



Geological context of lithic industries in Delia- FiumeGrande valley, Santa Ninfa (TP): Hypothetic early human population in Sicily?

Sandro Caracausi

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Sandro Caracausi

- DOCTORAL THESIS

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DOCTORAL THESIS

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UNIVERSITÀ
DEGLI STUDI
DI FERRARA
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IPHES

Institut Català de Paleoecologia
Humana i Evolució Social



UNIVERSITAT
ROVIRA I VIRGILI

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2018



UNIVERSITAT ROVIRA I VIRGLI

Tarragona, 15 de març de 2018

El sotasignat, Robert Sala Ramos, acredita que el present treball de recerca, titulat “Geological context of lithic industries in Delia-FiumeGrande valley, Santa Ninfa (TP): Hypothetic early human population in Sicily” presentat per Sandro Caracausi per obtenir el títol de Doctor dins del programa Erasmus Mundus en Quaternari i Prehistòria, ha estat realitzat sota la meva direcció al Departament d’Història i Història de l’Art de la URV i als laboratoris de l’IPHES, en codirecció amb la Dra. Marta Arzarello del Departament d’Humanitats de la Universitat de Ferrara. Aquesta tesi compleix tots els requisits per a ser defensada i obtenir el corresponent títol amb menció Europea.

Robert Sala Ramos

A handwritten signature in blue ink, which appears to be "Robert Sala Ramos", is written over the printed name. The signature is fluid and cursive, with a long horizontal stroke at the end.

Co-director de la tesi

Geological context of lithic industries in Delia- FiumeGrande valley, Santa Ninfa (TP):
Hypothetic early human population in Sicily?
Sandro Caracausi



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Ferrara, February 26th, 2018

I STATE that the present study, entitled “Geological context of lithic industries in Delia-FiumeGrande valley, Santa Ninfa (TP): Hypothetic early human population in Sicily?” presented by Sandro Caracausi for the award of the degree of Doctor, has been carried out under my supervision at the Department of Humanities of the University of Ferrara, and at the IPHES of the Universitat Rovira I Virgili. The thesis fulfils all the requirements to be eligible for the European Doctorate Award.

Doctoral Thesis Supervisor



Prof. Marta Arzarello

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ABSTRACT

The early human peopling in Sicily is one of the most debated topics in archaeology and anthropology (Sineo et al., 2015) since the discovery of lithic industries attributed to the Lower-Middle Palaeolithic in Sicily reported from the western (Trapanese and southern coast areas) to the eastern (Simeto Valley) part of the Sicily. In the Fiume-Grande/Delia Valley (Western Southern Sicily, Trapani District, Italy) this early peopling is known since the 1980s. Although if, to date, the lithic industries found in this region come from surface sampling, typical Middle Palaeolithic knapping methods has been identified (especially Levallois, but also discoid and SSDA).

The principal objective of this thesis is to fill the geological gap concerning the relationship between the lithic artefact found in this region and the territory; through the application of a multidisciplinary study (field activities, sedimentology, petrography and paleontology).

The research was carried out using different geological approaches: mapping geology, sedimentary analysis and petrographic analysis. Geological surveys were undertaken in order to identify lithologies, their stratigraphic relationships, and to characterize the geomorphology of the area. Sedimentological graphic log and facies analysis (Miall facies scheme) were used to describe fluvial morphological facies. GIS software (QGIS) were used to analysis the spatial elevation of the hillslopes along the river catchment and to distinguish the morphologic discontinuity of the fluvial terrace.

The sedimentological analysis was carried out following a standard method for the field sampling. 414 pebbles from seven sampling sites were collected and analysed: morphometric indexes (flatness, sphericity, roundness, oblate- prolate), analysis of the shape of the

sedimentary particles with Sneed and Folk ternary diagrams in order to distinguish fluvial or marine paleoenvironment. The petrographic study was aimed to recognize the petrographic characteristics of collected samples in order to understand the relationship between deposit, environment and its formation. Finally, the palaeontological analysis of *P. mnaidriensis* FC assemblage was carried out to understand the age of the deposit and the possible terraces.

Extensive field mapping (1:10000 scale), detailed sedimentological and petrographical analyses of outcropping sections processing have shown that a complex stratigraphic organisation characterised the studied successions. Results have allowed to recognise stratigraphic units controlled by tectonic, climatic, and environmental processes. The comparison, between the orders of fluvial terrace and global eustatic variations, shows an association of three high levels of sea events with formation of fluvial terraces.

Finally, this research covered different research fields, allowing to collect useful information for the contextualisation of the lithic industries found in the Grande\Delia river valley from a geological point of view. The sedimentological, petrographic, palaeontological and survey analysis on the territory highlight the possibility of a favourable environment for human presence in the valley during the Late-Middle Pleistocene, with a rapid transition from marine to the continental environment and formation of fluvial terraces.

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Summary

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INTRODUCTION

Aims of the PhD

This PhD project aims to develop a multidisciplinary study for a geological characterisation of Fiume-Grande\Delia valley, taking into account the stratigraphic and chronological context. The primary objectives are making a geological field survey and mapping sedimentary successions outcrops where we can probably find lithic artefacts by probable early human groups in Sicily. Early human population in Sicily is one of the debated topics of archaeological and anthropological discussion since the 20th century (Biddittu and Piperno, 1972; Segre et al., 1982; Chilardi et al., 1996; Zampetti et al., 2000; D'Amore et al., 2010; Sineo et al., 2015). In this context, the importance of the project is finalised to fill a gap in the field of Sicilian Lower and Middle Paleolithic anthropological\geological data because of limited direct archaeological data, related only to the Upper Paleolithic. Actually, the only records concerning the presence of early human populations are surface collections of lithic pieces, without any geochronological data and are also very sporadic. The objectives are, thus, to identify, describe, date rock outcrops, making a hypothesis about their evolution and the association between lithic findings and paleontological evidence (endemic faunas). Finding more detailed data on lithic industries can allow us to produce a first hypothetical early human population in Sicily.

Geological context of lithic industries in Delia- FiumeGrande valley, Santa Ninfa (TP):
Hypothetic early human population in Sicily?
Sandro Caracausi

1 Previous Studies and problematics

The centrality of Sicily in the Mediterranean basin and its closeness to the Italian Peninsula and northern Africa, at least during low stand sea level episodes, may indicate an important role in such early colonisation (Villa, 2001; Santonja and Villa, 2006). For this reason, the Sicily has been considered an open land of passage for an early human peopling coming from Africa into Europe (Alimen, 1975; Balter, 2001; Bar-Yosef and Belfer-Cohen, 2001; O'Regan et al., 2006; 2011). Nevertheless, numerous questions still opened and unsolved are a matter of discussion among palaeontologists and anthropologists (Bonfiglio and Burgio, 1992; Bonfiglio and Insacco, 1992; Tusa, 1999; Palombo, 2017). The possibility of Plio-Pleistocene dispersals between Africa and Europe across the Strait of Gibraltar and Sicily received much attention in the debate on human dispersal out of Africa (Collina-Girard, 2001; O'Regan et al., 2011; van der Made, 2011). Pleistocene climatic history may be characterised as a general cooling trend towards the present day, interrupted by stepped changes and periods of increasingly intense glacial cycles and During of low sea level periods (Shackleton et al., 1984; Agnesi et al., 2000). Hominids and modern humans could probably cross from Morocco to Spain, from Tunisia to Sicily (Flemming, 2012). Villa (2001) has shown that Middle Pleistocene settlement of Italy came from the north, not via Sicily because there is no Acheulian cultural material. Moreover when human colonisation occurred and how many times the migration event happened (Derricourt, 2005)?. The debate on the first human population in Sicily has long been focused on two crucial points. The studies of Vaufrey (Vaufrey, 1928; 1929) and the problems of pebbles lithic industries found by Bianchini (Bianchini, 1969; Peretto, 2006; Lopez, 2014) have effectively limited the development of studies on the Lower Paleolithic in Sicily. Vaufrey (1929) refused the existence of a connection between Africa and Sicily because of the bathymetric maps of Sicily, Malta and Northern Africa coasts at high depths. Secondly, the archaeological and paleontological data common shared fauna between Sicily and Malta. Magri (Magri, 2006) shows that the submarine ridge between Ragusa Platform and Maltese

archipelago was an epicontinental land bridge during the Pleistocene and facilitated the migration both northwards and southwards of exotic fauna. Unfortunately, the sea level had to lower to a too greater extent to permit the existence of such intercontinental land-bridge. For what concern the fauna, Vaufrey argued that Sicilian and Maltese elephants be different with no common forerunner. Finally, during his surveys in Sicily, Vaufrey did not recover any artefact either in deposits or on the ground surface that could belong to a lithic culture earlier than the Upper Palaeolithic (Vaufrey, 1928). In response, Alimen (1975) analysed bathymetric map that sea level lowering occurred during glaciations showing in a greatly reduce the distance between Africa and Sicily during Early Pleistocene. The combination of archaeological data and climatic changes permitting the existence of an intermittent land bridge on the Western edge of the Pelagian region and Shackleton et al. (1984) argued in particular that during the last glaciation acme sea level drowned of about -120 meters. The distance between Cape Bon and South-Western Sicily was reduced at about 60 Km and the distance while a narrow land bridge could have been formed in Messina Strait area (whose depth is about 90 Km). Moreover, even Maltese islands whose distance from the Sicilian coast is about 90 Km could have been connected by another land bridge (Villa, 2001). Even though the proximity of Sicily to the African coast during Late Pleistocene is confidently attested, cultural exchanges between Sicilian and African peoples are not considered possible by (Zampetti et al., 2000). Nevertheless, several authors (Rolland, 1992; Carto et al., 2009; O'Regan et al., 2011) does not exclude the possibility of human exchanges during Pleistocene between the Iberian Peninsula and the Maghreb through Gibraltar Strait and north to sud migration in Mediterranean basin. Unfortunately, the equation glaciation means sea is lowering and may appear too simplistic as involved forces are many (Van Andel, 1989; Mayewski et al., 2004). Moreover, Holocene and Late Pleistocene palaeogeographic data have to be used with much caution to infer land configurations during older periods as the geodynamic was very active in Western Mediterranean area (Monaco and Tortorici, 2000; Corti et al., 2006; Carminati et al., 2012;

Barreca et al., 2014). The South Western of Sicily is characterised by Quaternary marine deposits consisting of bioclastic limestone sands and gravels passing laterally and vertically through calcarenite and calcirudite (Ruggieri et al., 1975; D'Angelo and Vernuccio, 1994; 1996). These lands cover in contrast the Formation Marnoso-Arenacea of the Valle del Belice (Ruggieri and Unti, 1974), consisting of a sequence of lime-quaternary terrigenous (sandstone and limestone with clay interlaying). In-depth, after the pelagic calcilutites marly deposits of the Lower Pliocene (Trubi), follow the lands of the Messinian evaporitic succession (evaporitic limestone and chalks), resting in discordance on the conglomerate and/or sandy and clay marly deposits of the Formation Cozzo Terravecchia (Basilone, 2012). The lithological units described above are cut out from Quaternary marine and fluvial terraces, sometimes with deposits of sands, gravel and limestone placed in various orders (D'Angelo and Vernuccio, 1996; D'Angelo et al., 2001). as regards the discovery of lithic industries of the Lower-Middle Paleolithic in Sicily there are various reports from western (Trapanese and southern coast areas) to eastern (Simeto Valley) part of the island (Lo Vetro and Martini, 2012; Lopez, 2014). The Authors who have faced on the Sicilian Paleolithic accept the fact that the oldest human population of the island has happened to the Culture of the Pebble with one or more facies (Biddittu and Piperno, 1972; Segre et al., 1982; Venezia and Lentini, 1994; Accardo, 1997; Piperno, 1997; Lo Vetro and Martini, 2012; 2016; Forgia et al., 2014; Sineo et al., 2015). In this context, the association of the lithic industries from the Grande\Delia River Valley is included. The Lithic association (Figure 1.1-1; Figure 1.1-2) is briefly described in this work both for the high number of finds (around over 1300 pieces, many of which are geofacts) and for the different types of instruments found over the years (cores, flakes, chopper tools) and for the different techniques used for the production (Levallois, Kombewa, SSDA, unipolar s.l.) which, given its diversity, must be studied in further research.

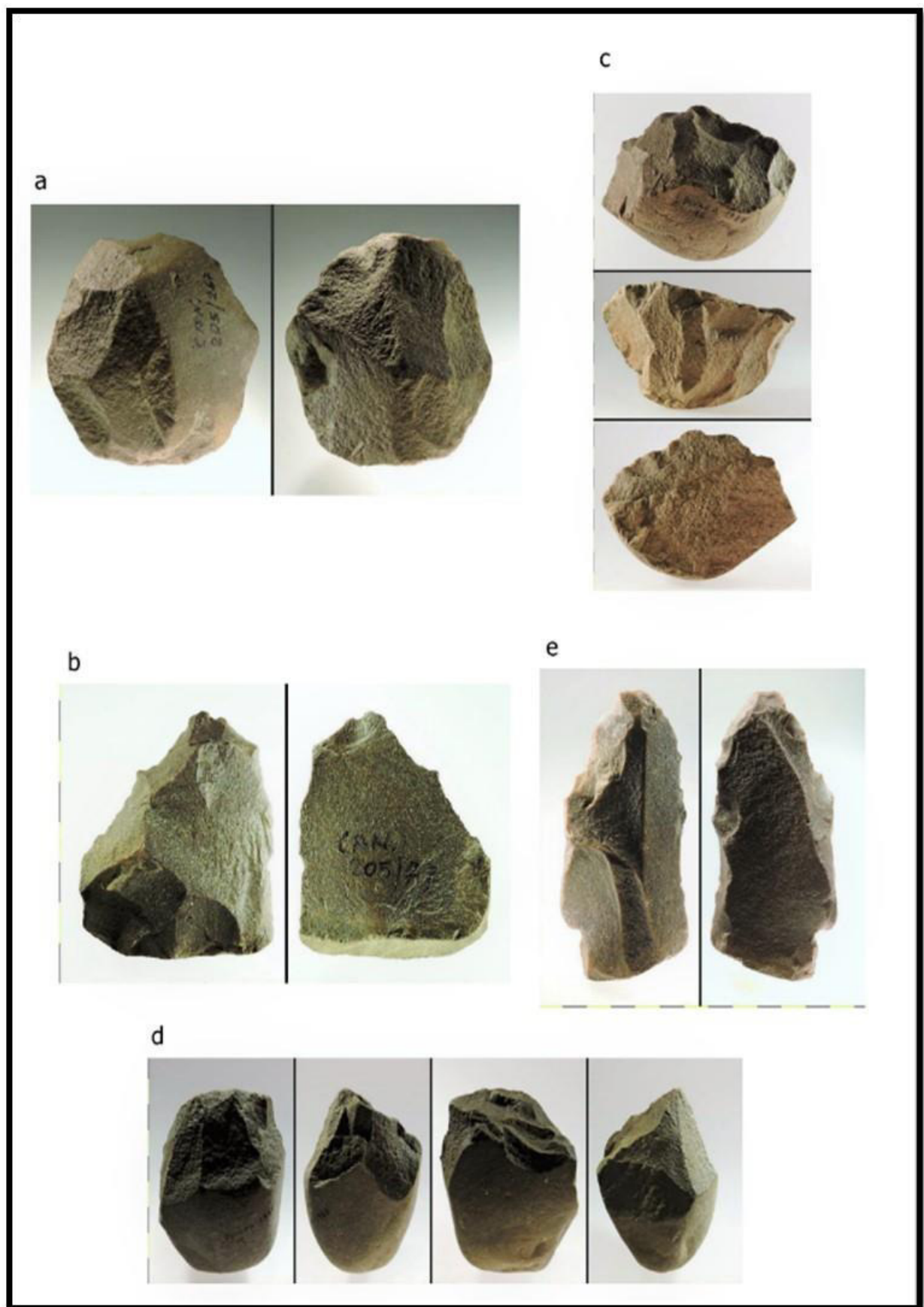


Figure 1.1-1: Lithic tools from Grande\Delia River basin: a) disk core; c-d) unipolar core; b-e) Flake. Photos modified from Lopez (2014)

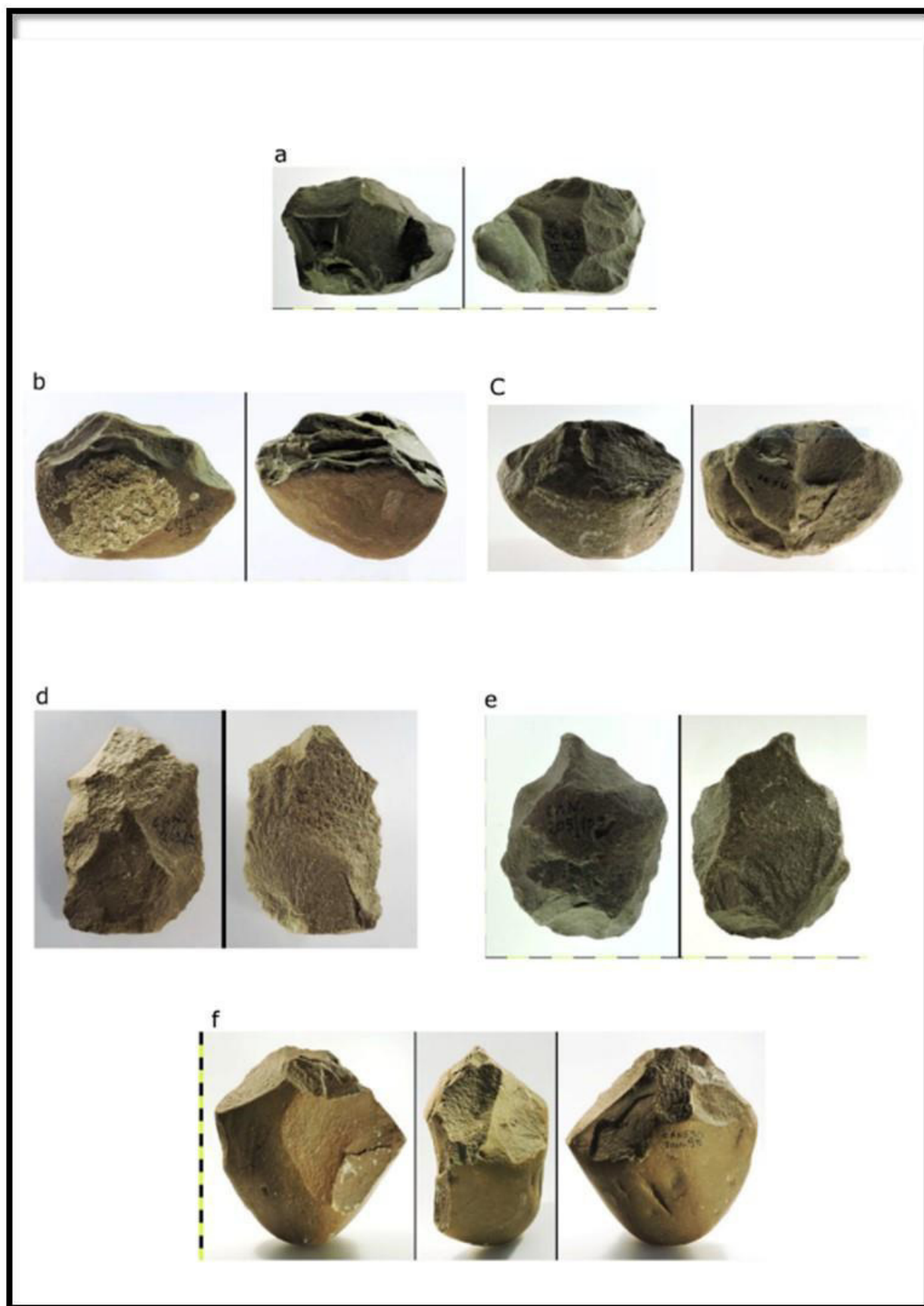


Figure 1.1-2: Lithic tools from Grande\Delia River basin: a) SSDA core; b-c-3) chopper core; d) Levallois flake; e) Unipolar core. Photos modified from Lopez (2014)

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1.1 Sicilian Geology Framework

For a better geological understanding of the study area of this doctoral thesis, it is necessary to have a clear understanding of the geological phenomena that have transformed the territory under investigation, from its formation to the current geo-morphological conformation. The geology of Sicily (Figure 1.1-1) consists mainly of three structural units as a result of the convergent tectonics. The structural Units have their current position after the collision between European and African plates from early Miocene to early Pliocene (Catalano et al., 2002; 2013b; 2017; Sulli et al., 2004).

