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THE NOCELLA CONGLOMERATES: A PROBLEMATIC OUTCROP HIGHLY SUSPENDED ON THE SOUTHERN SLOPE OF THE EASTERN SORRENTO PENINSULA (ITALY)

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ABSTRACT
A 130m thick sedimentary alluvial to slope deposits (Nocella Formation) rests on a concave up spur suspended between 660m and 800m on the southern coastal slope of the Sorrento Peninsula have been analized. Stratified slope waste deposits (Nocella breccias) unconformably and abruptly rest on Nocella alluvial deposits (Nocella Conglomerates). Facies analysis of the Nocella Conglomerates indicate a high-energy, gravel bed braided environment. In particular two facies association have been distinguished. The first one is representative of in-channel deposition and both vertical accretion and lateral and downstream migration of gravel bars. The second one reflect vertical accretion and downstream migration of low-relief gravel bars and extensive, locally in-channel, deposition by high-energy flood flows respectively. Paleocurrent data indicate a WNW-sloping paleoslope away from a, nowadays, lacking highland. Techniques of lateral profile analysis and hierarchical ordering of bounding surfaces has also been applied to the Nocella Conglomerates, and allows two different river model to be outlined.
Slope deposits also taper upslope coating a triangular facet belonging to the first fault scarp generation which occurred after the formation of the I order palaeosurface sailed by Nocella Conglomerates; they are cut by the second fault scarp generation together with relics of the II order palaeosurface such as the Agerola karst basin and the S.Maria del Castello erosional surface. We correlate the Nocella alluvial deposits with the S. Maria del Castello relic of II order palaeosurface and thus we propose a reconstruction of a part of the Sorrento Peninsula Early Pleistocene landscape. The source area of the Nocella Conglomerates should be a mountainous area located east-southeastward of Nocella site and should be the same as, on the opposite side, fed the clastic infilling of the Agerola karstic basin.

RIASSUNTO
Sul versante meridionale della Penisola Sorrentina, in corrispondenza di uno sperone sospeso tra 660m e 800m s.l.m., affiora una successione sedimentaria spessa circa 130 m costituita da depositi alluvionali su cui poggiano depositi di versante. I depositi di versante (Brecce di Nocella) giacciono in discordanza sui depositi alluvionali (Conglomerati di Nocella). L'analisi di facies sulla porzione alluvionale della successione è indicativa di un ambiente fluviale ad alta energia di tipo braided. *In particolare sono state distinte due associazioni di facies la cui differenza principale risiede nella maggiore o minore presenza di unità canalizzate, oltre alle loro geometrie, e nei caratteri geometrici delle forme migranti (barre). La direzione misurata delle paleocorrenti, che è WNW, evidenzia un chiara discordanza oroidrografica, in quanto l'attuale paesaggio manca completamente dei rilievi alimentatori. Nell'ambito delle porzione alluvionale della successione affiorante sono state applicate tecniche di analisi laterale dei depositi e di ordine gerarchico delle superfici che limitano i principali elementi architettonici individuati al fine di caratterizzare la tipologia di modello fluviale.*
I depositi di versante mantellano versanti a faccette triangolari derivanti dal modellamento della scarpata di faglia di prima generazione che ha smembrato e dislocato il I ordine di paleosuperfici ed è stata fossilizzata dai Conglomerati di Nocella. Essi sono dislocati da una ulteriore fase tettonica insieme ai relitti del II ordine di paleosuperfici, correlabili con quelli che bordano la conca carsica di Agerola e con la paleosuperficie di Santa Maria del Castello. Considerazioni di carattere morfostratigrafico ci hanno consentito di correlare i Conglomerati di Nocella con il relitto di II ordine di peleosuperfici di Santa Maria del Castello, e pertanto proponiamo una ricostruzione del paleopaesaggio che caratterizzava questo settore della Penisola Sorrentina durante il Pleistocene inferiore. Tale paleopaesaggio, che prevede la presenza di una area montuosa sorgente dei Conglomerati di Nocella a ESE della successione analizzata, probabilmente fungeva da area sorgente anche per i depositi che costituiscono il riempimento clastico della conca di Agerola.

Keywords: palaeosurfaces, fluvial deposits, facies analysis, Sorrento Peninsula, Early Pleistocene.

Parole chiave: paleosuperfici, depositi fluviali, analisi di facies, Penisola Sorrentina, Pleistocene inferiore.

1. INTRODUCTION

The Sorrento Peninsula is an ENE-WSW trending morphostructural high interposed between the perytyrrhenian depressions (grabens) of the Gulf of Naples-Campana Plain to the North, and the Gulf of Salerno-Sele Plain to the South (Fig.1). It consists mainly of a Mesozoic carbonate units (the Picentini Mts.-Mt. Taburno tectonic unit; Bonardi *et al.*, 1988) and of a Miocene terrigenous synorogenic units. Due to its position (it is one of the westernmost outcropping part of the Southern Apennines Chain) together with the conservativity of its lithologic units, the Sorrento Peninsula represents important evidence of the early phases of post orogenic morphostructural evolution of the Southern Apennine Chain (Cinque *et al.*, 1993).

As regards the structural setting of the Sorrento peninsula, it represents a NW dipping monocline which is dislocated into minor blocks by two systems of high angle fault trending NW-SE and NE-SW. In particular the anti-apenninic system is responsible for formation of the grabens of Napoli and Salerno (Bartole *et al.*, 1984; Sacchi *et al.*, 1994); an E-trending system fault has contributed to the development of the first one too. Previous Authors distinguished up to five block-faulting phases during Plio-Pleistocene time on the basis of structural data (Torrente *et al.*, 1999). By a morphostructural point of view, there are three main deformation phases

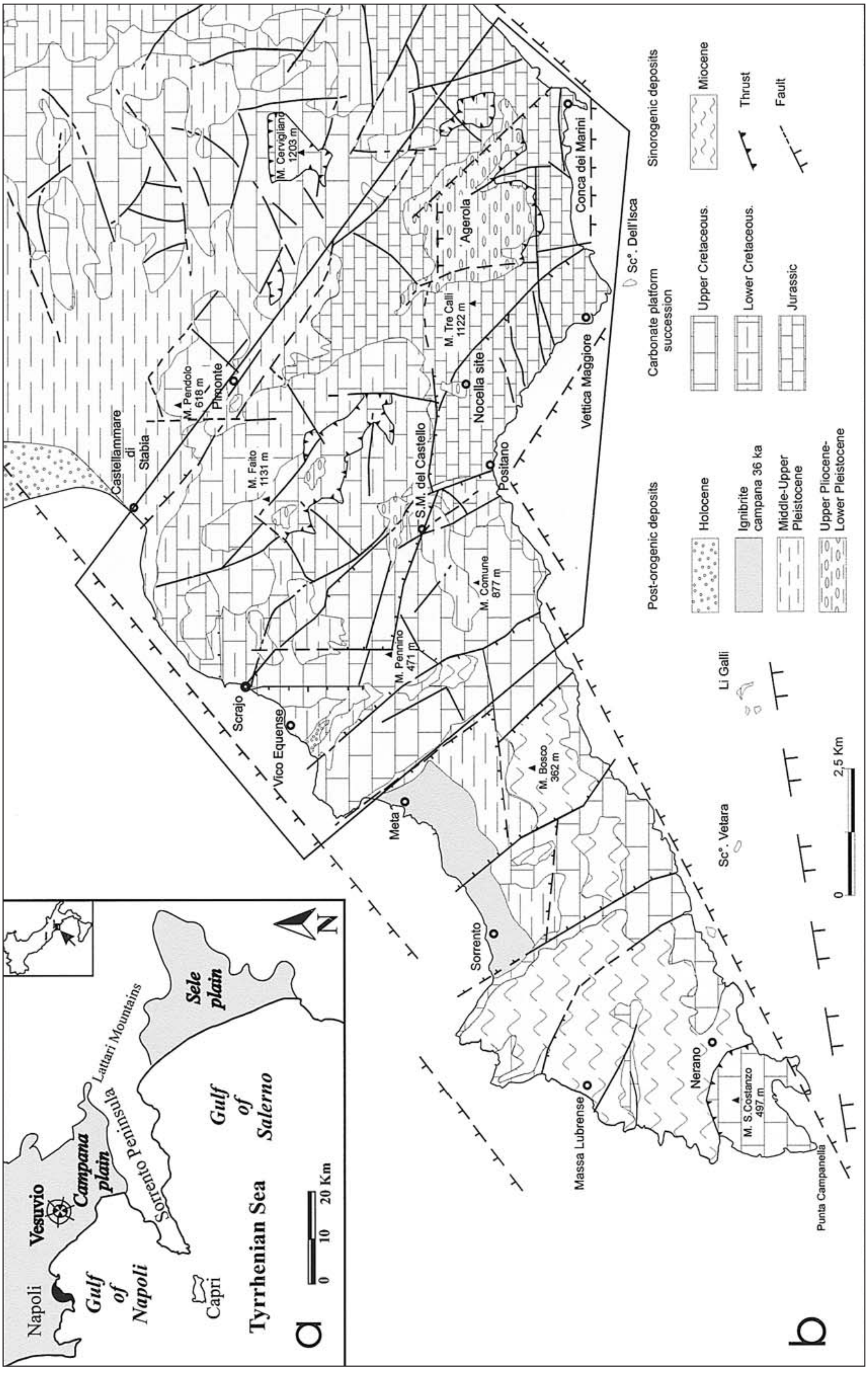

Fig. 1 - Geological sketch map of the Sorrento Peninsula (from Caiazzo et al., 2000, modified). The framed area corresponds to the one reported in Fig. 2.
Schema Geologico della Penisola Sorrentina (da Caiazzo et al., 2000, modificato). L'area nel riquadro corrisponde a quella rappresentata in Fig. 2.

