sicilian Maghrebian orogenic system, which is made of a series of foreland verging thrust-sheets emplaced during the Neogene (LENTINI & VEZZANI, 1978; LENTINI, 1982).

To the south, the Hyblean Plateau which represents the northernmost indentor of the Pelagian Block (African Plate) acted as a stable foreland during nappe emplacements (Figs. 1 & 2).

After the Middle Miocene deformation climax, during the Late Tortonian, large volumes of siliciclastic sediments were shed from the northern chain and deposited along the northern margin of the "Caltanissetta Basin". Coarse grained, fluviatile to deltaic deposits characterise proximal locations. Marine clays and marls become dominant to the south and characterise distal environments.

This siliciclastic succession, which contains discontinuous lenses of boundstones interleaved on its top levels (GRASSO & PEDLEY, 1988) is known as the Terravecchia Formation (SCHMIDT DI FRIEDBERG, 1962, 1965) and spans a time interval from Late Tortonian to Early Messinian.

STRATIGRAPHY

A generalised stratigraphy for the region is provided in figure 3. The oldest outcropping unit of the area is the 'Argille Scagliose', which is mainly composed of variegated red and grey clays with thin interbeds of green coloured cherty limestone often present. These Upper Cretaceous - Eocene deposits represent the fill of extensional basins that existed prior to continental collision between the African and European domains. The brown clays and quartz-arenitic sands of the 'Numidian' units are of late Oligocene - early Miocene age and were deposited mainly in the early foredeep basin which formed due to collisional tectonics. The calc-enriched arenites of the Serravalian are synorogenic strata which were deposited on the advancing thrust sheet and are often eroded out from stratigraphic sections in the field (FRAVEGA *et alii*, 1993; GRASSO *et alii*, 1994). Tortonian clays overlie the Serravalian with turbiditic sands sometimes present. Above these lies a

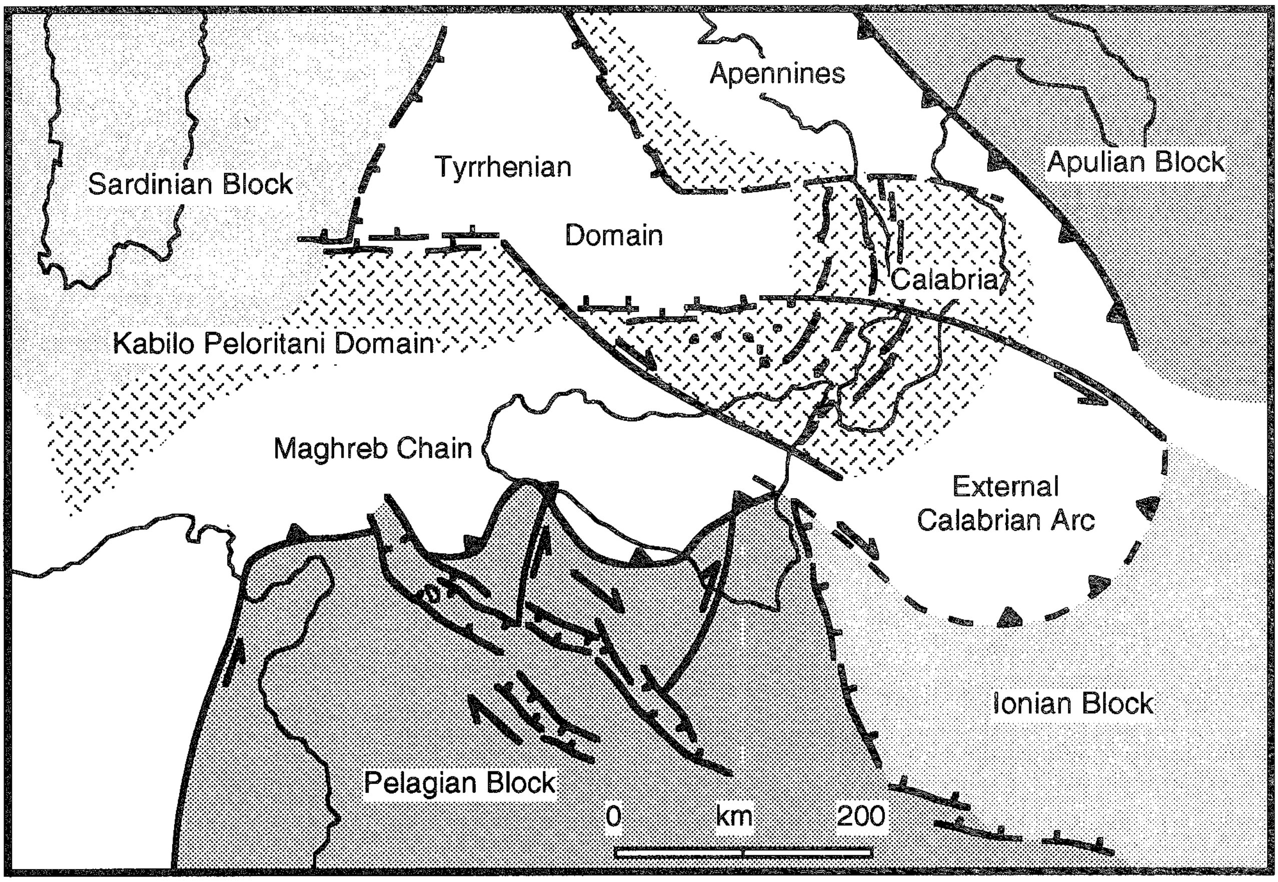

Fig. 1 - Regional kinematic scheme of the Central Mediterranean (modified after Ben Avraham *et alii*, 1992) showing principal structures and the area of deformation marking the zone of collision between Africa and Europe.

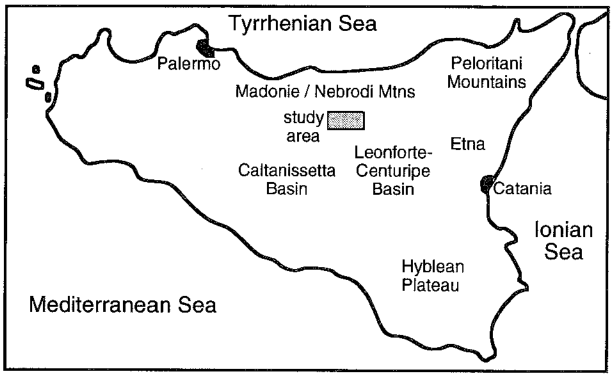

Fig. 2 - Location map of Sicily showing the position of the study area.

mixed sequence of Upper Tortonian - early Messinian sedimentary units that were deposited within a series of thrust-top basins (Grasso & Butler, 1991). The lowstand deposits of this sequence form the focus of this study and are detailed below. The upper Messinian is represented by various evaporitic and detrital sediments. Pliocene sediments are almost absent in outcrop within the area of study, but are largely represented within perched basins developed south of the study area, eg. Leonforte-Centuripe Basin.

UPPER TORTONIAN CONGLOMERATES AND THEIR COMPOSITION

The southern foothills of the Nebrodi and Madonie mountains of north-central Sicily preserve outcrops of cobble-boulder conglomerates which characterise alluvial/fluvial sedimentary facies (Fig. 4). The outcrops

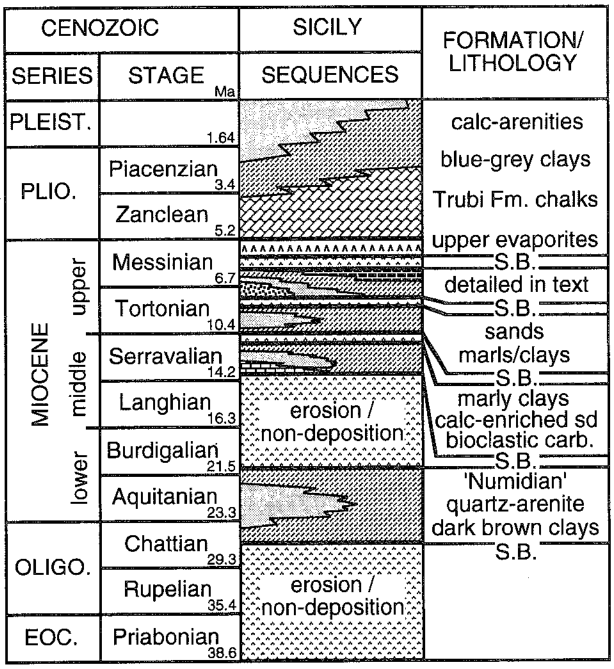

Fig. 3 - Generalised composite stratigraphic column for the outcrops of north-central Sicily. (Timescale taken from Harland *et alii*, 1990).

studied are interpreted as the lowstand deposits of a late Tortonian - early Messinian depositional sequence. Six graphic log sections (Fig. 5) have been correlated through recognition of a regional unconformity surface interpreted here as a depositional sequence boundary.

The mountains to the north of the outcrops have been uplifted in post-Tortonian times and no remnants of the studied depositional sequence are to be found on this core zone of uplift (CARBONE *et alii*, 1990). The only recorded remnants of coeval conglomerates closer to the Tyrrhenian coast are the red alluvial boulder conglomerates at Scillato, which represent a major dispersal pathway (GRASSO & BUTLER, 1991; BUTLER & GRASSO, 1993) for sediments sourced from northern areas. Remnants of older flysch units with conglomeratic members (eg. Reitano flysch) exist in the core-zone of uplift (GRASSO *et alii*, 1991) and on the northern margins of the belt (PEDLEY *et alii*, 1994).