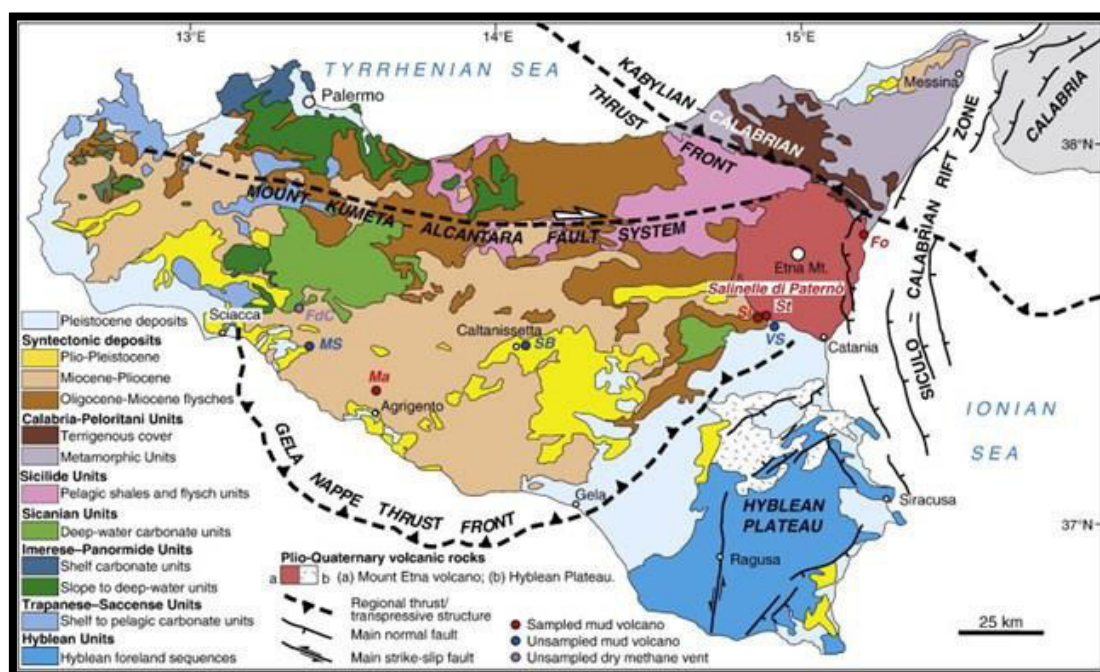


Figure 1.1-1: Geological map of Sicily from Catalano et al. 2002

Sicily, in fact, is located in Central-Western Mediterranean sea and is a portion of the Alpine system that develops along the plaque border between Africa and Europe and with the Sicilian mountain system. It connects the Maghrebidi (African mountain ranges) with the Southern Apennines, through the accretion wedge of Calabria. The chain, with its submerged extension, extends from the Sardinian bloc through Sicily to the Ionian-Pelagian sector and partly in the central-south Tyrrhenian Sea (Catalano et al., 2013a). The Sicilian deposits are essential of

marine type (Platform, Scarpata, Basin), with the succession of geological formations that reflect the different sedimentary environments. These successions are covered by different orogenic phases which started about 6 Ma (Oligocene sup-Miocene) and which led Sicily to structure itself in chains mountainous and mountainous areas emerged in Pleistocene, about 1 Ma (Agnesi, 2004; Di Maggio et al., 2009). Of the three structural units, the Hyblean carbonate plateau, which acted as a foreland region, occupies the southeast area of the island; central and central-western regions consist mainly of terrigenous sediments, there is a succession of tectonic units with varying palaeogeographic settings and rock associations. Carbonate units are prevalent in the western area (Palermo mountains) while metamorphic rocks and terrigenous sediments predominate in the eastern zone (Nebrodi and Peloritani mountains). Various Authors (Nigro et al., 2010; Napoli et al., 2012; Catalano et al., 2013a; 2013b; Morticelli et al., 2015) have described the ages of the orogenic construction of the Sicilian chain after the initial Alpine orogenic movements. Also, the most important compressive movements of this Mediterranean sector are to be connected to the counterclockwise rotation of the Sardo-Corso block within the framework of the evolution of the Apennine orogen (Vitale and Ciarcia, 2013). From the upper Oligocene, the orogenic construction started with the accretion of the Calabria-Peloritani wedge, and the deposition of flysch (e.g., Numidian flysch) in foreland basins. In this context, a Miocene contractional deformation originally produced the progressive detachment of the Sicilidi units and Numidian flysch cover and their stacking over deep water carbonates Imerese units (Rosenbaum et al., 2002; Rosenbaum and Lister, 2004; Puglisi, 2014). During Early–Middle Miocene the deformation first tectonic event covers the internal zone At the same time, the first wedge-top basins developed in their turn over Sicanian units and shallow water carbonates Panormide, Trapanese, and Saccense units (Accaino et al., 2011; Catalano et al., 2013a). From Late Miocene, a second tectonic event characterised by deep-seated transpressive deformation occurred, and extension took place in the Tyrrhenian Sea as the shortening and thrusting in the arcuate Apennines–Sicily, east- and southward-directed orogens (Parotto and

Praturlon, 2004). Deposition of coeval foredeep and wedge-top sediments (Butler et al. 2015; Gasparo Morticelli et al. 2015) accompanied the former event of shallow seated thrusting. The extensional deformation propagates towards the SE associated with the fast retreat and roll-back of the NW-dipping subduction of Adria–Ionian plate underneath Calabria (Lavecchia, 1988; Doglioni, 1991; Gueguen et al., 1998; Pepe et al., 2005). The rotation, which develops from upper Oligocene to lower Miocene, led to a collision of the Sardine-Corso block with the African continental margin, beginning, thus, Sicilian orogenesis. The structure of the tectonic building, emerging in Sicily, is largely originated from the deformation of the carbonate sequences, of the bacinal and Mesozoic carbonate platform placed on the edge of the African plaque. After the deposition of Mesozoic successions in Western Sicily and Eastern Sicily, terrigenous deposits of Serravalliano-Tortoniano emerge. Subsequently, during the Pliocene a deep-seated transpressive event deformed the innermost tectonic units stacked during the first Miocene event (Avellone et al. 2010) (Abate et al., 1991). Finally, a Plio–Pleistocene back-arc tectonics originates high-angle extensional faults affecting the northern coastal area of Sicily and southern Tyrrhenian Sea (Pepe et al., 2005; Corti et al., 2006)

These deposits are mainly clayey, and marly deposits, which cover the portions of the Mesozoic carbonatic sequences of the "Trapanese-Saccense" and Sicani during the lower Miocene or are found in discordance with the deformed sequences together with the layers of the Numidic Flysch (turbiditic clay-sandy deposits) that are formed within these basins. These terrigenous deposits are covered in discordance with polygenic yellow-reddish conglomerates, clay sandstone and marl of Terravecchia Formation (Tortoniano sup. -Messiniano inf.), while the Messinian Evaporites (Serie Gessosa solfifera) settle on an erosion surface that cuts through the underlying layers of Terravecchia Formation. The Messinian evaporitic succession is mainly eroded in the northern areas, while it appears extensively in the southern and eastern areas. On the roof, the chalky sulfide chalky series is covered in discordance with the well-known Trubi Formation, which is characterised by alternating levels of marl and limestone. Finally, an often

sedimentary wedge of mainly clastico carbonatic rocks covers the Trubi in both western Sicily and eastern Sicily. Sandy clay plots and low sea carbonates of Pliocene sup. -Pleistocene sup. finally cover the western and eastern areas, representing the end of the Sicilian orogenesis with the replacement of the current morphological structure (Figure 1.1-2).

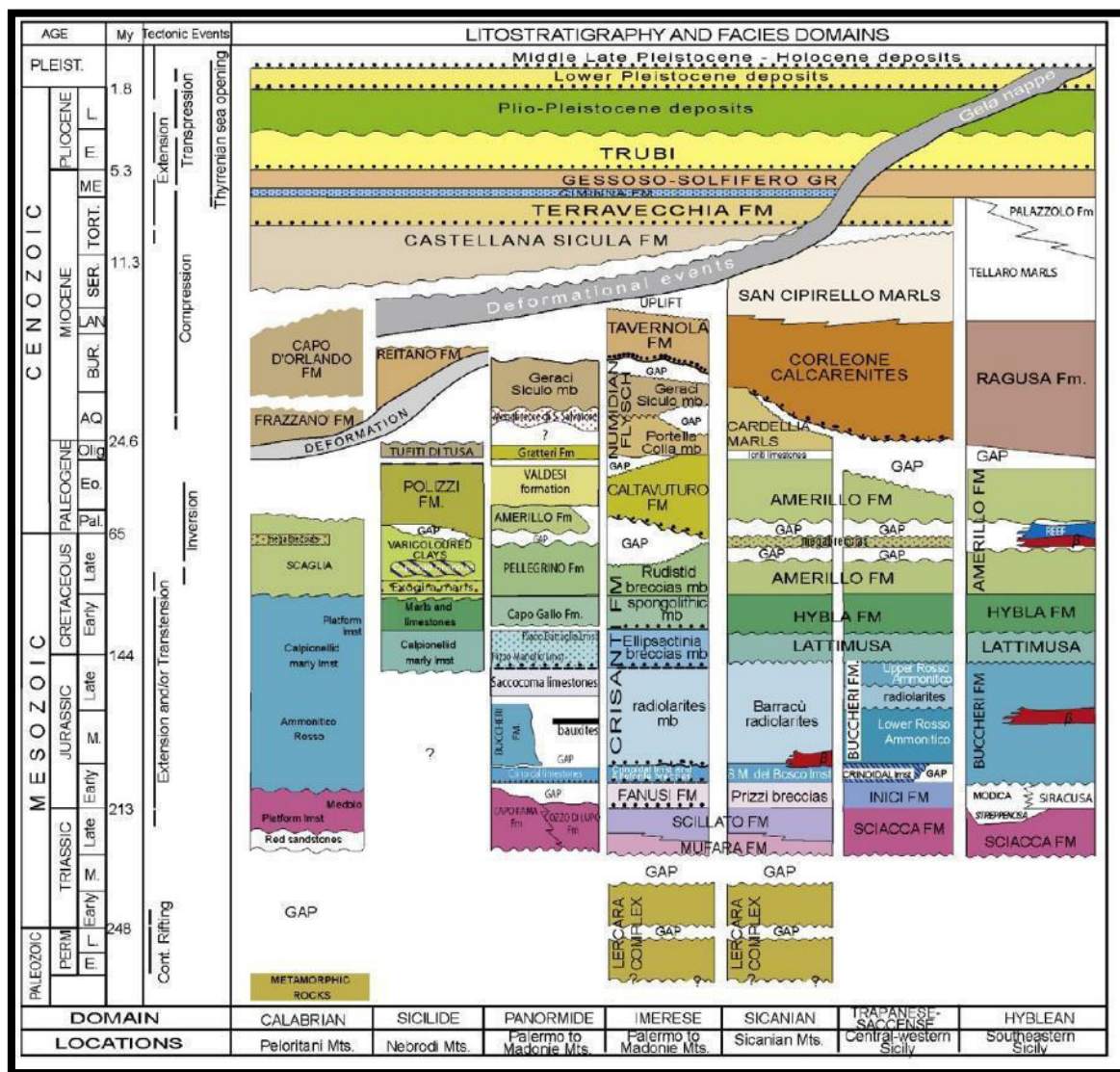


Figure 1.1-2: Stratigraphy and facies domains of Sicily (Accaino et al., 2011).

The stratigraphic architecture of western Sicily reflects the crustal differences highlighted by the seismic tomography as well as the subsidence history of the two sectors, which is remarkably different. Thick carbonate platform successions extend in the western sector (Hyblean-Pelagian structural units), while in the eastern zone deepwater sediments (Imerese-Sicanian structural units) have been accumulated in the Permian-Mesozoic and Tertiary. Moreover, the restored outline of the Mesozoic platform margins and slope aprons in Sciacca and Monti Sicani areas matches the crustal transition and accounts for the presence of a paleotectonic sheared zone that was reactivated several times either as transtensional or transpressional faults (Di Stefano et al., 2015).

1.2 Western Sicily

Western Sicily is part of the SE-verging Alpine orogenic belt in the central Mediterranean region and connects north-eastern Sicily, formed by a “European” element (Peloritani units), to the late Cenozoic Maghrebian chain. Tectonic evolution of western Sicily belt was a progressive accretion of thrust sheets (Catalano et al., 2002). This area is the emerged portion of a larger orogenic system (Figure 1.2-1) which developed in the central Mediterranean region as result of the Neogene-Quaternary Africa-Europe collision processes (Dewey et al., 1989; Ben-Avraham et al., 1990).

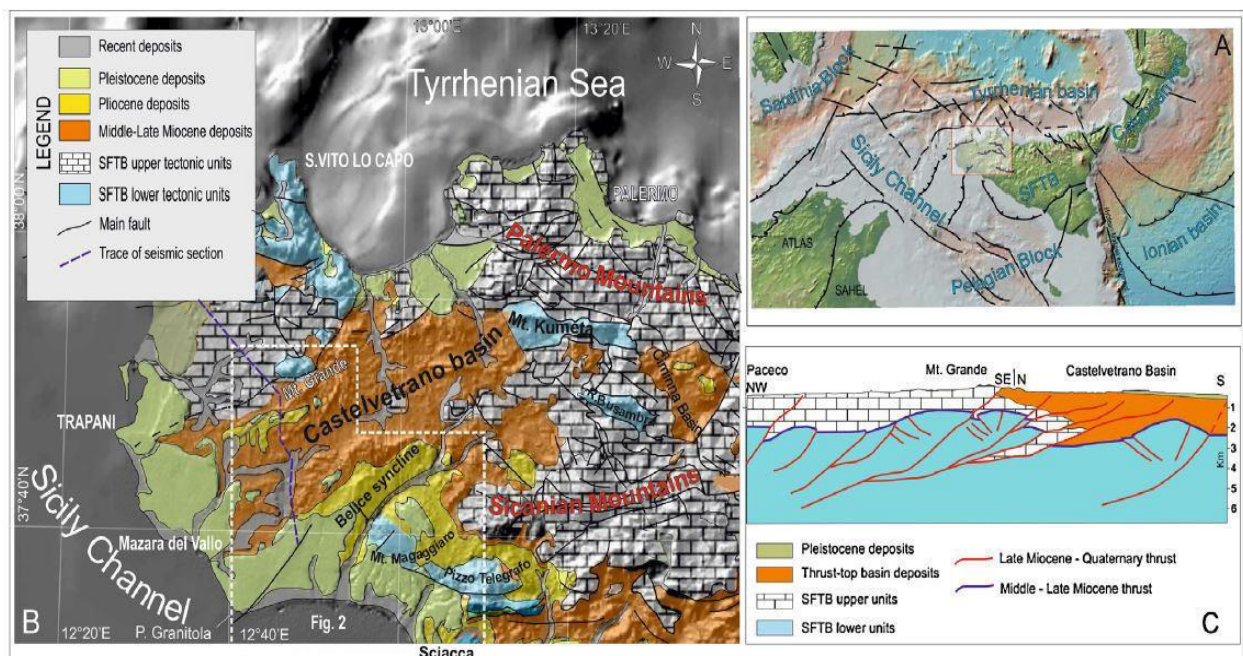


Figure 1.2-1: (A) Tectonic model of the Central Mediterranean. Lines represent the main Quaternary faults, lines with triangles represent the main thrusts. (B) Tectonic sketch map of western Sicily. (C) Geological cross-section (Barreca et al., 2014)

In this continental subduction collisional complex, several tectonic and stratigraphic elements are differentiated, and the structural architecture of the belt is imaged by deep seismic explorations (Catalano et al., 2002; 2013b; Accaino et al., 2011). The Western Sicily is an interesting area to investigate the collision between Europa and Africa (Abate et al., 1999; Nigro

and Renda, 2002; Di Stefano et al., 2015). A complex consisting of a SE-vergent fold and thrust belt, which is composed of a “Tethyan” element (Sicilidi units) and an African element (Sicilian units). The Sicilidi units are represented by repeated imbricate slice stack deriving from the deformation of Upper Jurassic–Oligocene basin carbonates and sandy mudstones located in the Sicilide facies domain (Morticelli et al., 2015). The Sicilian geological units are characterized by allochthonous tectonic units deriving from the deformation of Permian–Miocene deep-water carbonates and bedded cherts deposited in the Imerese and Sicanian basins (Basilone et al. 2014, 2016); and Mesozoic–Miocene shelf-to-pelagic carbonates located in the Panormide, Trapanese, Saccense, and Iblean-Pelagian carbonate platform or seamount facies domain. Upper Oligocene–middle Miocene turbiditic deposits (Numidian flysch) cover the Sicilide, Imerese, and Panormide rock successions. During lower–upper Miocene deformed foreland marls cover the Sicanian, Trapanese, and Saccense rock successions; Oligocene– Quaternary foreland open shelf carbonates cover the Iblean–Pelagian rock successions. A thick pack consisting of middle Miocene–Pleistocene foreland, wedge-top and foredeep basin deposits (terrigenous, evaporitic, and clastic carbonate rocks), which largely form the Gela Thrust System.

The main fold-thrust belt influences the relief of Sicily (Figure 1.2-2). An E–W mountain range (Sicilian Apennines) is its topographical expression. The sicilian Landscape is made by a continuous ridge in the northern region of Sicily, from Peloritani and Nebrodi to the Madonie and Palermo Mountains, locally interrupted by valley with North\Sud direction. These valley shows a primary line of drainage of rivers into the Tyrrhenian Sea of prin (Pollina, Imera Settentrionale, Torto, and San Leonardo rivers) (Nigro and Renda, 1999). In north-western and central-western areas the territory is formed by coastal plains and a set of rounded hills and broad valleys. In the western a quaternary tectonics shows a series of isolated reliefs from Trapani and Sicani Mountains breaks the physical continuity of the mountain range (Morticelli et al., 2015).



Figure 1.2-2: main geomorphological units of western Sicily (Di Maggio et al., 2017)

Mountain range and isolated peaks coincide with successions of “hard” and “resistant” rocks hundreds of metres thick (Mesozoic carbonate units)(Mauz et al., 1997), on which the highest relief lies; the deep, narrow or broad valleys and the set of rounded hills are situated on “weak” and easily erodible rocks (calclutites, marls, and clays of the Mesozoic basin units; Mio-Pliocene cover deposits).

The intense incision processes of these rivers produced deep V-shaped valleys with from medium to strongly inclined slopes, separated by usually sharp ridges. The valley bottoms become wide and flat only near the mouths along the discontinuous coastal plains (Agnesi et al., 2000; Agnesi, 2004).

Along, the larger distance between the mountain range and the southern coast enables the development of longer and slightly inclined rivers flowing from NNE to SSW (e.g., Belice, Platani, and Salso rivers) on a substrate of weak rocks (De Waele et al., 2017). The lower erosional power of these rivers has produced shallow valleys with gently inclined slopes and

flat or rounded bottoms, separated by low hills. The younger age of sicilian outcrop form a V-shaped valleys type only in the great catchment areas (Di Maggio et al., 2014b).