(Caiazzo *et al.*, 2000), which occurred during the Early Pliocene-late Middle Pleistocene time interval, in response to the eastward migration of the Thyrrenian extensive domain (Sartori, 1989, 1990). The presence of raised marine terraces indicates the uplift of the Sorrento peninsula from the Lower Pleistocene to the Middle Pleistocene, during which the width of the peninsula was progressively reduced by block faulting that affected the southern flank enlarging the contiguous Gulf of Salerno (Cinque, 1986). The emerged marine terraces along the southern slope of the Sorrento peninsula allow Cinque & Romano (1990) to infer that the latest phases of block faulting occurred during the late Middle Pleistocene and that Sorrento peninsula stopped rising no later than the last interglacial. On the contrary, the nearby Campana-Plain graben has continued to subside during the Upper Pleistocene to present time (Milia, 1996).

Since no absolute chronological constraints have ever been reported, the different stages in which the morphostructural evolution of the Sorrento Peninsula have been divided are only relatively dated. The beginning of the geomorphologic history of the Sorrento Peninsula is as old as the formation of the I order palaeosurface, suspended up to 1300 m a.s.l. on the top of Mt. Faito (Fig. 2), which has been ascribed to a probably Early – Middle Pliocene time (Caiazzo *et al.*, 2000). The oldest geomorphological elements are few hanging relics remnants of mature erosion landscape (I order palaeosurface). After a phase of block faulting that disrupted and uplifted the I order palaeosurface, a new base-level established some hundreds of meters below. In this paper we attempt to reconstruct the landscape of this geomorphological stage, now broken and suspended up to 850 m a.s.l., by considering different types of evidences preserved in the studied area and by analysing the stratigraphic and sedimentological characteristics of the here informally named Nocella formation.

2. GEOMORPHOLOGY

The Sorrento Peninsula is characterised by a clear structurally controlled landscape, as it is dominated by the occurrence of fault scarps and structural cliffs and valleys (Figg. 1, 2). Moreover, due to the vicinity of the sea, the area experienced a great number of eustatic controlled fluvial dissectional cycles, which actively contributed to reduce or even cancel the erosional landforms modelled during the pauses of the tectonic activity. Nonetheless, clear traces of ancient erosional cycles occur and we attempt to interpret them in terms of palaeoenvironment and relative age.

In the geomorphological map of Fig. 2, the main structural, erosional, and depositional landforms of the Eastern Sorrento Peninsula are reported, and the relative inferred ages are also proposed (see section 4 for discussion). Two sectors have been distinguished: the eastern one, which is dominated by the high homoclinal calcareous block of Mt. Faito, and the western one, which is sensibly lower. The two sectors are separated by the fault scarp of Mt. Faito which transversally crosses the Peninsula.

On both the sectors we recognise relics of palaeosurfaces testifying the occurrence of past phases of relief smoothing under the control of both local and general baselevels of erosion. Most of the relics cut across dipping strata, but in some cases they rest on almost horizontal strata. In few cases (e.g., Faito, Agerola) they are associated to outcrops of undated continental conglomerate. More frequently, these surfaces lack any type of deposits, so that their chronology is uncertain.

The only ancient (Early Pleistocene?) clastic deposits are the Nocella alluvial deposits (see section 3) suspended between 700 and 775 m a.s.l., on a policyclic slope. More precisely, these deposits are cut by the free face of a coastal fault scarp whose slope is about 35%. Above this free face the slope changes in about 25% and appears concave up to the summit where the top surface of Mt. Faito occurs. This change in slope gradient is due to a different lenght of the erosional processes which caused the decline and the slope replacement of the relative fault scarp planes.

The more ancient erosional cycle is well represented by the highest relics of palaeosurface occurring on the eastern uplifted block, indicated on the map of Fig. 2 as the I order palaeosurface.

The relics of the I order palaeosurface are almost reduced to flat watershed, but locally (see the top of ridge that limits the Agerola plain to the East) they include also wind gaps clearly unlinked to the modern valley network. As mentioned before, on the top of Mt. Faito these surfaces are associated with the outcrop of severely eroded clastic deposits, interpreted as slope and fan breccias, produced when the base level was very near to those of the I order palaosurface landscape. The Mt Faito palaeosurface could be Upper Pliocene in age, since it is younger than the Miocene N-verging thrustsand older of the phase of normal block –faulting (probably Late Pliocene – Early Pleistocene (Aucelli *et al.*, 1996).

The slope fault scarp of the Sorrento Peninsula can be divided in two main groups: a first characterized by concave up profiles with mean gradients of about 25 – 30 % , standing on the highest portions of reliefs, locally just behind the relics of the I order palaeosurface; the other ones is represented by the lower tracts of slopes, characterized by higher gradients (in the order of 40 % and more), convex profiles frequently disrupted by parallel fault planes.

These two different types of slope profile are locally separated by relics of the II order palaeosurface, that occur on both the eastern and the western sector. It is probable that part of the II order relics, as well as some lower erosional terraces must be interpreted as downfaulted portions of the I order palaeosurface that were simply remoulded during the pause of the tectonic activity that allow the II order palaosurface to be formed. Different examples of this type are widespread on the western downfaulted sector of the study area. We will describe two cases: the surface of the Agerola karst basin, and the S.Maria del Castello surface.

The Agerola graben was formed by the tectonic phase that disrupted the I order palaeosurface by the normal activity of the N-S trending faults on which the western slope of the Sproviere - Murillo ridge and the eastern slope of Mt. Tre Calli ridge are sculptured. The top surface of the graben can be considered a II order surface, it is a policyclic surface suspended at about