The Tortonian conglomerates of the study area are readily distinguished from the older flysch deposits because they are very rich in large cobble-boulder sized clasts of Numidian (early Miocene) sandstones. The older flysch deposits contain no Numidian clasts and it is therefore shown that the Tortonian conglomerates post-date deformation and uplift of the Numidian units. The conglomerates also contain a variety of exotic clasts such as Calabrian granites and Sardinian Permian volcanics. Clasts with such provenance could not have been sourced directly from those areas during the Upper Tortonian, because the Tyrrhenian basin had initiated by this period. It is suggested that these clasts are reworked clasts sourced from the conglomeratic members of the older flysch units that exist to the north (CIRRINCIONE *et alii*, 1994). This hypothesis is further supported by field observations. The clasts occur in proximal alluvial facies but are well rounded and generally have a medium-high sphericity as is consistent with a hypothesis of cannabalisation.

PALAEOCURRENTS AND FACIES

Palaeocurrent analyses and studies of facies distributions have revealed the palaeo-drainage patterns of the area on the southern foothills of the Nebrodi mountains. Two main trends have been identified showing the proximal divide between alluvial/fluvial pathways transporting sediments to the Caltanissetta Basin area and to the Leonforte-Centuripe Basin area during the late Tortonian (Fig. 6). The majority of palaeocurrent data was provided by orientation measurements taken from imbricated clasts. The plunge of the 'xy' plane of clasts was recorded and is presented as uncontoured stereographic projections. The data is presented in this linear format because the plunge of this plane lies 180° out of phase to the flow direction and allows the true spread of data to be seen.

Monte Alburchia section (1)

A large outcrop of red conglomerates dominates the area around Monte Alburchia (Log location 1, Fig. 4). The basal unconformity of the conglomerates oversteps across variegated clays and earlier Tortonian

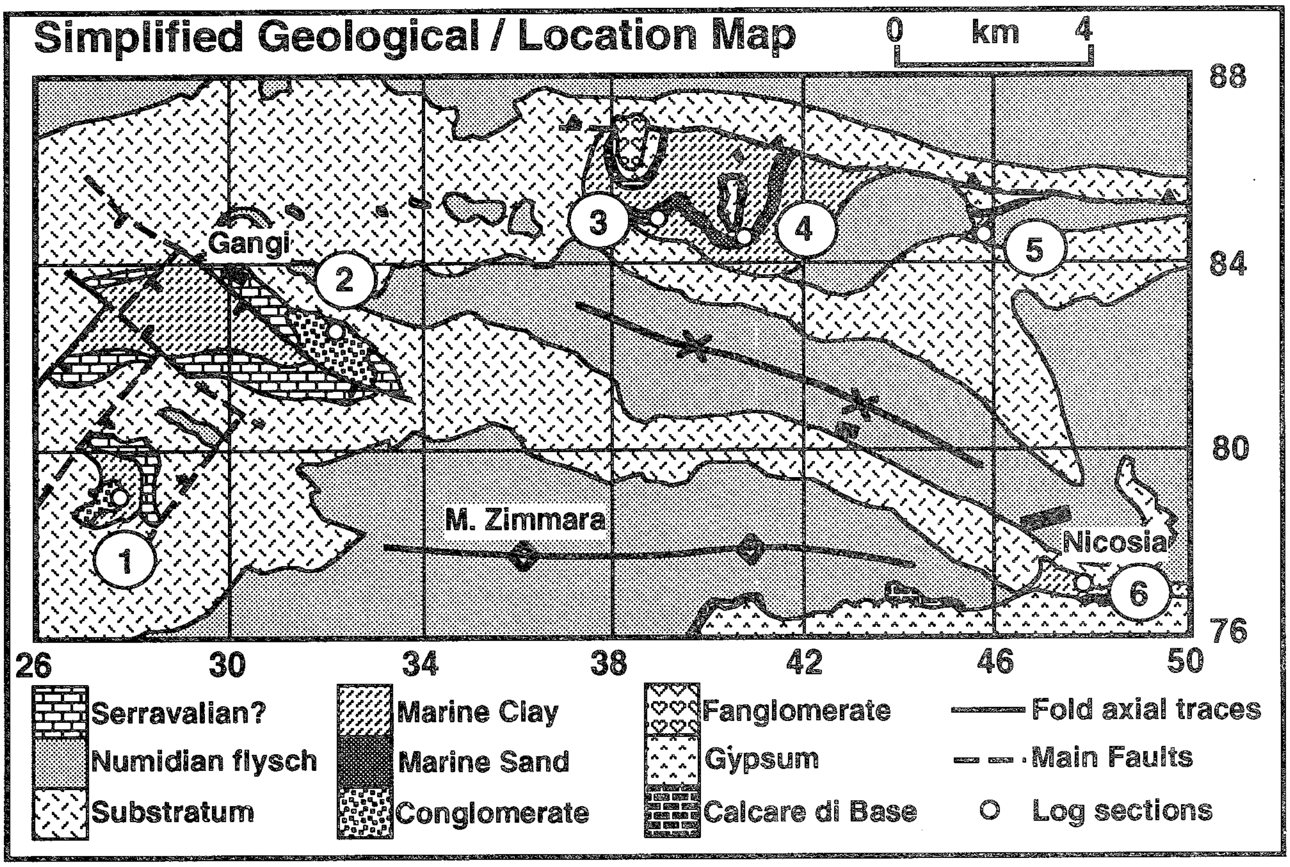

Fig. 4 - Simplified geological/location map of the study area.

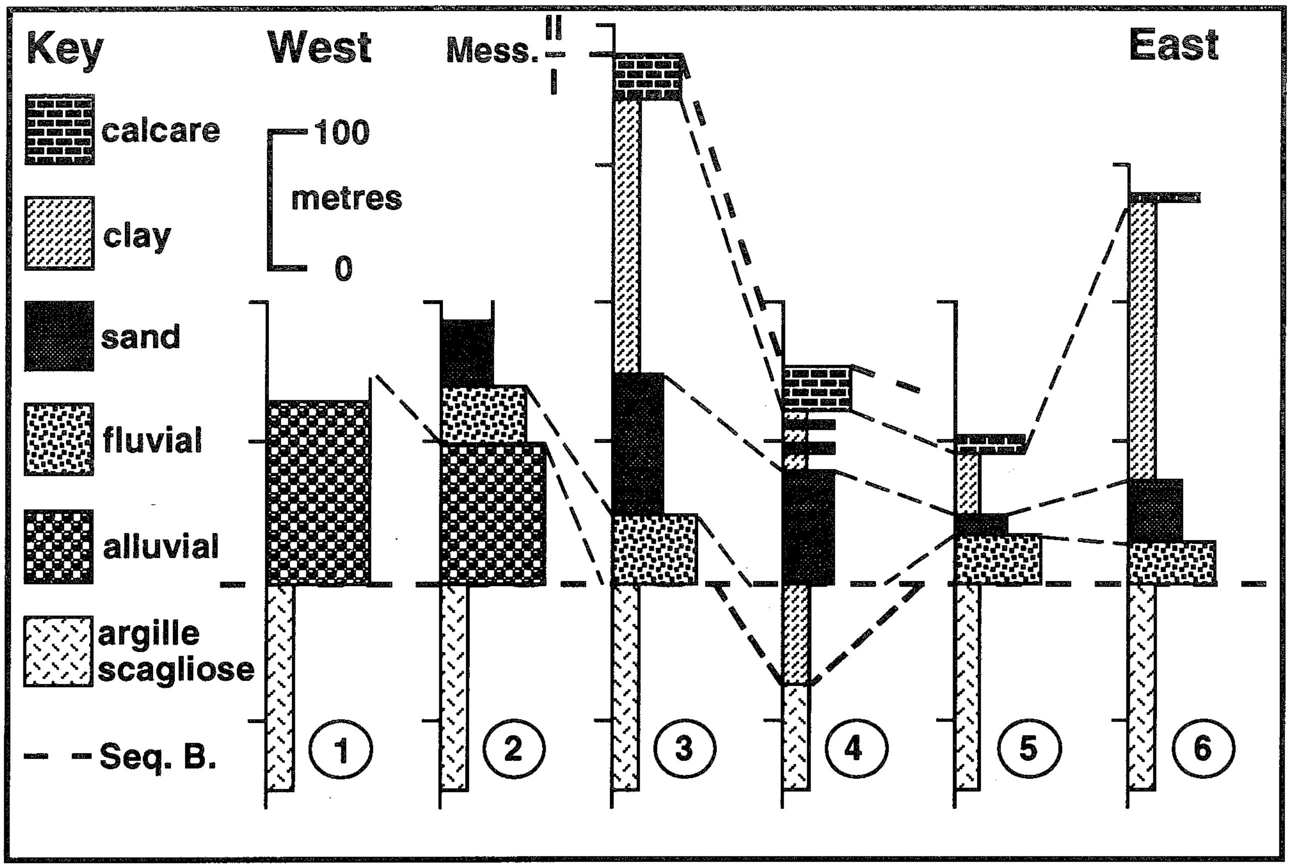

Fig. 5 - Graphic log sections correlated by the Upper Tortonian sequence bounding unconformity surface.