In the broad NW–SE coastal strip of the Sicilian Channel, the relief lowers gradually to a landscape of large plains, located in resistant Quaternary clastic rocks and cut by deep canyons with flat bottoms that become wider as they approach the mouth. Continental-to-marine Quaternary deposits outcrop in thin and patchly exposed successions in Sicily, overlying a previously deformed substrate, known as the Neogene-Early Quaternary chain.

1.3 Southern Western Sicily geomorphology Framework

The topography and geomorphology of Sicily is the result of constructive (tectonic) and destructive (erosional) forces following the collision between the African and European plates, which produced, among other things, the Sicilian Mountains chain (Tortorici et al., 2001; Parotto and Praturlon, 2004).

Since the first half of last century, several geomorphological studies have been performed and have undergone a boost in recent decades (Di Maggio et al., 2017). They deal with the reconstruction of the geomorphology of local areas (Mauz et al., 1997; Nigro and Renda, 1999) or specific thematic studies (Abate et al., 1991; Di Maggio et al., 1999; Ślącza et al., 2011; Chilardi et al., 2012; Stocchi et al., 2017). The geomorphological element that most characterises Southern Western of Sicily is undoubtedly constituted by the presence of very gentle "flat surface" (positioned at different heights) with sub-horizontal or weakly hanging towards the sea. Another side, the structural control on the action of morphological processes genetics is given by the presence of numerous derived structural forms, such as fault line embankments, structural control escarpments and inclined and bent structural surfaces (Basilone, 2018).

Based on successions of planation surfaces, erosion glacis on soft rocks and coastal terraces, developing between 1200 m a.s.l. and the present-day sea level The geomorphological processes that control the alternate between planation-abrasion surfaces are related to the trend of lowering the base level. (Di Maggio et al., 1999; Agnesi et al., 2000; Agnesi, 2004). Other geomorphological forms are marine terraces. In the coastline between Trapani and Marsala Ruggieri et al. (1968) found beach deposits containing *Strombus bubonius* between 2 and 5 m. Southeast, between Marsala and Mazara del Vallo, Ruggieri et al. (1975) published a geomorphological map containing a first-order terrace, the so-called "Grande Terrazzo Superiore" (GTS). The margin that reaches 150 m and covers large areal, this terrace cuts

Calcareniti di Marsala, Lower Pleistocene, Sicilian-Emilian stage (Ruggieri and Unti, 1974). Below an intermediate terrace of Middle Pleistocene age, this deposit is on a large terrace extending to the coast with an inner margin at 34 m above sea level (Antonioli et al., 2006). The morfoevolutive model of the studied area provides for a general tendency to develop the river, in response to the regional uplift that characterises most of the Sicilian areas. Uplift Trend produces time high energies of the survey that favouring the dismantling of the relief. Consequentially processes of intense denudation of the slopes that act selectively. For whole western Sicily, the geomorphological model shows numerous forms produced by river down-cutting characterised by strong erosional processes such as V-valleys and canyons. Recognized forms on the ground indicate that these processes have acted selectively, guided by the presence, in depth, between of alternating hard erosion-resistant and soft erodible rocks deposits (Agnesi et al., 2000). Besides, river down-cutting and development of “terraced surfaces” indicate a gradual lowering trend in the general base level of erosion (Agnesi et al., 2000; Di Maggio et al., 2017). Recently (Di Maggio et al., 2017). In the southwestern area, the action of an uplifted trend showing a develops of marine terraces ubicate at 450 m a.s.l. (Figure 1.3-1) (Vitale, 1990; Di Stefano et al., 2013) (Figure 1.3-1).

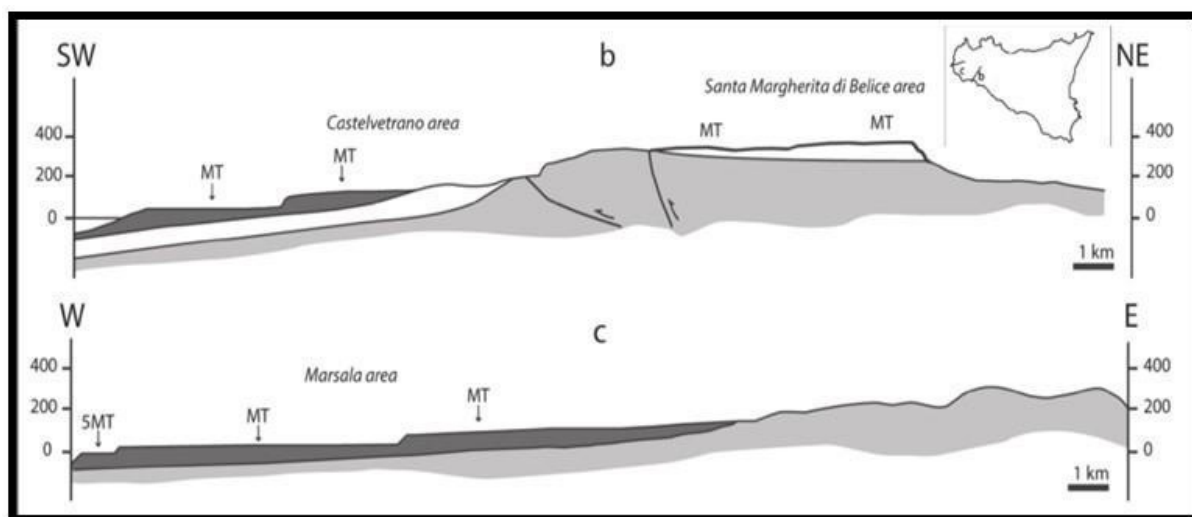


Figure 1.3-1: 5MT MIS 5.5 marine terrace; MT marine terrace, in the square the location of c-b cross section (Di Maggio et al., 2017).

In these areas, Marsala – Castelvetro – Sciacca area, the landscape is dominated by geomorphological process occurs to the marine terrace. The marine terraces are very well preserved and showing an extensive polycyclic coastal platform. In the internal areas (e.g. Salemi) the oldest marine terrace and the landscape shows marine terrace dissected by river valleys and become fragmented and some cycles of river terraces or erosion glacis are present in the valley slopes (Bommarito, 1981).

Marine terraces landscape shows the timing of marine terraces formation. In fact, landscape shows a relationship between the oldest and highest marine terraces carved in Calabrian clastic and younger marine terraces. As a result, the new erosive surface postdates the formation of the terraces to marine during at highstand sea level of the late Calabrian–Late Pleistocene (Ruggieri et al., 1968; Ruggieri and Unti, 1974; Di Maggio et al., 2014a).

Finally, as regards the geomorphological history of Sicily is controlled by tectonic and climate change elements. The modelling of Sicily through geomorphological processes can be summarised in some phases (Di Maggio et al., 2017). At beginner deep-water marly carbonates of the Trubi unit testify that western Sicily was still submerged mainly by the sea up to lower Pliocene (3.6 Ma). After this, marine clastic deposits indicate that the emersion of the southern areas of western Sicily, after the post-Santernian (1.5 Ma). Another side, the deposition of a group of sediments of shallow-water clastic deposits and their relationships with geological bedrock show that the areas of the northern side were above the surface in the pre-Emilian (before 1.5 Ma) but submerged during the Emilian–Sicilian interval (1.5 – 0.8 Ma ago). Following this the Sicily is again outcrops from the Sicilian stage (after 0.8 Ma ago). Finally, the emersion of the older areas of central and northern Sicily with the beginning of the first relief modelling processes occurred between 3.6 –1.5 Ma ago.

1.4 Fluvial Terraces

A river terrace is a flat surface bounded by sloping surfaces on the upslope and downslope sides, and its formation first requires the aggradation of channel and floodplain sediments, followed by a vertical incision in floor sediments or the bedrock (Stokes et al., 2008; 2012; Vandenberghe, 2008; Giano and Giannandrea, 2014).

River terraces can be distinguished into two categories: depositional\fill and erosional\strath terraces (Figure 1.4-1). The depositional terraces are made up of alluvial deposits carved and eroded laterally. Erosional terraces can be formed both by erosion of river deposits and impressed into rock (Wegmann and Pazzaglia, 2002; Pazzaglia, 2013).

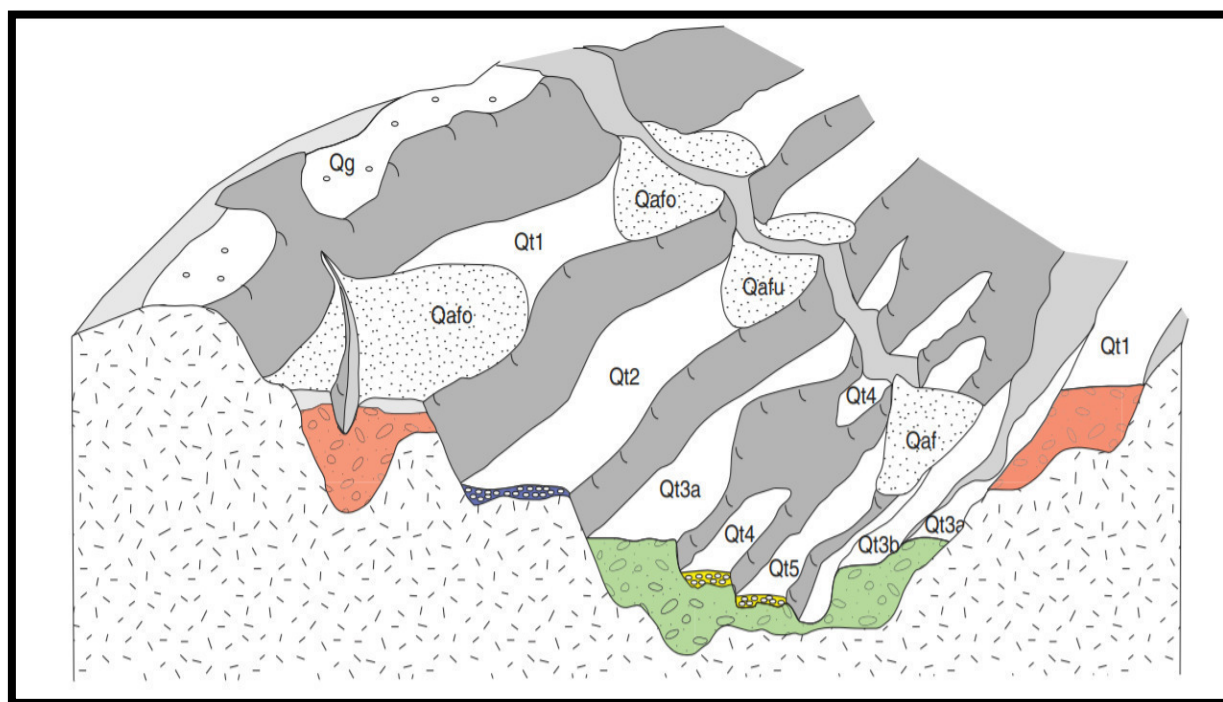


Figure 1.4-1: The diagram shows a different typology of Terraces: paired and unpaired fill, fill-cut, and strath terraces and Alluvial Fan (Qa). the numbering of the Terraces begins with the oldest ones. Numbers correspond to straths or former valley bottoms. Letters denote multiple treads being shared by one strath. Non-stratified upland but out of the context of the river valley (Qg). Paired filled terraces (Qt1-Qt3a). Unpaired strath terrace (Qt2). Fill-cut terrace (Qt3b). Unpaired strath terraces cut into alluvium (Qt4-Qt5). From Pazzaglia 2013

The strath terraces on the rock are always of erosional origin, and they are formed after the lateral erosion by the fluvial stream, along with the sides of the valleys in rock, led to the countersinking of a V valley (Pazzaglia, 2013). Another phenomenon of the erosional process that are generated terraced levels entirely made up to rock in place during polycycles downcutting of the river bed and subsequent lateral erosion of the banks. Lateral erosion is the dominant process constructing the tread, with flood scouring as the channel migrates laterally (Merritts et al., 1994a).

In the case of terraces formed by alluvial deposits, erosional terraces are called tread carved on contemporary deposits. Subsequent filling steps can lead to the formation of new depositional terraces in contact with older deposits. For both rock terraces and tread carved on deposits, erosion may act asymmetrically along the two sides, eroding a terrace shelf on one side and keeping it on the opposite side, producing unpaired terraces (Merritts et al., 1994a; Pazzaglia et al., 1998). Bedrock is any substrate into which the river valley is being developed and covered with a layer of gravel, cobbles, and boulders sediments that can make the distinction between bedrock and fluvial deposits are difficult to distinguish (Duvall et al., 2004; Pazzaglia, 2013).

A fill terrace differs from bedrock\strath terrace by a thick alluvial deposit. Also, in fill terrace, the thickness is less than 5 metres and to cover the river valley bottom. The base of a depositional terrace can be sub-horizontal like a strath, or it can also have unconformities and other features common to buried topography with high local relief (Bull, 1990; Pazzaglia, 2013). A result of fill terrace is the presence of valley buried. In the fill terrace, the valley buried has an irregular basal contact in its centre and more planar basal contacts with the valley walls on its flanks. In cross-section, the terrace and valley buried system shows shape looks like a valley with wings (Wegmann and Pazzaglia, 2002). In contrast, the stretch terrace has some small thick alluvial deposits and do not represent syn-bedrock erosion and bedload transport. Also, alluvium represents a period of aggradation and the lifting of the river off of bedrock to become

a purely alluvial channel. The valley fill is preserved as a terrace when the channel ceases aggrading and once again seeks out its former elevation, resulting in a vertical downcutting of the alluvial deposits. These characteristics of the fill terrace have long been recognised to indicate rapid and profound environmental changes in a watershed (Merritts et al., 1994b; Winsemann et al., 2015)

A fill terrace facies model is characterised by typical meandering and braided stream textures and bedforms. The grain size of these deposits including coarse gravel, laterally-accreted sand and gravel longitudinal, transverse, and point bars, and vertically accreted splay deposits, lacustrine silt and clay, and overbank mud (Pazzaglia et al., 1998; Zaprowski et al., 2005; Miall, 2006).

The relationship between erosion, sedimentation and incision involves different results between Terraces and floodplains. Besides, during the formation of floodplains may be terraces in the making but need not necessarily be preserved following river incision. When preserved, the terraces are useful tools as geomorphic markers in the river valley because of the terraces present as elongated benches parallel to and above the river channel. Therefore, the terraces can be found at different altitudes and with geometrical relationships of difficult reading. For example, a high rate of erosion can result in the disappearance of a surface or an increase in the aggregation of hiding ancient terraces (Bull, 1990; Whipple et al., 2000; Brocard et al., 2003). The formation of river terraces is common estimate by three parameters: climate change, sea level variations and tectonic uplift. The impact of these parameters is extensively debated (Blum and Törnqvist, 2000; Bridgland, 2000a; Wegmann and Pazzaglia, 2009; Vandenberghe, 2015). River terrace sequences are being recognised increasingly as an essential source of evidence for Quaternary palaeoenvironments (Bridgland and Westaway, 2008). Besides, Quaternary is characterised by glacial and interglacial cycles (Raymo et al., 1998; Lisiecki and Raymo, 2007). Alternation of glacial and interglacial cycles with a change in astronomical cycles (Imbrie et

al., 1984; Lisiecki and Raymo, 2007) reflected on the evolution of terraces. During glacial periods are typically associated event of fluvial aggradation with intensive slope denudation and an increase of the sediment supply in the valley floor (Bridgland, 2000b; Bridgland and Westaway, 2008). In contrast, at interglacial periods are associated events of vertical incision of the floodplain. As a result of the formation of terraces that are more concentrated, when an improvement of the vegetation cover reduced the sediment supply in the valley floor, in the initial transition from cold to warm conditions, or during a brief warm interstadial within a cold period (Vandenberghe, 2003; 2008; Pazzaglia, 2013).

The base level is a combination of eustasy and rock uplift with the former mostly lacking for more continental settings far from the coast. Climate refers not only to mean annual temperature and moisture, but also to precipitation intensity, seasonality, and inter-annual variability (Stokes et al., 2008; 2012). Glacioeustatic sea level fluctuation drive base level and produce river terrace in the lowland reach of fluvial valleys (Bridgland and Westaway, 2008). The climate change controls and leading to a single terrace. In contrast, the formation of multiple river terraces is necessary a base level with lowering trend (Bull, 1990; Stokes et al., 2012).

1.5 Paleontological framework

The earliest paleontological evidences of western Mediterranean islands records are not at all represented or covered by uncertainties. Such situation regards even the largest islands (Sicily and Sardinia) and is probably related to the low attraction exerted by those environments to hunter-gatherer populations (D'Amore et al., 2010; Mannino et al., 2011; Sineo et al., 2015).

Remains of Pleistocene land Vertebrates in Sicily, although traditionally associated with caves, identify environments that are very different and reproduce palaeogeographic conditions of Pleistocene. The uneven distribution of fossil sites in different parts of the island is also determined by the associated diversity of lithologies (Bonfiglio and Burgio, 1992; Bonfiglio et al., 2000; Palombo, 2017).

Fossil documentation of Quaternary Vertebrates in Sicily is not evenly distributed in time. A trend is evident towards a richer fossil record from Early Pleistocene to Late Glacial, fossils of the latter age being most widespread. Geographic distribution could be related to taphonomical factors and to effective differences in palaeogeography in the insular system which differ as regards their composition and the degree of endemism and correspond to diverse dispersal events of African and/or European provenance, controlled by filtering barriers of different intensities. Variation in palaeogeography caused by tectonics and glacial and eustatic marine cycles have controlled the processes and timing of Middle and Late Pleistocene Vertebrate faunal dispersion in Sicily, through temporary connections via Messina Strait and the Catanzaro isthmus (Southern Calabria) that played an important filter role in the colonization events of Sicily and Malta.

The continental record begins with the spotty remain of the third molar of a small sized mastodon of *Gomphotherium* in Early Burdigalian coastal calcarenites close to the village of Burgio near Agrigento (Checchia Rispoli, 1914; Kotsakis, 1986), the oldest Sicilian mammal assemblage is that from Gravitelli (Messina) (Bonfiglio et al., 2000; Marra, 2005). Gravitelli

fauna, which is not endemic, includes Eurasian and African taxa, e.g. the hippopotamus *Hexaprotodon*, and the bovid “*Gazella*” *deperdita* (Rook, 1999 Gallai and Rook, 2006 (Kotsakis, 1986). The assemblage was found in a lignite deposit overlain by the Messinian diatomite and gypsum marls of the Sicilian “Gessoso-Solfifera” Formation; it is therefore dated to the late Turolian. Rook et al. (2000) affirm that Gravitelli fauna attests to the existence of a Late Miocene Calabrian—Peloritan nonendemic palaeo-bioprovince, which is, however, still poorly defined. In Sicily, the true record begins during Early Pleistocene becoming consistent only from Middle Pleistocene. The succession of Quaternary mammalian population phases in Sicily is arranged in biochrons named as Faunal Complexes. Many authors (Bonfiglio et al., 2002; 2003; Palombo and Valli, 2003; Marra, 2005; Masini et al., 2013) proposed a division of the Pleistocene Vertebrate associations of Sicilia into five faunal complexes and the authors highlights has a low diversity yet includes strongly endemic (Figure 1.5-1).