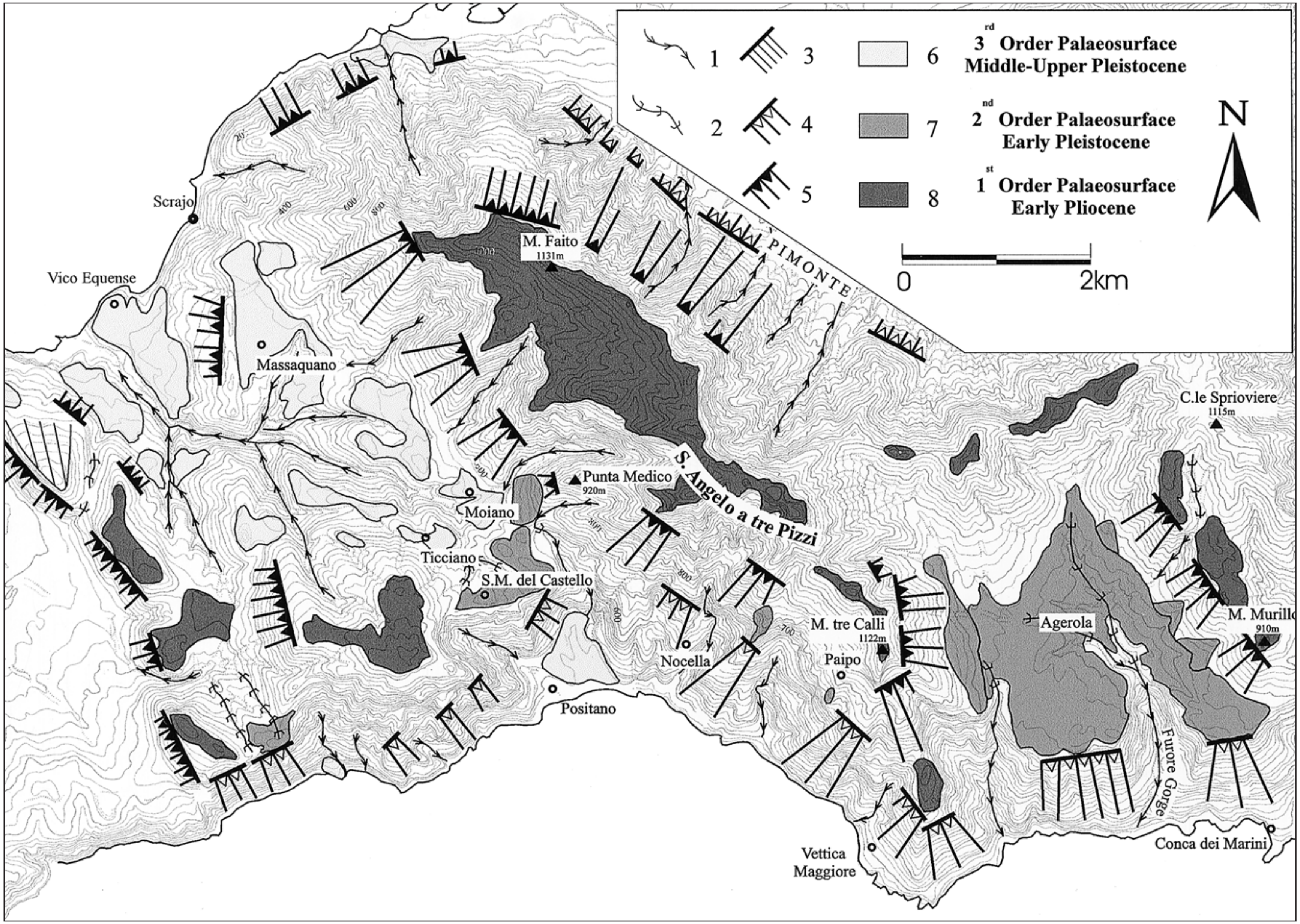

Fig. 2 - Geomorphological scheme of the South Eastern Sorrento Peninsula: 1) valley downcutting; 2) hanging valleys and wing gaps; 3) structural slope; 4) Middle Pleistocene fault scarp; 5) Early Pleistocene fault scarp; 6) Middle – Upper Pleistocene 3rd order palaeosurface; 7) Early Pleistocene 2nd order palaeosurface; 8) Early Pliocene 1st order palaeosurface.

Schema geomorfologico del settore sud – orientale della Penisola Sorrentina. 1) incisioni vallive; 2) valli sospese e valli relitte; 3) versante strutturale; 4) scarpata di faglia medio pleistocenica; 5) scarpata di faglia infrapleistocenica; 6) paleosuperficie di 3° ordine (Pleistocene medio – superiore); 7) paleosuperficie di 2° ordine (Pleistocene inferiore); paleosuperficie di 1° ordine (Pliocene inferiore).

650 m a.s.l. The graben infilling outcrop of few tens of meters in river incision and consists of a polygenic angular conglomerate composed of carbonatic and subordinate terrigenous clasts, the latter derived from a Miocene terrigenous unit outcropping during Early Pleistocene time and then tectonically drowned under the sea of the Salerno Gulf. Due to the bad exposition, a more precise facies interpretation and source direction are not available for these deposits, except for those outcropping along the rim of the graben, which are at the top of the clastic infilling body and can be interpreted as slope breccias deposits. We don't have enough elements to establish if the endoreic conditions date back to the birth of the graben or if they developed after, but surely they had a long duration as demonstrated by signs of remarkable karstic planation along the borders of the basin, suspended at about 630 and 570 m a.s.l.. The epikarstic activity was interrupted by the tectonic phase that downfaulted the southern rim of the Agerola intramontane endoreic basin and promoted its capture by the retrogressive deepening of the Schiato stream gorge.

The S. Maria del Castello surface is located on the western sector, it is an erosional landsurface suspended upon Positano town at about 650 m a.s.l. with the shape of a low gradient wide valley tract NW dipping. It is truncated by a fault scarp NE-SW oriented and dipping to the North, whose characteristics are those typical of the second, more recent type of slopes.

Toward the NE the S. Maria del Castello II order surface confine with the base of the Punta Medico slope, which is one of the triangular relics of the first type fault scarps formed by slope replacement and then deeply dissected.

Near S. Maria del Castello, entrenched within the II order palaeosurface are other terraced alluvial fan conglomerates, suspended between 500 and 550 m a.s.l. (Moiano conglomerates). Similar deposits occur near Pimonte, on the northeastern side of Mt. Faito. Both Moiano and Pimonte conglomerates are suspended and hence older than the other dissected alluvial fan occurring at lower elevations and located in the lower tracts of the valleys. These younger alluvial fans are Middle and Late Pleistocene in age. Similarly, the traces of marine terraces suspended between 6-8 m and 50 m a.s.l. on the southern coast are Late Pleistocene to Middle Pleistocene in age (Cinque & Romano, 1990). On the basis of the existing knowledge, the Moiano and Pimonte conglomerates can be referred to a generic Middle Pleistocene.

3. NOCELLA FORMATION

The Nocella Formation. lies with pronounced angular unconformity upon Jurassic dolomitic limestones, which constitute the bulk of the relief. The best exposed stratigraphic section , about 130m thick, outcrops on a hanging, concave up spur ranging between 660m and 800m in elevation (Fig. 3). Here stratified slope waste deposits (Nocella breccias) rest unconformably on Nocella alluvial deposits (Nocella Conglomerates) proofing that their deposition occurred soon after the alluvial one. Slope deposits tend to taper upslope coating a triangular facet which is one of the triangular relics of the Scrajo-Vettica fault scarp on

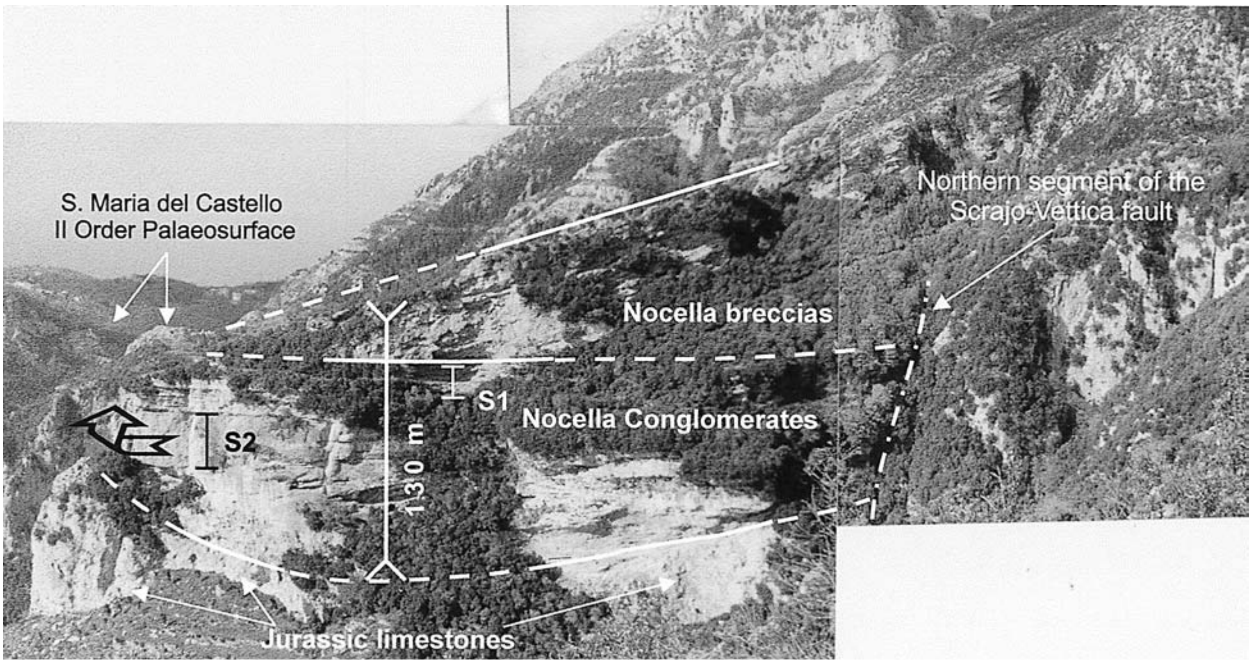

Fig. 3 - Overview photograph of the studied section. The location of the logs are marked and numbered. The Nocella formation, resting uncomformably above Jurassic limestones, consists of alluvial deposits (Nocella Conglomerates) overlaid by slope breccias (Nocella breccias). The northern segment of the Scrajo-Vettica fault is also marked.