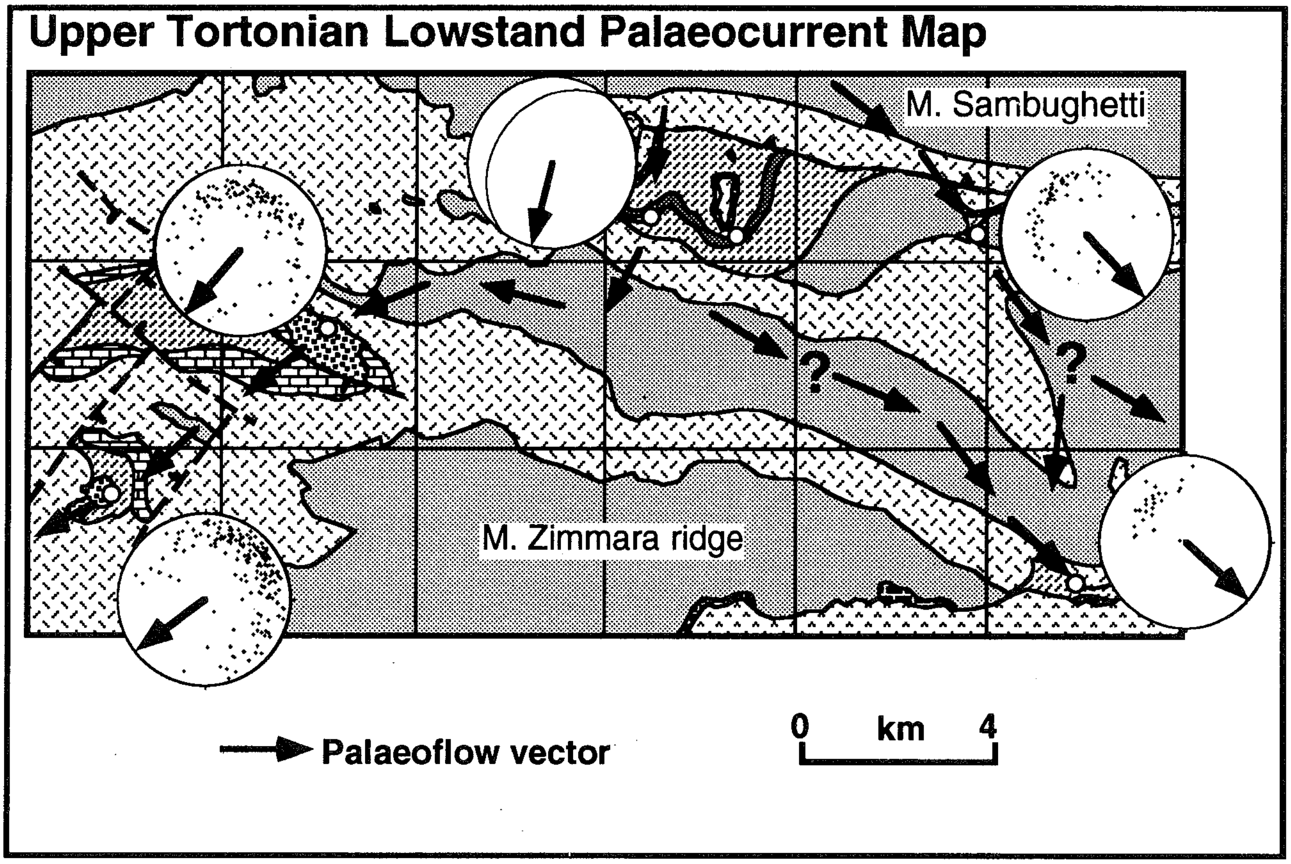

Fig. 6 - Palaeocurrent map detailing the proximal palaeodrainage patterns of the Upper Tortonian base-level lowstand.

clays, demonstrating the angular nature of the unconformity. Approximately 130 metres of vertical section is represented and is entirely of alluvial origin. This is shown in the detailed graphic log section of figure 7. The outcrop is well stratified with red cobble-boulder conglomerates dominant (Fig. 8). Sandy interbedded units are also well represented here, suggesting channel incision was not as intense at this locality as at others, because flow was spread over a wider areal extent. Higher stratigraphic levels of the Upper Tortonian are not preserved at this locality.

The lowest conglomerate levels do not outcrop too well and hence do not display good internal sedimentary structures or larger geometric characteristics. Cobble sized clast-supported conglomerates are most common with occasional imbrication and fining-up sequences identified, indicating bedload stream flow. Sorting is poor suggesting that these deposits are texturally immature as is to be expected in such a proximal alluvial facies. The roundness and sphericity of many clasts is however, unusually high. As mentioned previously, these seemingly contradictory lines of evidence can be explained by the possibility that these very well rounded, medium-high sphericity clasts are reworked clasts sourced from the conglomeratic members of older flysch units, thus resolving the paradox. The conclusions drawn from these textural observations are in complete agreement with the original hypothe-

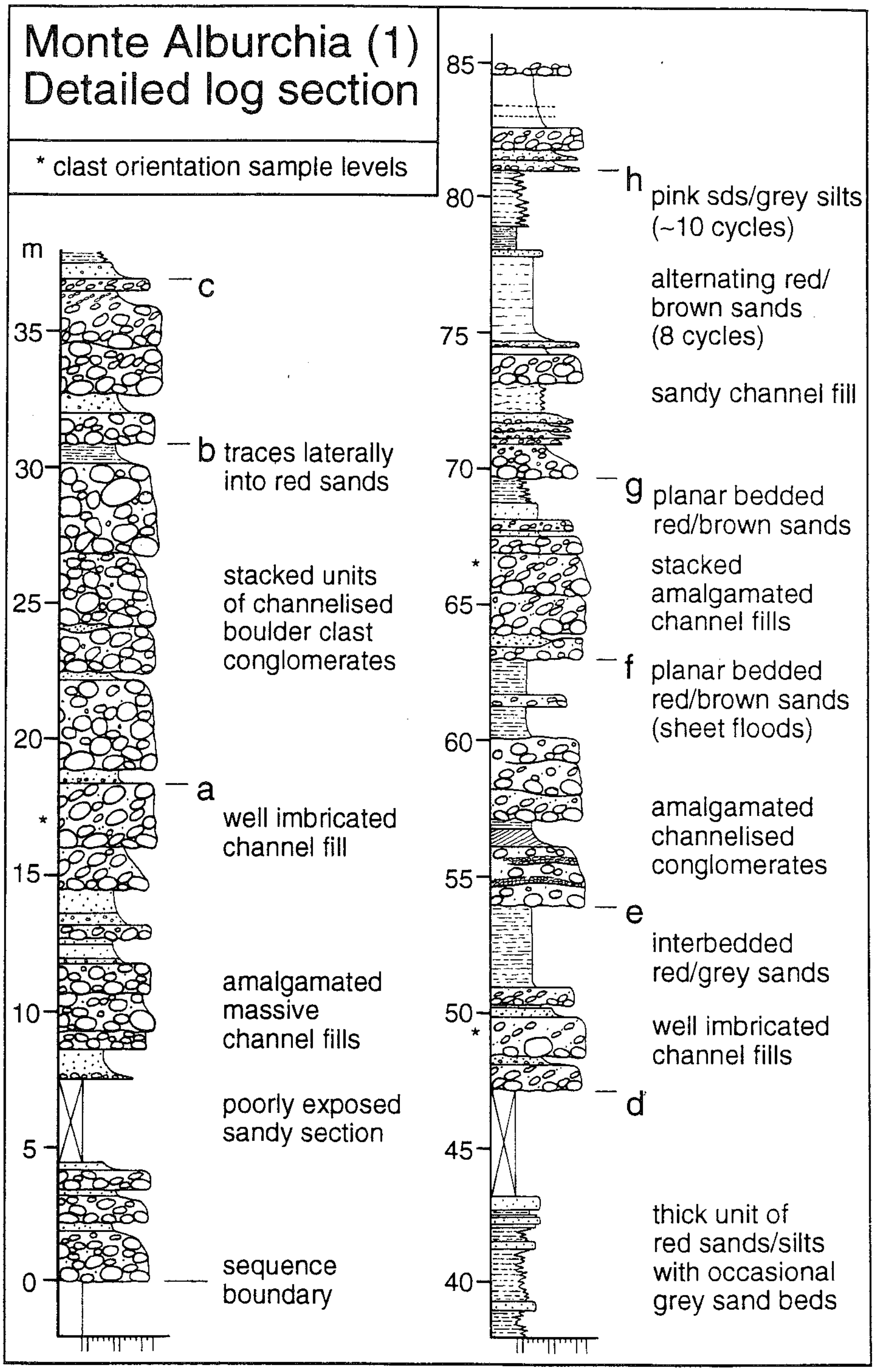

Fig. 7 - Detailed graphic log of the alluvial sedimentary section at Monte Alburchia (log location 1, Fig. 4).