"Monte Pellegrino"	"Elephas falconeri"	"Elephas mnaidriensis"	"Grotta S. Teodoro Pianetti"	"Castello"	Holocene
<i>Pannonictis arzilla</i>	<i>Vulpes</i> sp. <i>Nesolutra trinacriae</i>	<i>Panthera leo</i> <i>Crocota crocuta</i> cf. <i>spelaea</i>	<i>Crocota crocuta</i> cf. <i>spelaea</i> <i>Canis</i> cf. <i>lupus</i>	<i>Canis lupus</i> <i>Vulpes vulpes</i>	<i>Canis</i> cf. <i>lupus</i> <i>Vulpes vulpes</i>
<i>Asoriculus burgioi</i>			<i>Canis</i> cf. <i>lupus</i>		<i>Felis silvestris</i>
<i>Apodemus maximus</i>	<i>Elephas falconeri</i>	<i>Canis lupus</i>	<i>Vulpes vulpes</i>	<i>Equus caballus</i>	<i>Martes</i> sp.
<i>Leithia</i> sp.		<i>Nesolutra trinacriae</i>	<i>Ursus</i> cf. <i>arctos</i>	<i>Equus hydruntinus</i>	<i>Mustela</i> cf. <i>nivalis</i>
<i>Maltamys</i> cf. <i>gollcheri</i>	<i>Crocidura esuae</i>	<i>Ursus</i> cf. <i>arctos</i>		<i>Sus scrofa</i>	<i>Ursus</i> sp.
<i>Pellegrinia</i>	<i>Leithia cartei</i>		<i>Elephas mnaidriensis</i>	<i>Cervus elaphus</i>	<i>Monachus monachus</i>
<i>panormensis</i>	<i>Leithia melitensis</i>	<i>Elephas mnaidriensis</i>	<i>Sus scrofa</i>	<i>Bos primigenius</i>	
<i>Hypolagus</i> sp.	<i>Maltamys gollcheri</i>	<i>Sus scrofa</i>	<i>Equus hydruntinus</i>		<i>Sus scrofa</i>
	Bats, several species	<i>Hippopotamus pentlandi</i>	<i>Cervus elaphus siciliae</i>	<i>Erinaceus europaeus</i>	<i>Cervus</i> sp.
<i>Testudo graeca</i>		<i>Cervus elaphus siciliae</i>	<i>Bos primigenius siciliae</i>	<i>Crocidura</i> cf. <i>sicula</i>	<i>Bos primigenius</i>
	Birds	<i>Dama carburangelensis</i>		<i>Microtus (Terricola)</i>	
		<i>Bos primigenius siciliae</i>	<i>Erinacues</i> cf. <i>europaeus</i>	ex. gr. <i>savii</i>	<i>Erinaceus europaeus</i>
	<i>Emys orbicularis</i>	<i>Bison priscus siciliae</i>	<i>Crocidura</i> cf. <i>sicula</i>	<i>Apodemus</i> sp.	<i>Crocidura</i> sp.
	<i>Testudo hermanni</i>		<i>Apodemus</i> cf. <i>silvaticus</i>	<i>Lepus europaeus</i>	Chiroptera indet.
	<i>Geochelone</i> sp.	<i>Erinaceus europaeus</i>	<i>Microtus (Terricola)</i>		<i>Microtus (Terricola)</i>
	<i>Lacerta</i>	<i>Crocidura</i> aff. <i>esuae</i>	ex. gr. <i>savii</i>	Birds	cf. <i>savii</i>
	<i>siculomelitensis</i>	<i>Leithia</i> cf. <i>melitensis</i>	Chiroptera		<i>Apodemus</i> sp.
	<i>Lacerta viridis</i>	<i>Maltamys</i> cf. <i>wiendincitensis</i>			<i>Arvicola terrestris</i>
	<i>Lacerta</i> sp.		Birds		<i>Mioxus glis</i>
	<i>Coluber</i> cf.	Birds			
	<i>viridiflavus</i>		<i>Podarcis</i> sp.		Birds
	<i>Natrix</i> sp.	<i>Emys orbicularis</i>	Gekkonidae		
		<i>Testudo hermanni</i>	<i>Testudo</i> sp.		Turtle indet.
	<i>Discoglossus</i> cf.	<i>Lacerta siculomelitensis</i>	Anura		<i>Emys orbicularis</i>
	<i>pictus</i>				<i>Lacerta viridis</i>
	<i>Bufo</i> cf. <i>viridis</i>	<i>Discoglossus</i> cf. <i>pictus</i>	<i>Hyla</i> gr. <i>H. arborea</i>		<i>Bufo bufo</i>
	<i>Hyla</i> sp.		<i>Rana</i> sp.		<i>Bufo viridis</i>
			<i>Bufo</i> cf. <i>viridis</i>		
					Fishes

Figure 1.5-1: Faunal complexes of Sicily from Bonfiglio et al., 2002

The species derived from North African forms (*Pellegrinia panormensis* and possibly *Asoriculus burgioi*) spread during the Messinian, while the species derived from newcomers (*Hypolagus* sp. and *Pannonictics arzilla*) spread from the European mainland in more recent times (Bonfiglio and Burgio, 1992; Sala and Masini, 2007; Masini et al., 2008). In the paleogeographic reconstruction, Sicilia was still made up of two islands (Magrebidic Chain at Nord and Plateau Hybleo at Sud) as the volcano, Mt. Etna, had not yet emerged.

However, detailed paleogeographic reconstruction of the island in the Pleistocene and the extent of its connection separated by more or less wide sea straits with sporadic and difficult connections with the mainland during this period are only approximately depicted (Catalano, 1989; Rosenbaum and Lister, 2004; Palombo, 2018). Fauna probably entered the island through a strong filter and at Early Middle Pleistocene fauna was impoverished and unbalanced (Bonfiglio et al., 2002) dormice were still present in the insular system, while all the other small mammals were apparently extinct. Large mammals include the dwarf elephant *Elephas falconeri* (= *Palaeoloxodon falconeri*), strongly reduced in size, and a member of the Lutrinae (genus *Lutra*), while the occurrence of a small bear, and of 'Vulpes', is considered uncertain (Bonfiglio et al., 2002). Late Middle Pleistocene–Late Pleistocene fauna is almost completely renewed with respect to the previous one and includes an impoverished but balanced fauna, with top predators among the carnivores (Palombo and Ferretti, 2005). Herbivores were moderately modified with respect to the mainland ancestors, showing a slight reduction in size. In Late Pleistocene fauna, some taxa of the previous fauna became extinct and the newcomers have non-endemic features (Bonfiglio and Burgio, 1992; Bonfiglio et al., 2002; 2003). The arrival of the small mammals and of the horse (*Equus hydruntinus*) could be related to the opening of a land bridge as a consequence of a eustatic low stand (Bonfiglio et al., 2002). The Vertebrate assemblages recovered in Calabria (Bonfiglio and Berdar, 1986) have mainland characters and do not clarify the spreading to Sicilia. The latest Pleistocene fauna includes a continental fauna, without endemic elements and with humans (Bonfiglio et al., 2002) when

communication between Sicilia and Italy was easier., the faunas of Sicilia are characterised by an increasing biodiversity and a decreasing degree of endemism.

Quaternary Vertebrate fauna of Sicily is divided into five Faunal Complexes:

Monte Pellegrino FC, '*Elephas*' *falconeri*(= *Palaeoloxodon falconeri*) FC, '*Elephas*' *mnaidriensis* (= *Palaeoloxodon mnaidriensis*) FC, San Teodoro-Cave Pianetti FC, and Castello FC, showing from the oldest to the youngest an augment of biodiversity and a reduction in endemism, which suggest a decrease in the filtering power of barriers that separated the island from southern Italy. Sicily became more and more "continental" during late Middle Pleistocene, when exchanges with the mainland were more frequent and the faunal composition indicated a large island, with abundant resources and a well-developed trophic net (Marra, 2005).

In according to (Bonfiglio et al., 2001a; Masini et al., 2008; Bonfiglio, 2013) showing the five Sicilian Faunal Complex.

Montepellegrino FC

This FC is based on faunal assemblage discovering in Montepellegrino Mount (Palermo, Sicily, Italy) (Bonfiglio and Burgio, 1992). The poorly Montepellegrino FC is mainly composed of small mammals with different degrees of endemism and of different geographical affinity, which is indubitably of polyphasic origin (Masini et al., 2008). The small mammals as *Asoriculus burgioi*, '*Apodemus*' *maximus* and *Maltamys* sp. are endemic taxa, probably relics of an older (Messianan?) and unknown fauna. In contrast, the strongly endemic *Pellegrinia panormensis*, has the typical advanced characters of the African Ctenodactilids, thus indicating a dispersal from that region. Also *Hypolagus peregrinus* and *Mustelercta* (= *Pannonictis*) *arzilla*, are moderately endemic taxa of European origin (Burgio and Fiore, 1997; Fladerer and Fiore, 2002). Monte Pellegrino F.C. is considered as Early Pleistocene fauna to which a tentative age of about 1.6-1.5 Ma is assigned based on a comparative morphological study of the

mustelid *Mustelercta* (= *Pannonictis*) *arzilla* (Bonfiglio and Burgio, 1992; Burgio and Fiore, 1997; Masini et al., 2008)

Palaeoloxodon falconeri FC

The *Palaeoloxodon falconeri* FC is composed by following mammal association: *Crocidura esuae*, *Lutra trinacriae*, *Vulpes* sp., *Ursus* sp., *Palaeoloxodon falconeri*, *Leithia cartei*, *Leithia melitensis*, *Maltamys gollcheri*, also we found herpetofauna and avifauna (Pavia, 1999) and we found only taxon (*Maltamys* sp) shared with Monte Pellegrino FC (Bonfiglio et al., 2002). Palombo (2014; 2018) also includes the taxon *Palaeoloxodon antiquus*. Moreover, *Palaeoloxodon falconeri* FC is not very diversified and is very unbalanced, The small mammals assemblage is composed by a following taxa: the endemite of uncertain biogeographic, African or European affinity, shrew *Crocidura esuae* (Kotsakis, 1986b), the giant *Leithia melitensis*, the smaller and very rare *Leithia cartei*, and *Maltamys gollcheri*, which is the probable descendant of Monte Pellegrino dormouse (Sala and Masini, 2007; Masini et al., 2008). Also, the Large mammals assemblage include the “dwarf” elephant ‘*Elephas*’ *falconeri* (= *Palaeoloxodon falconeri*) (Ferretti, 2008), *Palaeoloxodon antiquus* and Nesolutra *Lutra trinacriae* (Burgio and Fiore, 1988b) indicates more characteristics and reveals a polyphasic origin from a strongly filtering barrier for this Faunal Complex. In fact, the sea branch separating the islands from the mainland can be crossed only by large mammals with exceptional swimming ability or a passive dispersal of small vertebrates. Probably, during this FC, Sicily are composed as an insular system with isolated and small islands that form difficult and sporadic connections with the mainland. The estimated age is assumed at about 0.8-0.9 Ma. and is indirectly based on correlations of marine terraces with the MIS curve (Di Maggio et al., 1999; 2009; Bonfiglio et al., 2003)

Palaeoloxodon mnaidriensis FC

Elephas’ *mnaidriensis* (= *Palaeoloxodon mnaidriensis*) Faunal Complex is completed renowned whit the large mammal assemblage more balanced, as it includes carnivore taxa: *Crocota*

crocuta spelaea, *Panthera leo*, *Canis lupus*, *Ursus arctos* and *Lutra trinacriae* and herbivore taxa: *Palaeoloxodon mnaidriensis*, *Bison priscus siciliae*, *Bos primigenius siciliae*, *Cervus elaphus siciliae*, *Dama carburangelensis*, *Sus scrofa*, and *Hippopotamus pentlandi* which, apart *P. mnaidriensis*, are just moderately modified from the congeneric/conspecific taxa of the Italian Peninsula (Palombo and Ferretti, 2005; Ferretti, 2008; Masini et al., 2008). The small mammal assemblage includes taxa from the extinct *E. falconeri* F.C.: *Crocidura esuae*, *Erinaceus europaeus*, *Leithia melitensis*, *Maltamys wiedincitensis*, *Microtus (Terricola) sp.* (Locatelli, 2010) and a diversifications of herpetofauna and avifauna (Pavia, 1999; 2001; Delfino, 2003). The characteristics of the assemblage suggest that the large mammal fauna dispersed from the Italian Peninsula and Many authors (Bonfiglio et al., 2003; Masini et al., 2008; Palombo, 2016; 2017) according to identifies in renewal of this FC as a change of paleogeographic condition. Sicily passed from the condition of an “oceanic island”, like Sardinia and characterised by severe barriers to dispersals, to that of a “continental island”, suggests a reduction of the barrier before the end of the Middle Pleistocene. A continental island condition allows a presence of *continental corridors* with the mainland during the glacial marine low stand and that became a part of the mainland when emerged corridors such as a partially emerged sea floor or a swampy lagoon system (Bonfiglio and Burgio, 1992; Agnesi et al., 2000; Antonioli et al., 2012). The beginning of the *P. mnaidriensis* F.C. is commonly assigned to beginning age of 0.3 Ma (top on Mis 5e) (Masini et al., 2008) with stratigraphic correlations from continental vertebrate deposit to marine isotopic curve in Di Maggio et al. (1999) and Bonfiglio et al. (Bonfiglio et al., 2003). However, the presence of *Hippopotamus pentlandi*, *Maltamys* and *Leithia* taxa in the Site K22 (San Vito Lo Capo, Trapani), laying at the top of a marine deposit, suggests that FC was already established on the island before the beginning of Late Pleistocene and that species of the *P. mnaidriensis* FC were already present in Sicily before MIS 8 (Bonfiglio et al., 2001a; 2001b).

San Teodoro-Contrada Pianetti FC

The composition of large mammal assemblage of San Teodoro-Contrada Pianetti FC is very similar to *Palaeoloxodon mnaidriensis* FC but it difficult to ascertain that there is a directly descend from precedent FC or for successive dispersal events (Kostopoulos et al., 2007; Palombo, 2017). This FC include the following taxa: *Crocota crocuta cf. spelaeon*, *Canis cf. lupus*, *Vulpes vulpes*, *Ursus cf. arctos*, *Palaeoloxodon mnaidriensis*, *Sus scrofa*, *Equus hydruntinus*, *Cervus elaphus siciliae*, *Bos primigenius siciliae* but we don't find *Hippopotamus pentlandi* and *Panthera leo* taxa in this association. Also, San Teodoro-Contrada Pianetti FC shows a faunal turnover to small mammals with new insectivores and rodents (*Crocidura cf. sicula*, *Apodemus cf. silvaticus*, *Microtus (Terricola) ex. gr. savii*). The turnover of small mammals has been interpreted as a response to climate change by Last Glacial severe climatic deterioration and the arrival of small-sized terrestrial predators. Moreover, from a palaeogeographical point of view, the presence of *Microtus (Terricola) ex. gr. savii* and the entrance of equids (*Equus hydruntinus*) suggest a stable land bridge temporarily emerged between 21.5 and 20 cal ka BP, as supported by the age of the oldest fossil record of the species thus far known in Sicily (Antonioli et al., 2012). San Teodoro-Contrada Pianetti FC is collocated in a chronological range from to the last glacial cycle and to the Late Glacial respectively. Also, preliminary radiometric $^{230}\text{Th}/^{234}\text{U}$ dating carried on a speleothem in the San Teodoro cave (Messina, Sicily) yielded an age of 32.0 ± 4 ka (Bonfiglio et al., 2001a; 2008). Nevertheless, a tentative age of 70 ka (MIS4) is proposed for the beginning of this Faunal Complex (Bonfiglio et al., 1997; 2003).

1.6 Geographical and Geomorphological study area

The area under study falls within Western Sicily, within the territory of the province of Trapani and includes the territory of three municipalities: Salemi, Santa Ninfa and Castelvetrano to the entire catchment area of the river Grande-Delia. The studied territory is located within the 50 sheet 618 series at scale 1:50,000 topographic map of the Italian state generated by the Istituto Geografico Militare Nazionale (I.G.M.) and in the official topographical maps of the Region of Sicily (C.T.R.) within the sections No 606140, 606150, 618010, 618020, 618020, 618030, 618050, 618060 and partly in numbers 618090 and 618010. The size of the study area is about 175sq.km (Figure 1.6-1).

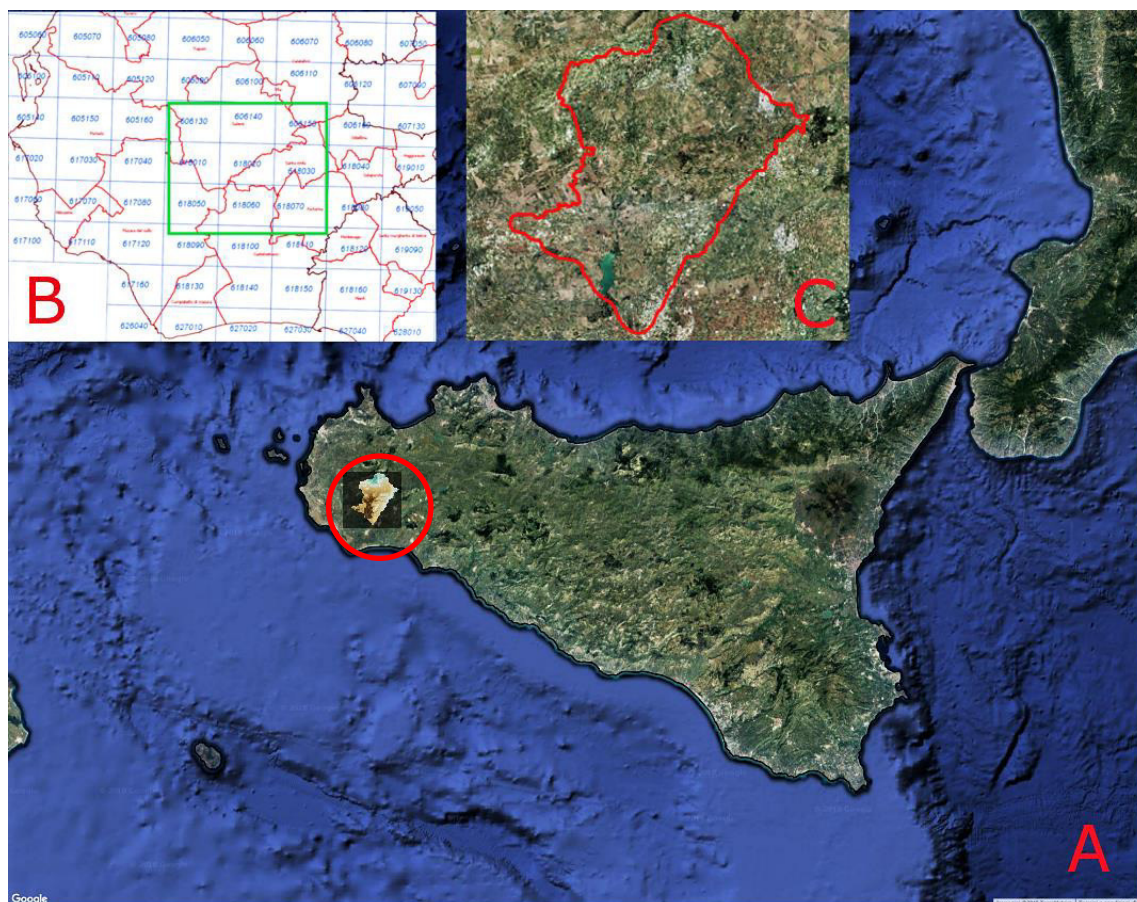


Figure 1.6-1: Location of the study area: A) Location of the study area in Sicilia Region from google earth. B) CTR union framework C) ortofoto 1:50.000 of Grande\Delia River Basin.

The topographic study, together with the vision of the interesting areas in this project, allows having a clear idea about the geomorphology of the area and the evolution of the landscape. The geomorphological structure of the territory is controlled by the morphostructures placed in place during the geological history of Sicily. The territory thus reflects the great orogenic deformations that have led to the current conformation of the landscape with the formation of morphostructures where geomorphological processes are set up. One part of the tectonic movements were responsible for the genesis of low and high structural areas, on which low and high topographical areas respectively were set; on the other, selective erosion further accentuated the differences in height between these two areas thanks to the presence, in the lowlands topographical / structural, of not well cementate rocks. In the studied territory we can distinguish at least three geomorphologic macro-areas: east of the chalky plateau of Santa Ninfa, west of the marly arenaceous plateau of Salemi and in the central area we found Quaternary covers (Figure 1.6-2).



Figure 1.6-2:Valley of Grande\Delia River. From Santa Ninfa to Salemi city (to background).