Panoramica dell'area studiata. S1 ed S2 indicano le sezioni esaminate. La formazione di Nocella, discordante sui calcari giurassici, è costituita da una porzione inferiore alluvionale (Conglomerati di Nocella) passanti verso l'alto a brecce di versante (Brecce di Nocella). In figura è inoltre segnalata la traccia del segmento settentrionale della faglia Scrajo-Vettica.

which the south-eastern slope of the Mt. Tre Calli ridge are sculptured by slope replacement processes coupled with consequent river dissection. The basal angular unconformity represent an asymmetric paleovalley into which Nocella Conglomerates were deposited and, in particular, sail the north-eastern segment of the Scrajo-Vettica fault zone.

Steep and high scarp perimeters the spur at issue which reflects the re-activation of the the Scrajo – Vettica fault zone and its dissection by consequent incisions characterised by steep flanked V-shaped valleys having high longitudinal gradients. Their longitudinal cross-profile is characterized by upper reach steeper than the slope they dissect.

The Nocella Conglomerates, about 90m thick, has been chosen as a type section for detailed description of the sedimentary facies. As the vertical cliff which confines the spur does not allow a complete sedimentary log to be given, only the middle and the upper portion of the Nocella Conglomerates have been analysed in detail (Fig. 3); they outcrop on the north-western and south-eastern part of the spur respectively. Minor exposures of clastic deposits belonging to the same morphoevolutive stage occur close to hanging, concave-up footslope of the Scrajo-Vettica Fault zone.

The Nocella type section consists of a crudely CU sequence characterized by the dominance of conglomerate lithofacies (>95%) with very subordinate sandstone lithofacies. Fine grained lithofacies were not observed. Conglomerate lithofacies are clast supported, poorly to moderately sorted, and contain angular to subrounded clasts. Clast size is generally in the pebble to cobble range although boulders up to 30 cm occur in the topmost part of the sequence. The lithology does not vary over the study area; dominant clasts include white to greyish dolomitic limestone mainly of Jurassic age (coming from the Jurassic part of the local Mesozoic succession). Rare clasts of Miocene flysch deposits also occur, suggesting that Miocene terrigenous deposits outcropped in the source area of Nocella Conglomerates.

3.1 Lithofacies description

The Nocella Conglomerates is characterized by six sedimentary facies distinguished on the basis of sedimentary structures and bed geometry. Paleocurrent data indicate WNW-ward paleoflows close parallel to the Scrajo-Vettica fault zone. Two sedimentary logs are given in Fig. 4; they are representative of the middle and the upper part of the Nocella Conglomerates and are located respectively along the NW and SE side of the spur (Figg. 3 and 4). Table 1 summarizes the lithofacies codes used in describing Nocella Conglomerates, based on the fluvial lithofacies code modified from Miall (1996).

Lithofacies Gcm – Structureless, clast-supported conglomerate

This facies consists of pebble to cobble-size clasts subangular in shape; they are moderately to poorly sorted and display a clast-supported texture (Fig. 5). Matrix content is generally less than 20% and consists of coarse sand and granules. Conglomerate fabric is disorganized, although it appears locally to be a preferred clast orientation. The longest a-axes of some elongate clasts are parallel to paleoflow directions; locally *a*(p)*a*(i) fabric mode occur. Grading is absent or basal inverse grading and crudely normal grading locally occur. The conglomerates consist of lenticular or laterally apparently continuous, non erosive-based units whose thickness range between 10 to 45cm. This lithofacies occurs mostly in the upper part of Nocella Conglomerates and is interbedded with Gci and Gh lithofacies

Lithofacies Gci – Inversely graded, clast-supported conglomerate

This facies consists of pebble-size clast, although cobbles up to 20 cm locally occur. The clasts are angular to subrounded; they are moderately sorted and characterised by a clast-supported texture, with a coarse sand matrix locally absent. Inverse grading is well developed and *a*(t)*b*(i) fabric mode is locally present. Beds of this facies have sharp non erosional lower contacts and occur in lenticular units that are up to 30 cm thick and up to 8m wide; locally such lenticular beds show a convex-top boundary. As for Gcm facies, this lithofacies has been well recognized in the upper part of Nocella Conglomerates.

Lithofacies Gh – Horizontally stratified clast-supported conglomerate

Pebble to fine cobble-size clasts in this facies are subangular to subrounded; they are moderately to well sorted with a clast-supported texture (Fig. 5). Well developed bedding and horizontal stratification is ubiquitous;

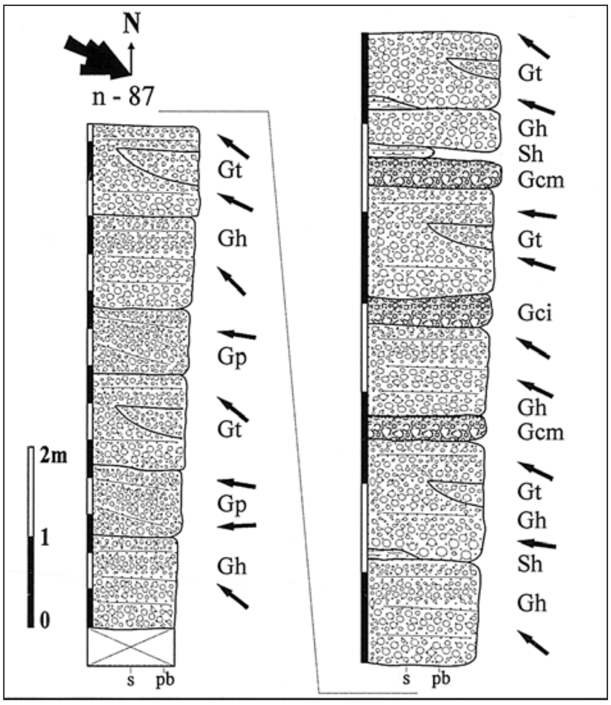

Fig. 4 - Logs of the Nocella Conglomerates along the north-western (S1 in Fig. 2) and south-eastern (S2 in Fig. 2) side of the Nocella spur (Fig. 2). Letters refer to lithofacies and arrows indicate paleocurrent. The paleocurrent rose refers to the total number of measurements.

Sezioni stratigrafico-sedimentologiche dei Conglomerati di Nocella sul lato nord-occidentale (S1 in Fig. 2) e sud-orientale (S2 in Fig. 2) dello sperone visibile in Fig. 2. Le sigle si riferiscono alle litofacies mentre le frecce indicano la direzione delle paleocorrenti. Il diagramma si riferisce al totale delle misure effettuate.

Facies code	Facies	Sedimentary structures	Intepretation
Gcm	Massive, clast supported gravel	None or weak grading	Pseudoplastic cohesionless debris flow or high sediment-concentration flood flows
Gci	Clast-supported gravel	Inverse grading, locally imbrication	Clast-rich debris flow or hyperconcentrated flood-flows; filling of broad, sheet-like channels
Gh	Clast-supported, well bedded gravel	Horizontal bedding, imbrication	Accreditionary units longitudinal bars
Gt	Gravel, stratified	Trough cross-beds	Minor channel fills
Gt_1	gravel, stratified	Low-angle and/or horizontal bedding	Rapid scour fills by high-concentration flood-flows
Gp	Gravel, stratified	Planar cross-beds	Transverse accretion units of bars
Sh	Coarse sand, many be pebbly	Crude horizontal lamination, locally massive	Deposition from heavily sediment-laden flows during waning floods above bars

Table 1 - Description and interpretation of sedimentary facies adapted from Bridge (1993) and Miall (1996)

pebble-size clasts show a local well developed a(t)b(i) fabric mode. Imbrication and cluster bedforms indicate paleoflow directions toward WNW. Conglomerate beds are usually normal graded (Fig. 5); medium to coarse sand matrix is usually present but open framework conglomerate beds also occur (Fig. 5). Local beds exhibit bimodality both (Fig. 5) in the lower and in the upper band of each bed - textural inversion of Nemec & Steel (1984) and Steel & Thompson (1983). These conglomerates occur in laterally continuous beds that can be traced for at least 20m; basal contacts are usually sharp and planar, but local scour surfaces may be observed. These sheet-like units, tipically few dm thick (up to 40cm), set up multistory units up to about 4m thick. This lithofacies is interbedded with Gcm and Gci lithofacies, but is well developed also in the middle part of the Nocella Conglomerates.