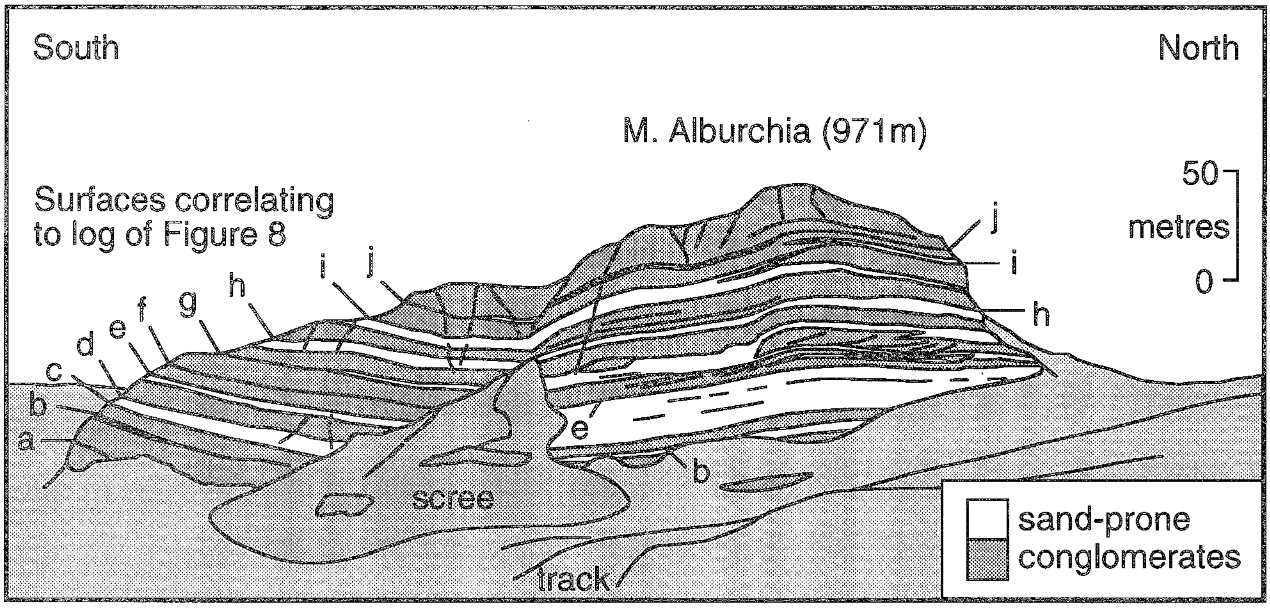

Fig. 8 - View of the M. Alburchia section showing lateral continuity and variations.

sis of clast cannabalisation presented by CIRRINCIONE *et alii* (1994) through studies of clast provenance.

Throughout the excellent exposure on the main cliff face, cobble to boulder beds constitute the major lithotype. A cyclicity of bedding patterns is evident with alternation between units of amalgamated erosive based conglomerate beds and well developed units of thin planar bedded sand and silt beds. The conglomerate units all display in part at least, good internal clast imbrication. The good lateral continuity of the outcrop displays changing levels of incision and wide channel profiles. Lateral accretion surfaces can be seen within some units and a lateral change from conglomerates to sands can also be seen in others as channels die out. The red conglomerate beds represent successive high energy erosive episodes across an exposed alluvial plane where high water stage flows resulted in widespread deposition of clast-supported conglomerates by bedload streams. The planar interbedded units represent a series of sheet flood episodes that deposited finer grained sediments across the entire alluvial plane.

Clast imbrication data collected at various levels through the section yields a consistent broadly unidirectional palaeocurrent trend, with flow directed generally towards the south west (Fig. 9a). This suggests the system was fed from the north east, ie. from the Rupe Rossa area (see below).

Rupe Rossa section (2)

An extensive outcrop of conglomerates occurs at this locality. The sequence bounding unconformity lies directly on variegated clays to the north side and oversteps onto calc-enriched arenites to the south of the outcrop (Log location 2, Fig. 4). A detailed graphic log section was constructed through the road section on the northern side of the outcrop (base at G.R. 3200 8300) and is shown in figure 10. Clast orientation data was collected from six seperate conglomerate beds at various levels in the stratigraphy. A consistent unidirectional palaeocurrent trend was recorded through all measured units with flow directed towards the south west (Fig. 9b).

The most basal succession of conglomerates are of alluvial nature, with almost 100 metres of alluvial stratigraphy present. There is a strong red coloration evident and some indications of long term emergence, with the first stages of calcrete formation sometimes present. Massive conglomerate beds dominate this part of the section with only minor preservation of sandier units. Basal channel lags and fining up units become more common through higher stratal levels. These well stratified orthoconglomerates contain an abundance of boulder sized clasts, are poorly sorted, clast-supported and often imbricated. The sphericity of clasts is generally medium - high and the vast majority of clasts are well - very well rounded. These alluvial conglomerate beds are interpreted as high energy bedload stream sediments deposited intermittently with long periods of exposure between the deposition of units. The sand dominated levels represent waning flow sheet flood fines, but are often missing due to erosion by later conglomerate beds. This results in an amalgamation of conglomerate beds in much of this lower stratigraphy.

The alluvial strata grade upwards into a more sand prone facies with red coloration weak or absent. The conglomerates become less massive and channel geometries may be observed incising sandy sheet flood deposits which are often well preserved. The conglomerates may be massive, imbricated or display lateral accretion surfaces. All sedimentary structures provide a consistent indication of palaeoflow directed to the south west.

The uppermost stratigraphic levels on the eastern flanks of this outcrop are very sand prone. Sedimentary structures are not well preserved within these sands and it is difficult to distinguish whether these sediments were deposited in a sandy fluvial system or in a shallow marine setting. The nature of other outcrops in the region suggests these may be of marine origin as other sections show a marine transgression occurred not long after the deposition of fluvial conglomerates.

The northern flank of this outcrop is particularly vital for its geometric relationships. It can clearly be seen that the conglomerates sit within the confines of

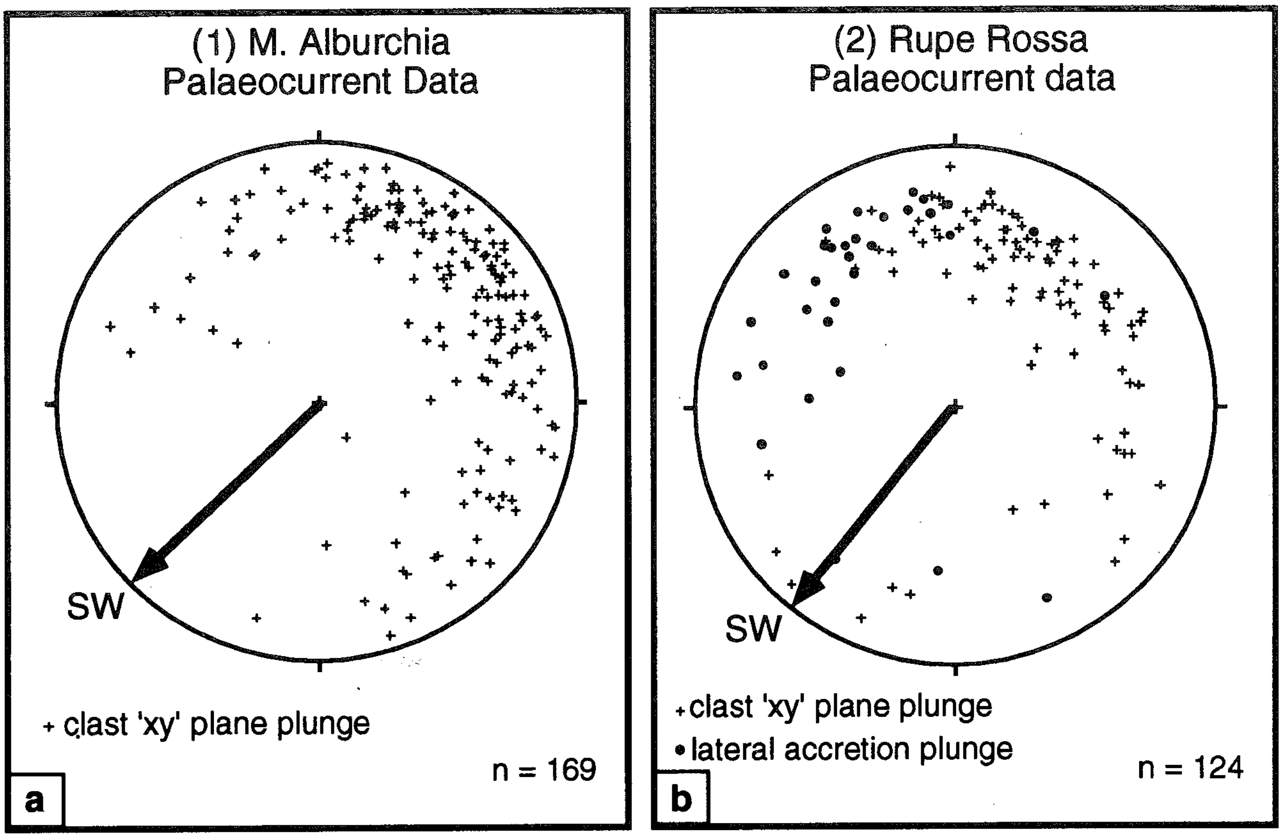

Fig. 9 - (a) Clast orientation data from the M. Alburchia section. (b) Clast orientation data from the Rupe Rossa section.

a palaeovalley. Numerous bedding surfaces can be traced laterally and terminate out against the sequence bounding unconformity (Fig. 11). This is conclusive evidence of progressive onlap onto the sides of an incised palaeovalley. The confinement of these deposits also accounts for the consistent trend shown by the palaeocurrent data. In sequence stratigraphic terms (Van Wagoner *et alii*, 1988) these deposits can be interpreted as a lowstand incised valley fill.

Monte della Grassa Section(3)

A complete unconformity bounded section through the Upper Tortonian - early Messinian depositional sequence is displayed at this locality (Log location 3, Fig. 4), see also Lentini & Vezzani (1974) and Grasso *et alii* (1978). The base of the section initiates with clast-supported, cobble - boulder conglomerates of a fluvial nature at Cozzo Parrizzo (G. R. 3890 8478), which lie directly upon the lower sequence bounding unconformity which is used to correlate the various log sections (Fig. 5). The coarse conglomerates are interbedded with a variety of sands, gravels and microconglomerates. These basal deposits grade upwards into fairly well sorted fluvial sands displaying good erosively based channel geometries and lateral accretion surfaces. A thick succession of poorly exposed clays overlie the sands with only occasional thin sand levels encountered. These deposits are of marine origin and demonstrate a marine transgression. At the top of the section is a replacive limestone unit known as the 'Calcare di Base'. This unit is of evaporitic origin and represents marine regression due to falling base-level into the Messinian, and is capped by gypsum levels.