The geomorphological configuration is essentially dominated by the existence of two different landscapes, one of which is typically hilly, characteristic of the reliefs that delimit to the north, east and west the water catchment area under the Delia river, where the greatest relief is that of Monte Polizzo (713 m asl) (Salemi,TP). The altimetry of the marnly-clay reliefs is not very

high and do not show particular landslides. To the south of the study area, these slopes are truncated to the summit by morphological levelling characterised by limestone soils which take the name of the Great Upper Terrace G. T. S. (Ruggieri et al., 1975; D'Angelo and Vernuccio, 1994; 1996). In the area of the Santa Ninfa plateau, we find different lithologies with a different degree of response to modelling factors. The main lithologies in the area of Santa Ninfa are Trubi Fm. which rest on the Pliocene clays where the landscape are dominated by large banks of Evaporitic rocks *s.l.* by Fm. Gessoso-Solfifera. The nature of these formations, therefore, makes the landscape very rugged, with steeply sloping hills and elevations between 400 and 500 metres above sea level. The presence of soluble rocks (Gypsum) the hydrographic network and the widespread network of fractures caused by the tectonic evolution of the area involves a selective morphogenesis action. In fact, the landscape is controlled by a dense network of escarpments that disjoints selenitic banks in a discontinuous way. In addition, the area is rich in hypogea that take on different forms: swallowed, horizontal and vertical caves where the main cave is the cave of Santa nymph. The karst network, therefore, feeds, through the ingesting of watercourses, the underground network by loading it of salts present in the evaporitic rocks. The second landscape with a mainly valley conformation with large flat or slightly deformed areas, and furrowed by torrential streams that are found in the areas between the hills. This type of landscape is found west of the chalky backbone of Santa Ninfa, where territory is modelled on the lithologies of Terravecchia Fm. The morphogenesis is applied by erosion processes in the reliefs and with forms of accumulation along the valley floor through the formation of alluvial coulters. Examples are some tributaries of the Delia River (Channel and Mokarta) which affect recent alluvial deposits and probably the oldest terraced deposits. To the West, territory is dominated by the reliefs in Salemi landscape. Through a rupture of slope due, also in this case, to the presence of tectonic features, we find a dorsal formed by terrigenous hairy-arenaceous deposits (Fm. Marnoso-Arenacea of Belice Valley) at an altitude between 500 and 600 meters. The reliefs of this ridge are also truncated by a calcarenite plateau passing through

conglomerates of the middle Pleistocene from where start numerous lines of water rush that involve on the one hand a slow dismantling of arenaceous deposits and on the other hand contribute to feeding the hydrographic network.

The hydrographic network presents itself with a "Pinnate" trend in the north-eastern part of the basin, shaping the hillsides with the formation of V valleys and evolves with a dendritic trend towards the sea in lithologies with more incoherent behaviour. The primary river of the area is the Grande\Delia river, which crosses the study altar until it flows into the sea. Along your route, it takes on various denominations: River Grande upstream, Delia in the plain until reaching the artificial lake (Trinity Lake), Arena river from the dam of Trinity Lake to the sea. In the central area of the basin, the idroglogical reticle takes on a sub-dendritic trend, since the low slopes of the slopes are associated with different permeability lithologies that determine a different degree of erosion. The main section, about 48 Km long, has a recessed meander, with two distinct degrees of evolutionary maturity: a more mature stage in the final part, after Trinity Dam, while it has a less mature stage upstream of Trinity Lake, where the valley floor is not perfectly calibrated.

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MATERIAL AND METHODS

2 Material and Methods

Methodology adopted in this research must necessarily be adapted to the different study phases and to the different fields of application. The correct implementation of the methodology is necessary in order to integrate the data from different types of studies. The complexity of the project's objectives, therefore, implies a multidisciplinary approach and must be able to provide the necessary data for a correct interpretation of the geology of the study area. These data must, therefore, be processed according to the different fields of study and then comparing the results from the different methodologies. The methodology adopted, therefore, is based on a multidisciplinary approach in studying the territory of Grande\Delia river from three different points of view. The research was carried out using different study methods: mapping geology, sedimentary analysis and petrographic analysis. Given the complexity of the research, the work was divided into four phases: Geological Mapping, Analysis Phase (Sedimentologic, Petrographic, Palaeontological) and comparison of results. Each of these steps is analysed in the following paragraphs. The first phase, the geological survey, is adopted to identify and map the different lithologies present in the area, their stratigraphic relationships, and to identify the geomorphological characters. Another objective was the identification of outcrops useful for creating stratigraphic sections and studying them with detailed studies. The second phase was based on an approach of sedimentological analysis to recognize common lithologies, textures and sedimentary structures, and how to record and measure these features in order to characterize both present and fossil sediments. It was useful to reconstruct, within the framework of geological history, environment of formation, origin, modes of transport and deposition in order to characterize the possible river terraces present. Through the petrographic study, it was aimed to recognize the petrographic characteristics of collected samples in order to understand the relationship between deposit, environment and its formation. Finally, the palaeontological analysis was aimed to understand the age of formation of deposits and possible terraces.

2.1 Geological Mapping

Geological mapping was performed using 1:10.000 (Carta Tecnica Regionale of Regione Sicilia) and 1:25.000 (Carta Topografica d'Italia, Serie 25 of I.G.M) topographic maps. Accurate positioning of geological features was aided by a global positioning system (GPS). Where possible, stratigraphic boundaries and tectonic structures were tracked by using the GPS Essential Android app. KML files generated by the app. were exported into Shapefile format and managed within a geographic information system (QGIS software). During fieldwork, the distinct mapped units were identified using lithostratigraphic criteria such as lithological properties and stratigraphic relations, according to the International Stratigraphic Guide and CARG project. Topographic maps including hand-drawn geological elements were successively converted to raster image files and geo-referenced to WGS84 Ellipsoid UTM zone 33 Projection. By using a GIS software (Quantum GIS), georeferenced hand-drawn images were combined with 1:10.000 scale ortho-photos and with a hill-shade representation of a high resolution (2 m cell size) digital terrain model (DTM) of the area. The analysis of spatial elevation of the hillslopes along of river catchment allows distinguishing the morphologic discontinuity as fluvial Terrace. Moreover, fluvial and terraces profiles were made with Qgis (Geomorphological analysis plugin). Profiles were built extracting one elevation point (along to the river) ever 100 meters of the river (starting from the source and following the curvilinear distance of the river) from a 2 m digital elevation model (DEM by Regione Sicilia). While to fluvial terraces profiles have been made discontinuously Grande\Delia River with cross section. Afterwards, profiles were made using graph software (i.e. Excel) and using the same X values (distance from the source) as the longitudinal profile of the river. These profiles were thus analysed jointly with the geological features of the study area. Also, Rivers are linear systems that show a gradient of characters along their length and longitudinal profile of a river is concave with a steep upper portion near the source, giving way progressively to reaches of less gradient as the mouth is approached (Miall, 2000; Julien, 2010). However, profile could have steps, called knickpoints, which can

be originated by differential erosion controlled by either lithological, flow regime contrasts or base level change (led by tectonic or eustatic variation). Knickpoint can migrate upstream and lead to the formation of a river terrace (Zaprowski et al., 2005). The profiles are successively elaborated with x-y plot Excel for normalized the different elevations of the rivers and the curvilinear distance of the Grande\Delia river (Figure 2.1-1)

Finally, in order to complete and detail the information acquired from the previous tools and techniques (QGIS and EXCEL) is required a field work. In this way, sedimentologic, stratigraphic and morphologic data of outcrops can be collected, and also local relation between terraces and geological and geomorphologic characteristic of Grande\Delia River basin. In this project, the thickness of the deposit and heights of the terraces above the current riverbed were measured using a measuring tape and GPS.

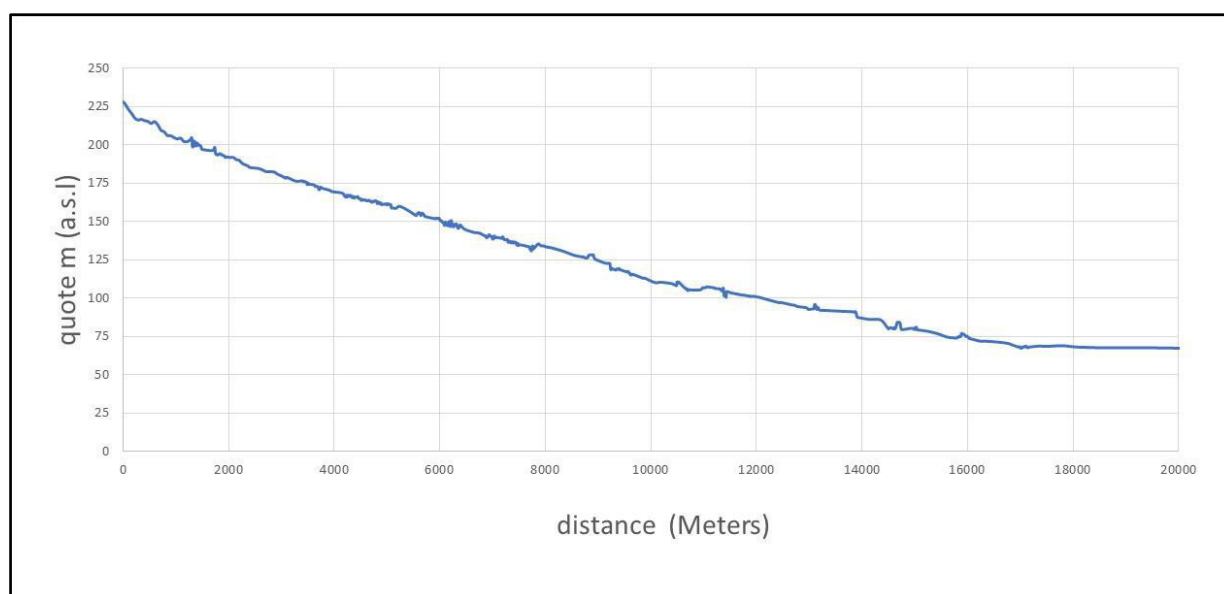


Figure 2.1-1: Longitudinal Grande\Delia river profile.

Finally, to identify the geological and sedimentary characterised used a Miall classification during field activity (Figure 2.1-2). The Miall classification (Miall, 1978; 2000; 2006) has been used for the classification and coding of terrigenous deposits. Classification divided in three fields of interest: the lithofacies definition based on particle sizes and sedimentary structures; the identification of boundary areas “architectural elements”, the definition, by means of lithofacies and boundary surfaces, of "architectural elements" and make it possible to reconstruct depositional environments and subenvironments. The architectural elements are defined as components within the sediments that are characterized by a distinct facies assemblage, internal geometry and external form. These architectural elements are generally larger than individual facies units and are smaller than a channel fill (Miall, 2006).

This classification includes facies such as matrix supported massive gravel (Gmm), and sand, fine to very coarse may be pebbly (St); gravel bars and bedforms GB; sand bedforms SB; Downstream-accretion macroform DA; Lateral-accretion macroform Scour hollows HO; Sediment gravity flows SG; Laminated sand sheet LS; Overbank fines FF.

Facies Code	Facies	Sedimentary Structures	Interpretation
Gmm	Matrix-supported, massive gravel	Weak grading	Plastic debris flow
Gmg	Matrix-supported gravel	Inverse to normal grading	Pseudoplastic debris flow
Gci	Clast-supported gravel	Inverse grading	Clast-rich debris flow
Gcm	Clast-supported massive gravel	-	Pseudoplastic debris flow
Gh	Clast-supported, crudely bedded gravel	Horizontal bedding, imbrication	Longitudinal bedforms and lags
Gt	Gravel-stratified	Trough cross-beds	Minor channel fills
Gp	Gravel Stratified	Planar cross-beds	Transverse bedforms
St	Sand, fine to very coarse may be pebbly	Solitary or grouped cross-beds	3D dunes
Sp	Sand, fine to very coarse may be pebbly	Solitary or grouped cross-beds	2D dunes
Sr	Sand, very fine to coarse	Ripple cross lamination	Ripples (lower flow regime)
Sh	Sand, fine to very coarse may be pebbly	Horizotnal lamination parting	Plane-bed flow (critical flow)
Sl	Sand, fine to very coarse may be pebbly	Low-angle cross beds	Scour fills, antidunes
Ss	Sand, fine to very coarse may be pebbly	Broad, shallow scours	Scour fill
Sm	Sand, fine to coarse	Massive, or faint lamination	Sediment-gravity flow
Fl	Sand, silt mud	Fine lamination, very small ripples	Overbank
Fsm	Silt, mud	Massive	Backswamp, abandoned channel, drape
Fm	Mud, silt	Massive, desiccation cracks	Overbank, abandoned channel, drape
Fr	Mud, silt	Massive, roots, bioturbation	Root bed
C	Coal, carbonaceous mud	Plant, mud films	Vegetated swamp
P	Paleosol carbonate	Pedogenic feature	Soil

Figure 2.1-2: Classification's Miall. Fluvial Lithofacies scheme.

2.1.1 Graphic Logs

The graphic sedimentary log is the standard method used by geologists to present data related to successions of rocks (Collinson et al., 2006). The standard method used to collect field data of sediments/sedimentary rocks is to construct a graphic log of the outcrops. A sedimentary log is a graphical method for representing a series of sediments beds or sedimentary rocks (Figure 2.1-3).

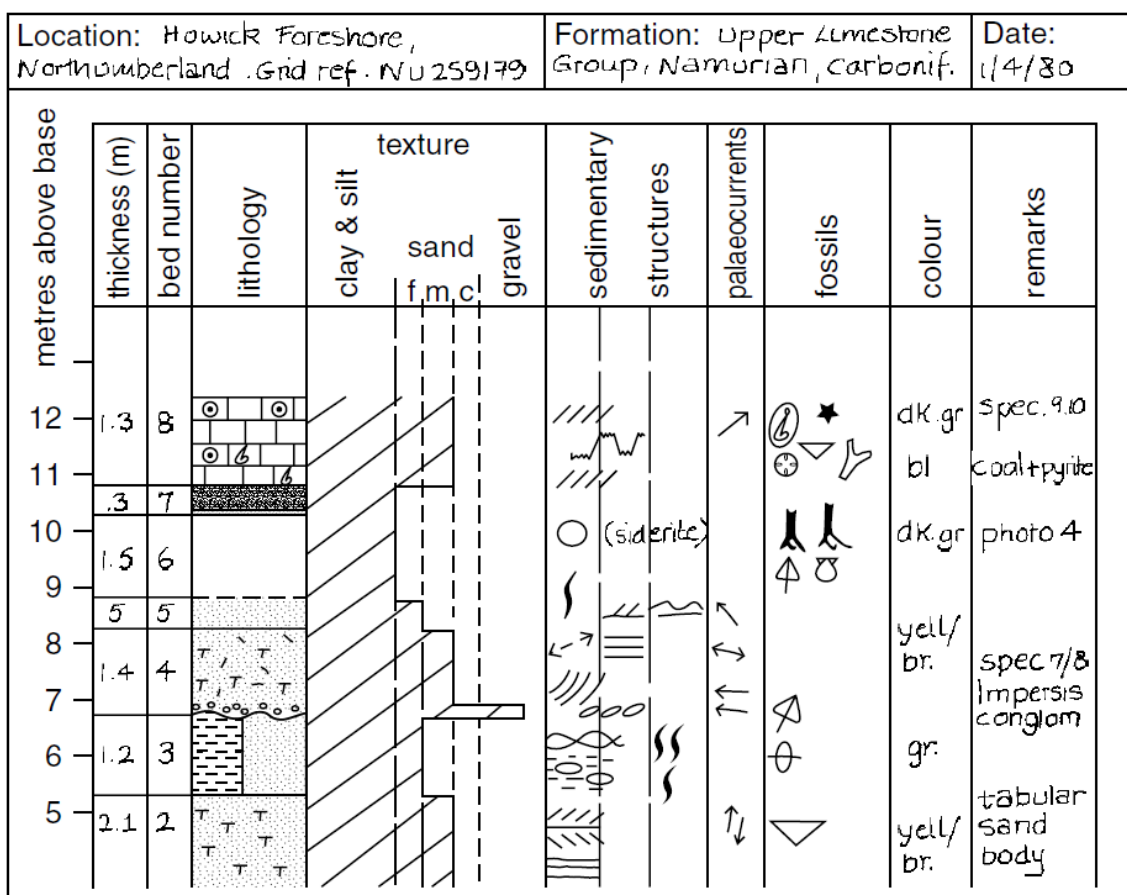


Figure 2.1-3: example of a graphic log (Tucker, 2011).

Many different schemes can be used, but they are all variants on a theme. The format presented here closely follows that of Tucker (2011). Logs give a visual of the section and are a convenient way of making correlations and comparisons between equivalent sections from different areas. Repetitions of facies, sedimentary cycles and general trends may become apparent, such as a systematic upward change in bed or cycle thickness or in grain-size,

increasing or decreasing upward. In addition, the graphic log helps the interpretation of the succession. However, a log does emphasise the vertical changes in the succession, at the expense of lateral variations (Tucker, 2011). This information is represented on the graphics log using a vertical scale for the bed thickness, patterns to represent different lithologies ('dots' for sandstone, 'bricks' for limestone and so on) and symbols to illustrate structures and fossils. Moreover, the log allows to annotate more information. Other features such the location of site, the coluro of sample, the rock. Besides, graphic logs are a useful tool to compare strata between different areas and data may be extracted from the log to analyse trends in bed thickness, distribution of lithologies or other features. Log is a tool to drawn in the field like summary sketch logs, or on log sheets that contain all the data (Collinson, 2005; Stow, 2005; Tucker, 2011).

2.1.2 SEDLOG

SedLog is a free multi-platform software package for creating graphics sediment logs providing an intuitive graphical user interface. The graphics sediment logs generated by SedLog can be exported as PDF, Scalable Vector Graphics (SVG), or JPEG to be used for use by other drawing applications or for publications. Log data can be imported and exported in Comma Separated Values (CSV) format. The logs can also be printed to any paper size the user wants. Zoom In, Zoom Out, Fit page, Fit Height and Fit Width facilities are also provided to enable the user to customise the workspace size (Zervas et al., 2009).

2.2 Sedimentological analisys

2.2.1 Methodology and Sampling

several surveys within the study area and several samplings has been carried out. 412 pebbles have been collected in 5 stations distributed in a causal way within the study area, while 2 stations were located in outcrops (Figure 2.2-1). For each sampling site, geographical coordinates have been taken both in degrees, minutes, seconds (DMS) format through the use of the WGS84 format to facilitate the use of the different software used in this search (Table 2-1).