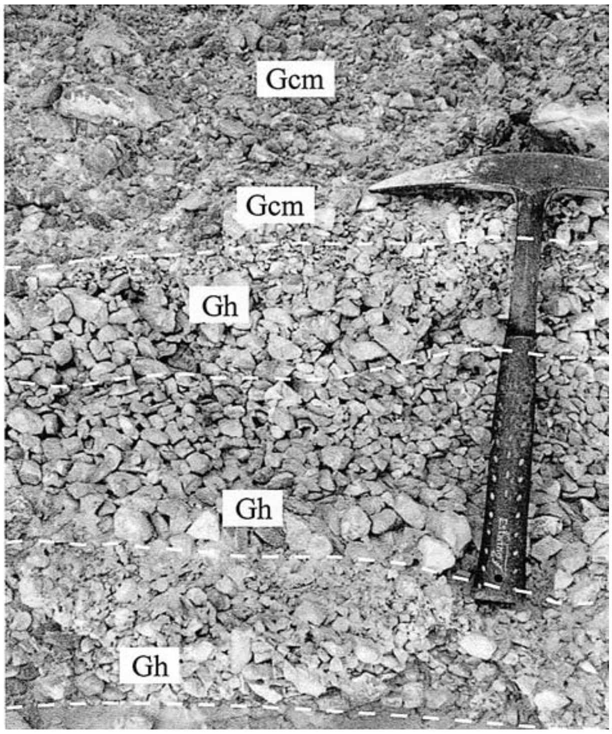

Fig. 5 - Set of clast-supported conglomerates with disorganized fabric (Gcm facies) overlay normal graded, horizontally stratified conglomerates (Facies Gh). Note also the poor degree of rounding of the clasts. Paleoflow is obliquely into the face and to the left.

Strati di conglomerati massivi, clasto-sostenuti (facies Gcm) ricoprono conglomerati stratificati organizzati in unità normalmente gradate (facies Gh). Si può notare lo scarso grado di arrotondamento dei clasti. I paleoflussi sono obliqui e diretti verso sinistra.

Lithofacies Gp – Planar cross-bedded clast-supported conglomerate

This facies consists of subangular to subrounded pebbles. The clasts are moderately to well sorted and characterised by a clast-supported texture. Well developed planar cross-stratification occurs; the foreset beds, up to 15cm thick, consist of alternating fine and coarse pebbles without any signs of rhythmic organization. Dip azimuth of the foreset beds is toward SSE; dip angle range from few degrees up to 13°. Foreset beds appear to be ungraded. Sandy matrix is scarce but usually present; some local foreset beds have an open framework. These conglomerates occur in laterally continuous tabular units, ranging from 50 to 110cm in thickness, with internal scour surfaces. Basal contacts are sharp and non erosive; top contact shows a local convex-up boundary (Fig.6). This lithofacies occurs in the middle part of the Nocelle Conglomerates and grade laterally into Gh lithofacies.

Lithofacies Gt and Gt1 – Trough cross-stratified conglomerate

Trough cross-stratified conglomerate occur as single sets ranging from 0.6m to 1,5m deep and from 1,2m to 7.4m in width. Basal scours affect both the conglomerate facies and sandy ones; channel margins are gentler in slope with increasing channel width The bigger ones occur in the middle part of the Nocella Conglomerates (Fig. 7A). This facies is developed in pebble size clasts, subangular to subrounded; they are moderately to well sorted with a clast-supported texture.

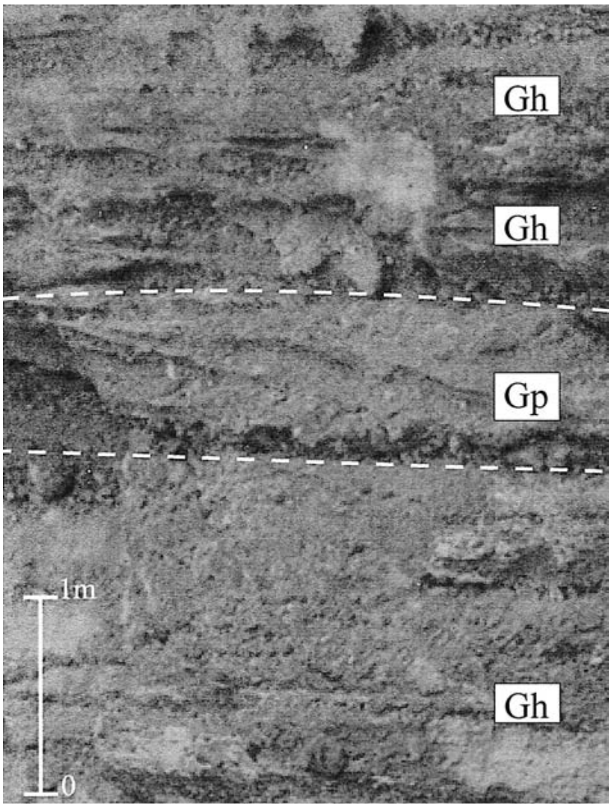

Fig. 6 - Middle part of the Nocella Conglomerates: one large-scale sets of planar cross-stratified conglomerates (Gp facies) overlain and underlain by horizontally stratified conglomerates (Gh facies).

Porzione intermedia dei Conglomerati di Nocella: si nota un intervallo a stratificazione incrociata-planare (facies Gp) intercalato in conglomerati a stratificazione orizzontale (facies Gh).

Trough fill consists of non rhythmic alternating fining upward and ungraded low angle sets (*Gt* lithofacies Fig.7A); their thickness is up to 15cm and they dip of about 10°.

Locally lag deposits of coarser grain size (up to fine boulders) grading upward into Gci lithofacies occur above a bowl-shaped, erosional bases of trough sets (Gt_1 lithofacies; Fig. 7B). Through fill consists also of stacked sets of Gh lithofacies. Just once (Fig. 7C) well developed foreset beds dipping north-westward was observed overlying Gt_1 lithofacies; these beds may be considered as Gp lithofacies and grade upward into Gh lithofacies.

Lithofacies Sh – Horizontally stratified sandstone

This lithofacies consists of sand to granule size clasts, with a local occurrence of isolated out-sized clasts (*a*-axes>5cm). It is organized in lenses and/or wedge-shaped units locally up to 15cm thick and over 7m extended. Locally they show crude horizontal stratification. Massive texture was also observed. Sandy facies usually rest on Gh lithofacies.

3.2 Facies associations interpretation

Lateral and vertical facies associations, paleocurrent and coarse-grained texture suggest that the Nocella Conglomerates was deposited in a high velocity stream.

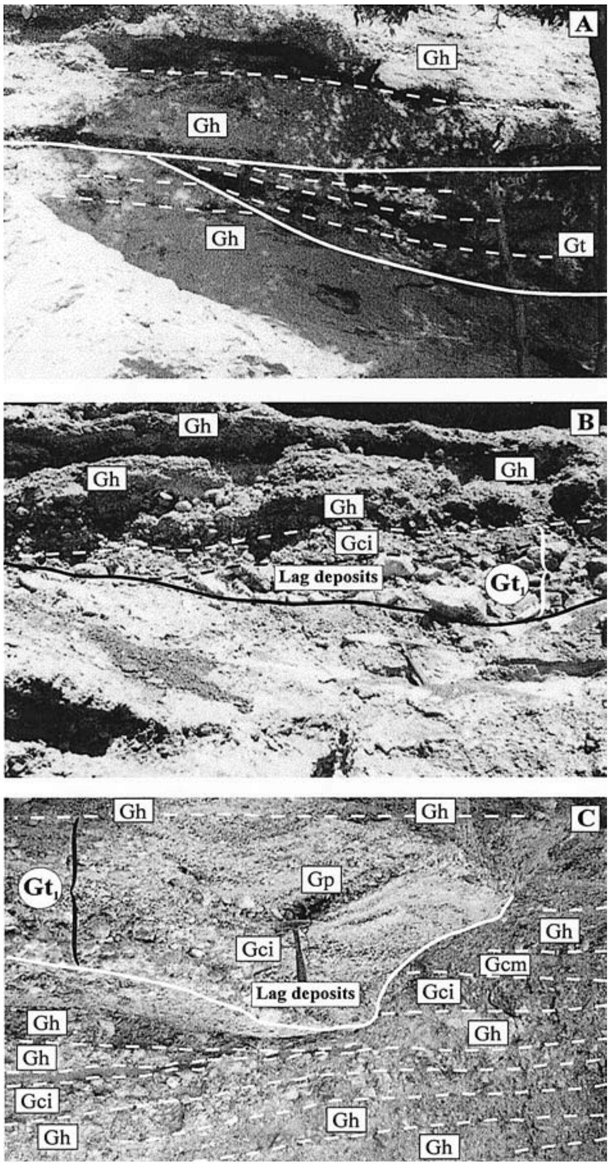

Fig. 7 - Trough cross-stratified conglomerates: A – Example of large-scale Gt facies cut into Gh ones near the middle of the Nocella Conglomerates. B – Oblique view of trough cross-stratified conglomerates (Gt_1 facies), underlying horizontally stratified conglomerates (Gh facies). C – Oblique view of trough cross-stratified conglomerates (Gt_1 facies), showing coarse lag above scour surface; trough fill consists of alternating fine and coarse pebble foresets (Gp facies) characterized by a decrease of dip angle with a gradual transition into Gh facies.