The conglomerate beds at the base of the section do not outcrop too well and imbrication data is difficult to collect because the necessary precise bedding orientations are difficult to determine. However, cross stratified sand interbeds show palaeocurrent flow was directed generally south-south-westwards (Fig. 12). The conglomeratic section is entirely fluvial and no red coloration is present. This outcrop is the proximal portion of the Rupe Rossa/M. Alburchia sediment dispersal pathway, palaeoflow being deflected towards Rupe Rossa due to the presence of the uplifted M. Zimmara ridge (Figs. 4 and 6).

Cozzo della Croce section (4)

Conglomerates are absent from the base of this section (Log location 4, Fig. 4) with cross bedded marine sands lying directly on the sequence bounding unconformity. The unconformity in this section represents a subaerial bypass/erosion surface at the time of alluvial/fluvial deposition in the basal portion of other sections. Sedimentation across the unconformity surface only began after the marine transgression occurred with no lowstand deposition represented. The section comprises three sand units with clays between them. The succession of repeated sand-clay cycles represents a series of transgressive/regressive episodes. These are probably the result of higher order eustatic fluctuations superimposed over the 3rd order cycle of base-level change which defines the Upper Tortonian - early Messinian sequence. In the sequence stratigraphic terms of Hunt & Tucker (1992), these units are associated with Transgressive and Highstand Systems Tracts. The thin gyps-arenites and 'Calcare di Base' unit that cap the section are associated to a Regressive Systems Tract (ie. falling base-level).

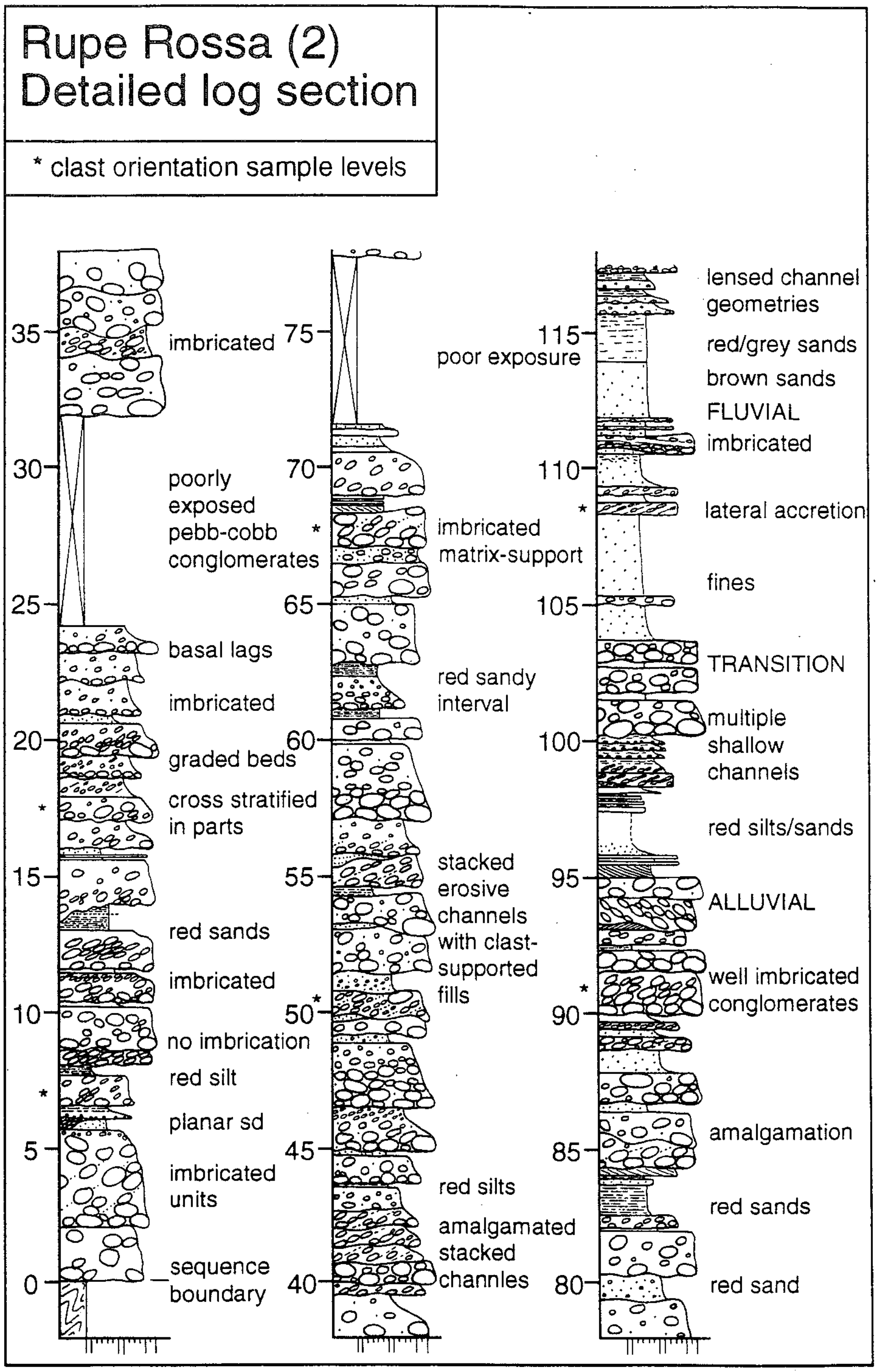

Fig. 10 - Detailed graphic log of the alluvial/fluvial sediments of the Rupe Rossa section (log location 2, Fig. 4).

Monte Bauda section (5)

This section lies approximately 5 km north east of the town of Sperlinga (Log location 5, Fig. 4). The outcrop of Upper Tortonian units is less substantial at this location than at those previously considered. The sequence initiates with over 30 metres of fluvial conglomerates which are well exposed in the south east face of Cozzo Grottevascia (G. R. 4525 8966). The base of the conglomerates oversteps the boundary between variegated clays and Numidian sands and clays, demonstrating the angular nature of the unconformity. These coarse fluvial beds grade up into mixed sands and conglomerates, which become more sand prone until conglomerates are absent. A section of clays 40 metres thick follows and is capped by 'Calcare di Base' and gypsum of the early Messinian (I cycle) lying to the south west of Monte Bauda.

The basal conglomerates in Cozzo Grottevascia are cobble sized and clast-supported, with a coarse poorly sorted, mainly granule - small pebble matrix. Sorting is poor throughout and clasts are mostly well rounded. The deposits are rich in clasts of 'Numidian' sandstones and a variety of Mesozoic limestones, Calabrian units-derived granites, metamorphic clasts, conglomerates from previous flysch units and importantly, clasts of Sardinian Block-derived Permian basalts. Very few sand levels exist in the conglomerate section due to successive episodes of incision, with amalgama-

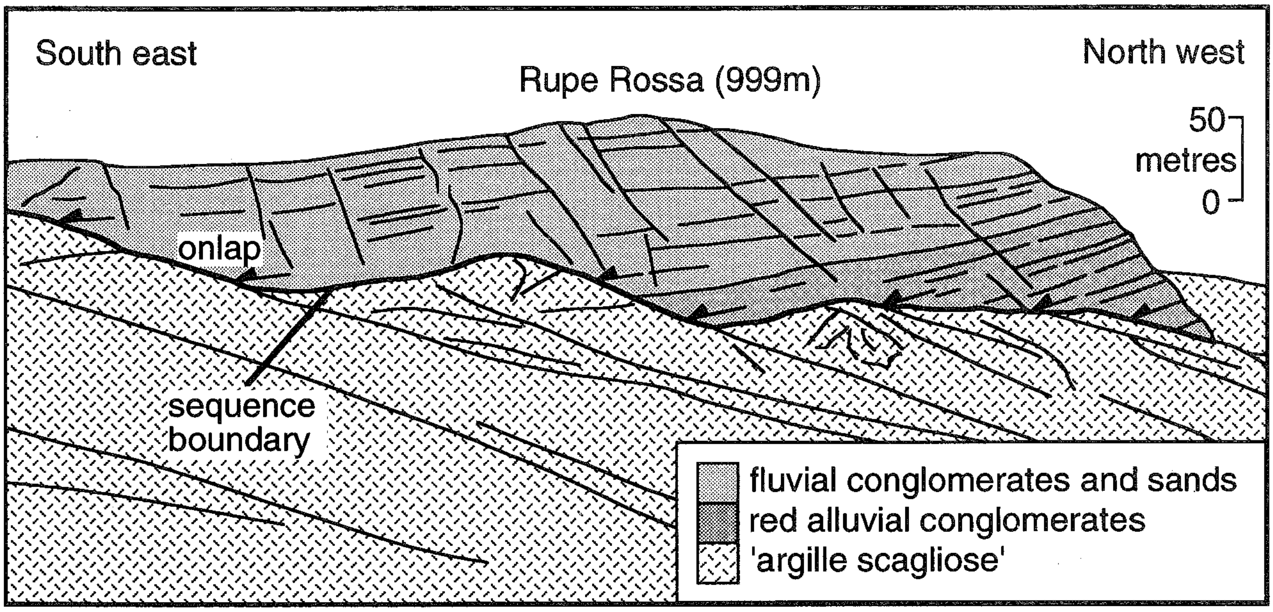

Fig. 11 - View of the Rupe Rossa section showing the confinement of conglomerates within a palaeovalley. The deposits progressively onlap against the sequence bounding unconformity and are interpreted as a lowstand incised valley fill.