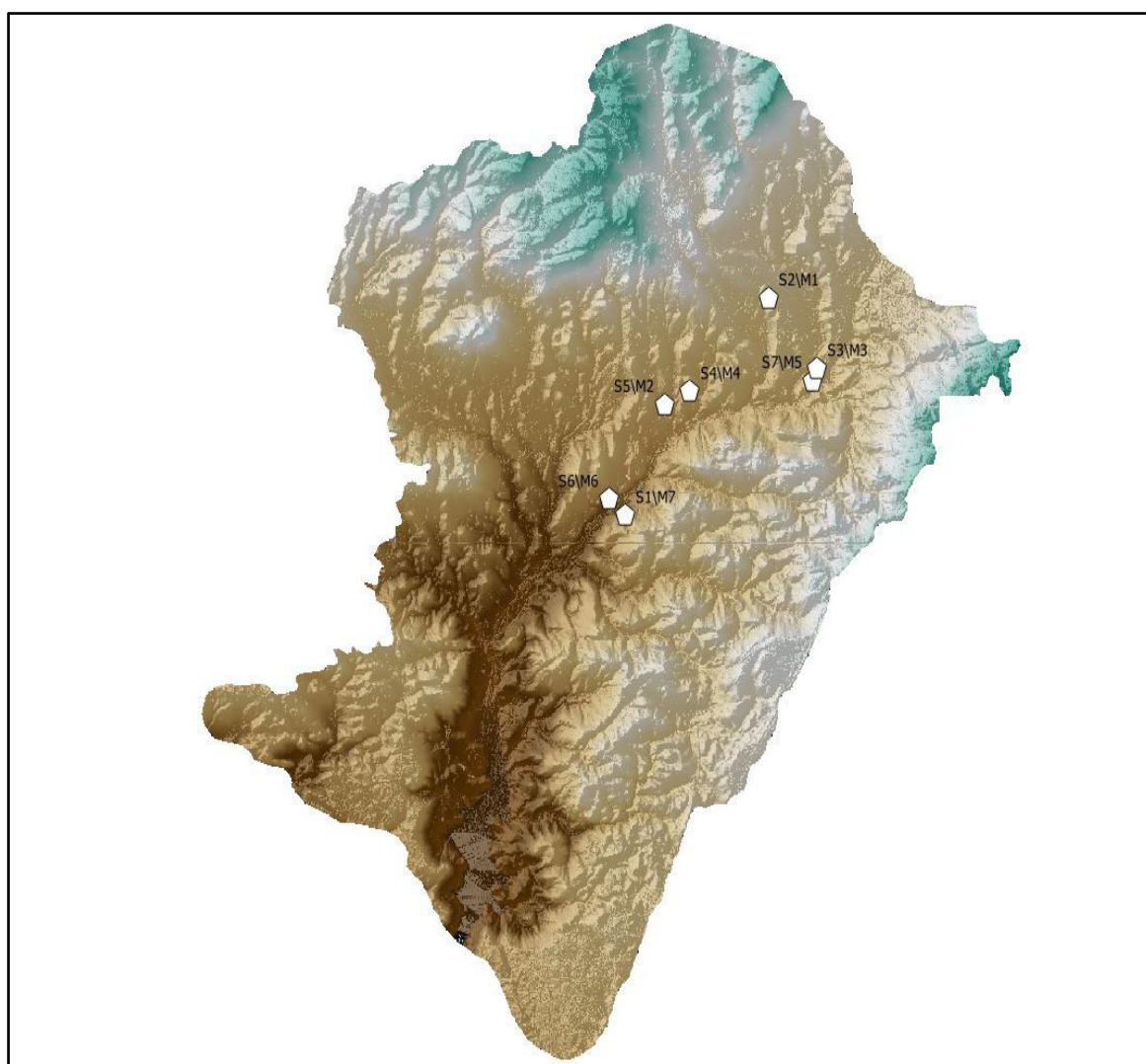


Figure 2.2-1: Location of sample to particle shape analysis.

site	Surface\Outcrop	DMS coordinates	WSG coordinates
S1	Outcrop	37°46'06.6"N 12°47'41.3"E	37.768507, 12.794795
S2	Surface	37°48'32.1"N 12°50'02.0"E	37.808906, 12.833901
S3	Surface	37°47'44.9"N 12°50'51.4"E	37.795801, 12.847599
S4	Surface	37°47'29.4"N 12°48'46.6"E	37,7914882; 12,8129369
S5	Surface	37°47'19.8"N 12°48'21.4"E	37.788829, 12.805935
S6	Surface	37°46'17.5"N 12°47'28.3"E	37.771522, 12.791205
S7	Outcrop	37°47'36.5"N 12°50'46.0"E	37.793478, 12.846099

Table 2-1: Geographical position by location of sampling sites

Field measurement of particle shape continues to be a widely used and valuable technique in studies of pebble- and cobble-sized material (Benn and Ballantyne, 1993). The study of sedimentary particles is widely acknowledged to be an important source of information on sediment provenance, transport and depositional environment. Terrigenous clastic sediments are made up of transported fragments derived from the weathering of pre-existing igneous, sedimentary or metamorphic rocks. These rocks are classified initially according to grain size, using the Udden-Wentworth scale (Figure 2.2-2). Grain size is a fundamental attribute of siliciclastic sedimentary rocks and thus one of the important descriptive properties of such rocks (Boggs, 2006). A useful modification of the Udden-Wentworth scale (Figure 2.2-2) is the logarithmic phi scale, which allows grain-size data to be saided in units of equal value for the purpose of graphical plotting and statistical calculations. This scale, proposed by Krumbein in 1934, is based on the following relationship where ϕ is phi size and d is the grain diameter in millimetres (Tucker, 2011) = $\phi > -\log_2 d$.

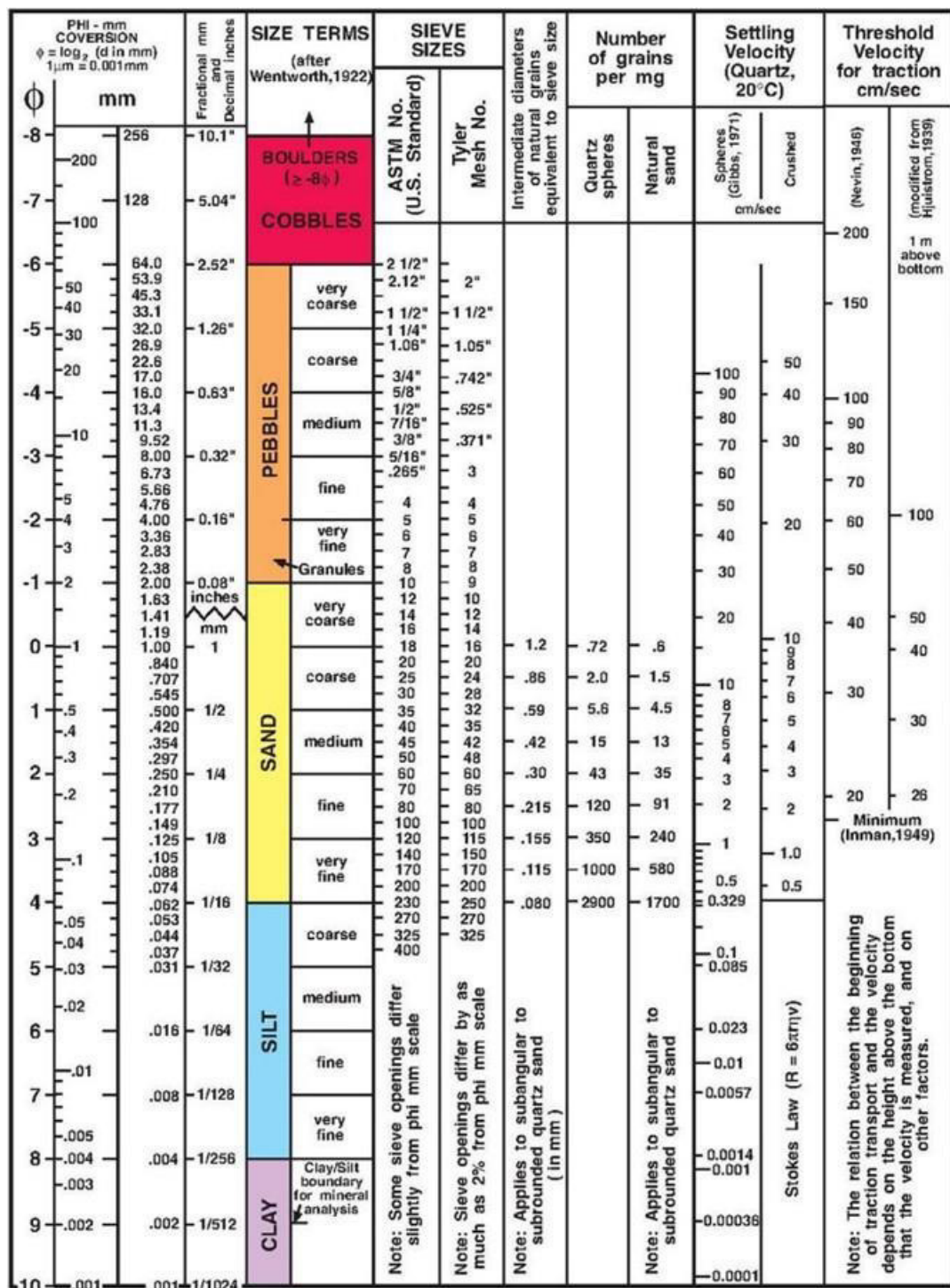


Figure 2.2-2 Grain size can tell us a lot about the energy of the depositional environment. In general, if the energy is high, only coarse particles would deposit and fine particles would be carried away. When energy is lower, the lighter particles can be deposited. (Williams et al., 2006)

50 pebbles were measured in S1 station, 51 pebbles were measured in S2 station, 72 pebbles were measured in S3 station, 60 pebbles were measured in S4 station, 64 pebbles were measured in S5 station, 51 pebbles were measured in the S6 station and 64 pebbles were measured in S7

station. Lithological, morphometric and dimensional investigations were carried out on samples. The measurement of the mid-axis b has allowed the pebbles division into 5 particle size classes: 8-16 mm, 16-32 mm, 32-64 mm, 64-128 mm and 128-256 mm. At a later time, a sixth class (32-48 mm) was added to the previous division into five classes to highlight more clearly the changes in the medium diameter of the different sites. In all the sites on each pebble the lithological type was defined macroscopically and for some lithotypes a petrographic survey of the thin section was necessary. The form of sedimentary particles is related to their shape (the relative lengths of each axis), roundness (smoothness or angularity of the edges) and texture (surface roughness) (Benn and Ballantyne, 1993; Benn and Lehmkuhl, 2000) as shown in Figure 2.2-3.

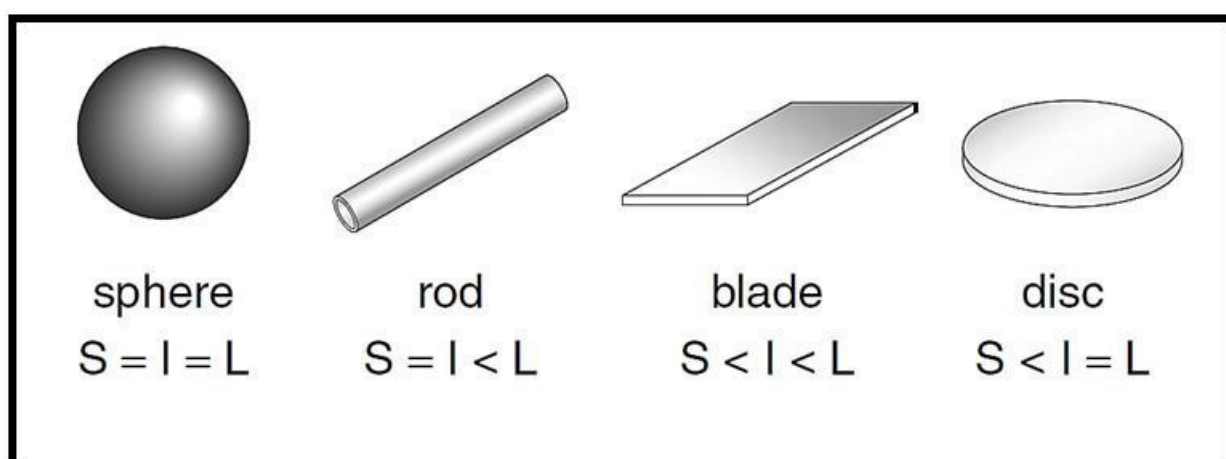


Figure 2.2-3: The four common shapes of pebbles; S , I and L are the short, intermediate and long diameters, respectively (Tucker, 2011).

These characteristics provide means of differentiating facies, clues about transport history of the sediment, and the characterization of depositional environments. Major a , medium b and minor c axis were measured on each pebble with a gauge. The measurement of these three axes made it possible, for each pebble in the sample, to calculate the flattening index (Cailleux, 1945), the oblate-produced index (Dobkins and Folk, 1970) and the spherical index (Folk and Ward, 1957) and to determine the shape by means of the classification diagram of SNEED &

FOLK shapes (Sneed and Folk, 1958; Graham and Midgley, 2000). Methods of presenting primary particle shape data have been the subject of heated discussion during recent years and a variety of schemes being advocated (Benn and Ballantyne, 1993; Graham and Midgley, 2000). These arguments are not repeated here, except to note that each of these schemes has its merits, while none is ideal for all situations. To some extent, the precise method of representing particle shape is less important than the adoption of common standards to enable the direct comparison of work undertaken by different researchers. The establishment of a 'critical mass' of work using one scheme is probably the critical factor that will determine the standard adopted (Graham and Midgley, 2000). Benn and Ballantyne (1993) advocated the adoption of (Sneed and Folk, 1958) triangular diagrams for the presentation of primary particle shape. The shape of grain is measured by various ratios involving the long (a), intermediate (b) and short (c) axes. The shape is most plotted efficiently on a triangular diagram with the end members spheres, discs and rods, with blades being intermediate between the last two ones Figure 2.2-4.

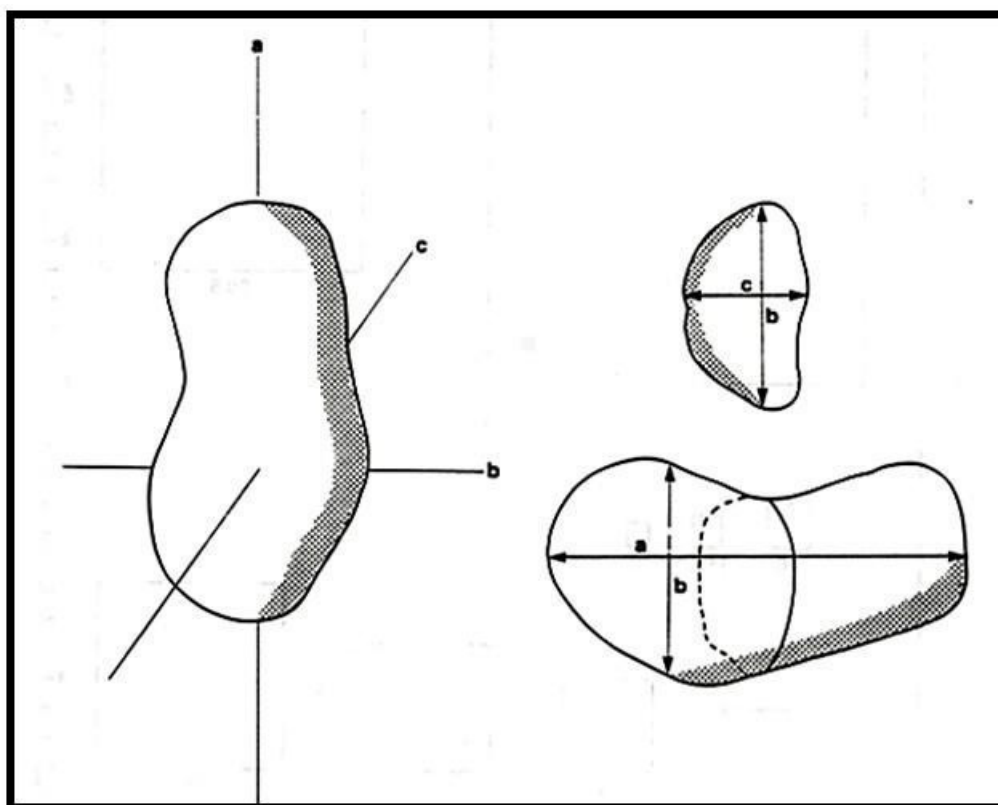


Figure 2.2-4: The longer axis dimension corresponds to the a-axis, the intermediate to the b-axis, and the smallest to the c-axis using digital Vernier Calliper (Yuzyk and Winkler, 1991).

2.2.2 Grain Morphology

Different characteristics describe the grain: roundness index, the spherical of the grain and shape form. These characteristics indicated transport by a fluid media would round particles. The degree of rounding is proportional to the duration of transport. A grain that has travelled a shorter distance from its host will tend to be angular, whereas one that travelled a long distance will tend to be rounder

Sphericity

Sphericity is a measure of how closely the grain shape approaches a sphere.

$$\sqrt[3]{c^2 / (a \times b)}$$

Particles sphericity in sedimentary deposits is mainly a function of grains original shapes, although the gravel-size particles shapes can be modified somewhat by abrasion and breakage during transport. First mathematical formulae described sphericity as the ratio between the diameter of a sphere with the same volume as a particle and the diameter of the smallest circle that would just enclose or circumscribe the outline of the particle (Wadell, 1935). Also, Zingg (1935) proposed the use of two shape indices b/a and c/b to define four shape fields (Figure 2.2-5) on a bivariate plot: oblate (disc), equant (spheres), bladed, and prolate (rollers).

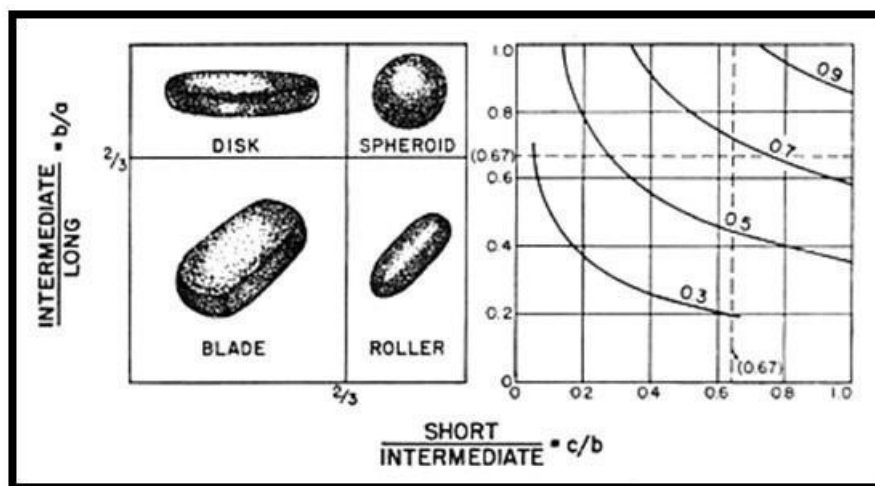


Figure 2.2-5: Zingg Diagram (W. C. Krumbein, 1941).

Roundness

The roundness of grains in a sedimentary deposit is a function of grain composition, grain size type of transport process, and distance of transport. The roundness of a particle is defined as the average radius of the circles that are fitted to the corners of the grain divided by the radius of the largest inscribed circle of the grain (Wadell, 1932) and six classes from very angular to well rounded are usually distinguished (Figure 2.2-6).

The expression of roundness is:

$$r = \frac{\sum_{i=1}^n r_i}{n R} \quad (\text{Wadell, 1932})$$

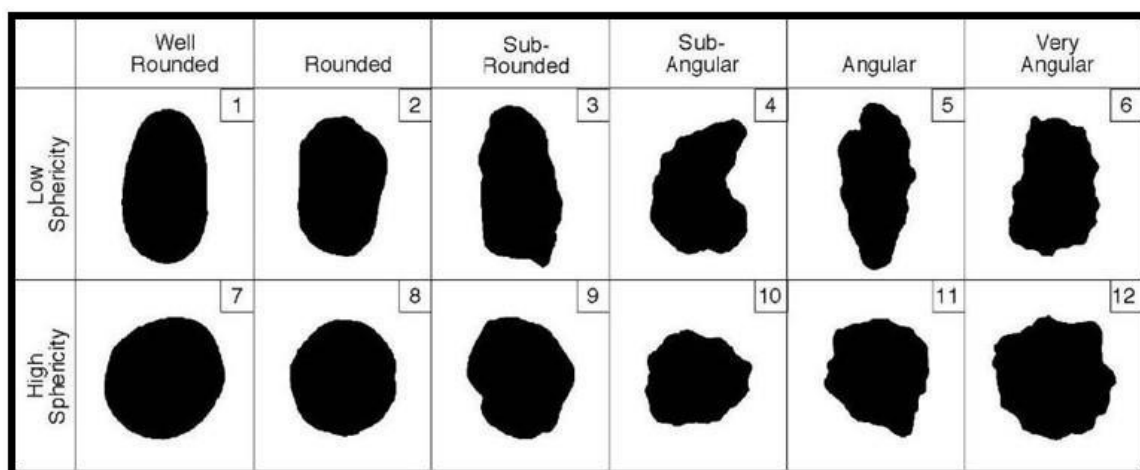


Figure 2.2-6: Visual grain roundness scale (MacLeod, 2002)

2.2.3 Sorting

The sorting of a grain population is a measure of grain sizes range and magnitude of spread or scatter of these sizes around the mean size. Sorting can be estimated in the field to a visual estimation chart (Figure 2.2-7).