.Conglomerati organizzati in unità canalizzate: A – Esempio di unità canalizzata (facies Gt) che incide conglomerati a stratificazione orizzontale (facies Gh) nella porzione intermedia dei Conglomerati di Nocella. B – Vista obliqua di conglomerati organizzati in unità canalizzate (facies Gt_1), cui seguono in successione conglomerati a stratificazione orizzontale (facies Gh). C – Vista oblique di conglomerati organizzati in unità canalizzate (facies Gt1), in cui si osservano i depositi residuali basali poggianti sulla superficie di erosione; il riempimento è costituito da un'alternanza di ghiaie fini e grossolane a stratificazione incrociata-planare (facies Gp) e di cui gli strati sono caratterizzati da una riduzione della pendenza e da un graduale passaggio alla facies Gh.

On the basis of comparisons with the degree of rounding shown by other Pleistocene alluvial units of the area, we can estimate that the river reach upstream of Nocella outcrop, i.e. the feeding stream, was at least a 2-3 kilometres long.

Two facies associations have been distinguished, and their depositional systems have been reconstructed accordingly as follows:

Facies association 1 is restricted to the middle portion of the Nocella Conglomerates. Horizontally stratified conglomerates (Gh lithofacies) is the most common facies typically forming sheet-like units. Subordinate lithofacies are represented by planar cross-stratified conglomerates (Gp lithofacies). Minor lithofacies consist of trough cross-stratified conglomerates (Gt lithofacies) and horizontally stratified sandstones (Sh lithofacies).

Contacts between Gh and Gp lithofacies are usually sharp and flat, but locally they are slightly scoured. These conglomeratic lithofacies occur in laterally continuous tabular beds that can be traced for several meters.

The dominance of horizontally stratified conglomerates with local internal scour indicates that high-energy tractional processes were involved, as the coarse-grained texture and the absence of fines also suggest. In particular, the dominance of tabular conglomerate sheets indicates that deposition was laterally extensive; although the occurrence of broad and shallow channels is shown by internal erosive surfaces. As a whole this facies is interpreted as being formed by deposition and migration of bars in a high-energy gravel-bed river (Miall, 1977; Rust, 1978; Collinson, 1986; Miall,1996). Evidence for stream flow processes includes also clast-supported framework, *a*(t)*b*(i) fabric mode and lenticular trough cross-stratified conglomerates, the latter occur as minor lithofacies. The channel-like bedforms consist of few local scours over 1m deep and 5m wide. The cross-cut relationship with Gh lithofacies suggest that trough-cross stratified conglomerates may be representative of channels cutting across bars top and/or front during falling water, followed by gradual infilling of the scours.

The southern tip of the western measured section represent the one and only place at which the continuity of exposure allows us to attempt a hierarchical classification of the depositional units and bounding surfaces. However, even there the impossibility to look frontally at the whole exposure prevents us from getting reliable results. Nevertheless, it is noteworthy that horizontally stratified conglomerate grade laterally into gently inclined Gp lithofacies (Fig. 8; Tab. 2), which can be interpreted as lateral accretion of gravel sheets on inclined surfaces, indicating a margin of a macroform (Tab.2; element LA *sensu* Miall, 1985; 1988). The overlying and underlying horizontally stratified conglomerate have been interpreted as indicative of element GB of Miall (1985, 1988). Therefore the presence of element GB (Tab.2) and the occurrence of locally interbedded element LA (Tab.2) may be interpreted, according to Miall (1996), as representative of a shallow to relatively deep, gravel-bed braided river. An architectural model of this type of river may be considered the model 3 of Miall (1985)

Facies association 2 is restricted to the upper portion of the Nocella Conglomerates. The most common facies is the horizontally stratified conglomerates (Gh), typically forming sheet-like units. Subordinate lithofacies

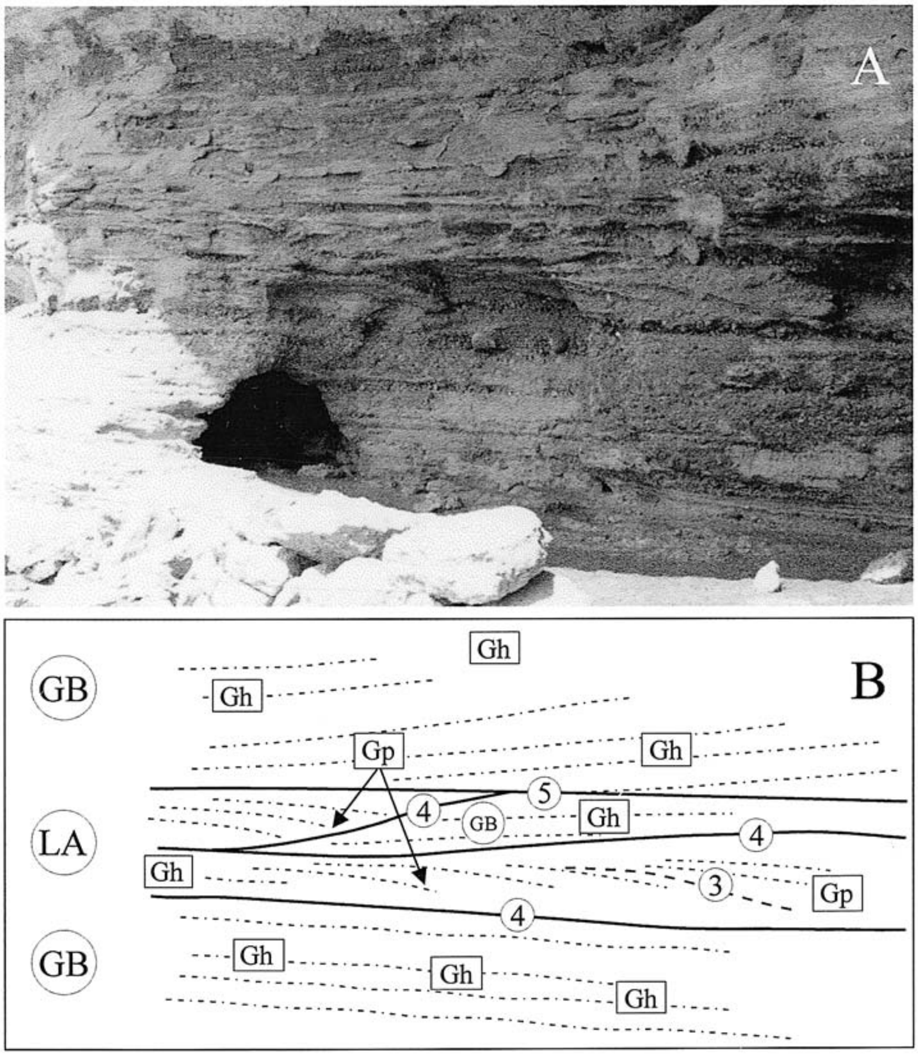

Fig. 8 – Oblique view (A) and interpretation of the photograph (B). For element and facies codes see tables 1 and 2. Circled numbers refer to the order of bounding surface. Circled letters are architectural elements. For element and facies codes see Tables 1 and 2.

Vista obliqua (A) ed interpretazione (B) di una porzione della sezione S1. Per le sigle delle facies e degli elementi architettonici vedi le tabelle 1 e 2. I numeri si riferiscono all'ordine gerarchico delle superfici che limitano gli elementi architettonici (lettere cerchiate). Le sigle delle facies e degli elementi architettonici sono indicate rispettivamente in Tabella 1 and 2.

are represented by massive conglomerates (Gcm lithofacies) and inversely graded conglomerates (Gci lithocacies). Minor lithofacies consist of trough cross-stratified conglomerates (Gt and Gt_1 lithofacies) and horizzontally stratified sandstones (Sh lithofacies). Gp lithofacies was not observed.