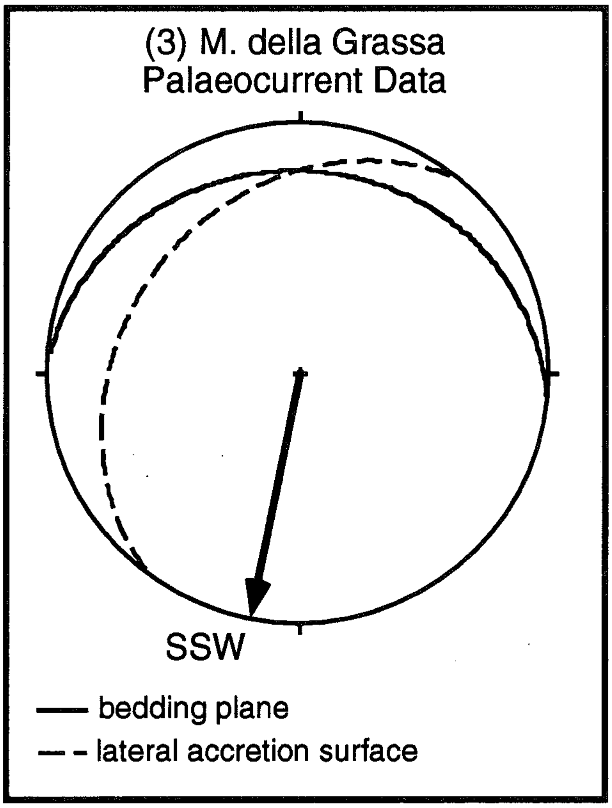

Fig. 12 - Clast orientation data from the Monte della Grassa section (log location 3, Fig. 4).

tion of beds common. The beds are often well imbricated and of fluvial origin, although there is some weak red coloration in places.

Clast orientation measurements of imbricated clasts show that flow was unidirectional indicating the palaeocurrent was directed towards the south east (Fig. 13a). The different scale of the deposits and the palaeoflow indicators show that this section forms a seperate sediment dispersal pathway and is not directly linked with the M. della Grassa/Rupe Rossa/M. Alburchia pathway (Fig. 6) that flowed to the Caltanissetta Basin. This section represents the proximal portion of a fluvial system that drained the area of the palaeo-Nebrodi mountains and flowed towards the south east.

Nicosia section (6)

Conglomerates equivalent to those near Monte Bauda (5) outcrop just south of the town of Nicosia (Log location 6, Fig.4). A complete stratigraphy through the Upper Tortonian - early Messinian sequence is present at this locality, although it is dissected in part by later minor normal faults. Approximately 30 metres of fluvial conglomerate dominated strata are present at the base of the section. These grade up into about 35 metres of sands which are mainly of marine origin, which in turn give way to deeper marine clays illustrating a progressive marine transgression. The clays (which outcrop best near the old brickworks, G. R. 4621 7719) contain some thin, poorly outcropping, sand levels. The top of the section terminates with 6.5metres of the regressive 'Calcare di Base' limestones.

Palaeocurrent data collected from an imbricated section of the basal fluvial conglomerates indicates unidirectional flow towards the south east (Fig. 13b). This is consistent with palaeoflow indicators from the Monte Bauda section and the two sections are considered to be part of the same sediment dispersal pathway that fed out towards the Leonforte-Centuripe Basin area (Fig. 6).

SEDIMENT DISPERSAL PATHWAYS

A major fluvial/alluvial system existed from M. della Grassa (3), 5 km north-west of Sperlinga and flowed generally south-westwards through Rupe Rossa

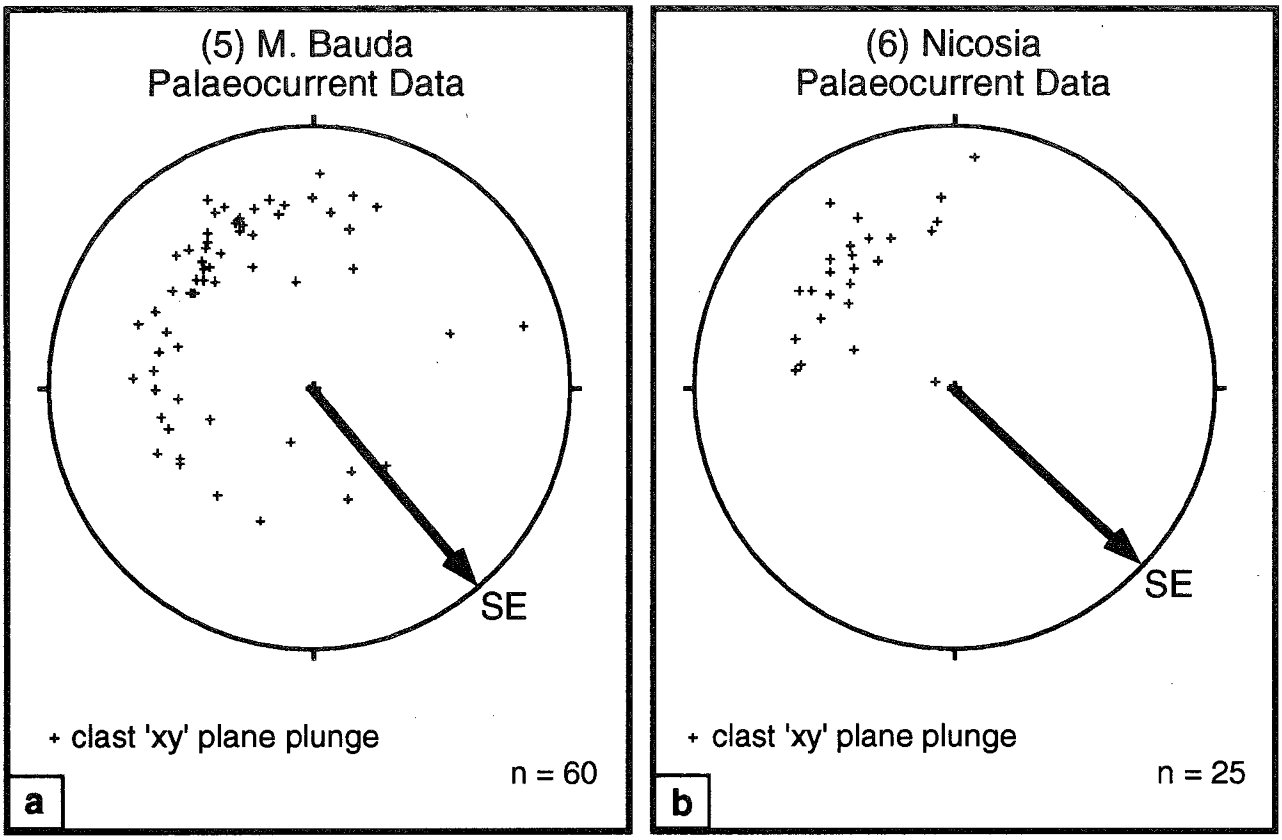

Fig. 13 - (a) Clast orientation data from the Monte Bauda section (log location 5, Fig. 4). (b) Clast orientation data from the Nicosia section (log location 6, Fig. 4).

(2) near Gangi and on to M. Alburchia (1) 5km away (Fig. 6). The large alluvial to fluvial succession at Rupe Rossa near Gangi represents a base-level lowstand incised valley fill with onlap onto the palaeovalley sides observed in outcrop (Fig. 11). This system flowed axially along the north of the M. Zimmara ridge of Numidian sandstones showing that this ridge was also uplifted in pre-late Tortonian times. South-west of M. Alburchia, the system flows into an unrestricted basin north of Alimena where an extensive braid plain developed. Another fluvial pathway existed from near M. Bauda (5), 4km north-northeast of Sperlinga and flowed generally south-eastwards towards Nicosia (6) and on towards the Leonforte-Centuripe basin (Fig. 6).

PALAEOTECTONIC AND PALAEOGEOGRAPHIC IMPLICATIONS

This study has allowed the palaeotectonic and palaeogeographic evolution of the area to be constrained. The structure of the area is illustrated by the schematic cross section of Figure 14. This simplified diagram shows the major thrust related structures of the area. Smaller scale normal/strike-slip faults do exist, but formed mainly during the Pliocene and are not represented here. The Numidian units of the Zimmara ridge and southern margins of the Nebrodi mountains belong to the Imerese palaeogeographic domain. The Numidian units between, belong to the more northerly Sicilide palaeogeographic domain. The Sicilide unit therefore, must have been thrust emplaced over the Imerese unit of the Zimmara ridge. The Zimmara ridge itself must have been uplifted prior to deposition of the Upper Tortonian conglomerates as it has been shown that the ridge deflected the sediment dispersal pathways. The Numidian units of the Nebrodi mountains must also have been uplifting prior to/during this time because an abundance of eroded clasts are included within the Upper Tortonian conglomerates. Breaching of the Monte Sambughetti thrust occurred during the early Pliocene. The tectonic evolution of the area is represented in figure 15.