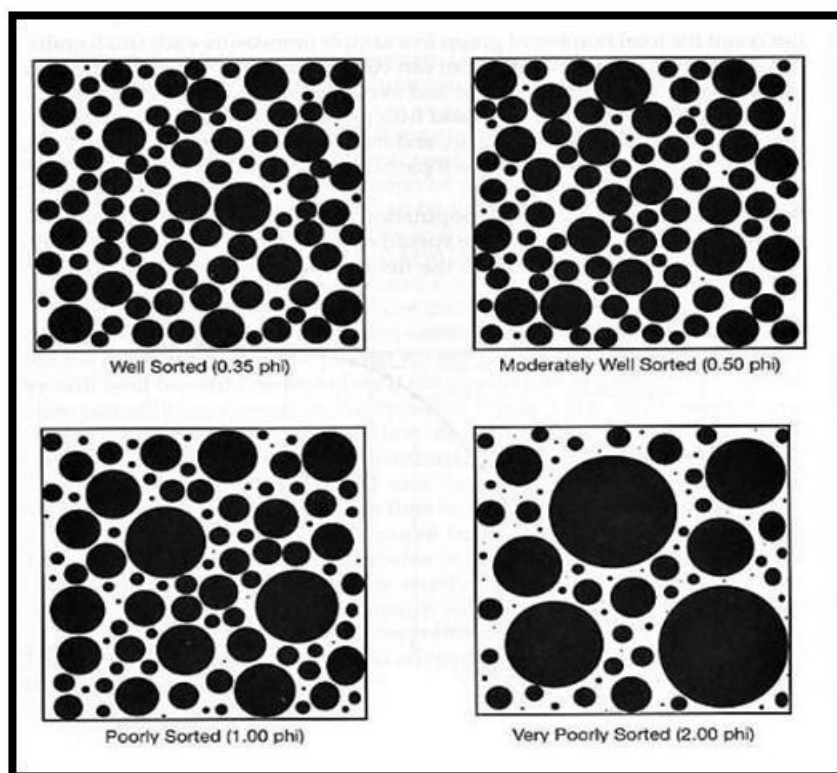


Figure 2.2-7: Visual estimation of sorting (Boggs, 2006).

In short, the values of the long, intermediate and short axes were loaded into the excel spreadsheet. The following formulas were imputed and used:

2.2.4 TRI-PLOT The Sneed & Folk diagram

TRI-PLOT is a free Spreadsheet to plot standard ternary diagrams to represent particle size. Moreover, TRI-PLOT has been developed by the Department of Geography of Loughborough University (Leicestershire, UK) and is described in Graham and Midgley (2000). This spreadsheet plots triangular (ternary) diagrams for the representation of particle shape following the method recommended by Benn and Ballantyne (1993) and first proposed by Sneed and Folk (1958). Ordinary ternary diagram plotting software is unable to plot these diagrams as the parameters on the three axes do not sum to 1. The Sneed & Folk (1958) method of representing particle shape employs a triangular diagram in which ratios of the three orthogonal axes of the particle are plotted as in Figure 2.2-8 (Sneed and Folk, 1958; Graham and Midgley, 2000).

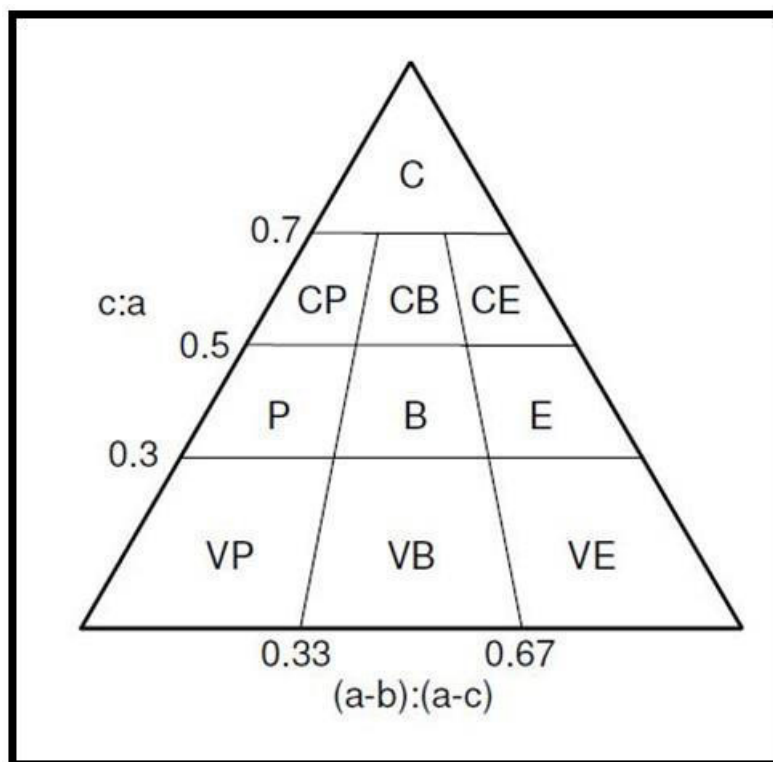


Figure 2.2-8: Sneed and Folk Ternary diagram for morphometric studies (Graham and Midgley, 2000)

Particles are envisaged as lying in the continuum between blocks (or spheres), slabs (discs, oblate) and rods (prolate) that demarcate the corners of the diagram. The Sneed & Folk Diagram subdivide particles into 10 classes: Compact, Compact-Platy, Compact-Bladed, Compact-Elongate, Platy, Bladed, Elongate, Very-Platy, Very-Bladed, Very-Elongate.

The conventional and Sneed & Folk scalings of the triangular diagram provide a means of representing fundamentally different things. Conventional diagrams are used to represent the proportions of three variables that sum to a whole. The three variables are related: an increase in one must be reflected in a decrease in another one or both the other two variables. In this context, the relative proportions of gravel, sand and mud in a geological sample can be considered an example. In contrast, Sneed & Folk scaling enables independent (although related) variables to be plotted. Changes in one variable need not affect the other two ones.

2.3 Petrography analysis

Thanks to the collaboration of the “Dipartimento di Fisica e Scienze della Terra” of University of Ferrara, it has been possible to use microscopic instrumentation to carry out a petrographic study on samples taken from lithologies emerging within the area under study. The aim of this research phase is to have a better understanding of the geology of territory and to create a first atlas of the territory lithologies useful as a scheme for future research.

In addition, samples collected during this project were prepared to be studied in two separate phases. Petrographic analysis can be divided into two phases, the first phase was to analyse and describe from a macroscopic point of view collected samples through stereomicroscope.

The second phase, instead, concerned samples petrographic characterisation in thin sections. The second phase, instead, concerned samples petrographic characterization in thin sections. Stereomicroscope is characterized by a 3D vision of what is being observed as it is equipped with pairs of lenses and eyepieces that work simultaneously giving a realistic vision of the subject. For macroscopic analysis I used a trinocular microscope OPTIKA SZ6745TR with 0.67x-4.5x zoom range (6.72:1 zoom ratio), being purposely designed for these inspections. This zoom ratio enables most samples to be observed at the appropriate magnifications (Figure 2.3-1). Moreover, combined with proper accessories (2x additional lens and 20x eyepieces), is possible to have excellent image quality up to 225X. This microscope is composed of an illuminated addition lens (LED-72T) and a camera (moticam 2500) that allows you to take pictures through your MOTIC IMAGES PLUS 2.0 software. For the study of thin sections, the Optika petrographic microscope with MOTICAM 5 camera was used with the use of MOTIC IMAGES PLUS 2.0 software.

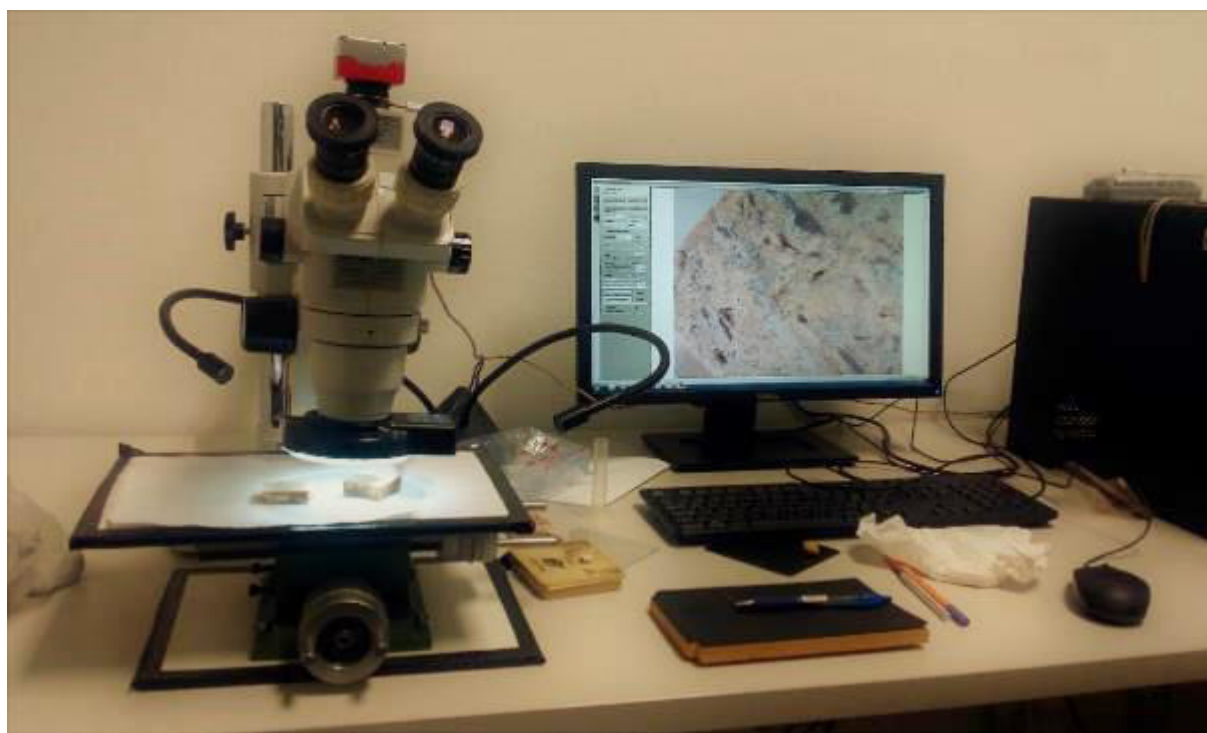


Figure 2.3-1: Stereomicroscope workstation used to analyse the surface of the sample (Laboratory of Optic Microscopy- Università degli Studi di Ferrara, Dipartimento di Fisica e Scienze della Terra).

Using the stereomicroscope prior to study thin sections allows us to study all the parameters that allow to classify a rock from a mineralogical, textured and rock formation point of view. This phase produced some laboratory sheets that have led to observe and describe the main characteristics such as weaving, orientation and nature and shape of the clasts and their granulometry. The collection of these parameters makes it possible to classify type of rock through the rock classifications and reconstruct the formation (Wentworth, 1922; Wadell, 1935; Terry and Chilingar, 1955; Dunham, 1962; Folk, 1962; 1980). Sample preparation for the stereomicroscope study is a step in the procedure used to prepare thin sections. Initially, depending on the degree of consolidation, the sample with poor consistency is subjected to resin consolidation. Afterwards, the samples are cut by a diamond-cutting machine, in order to obtain slices of rock with the desired size of section. After cutting, the sample is treated with 600 grit silicon carbide abrasive particle to smooth and polish sample surface (Figure 2.3-2).

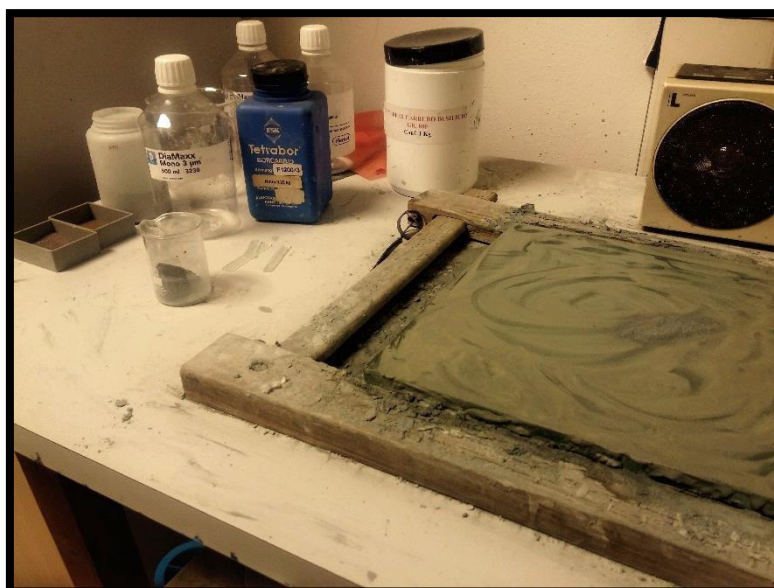


Figure 2.3-2: Final step of sample preparation to Stereomicroscope observation, when Silicon carbide abrasive 600 grit is used to smooth and polish sample surface.

The study of thin sections is necessary and can provide us an exact picture of sample minerals arrangement, texture, genesis, structure and granulometry. Identification of minerals under the polarized-light microscope is based on optical and morphological properties (Adams et al., 1988; Adams and MacKenzie, 1998; Barker, 2014). Among the mineralogical investigation methods, optical microscopy represents a methodology of great importance for versatility, excellent cost-benefit ratio and high information quality and quantity. 20 thin sections from different areas of the valley were prepared (Table 2-2). The thin sections concern the different lithologies found on the field. The thin sections of rock were obtained by cutting an extremely thin slice of about a couple of millimetres with a special saw. The obtained slices were polished and ground to a thickness of $0,01 \div 0,05$ mm. The sheets were, then, glued by balm of Canada between two slides. The resulting preparation had $2 \div 3 \times 4 \div 5$ cm size. Finally, polishing is carried out using the various polishers in the laboratory using polishing cloths and alumina powders or diamond pastes of 6,3 and 1 microns. These slides can be viewed under a petrographical microscope and analysed in both natural and polarized light.

Thin section sample	Lithology	Surface\ Outcrop	DMS Coordinates
1\Calc\3a	Sandstone	Surface	37°47'42.8"N 12°50'31.7"E
2\M1	Clastic	Surface	37°48'32.1"N 12°50'02.0"E
3\M1	Clastic	Surface	37°48'32.1"N 12°50'02.0"E
4\M3	Quarzarenite	Surface	37°47'44.9"N 12°50'51.4"E
5\M2	Quartzarenite	Surface	37°47'19.8"N 12°48'21.4"E
6\M4	Quartzarenite	Surface	37°47'29.4"N 12°48'46.6"E
7\CTRA	<i>Calcareous Crust</i>	Outcrop	37°41'57.9"N 12°44'32.3"E
8\AG3	Sandstone	Outcrop	37°46'06.6"N 12°47'41.3"E
9\M2	Sandstone	Surface	37°47'19.8"N 12°48'21.4"E
10\CZ4	Sandstone	Surface	37°46'17.5"N 12°47'28.3"E
11\Calc\2	Sandstone	Outcrop	37°42'56.8"N 12°43'28.6"E
12\Calc\4	Sandstone	Outcrop	37°47'18.3"N 12°48'00.3"E
13\Calc\3d	Sandstone	Outcrop	37°47'42.8"N 12°50'31.7"E
14\CC4\b	Conglomerate	Outcrop	37°47'44.1"N 12°50'33.3"E
15\Calc\1	Sandstone	Surface	37°47'32.5"N 12°51'21.9"E
16\CC2	Conglomerate	Outcrop	37°47'31.6"N 12°51'17.2"E
17\CC3\b	Conglomerate	Outcrop	37°45'13.7"N 12°46'12.3"E
18\CC10	Conglomerate	Outcrop	37°47'11.3"N 12°48'26.8"E
19\CC5	Conglomerate	Surface	37°47'18.1"N 12°47'60.0"E
20\CC3	Conglomerate	Surface	37°45'13.7"N 12°46'12.3"E
21\CC1	Conglomerate	Surface	37°47'44.8"N 12°50'55.6"E
22\TRAV	Travertine?	Surface	37°47'44.8"N 12°50'55.6"E

Table 2-2: the table shows main features of thin section samples

For the study of thin sections, I used an Optika petrographic microscope. The petrographic microscope has differences from a normal optical microscope and is distinguished by the presence of a polarizer. The polarizer is a filter placed between the light source and the glove table, which transforms the light from "parallel" to polarized; Polaroid filters are used for this purpose. If the light beam, incident on the sample to be analysed, is not polarized, you would have a vibrating beam in all directions of space that would hit the sample in many different directions. Erroneously, light direction makes it impossible to analyze thin sections objectively. Another part that differentiates the two microscopes is the presence of an analyzer. The analyzer is a filter placed between the lenses and the eyepiece which, when activated simultaneously with the polarizer filter, leads to the so-called extinction condition. The extinction is a property used by the microscope that uses light undulatory nature or, when the incident light ray is suppressed, it makes the extinction figure visible in the eyepiece as completely black because of the polar-

izing action perpendicular to the polarizer. The third difference between the two types of microscopes is the presence of a goniometer table. The rotary and graduated small table of objects (useful for samples rotating by observing them with different incident light angles), graduated in its perimeter, also allows making measurements of various types on the sample. Ultimately, when we look at our rock section with the polarizer alone we say that we are doing parallel Nicol observation, if we also insert the analyzer then we will make cross Nicol observations.

RESULTS

3 Results

The research work has been divided into four research themes (field recognition, sedimentological, petrographic and paleontological analysis). These are significant to be able to frame, from a geological point of view, the lithic industries found in the valley of the Delia River. These results are intended to be preliminary and to be a starting point for further research. In fact, the different research topics (sedimentology, petrography, paleontology) can provide further data and reflections on the area of study of the single themes. In fact, the results obtained provide an input to understand the different geomorphological processes that have taken place in the valley. The choice, of a multidisciplinary approach, compared to specialised study, is due to the fact that research on the Continental Quaternary in this area is very scarce and probably could only provide a partial vision. The multidisciplinary approach has allowed us to provide a geological map of the Delia\Grande basin. Besides, the geological survey describes various fluvial terraces, their stratigraphic relationships and therefore the choice of suitable outcrops for petrographic and sedimentological study. The sedimentological study has allowed the characterisation of gravels located on river terraces and the understanding the environmental aspect. The petrographic study has highlighted how the pebbles used for stone industry come from Terravecchia Fm. The different lithologies analysed give information on the geological evolution of this valley during Pleistocene. The petrographic analysis provides additional insights into the feeding basins of Terravecchia Fm. The paleontological study, even if general and descriptive, allows providing data on the faunal ensemble and the age of the terraces.

3.1 Geological Mapping

Extensive field mapping and detailed sedimentological analyses of outcropping sections have shown that the studied successions are characterised by a complex stratigraphic organisation. This chapter, therefore, describes the results of field activities, GIS analysis, and data processing of the elevations of fluvial terraces relative to marine terraces. The geological survey field is central to characterise different depositional facies and stratigraphic section outcrops. Log graphs, topographic detailed cartography 1:10.000 and 1:5.000 scale of the territory to detect the sedimentary successions\stratigraphic sections. Data processing allow to make a detailed geological map of lithological deposits in the studied area. The data collected in the field were processed by QGIS software. The use of GIS software has a crucial role in the spatial representation and analysis of geological data. The marine oxygen isotope record of Lisiecki and Raymo (2005) as a long-term framework for identifying likely times of strath cutting and channel aggradation or incision. In the absence of numeric ages chronology of the marine isotope record and sea level changes are used to the best approximation for terrace age.