This association is characterized by stacked-sheets of graded and massive clast-supported conglomerates. The sheet-like beds range from few centimeters up to 50 cm in thickness and can be traced over a distance of several meters (see Fig. 3, upper part of Nocella Conglomerates). The bases of the conglomerate sheet.-like bedforms are sharp and flat, but scour surfaces occur so lenticular units may be recognized. As for the facies association 1, the dominance of horizontally stratified conglomerates suggests that high-energy traction-current processes were the main depositional processes. Therefore this facies is interpreted as being formed by migration of shallow and broad braided channels with abundant low-relief bars in high-energy gravel-bed river. The lack of evidence of planar cross-beds (*Gp* lithofacies), whose origin requires deep-water channel (Bluck, 1979; Steel & Thompson, 1983; Kraus, 1984), provides evidence of the shallow depth of the paleochannels. Clast-supported framework, *a*(t)*b*(i) fabric mode and cluster bedforms are further evidences for stream flow processes.

The massive (Gcm) and inversely graded (Gci) lithofacies suggest that depositional events were occasionally of very high energy; in particular, according to Shultz (1984) Gcm and Gci lithofacies can be considered as depositional evidences of pseudoplastic debris flow and clast-rich debris flow respectively; as also suggested by Lowe (1982), Gloppen & Steel (1981) and Nemec & Steel (1984), or representative of very high sediment-concentration dispersions (dilution of debris flows) such as hyperconcentrated flood-flows (Pierson, 1980; Pierson & Scott, 1985; Ridgway & DeCelles, 1993; Scott, 1988; Smith, 1986; Smith & Lowe, 1991; Waresback & Turbeville, 1990). Todd (1989) suggests a stream driven origin (high-density gravelly traction carpets) for the Gcm and Gci lithofacies; in particular Gci lithofacies is representative of granular flows in which during motion a dispersive pressure dominates (Lowe, 1982; Sohn *et al.*, 1999; Todd, 1989). The massive, structureless conglomerates represent the deposits of cohesionless debris-flow (Smith & Lowe, 1991; Sohn *et al.*, 1999) dominated by frictional grain interactions in which clast collision is hampered resulting in the lack of inverse grading and clast imbrication.

The lenticular trough cross-stratified conglomerates consist of few local bowl-like channels less than 1m deep and 5m wide. The local infillings consists of in-channel deposition by high-magnitude flood-flows (Gt_1 lithofacies, Figg.7B and 7C; Hein & Walker, 1977; Miall, 1977; Nemec & Postma, 1993; Jo & Chough, 2001); in particular Gp lithofacies (Fig. 7C) may be interpreted as cross-bedded conglomerates developing where channels debouche into pools (Ramos & Sopena, 1983).

As a whole we may interpret the laterally extensive conglomerate sheets as elements GB (*sensu* Miall, 1985; 1988; Tab. 2) in which high energy flood-flow deposits (Gcm and Gci lithofacies) are subordinate and representative of broad, low-relief channel fill. Element GB consists of three types of gravel tractions-current deposits; Gh lithofacies predominates, whereas tha Gt and Gt1 ones are very subordinate. The interbedded lenses of horizontally stratified sandstones (Sh lithofacies) may represent remnants of element SB due to rapid deposition from heavily sediment-laden flows

Element and Symbol	Description	Principal facies assemblage	Interpretation	Bounding surfaces
Horizontally stratified sets (GB)	Stacked sets of horizontally stratified conglomerates; individual sets, decimeters thick and meters (up to 20 m) in lateral extent, parallel strata.	Gh, Gcm and Gci interbedded	Vertical aggradation and downstream migration of broad, low-relief bars. Filling of broad, sheet-like channels by deposition from highly concentrated flows	Bound by erosively and accretionary fourth-order surfaces, planar to convex-up
Large-scale, planar cross-stratified set (LA)	Solitary set of planar cross-stratified conglomerates dipping about perpendicular to paleocurrent direction; decimeters thick and meters in lateral extent.	Gp, Gh	Lateral accretion of bars with internal re-activation surfaces	Bound by fourth-order surfaces and internal third -order surfaces between accretion elements
Channel (CH)	Lenticular unit with concave-up, erosional base; up to 5m thick and tens of meters wide.	Any conbination	Filling of major channels	Bound with concave-up, fifth-order surfaces
Small-scale scour fill (CH^1)	Lenticular unit with concave-up, erosional base; solitary unit, decimeters to 1,2m thick and meters wide.	Gt, Gt_1, Gp and Gh	Filling of minor channels and scours on bars	Provide palaeocurrent of downstream accretion directions. Associated with concave-up, fourth-order surfaces

Table 2 - Description and interpretation of architectural elements adapted from Miall (1985, 1988, 1996) and Bridge (1993)

during waning flood (Todd, 1989; Maizels, 1993; Jo & Chough, 2001).

This kind of facies architecture, according to Miall (1996), is consistent with a shallow, gravel-bed braided river interpretation. The architectural model of this type of river could be the model 2 of Miall (1985).

4. DISCUSSION

The sedimentologic and geomorphologic data reported above allows us to propose a new and more complete interpretation of the highly hanging clastic deposits outcropping near to Nocella village, previously interpreted as slope replacement breccia by Brancaccio *et al*. (1979) and Cinque (1986). The detailed facies analyses of the Nocella Conglomerates have documented an high-energy, gravel-bed fluvial setting with a WNW-sloping paleoslope, the latter suggested by paleocurrent data.

Facies association 1, although characterized by a dominance of horizontally stratified conglomerates (Gh lithofacies), consists also of laterally extended sets of planar cross-stratified conglomerates (Gp lithofacies) that grade laterally into the Gh one (lateral accretion of gravel bars on inclined surfaces; element LA *sensu* Miall, 1985; 1988).

Facies association 2 is characterized by Gh lithofacies with subordinate Gcm and Gci ones, and a lack of planar cross-stratified conglomerates. The dominance of laterally extensive gravelly sheets coupled with the absence of Gp lithofacies suggests that flow depths were more shallow than ones suggested by facies association 1.

On the basis of comparisons with the sedimentological features offered by the Pleistocene alluvial fan deposits of the Pimonte area (Aucelli *et al*., 1996), a confined alluvial fan interpretation may be proposed as the Nocella Conglomerates consists mainly of stacked-sheets of graded and massive clast-supported conglomerate, which can be traced over a distance of several meters; in fact the gathered data are indicative of deposition and migration of low-relief longitudinal bars in shallow, high-velocity gravel-bed stream. But the lack of other outcrops beside that of Nocella does not enable us to definitely confirm this hypothesis as an abrupt basinward facies transition may not be observed. Although a vertical change from more distal to proximal fluvial settings is suggested by both the disappearing of macroforms interpreted as laterally accretion of gravel-bars and the upward abrupt increase of high energy flow deposits (Gcm and Gci lithofacies).

In order to interpret the vertical change of the facies associations within the Nocella succession, different factors can be considered. First of all the angular to subrounded shape of the Nocella Conglomerates clasts prove that slope deposits produced by Paipo fault scarp retreat are poorly reworked by fluvial processes as the absence of slope deposits interfingering with fluvial ones suggest. A climatic factor could also be considered to unravel the varying vertical facies association of the Nocella Conglomerates: the river models deduced by analysing the facies architecture may witness a decrease of water discharge and/or an increase of sediment supply. The abrupt transition from fluvial deposits to slope ones should be due to Early – Middle Pleistocene re-activation of the southern segment of the Scrajo-Vettica fault zone which could have beheaded the upper reach of the catchment. Conversely, the same abrupt transition could also be due either to a sudden lateral (south-westward) shifting of the watercourse or to the advancing of the debris slope after a phase of downcutting.

Moving north-westward suspended at about 600 – 650 m a.s.l. stand the S. Maria del Castello II order relic (Figg. 2 and 3) and a small erosional hanging terrace both sealing the Scrajo – Vettica fault. Also the Paipo breccias, located south-eastward of Nocella site, seal the older segment of the Scraio-Vettica fault zone. These erosional and depositional landforms have been interpreted to belong to the same geomorphological stage, apart from the uppermost slope deposits which could also be more recent, in the case of a preceeding phase of downcutting or tectonic behading of the upper catchement.