During the late Tortonian lowstand two major sediment dispersal pathways existed supplying the area known as the "Caltanissetta Basin". The thrust-top basins occupying the northern parts of the "Caltanissetta Basin" (Grasso & Butler, 1991) were exposed, with the marine margin situated in the area ahead of the Marcasita anticline. An outline of the basic palaeogeographic setting at the beginning of the Upper Tortonian - early Messinian sequence is illustrated in figure 16. The main alluvial pathway flowed generally north to south from the Scillato area and was sourced from the palaeo-Madonie mountains and Calabrian crystalline units lying north of them. A large tributary draining the palaeo-Nebrodi mountains joined this system from the north-east. This tributary had a spacially confined proximal portion (incised palaeovalley) which drained axially and evolved into a braid plain as it continued further south-west. The system can be traced southwards into basal fluvial deposits and terminates in the area of the Caltanissetta/Palermo-Catania motorway junction where a lowstand prograding deltaic wedge was deposited at the late Tortonian marine margin (Fig. 17). The dramatic change in palaeodrainage patterns

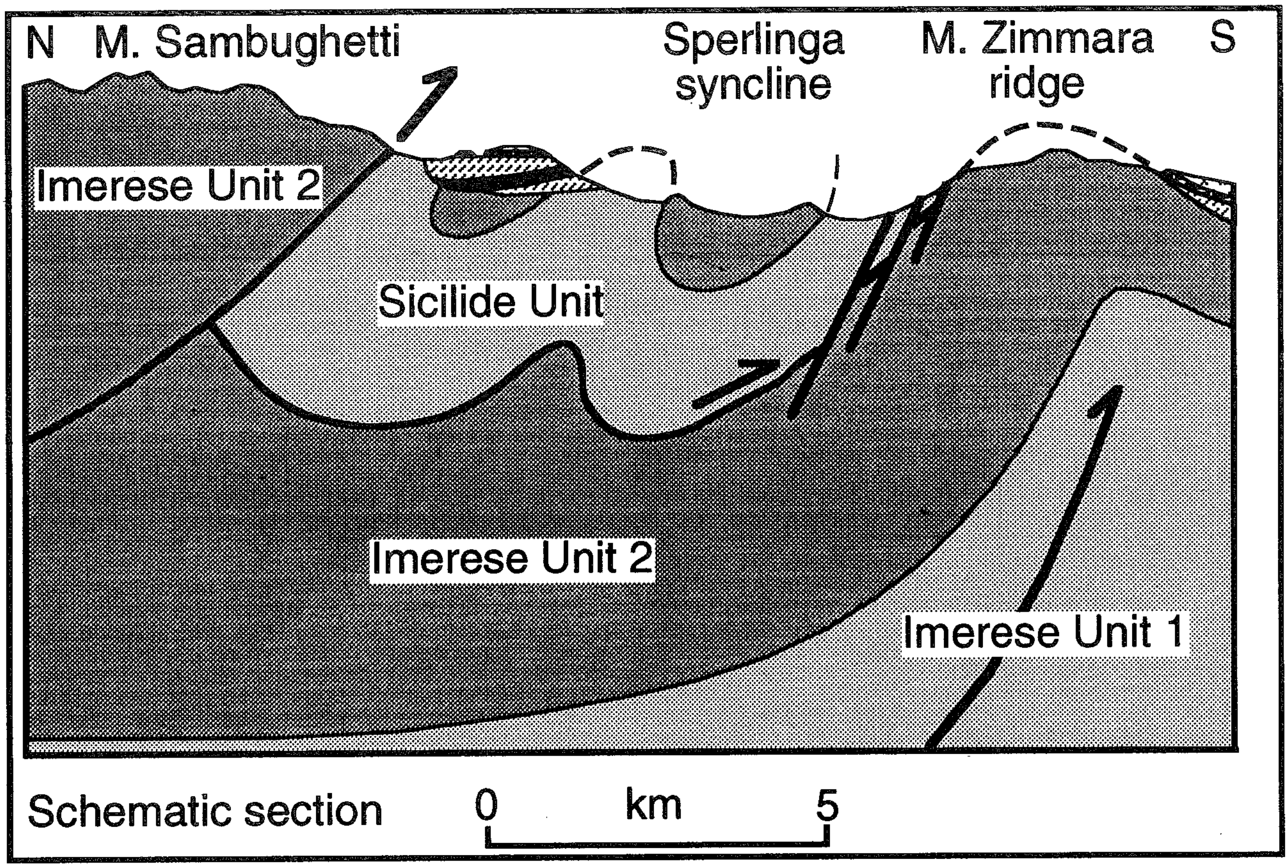

Fig. 14 - Schematic structural cross section through the central portion of the study area.

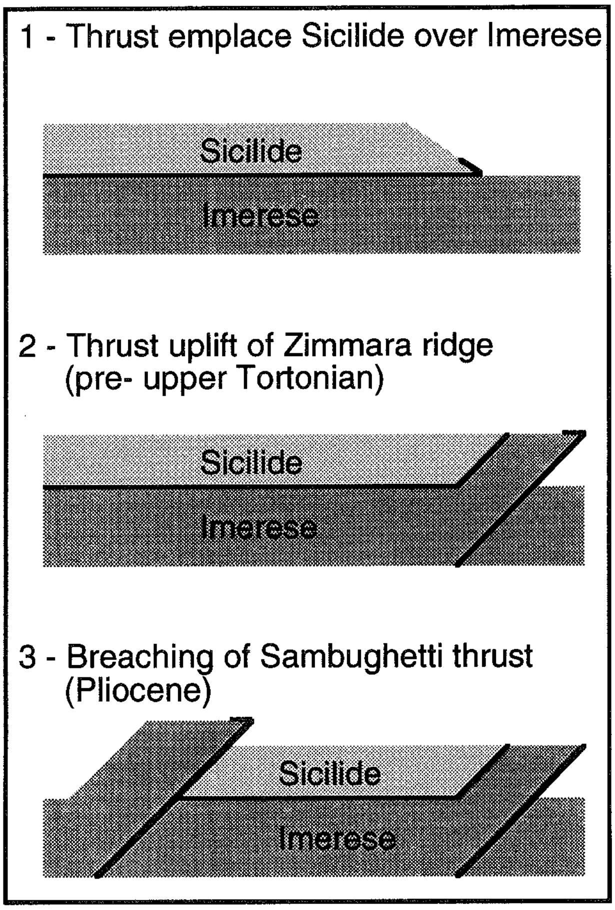

Fig. 15 - Simplified diagram illustrating the tectonic evolution of the study area.

from early to late Miocene times serves to characterise the palaeotectonic evolution of the area.

CONCLUSIONS

The conglomeratic units documented within the study area represent the lowstand deposits of an Upper Tortonian - early Messinian depositional sequence. The region was uplifted by thrust tectonic processes during the Middle Miocene through to Pliocene. The Numidian sands of both the Nebrodi mountains and the M. Zimmara ridge had been uplifted prior to the evolution of the late Tortonian - early Messinian depositional sequence. This is illustrated by the inclusion of large volumes of Numidian clasts within the proximal conglomerates and by the deflection of the palaeodrainage and confinement of deposits in an axially flowing system. Uplift must have post-dated deposition of the flysch units in the zone of uplift too, because these are also reworked and incorporated within the conglomerates of the late Tortonian base-level lowstand.

ACKNOWLEDGEMENTS

Work carried out by R.E. Jones for this paper was funded by a U.K. Natural Environment Research Council Studentship. M. Grasso acknowledges MURST grants 60% and 40% (1993-1994).