As a whole it was concluded that the paleomorphology of the study area, at the time of the Nocella Conglomerates deposition, was quite different from the modern one. The source area of the Nocella Conglomerates has to be related to a small river catchment nested into a nowadays lost morphostructural high located east-southeastward of the study area (Fig. 2). This topographic high had to include also the mountainous area that fed the clastic infilling of the Agerola karstic basin, whose western deposits show a clear dip towards northeast (Brancaccio *et al*., 1976; Cinque, 1986). Moreover, the gentle landscape of S. Maria del Castello site settled at the footslope of the Scraio-Vettica Maggiore fault scarp, represents the WNW part of a low relief landscape, that we interpret as part of the WNW-sloping paleoslope of the river basin in which the Nocella Conglomerates were deposited.

In order to better clarify the chronological frame of the II order palaeosurface and its correlative deposits of Nocella Formation we summarize the whole geomorphological evolution of the Sorrento peninsula.

The oldest geomorphological stage is recorded by the formation of the I order palaeosurface (Fig.9-I) There follows a phase of block-faulting driven by NE-SW direction of extension led to the fragmentation of this landscape, well documented by the structural analysis carried out on the Scraio Vettica fault (Fig. 9-II; Caiazzo *et al*., 2000). After the Early Pleistocene activity, the II order palaeosurface developed with a base–level ranging between 600 – 750 m a.s.l.(Fig. 9-III). As reported by Caiazzo *et al*., 2000 part of the Scraio Vettica fault zone was reactivated during Early Pleistocene – Middle Pleistocene p.p. and driven by NW-SE direction of extension; the only southern segment coinciding with the present structural sea-cliff between Positano and Vettica towns moved during this more recent phase. After the Early Pleistocene – Middle Pleistocene p.p. tectonic phase, the relics of the II order landscape were suspended, the Nocella fm. and the Paipo breccias were truncated, and, seemingly, whole portions of the II order landscape (southern portions of the area) which had to represent the source area of these clastic units, were definitively drowned (Fig. 9-IV). As a consequence, the age of the II order palaelandscape should be Early Pleistocene.

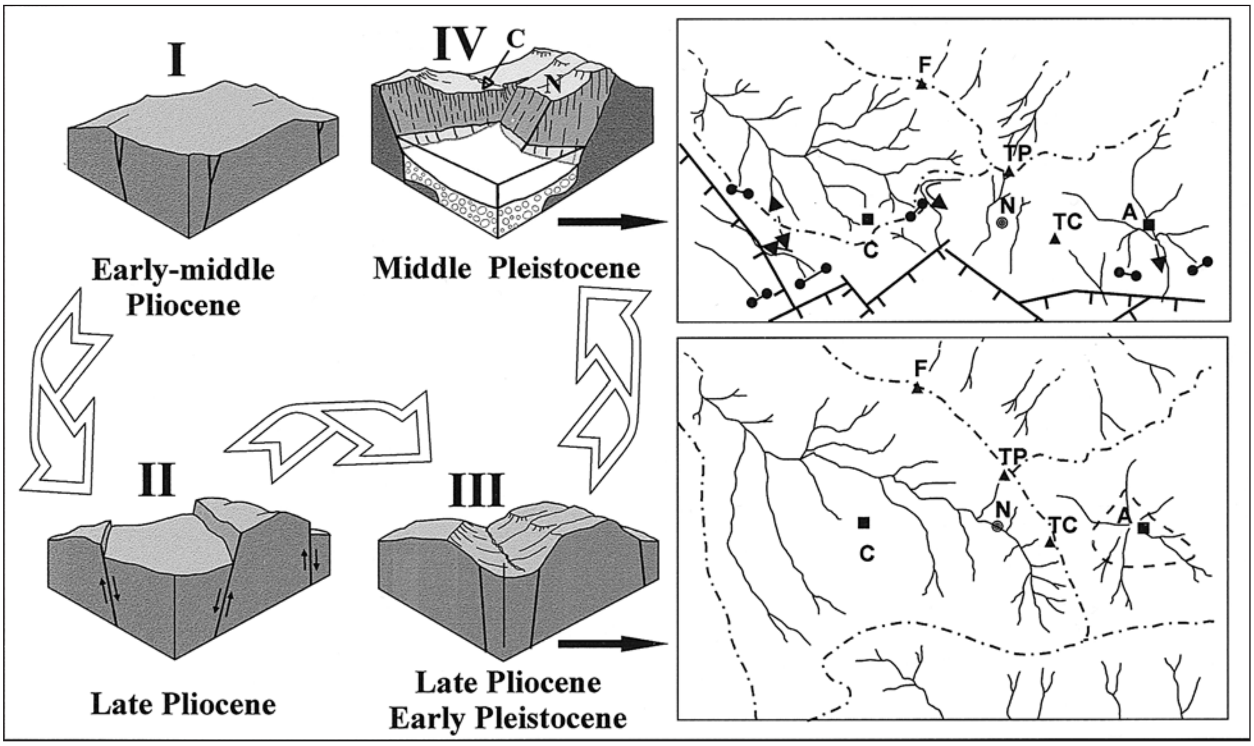

Fig. 9 - Main stages of the morphotectonic and the drainage evolution of the study area. C marks S.Maria al Castello; **N** marks Nocella site; **F** marks Mt. Faito; **TP** marks S. Angelo a tre Pizzi; **TC** marks Mt. Tre Calli; A marks Agerola; I, II, III; IV modified from Caiazzo et al. (2000); ●——● : beheaded valley; ◄– – –► : relic valley; ——► : river capture.

*Principali tappe dell'evoluzione morfotettonica e del reticolo idrografico. Le lettere **C**, **N**, **F**, **TP**, **TC**, **A**, indicano rispettivamente le località di S.Maria al Castello, il sito studiato di Nocella, M. Faito, M. S. Angelo a tre Pizzi, M. Tre Calli ed Agerola. I, II, III e IV modificate da Caiazzo et al. (2000); ●——●: valli tronche; ◄– – –► : valli relitte; ——► ; catture fluviali.*

5. CONCLUSION

We have reconstructed the Early Pleistocene palaeolandscape of a portion of the eastern Sorrento Peninsula by detailed geomorphologic survey and sedimentological analysis of the Nocella Formation.

On the basis of our data this hanging succession, previously interpreted as entirely composed of slope breccias, consists of a basal portion (about 90m thick) of alluvial deposits (Nocella Conglomerates), overlain by stratified slope deposits (Nocella breccias). The Nocella Conglomerates can be referred to the geomorphologic stage immediately successive to the tectonic fragmentation of the I order palaeosurface (Pliocene - Early Pleistocene in age), which is the oldest geomorphologic element of this region (Fig. 9). At that time the block-faulting caused the deepening and widening of the Gulf of Salerno and allowed the Sorrento peninsula to be further uplifted; in the meanwhile the width of the peninsula itself was progressively reduced and the Agerola tectonic depression was created. During this period the peninsula was towards the South still wider and lower in elevation than today. Subsequently a period of relative tectonic stability occurred and a new generation of low relief landscape (II Order Palaeosurface) was formed. Uplifted remnants of the II Order palaeosurface occur in several places at elevations from 500 m to 800 m (Fig. 2). In fact the Agerola graben, whose southern rim at present is open towards the South, by that time was entirely closed and received clastic imputs also from the southern reliefs. These ones had to include also the mountainous area into which a small river catchment had to be nested and fed the clastic infilling of Nocella palaeovalley; the sedimentologic analysis of the Nocella Conglomerates also suggests a source area which extended for some Km to the South-East. The palaeovalley had to be flanked by Mt. Tre Calli to the North-East and some other reliefs of similar height (higher than about 800m in any case) to the South-West. These reliefs were part of morphostructural high which close towards the South and fed the alluvial clastic infilling of the Agerola depression. Furthermore, the S. Maria del Castello II order surface has been interpreted as the basinward portion of the low gradient paleoslope on which the Nocella river was flowing. Other small hanging concave up footslopes (erosional landforms beside Moiano, Ticciano and Massaquano settlements), have been interpreted as erosional and depositional landforms connecting the Scrajo-Vettica fault scarp to the Nocella river valley.

After the development of the the II Order Palaeosurfaces, the study area was affected by a tectonic phase driven by a NW-trending direction of extension which allow NE- trending fault scarps to be formed (Caiazzo *et al.*, 2000). According to the Authors this tectonic event may be ascribed to the beginning of the middle Pleistocene. Furthermore, the southern segment of the Scrajo-Vettica fault zone was reactivated as transfer fault. The peninsula was progressively reduced by block faulting that affected its southern flank which enlarged the contiguous Gulf of Salerno and drawing the present-day coastal profile.

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