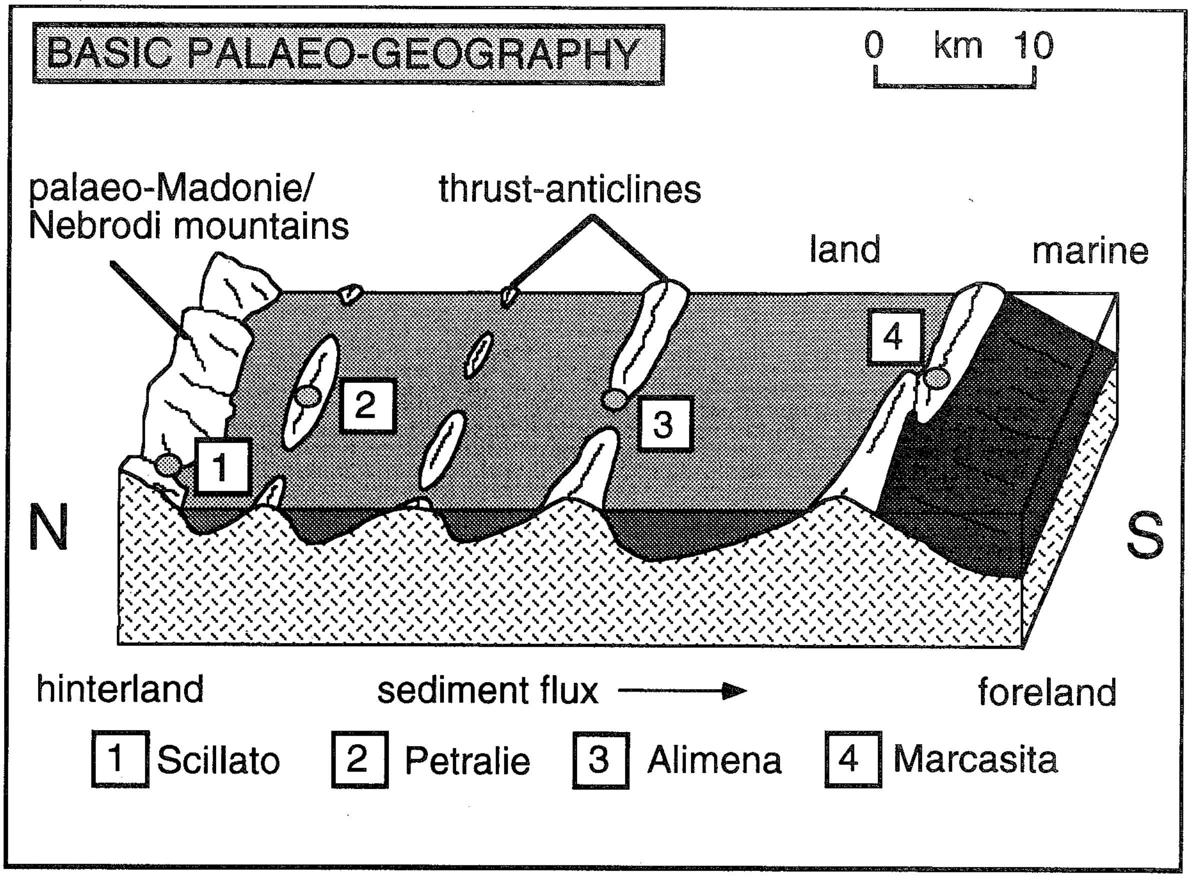

Fig. 16 - Regional palaeo-geographic setting prior to deposition of the Upper Tortonian - Lower Messinian depositional sequence.

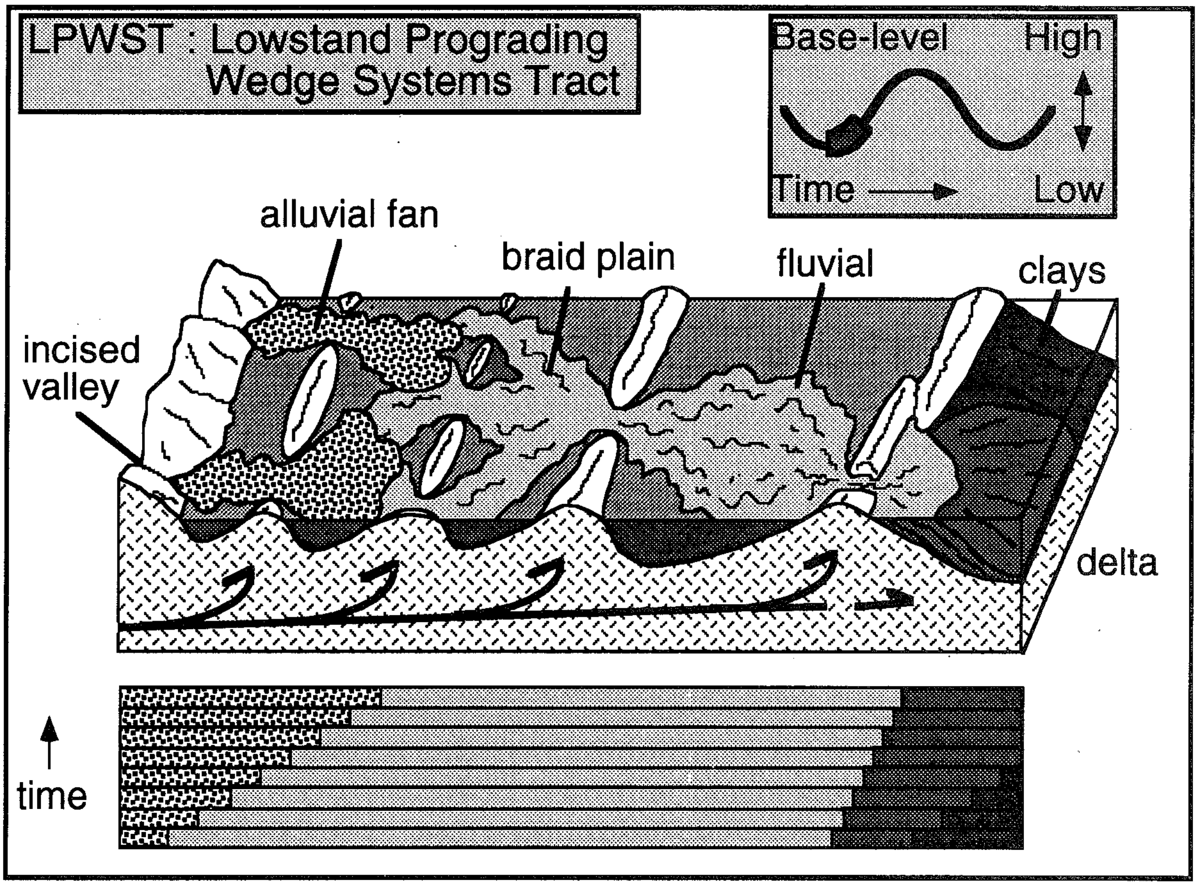

Fig. 17 - Lowstand Prograding Wedge Systems Tract (LPWST) block diagram with schematic chronostratigraphy below.

REFERENCES

BEN AVRAHAM Z., BOCCALETTI M., CELLO G., GRASSO M., LENTINI F., TORELLI L. & TORTORICI L. (1992) - *Principali domini strutturali originatisi dalla collisione neogenico-quaternaria nel Mediterraneo centrale*. Mem. Soc. Geol. It., **45** (1990), 453-462.

BUTLER R.W. & GRASSO M. (1993) - *Tectonic controls on base-level variations and depositional sequences within thrust-top and foredeep basins: examples from the Neogene thrust belt of Sicily*. Basin Research, **5**, 137-151.

CARBONE S., CATALANO S., GRASSO M., LENTINI F. & MONACO C. (1990) - *Carta geologica della Sicilia centro-orientale*. Map scale 1:50.000. S.EL.CA., Firenze.

CIRRINCIONE R., GRASSO M., TORELLI L., ATZORI P. & MAZZOLENI P. (1994) - *The porphyritic clasts of the Tortonian conglomerates of north-central Sicily: palaeogeographic and palaeotectonic implications*. Boll. Soc. Geol. It., **114**, 131-145.

FRAVEGA P., GRASSO M. & PEDLEY H.M. (1993) - *Sedimentology, palaeoenvironment, age and tectonic setting of the Sperlinga carbonate deposits, central Sicily*. Boll. Soc. Geol. It., **112**, 191-200.

GRASSO M. & BUTLER R.W.H. (1991) - *Tectonic control on the deposition of late Tortonian sediments in the Caltanissetta Basin of central Sicily*. Mem. Soc. Geol. It., **47**, 313-324.

GRASSO M., GUERRERA F., LA MANNA F., MANISCALCO R., MORETTI E., PUGLISI D. & VIGO F. (1991) - *Caratteri stratigrafici, sedimentologici e petrografici delle calciruditi e calcareniti del M. Pomiere (Auct.) - Monti Nebrodi, Sicilia centro-settentrionale*. Mem. Soc. Geol. It., **47**, 115-127.

GRASSO M., LENTINI F. & VEZZANI L. (1978) - *Lineamenti stratigrafico-strutturali della Madonie (Sicilia centro-settentrionale)*. Geol. Romana, **17**, 45-69.

GRASSO M & PEDLEY H.M. (1988) - *The sedimentology and development of Terravecchia Formation carbonates (Upper Miocene) of North Central Sicily: possible eustatic influence on facies development*. Sed. Geol., **57**, 137-149.

GRASSO M., PEDLEY H.M. & MANISCALCO R. (1994) - *The application of a Late Burdigalian - Early Langhian Highstand event in correlating complex Tertiary orogenic carbonate successions within the Central Mediterranean*. Geòlogie Méditerranéenne, **21** (1-2), 69-83.

HARLAND W.B., ARMSTRONG R.L., COX A.V., CREAIG L.E., SMITH A.G. & SMITH D.G. (1990) - *A Geologic Timescale 1989*. Cambridge University Press, pp.263.

HUNT D. & TUCKER M.E. (1992) - *Stranded parasequences and the forced regressive wedge systems tract: deposition during base-level fall*. Sedimentary Geology, **81**, 1-9.

LENTINI F. (1982) - *The geology of the Mt. Etna basement*. Mem. Soc. Geol. It., **23**, 7-25.

LENTINI F. & VEZZANI L. (1974) - *Carta Geologica delle Madonie*. Map scale 1:50 000. L.A.C., Firenze.

LENTINI F. & VEZZANI L. (1978) - *Tentativo di elaborazione di uno schema strutturale della Sicilia orientale*. Mem. Soc. Geol. It., **19**, 495-500.

PEDLEY H.M., LA MANNA F. & GRASSO M. (1994) - *A new record of Upper Miocene reef carbonates from Santo Stefano di Camastra-Caronia area (northern Sicily) and its regional significance*. Boll. Soc. Geol. It., **113**, 435-444.

SCHMIDT DI FRIEDBERG P. (1962) - *Introduction a la geologie petroliere de la Sicilie*. Rev. Inst. Fr. Pet., **17** (5), 635-668.

SCHMIDT DI FRIEDBERG P. (1965) - *Litostratigrafia petrolifera della Sicilia*. Riv. Min. Sicil., **88-90** (1964), **91-93** (1965), 43 pp.

VAN VAGONER J.C., MITCHUM R.M., CAMPION K.M. & RAHMANIAN V.D. (1988) - *Siliciclastic sequence stratigraphy in well logs, cores and outcrops*. AAPG Methods Expl. Ser., **7**, 55 pp.