3.2 Geological unit

In accordance with CARG Project (Geological Cartography) that involves the creation of geological sheets on a scale of 1:50,000 that cover the entire Italian national area. The lithological nomenclature used following the name of near sheet 619 “Santa Margherita Belice” (Di Stefano et al., 2013). The principal Geological Formations between Salemi and Santa Ninfa are listed and described below.

3.2.1 *Terravecchia Formation*

Terravecchia Formation (Schmidt Di Friedberg, 1965) is a composite, and still informal lithostratigraphic unit made up of conglomerates, sandstones, marls and clays (Basilone, 2012). These rocks have been dated to late Tortonian and early Messinian and interpreted as the sedimentary fill of quite different syn-tectonic basins located across Late Miocene Sicilian Foreland Basin System (Abate et al., 1999; Nigro and Renda, 1999; Gugliotta, 2010). Terravecchia Fm is formalised in the CARG project with its subdivision into three distinct members from the conglomerate Texture. From the lower side, polygenic orthoconglomerates are observed, which towards the top of the succession pass to para conglomerates, with rounded elements immersed in a sandy-clayey brown matrix (conglomerate member, TRV1). Towards the top we move on to quartzly sands, yellowish brown and/or reddish brown, with variable levels of lithic granules from incoherent to weakly cemented, which intercalate hairy levels and, in rare cases, banks of the metric thickness of sandstones with a similar composition. A mild oblique rolling can be found in such deposits. Sometimes in the association, thinly sloping conglomerate lenses, with flattened imbricated pebbles (TRV2 sandy member). The deposits of the sandy member pass laterally and upwards to clay marl with varying amounts of quartz sand constituting the third member (TRV3). The three members also represent three different depositional environments: the TRV1 indicates an alluvial plain, while the TRV2 a delta environment and the TRV3 an open marine platform environment.

3.2.2 *Gessoso-Solfifera Group*

The group of the "Gessoso-Solfifera " (G.S.G.) consists of deposits of gypsum, calcium sulfiferous, rock salt and other more soluble salts intercalated with terrigenous deposits of the upper Miocene age. In Sicily, this complex is divided informally into two units (Pasquasia and Cattolica Formations). Besides, two evaporitic episodes distinct from the Messinian salinity crisis: a lower evaporitic complex with selenitic gypsum of Cattolica (AG) and a superior evaporitic complex, identified with gypsum of Pasquasia (Bertini et al., 1998; Catalano et al., 2013b). This unit includes all the deposits related to the Messinian salinity crisis *s. s.*, and ranks between 5.96 and 5.33 Ma (Manzi et al., 2011; Roveri et al., 2014) while the subdivision into the two complexes is evidenced by an erosive and depositional intra-Messinian discontinuity. This discontinuity is attributable to a central phase of tectonic deformation that has affected various geodynamic contexts, and that coincided with the acme phase of the salinity crisis. Deposits of G.S.G. are exposed in Salemi and Santa Ninfa district (Figure 3.2-1). At Santa, Ninfa is evident intense karst phenomena on evaporitic rocks (e.g. caves in gypsum).



Figure 3.2-1: Outcrop gypsum in Salemi Area (M. Porticato, Salemi).

3.2.3 Trubi Formation

This unit has long been known in literature because it has been found widely in Sicily and Italy, now formalised (Delfrati, 2007). The dominant lithotypes are made up of marly limestone rhythms and white *globigerine* marl, in parallel flat layers of varying thickness from 30 cm to 1 m. The lithotypes show an angular discordance resting on the different units that form the Sicilian chain. Their basis marks the return of marine conditions in the Mediterranean after the Messinian salinity crisis with a pelagic environment (Roveri et al., 2014). Often this unit can be found resting on the articulated paleotopography of Messinian with an onlap geometry. For example, along with the active fronts of the chain orogenesis and involved in the deformations

themselves and with a syndepositional basin. Locally, there are bodies of megabreeds with lithoclasts of Triassic age, deriving from phenomena of collapse from the sides of escarpments with tectonic control (Vitale, 1990). Their thickness is about 40-50 m and can reach about one hundred meters when underground megabreeds are present. The abundant foraminiferous microfossils and the associations with nannofossils allow a dating from Zanclean to Piacenziano lower (Thunell et al., 1991). The depositional environment is pelagic, with occasional debris inputs from adjacent escarpments. These deposits show small outcrops in Santa Ninfa Area and various zone at Northern of the basin.

3.2.4 Marnoso Arenacea del Belice formation

The Marnoso Arenacea del Belice formation (Ruggieri and Torre, 1989) consists principally of clay and marly clays with the presence of quartz sands with an influential series of biocalcarenites, with evident stratification from parallel to inclined planes, passing sideways and upwards through sandy blue-grey clays, with limestone interlayers. The various association of calcareous nannofossils allows going back to an age referable to the middle and upper Pliocene (Piacenzian Gelasian stage). In the lower part of the formation, there are thick interlacements of turbid hybrid sandstone (BLCa). The sandstones have Normal gradation at the base, followed by parallel flat rolling and rarely crossed upwards. In some circumstances, the layers are sorted into a predominantly quartz lower portion and a carbonate upper portion. In the upper-middle part of the formation, biocalcarenite and molluscs (BLCb) layers are present. These layers are organised in banks from 0.5 to about 2 m thick, often graded, containing abundant shells of disjointed bivalves (pectinids, ostreids, e.g.). Overall facies associations are indicative of deposits of temperate carbonate platform produced in high structures that constituted the outer flank of the Pliocene basin of Belice. They laterally passed to the furthest terms of the BLC. Above these soils are cut off by abrasion surfaces and are covered, in slight angular discordance, by Quaternary deposits (Ruggieri and Unti, 1974). In the study Area, this formation is exposed in several

outcrops in the northern side of Salemi, from E-W in M. Rose (Figure 3.2-2). In several zones around Salemi city, orogenic movement shows the Gessoso Solfiera Group Thrust to Marnoso Arenacea fm deposits (Figure 3.2-3).



Figure 3.2-2: Marnoso Arenacea Fm. outcrop in Mount Rose (Salemi, TP.)



Figure 3.2-3: Tectonic contact between Gessoso Solfifera Group (A), Marnoso arenacea Fm (B) and Terravecchia Fm (C)

3.2.5 *Marsala synthem*

This unit was used to unify the calcarenite deposits, sands and conglomerates described in Western Sicily by Ruggieri et al. (1975) as Marsala Calcarenite and attributed to the interval that extends from the upper part of Emiliano to Sicilian (Ruggieri, 1978). The common lithofacies are biocalcarenes with molluscs, passing through biocalcarenes in thick banks, often combined, separated in some cases by thin layers of marl and sands (e.g. Figure 3.2-5). The lower limit of the unit in the area considered is an unconfirming surface area on Pliocene deposits and, in small areas, directly on the Mesozoic substrate. The total thickness of the deposits attributable to this unit varies from 20 to 50 m. The environment is mainly coastal, passing through an open platform, as indicated by pelitic deposits. Age is attributable to the upper part of the Lower Pleistocene (Emilian *p. p.* - Sicilian). This formation exposed as a flat surface in the southern Delia\Grande Basin. These deposits are cut from Delia\Grande river and Trinità lake and on hydrographic side form a Castelvetro plateau (Figure 3.2-4).



Figure 3.2-4: Road cut of calcarenite deposits of Grande Terrazzo Superiore (G.T.S). In square frontal view of calcarenites, in this point sample, Calc\2 was sampled

Quaternary deposits are also exposed along the river channel and probably rest in discordance on the silty member of Terravecchia Fm (Figure 3.2-5). Sandstone deposits emerge discontinuously from C\da Bovara to C.\da Pozzillo sites. Sandstone deposits, sometimes rich in quartz, are sometimes on the surface because of the intense human processing (artificial lakes, agriculture) up to 2 metres deep.



Figure 3.2-5: Calcarenites outcrops in C\da Bovara (near airfield). The picture shows across bedding stratification.

3.2.6 Quaternary Continental deposits

These deposits are exposed along the Grande\Delia River. The conglomerate layer, with a thickness of about 1-1.5 meters, with gradual contacts sometimes even more markedly erosive contacts is placed above the calcarenites deposits. These deposits emerge along the flat areas of the river terraces up to about half of the basin. The conglomerates are well cemented and not very sorting,;sometimes a calcite crust covers the clasts. Moreover, above this conglomerate level, fossils of *P. mnaidriensis* are sometimes included in this conglomerate matrix (Figure 3.2-6).



Figure 3.2-6: Conglomerates from outcrops c\da Pozzillo. A) Zenit photo of conglomerates surface and pebble cluster form (blank line). B) lateral photo of contact erosive from sandstones and conglomerates (black line) and inversal grading.

Gravels are polygenic and of variable size, with predominant sedimentary clasts, mostly rounded, of variable diameter and with a sand-sand-clay matrix of brown colour; the presence of pebbly sands with a clayey clay matrix with a bland depositional stratigraphy (Figure 3.2-7) in a fluvial environment.



Figure 3.2-7: conglomerates fluvial deposit with tractive form (line), to the top conglomerate turn in a matrix-clast supported (c\da Bovara)

The composition of the clasts, relatively homogeneous, is represented by all the lithotypes of the substrate with the prevalence of siliceous and/or arenitic siliciclastic (Quartzarenite). The fabrics are varying mainly from gravels to sandy-gravels. Along the river channel, the nature of the pebbles is a function of the rocks emerging in the paleo-basins (Figure 3.2-8). The terraced alluvial deposits are located at different heights on the current banks of the entire hydrographic network, slightly inclined towards the valley and arranged in several orders, not numbered in the current geological literature. The lower surface is discordant and erosive on the various substrate terms. In the absence of absolute chronological dating of these terraces, they have been dated to the Pleistocene-current by stratigraphic position. Finally, deposits are usually covered by soils.



Figure 3.2-8: several examples of gravels outcrops: A) calcarenites block, B) quartzite pebbles and calcarenites, C) Quartzarenites pebbles-gravels D) gravel-pebbles polygenic

Finally, result data sampling is the draft a geological map of Grande\Delia River Basin after several geological field surveys. The geological map is based on 1:10.000 topographic map and for this reason, some outcrops are not visible (e.g. outcrop of paleo soil and some sandstones). The principal geological unit described above are plotted. The scale of the geological map in Figure 3.2-9 is 1:125:000, and it is a result of several mapping fieldworks based on 1:10.000 topographic maps. Topographic maps used for the geological survey are described in material and methods chapter.

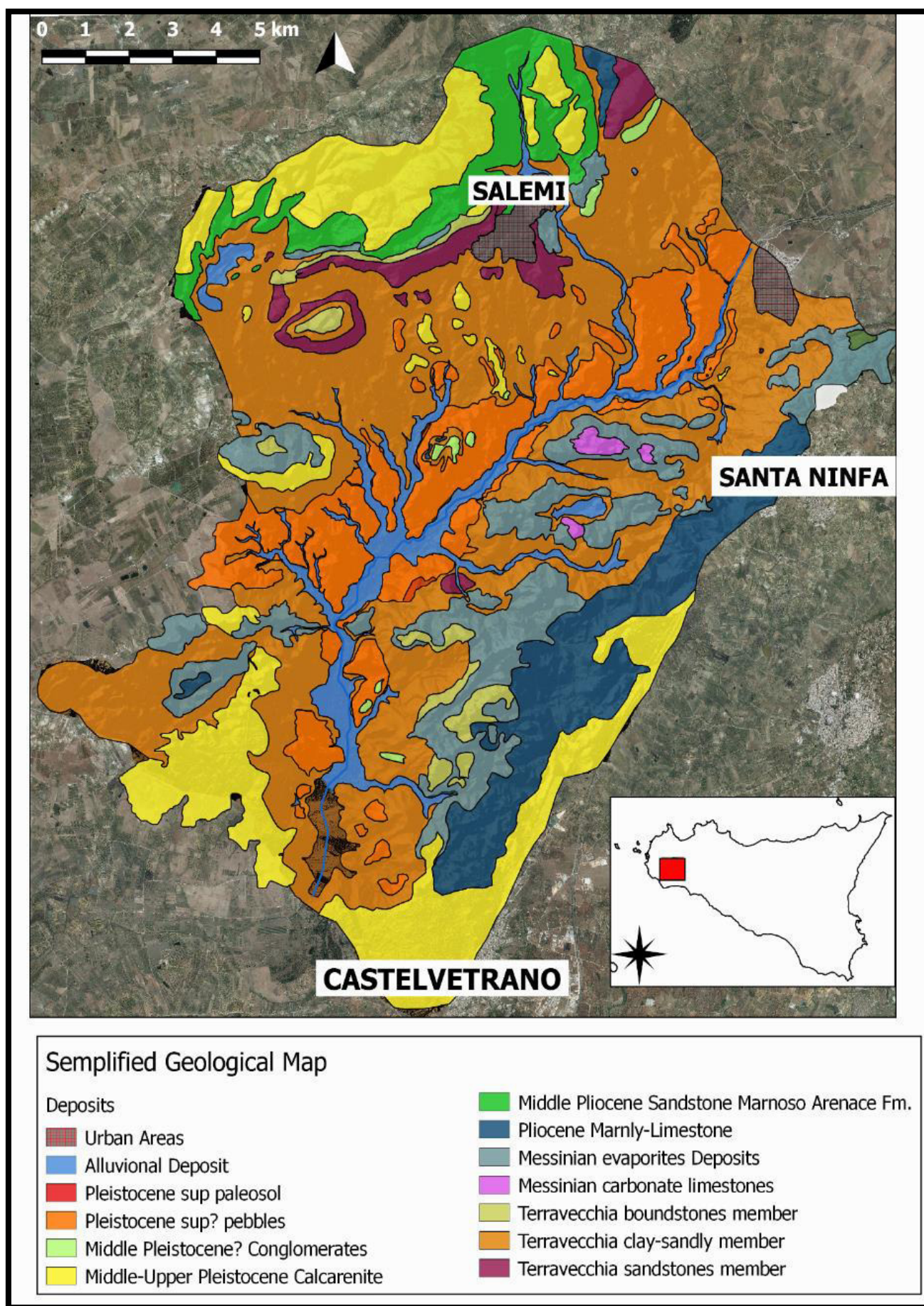


Figure 3.2-9: Geological map of Grande\Delia River Basin 1:125.000 scale.

3.3 GIS Analysis

The data collected during the mapping phase of the Delia-Grande river valley territory were computerised and analysed using the Qgis software. The Data processing starts from DEM provided by the Region of Sicily with a definition of pixels 2x2 m (Figure 3.3-1). The Dem has considerable importance because it allows visualising a lot of environmental data. For example, in the East of Salemi mountain relief was affected by a remarkable erosive action that led to the formation of two isolated hills. The analysis of spatial elevation of the hillslopes along river catchment allowed the distinction of the morphologic discontinuity of the relief and had been used to identify fluvial terraces

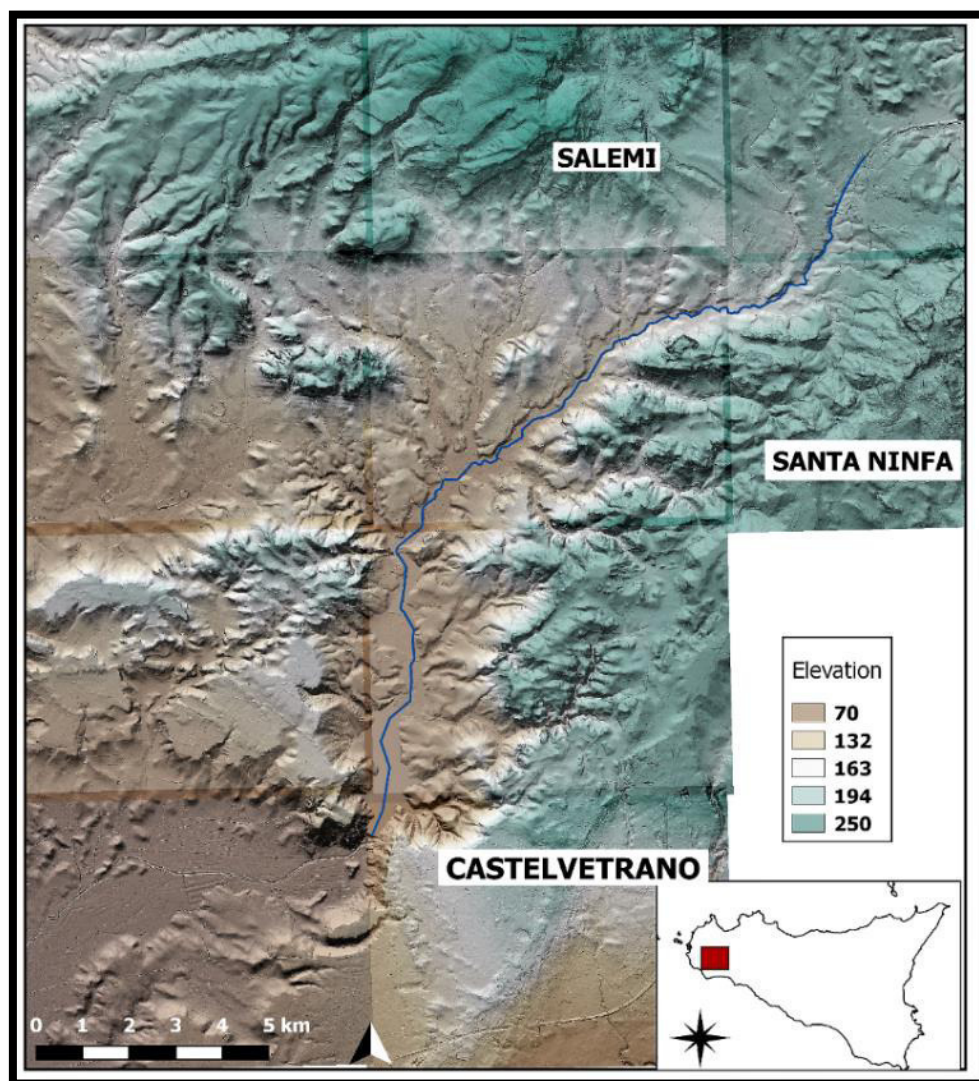


Figure 3.3-1: DEM map of Delia\Grande valley modified from source data of Regione Sicilia (SITR Department).

Furthermore, the plugin Cs Map Marker in the Qgis library was used to identify river terraces. The plugin employs elevation data, the curvature of profile and slope to make a shaded relief topographic map (Kennelly 2009). CS topographic map represents valleys by blueish colour and ridges by reddish colour thanks to the curvature profile; the river embankments are highlighted (Figure 3.3-2). Moreover, observing the figure (Figure 3.3-2) terrace scarps are evident along the course of the river and divide floodplain at terrace surface with angles of about 20-30° and are highlighted by the dark brown colour. The scarps present to the North of Salemi (Sandstone deposits) and the East of Santa Ninfa (evaporitic Unit) with the formation of more obvious slope breaks are the result of the response by different lithologies to erosive action. The use of the QGIS software makes it possible to identify various geomorphological units. Among the deposits that give rise to morphological contrasts are the level of the Marnoso - arenacea del Belice Fm. and the sandstones of the lower Pleistocene. In particular, outcrops of Pleistocene sandstone have layering almost sub-horizontal, the morphology is often characterized by tabular reliefs that can be interpreted as structural surfaces (Monaco et al., 1996; Tortorici et al., 2001). This relief is cut by a series of streams that feed the Delia\Grande river basin. The levelling surface can be considered as the last depositional phase of this basin. A second unit is the Santa Ninfa mountain range with gypsum karst landscapes like caves and surface karst. Hillslope and terraces landscape are present, between units, with the Terravecchia Fm. is a substrate for river dynamics during the Quaternary. The fold-shape is actually imprinted in the planform of the derived morphostructures.

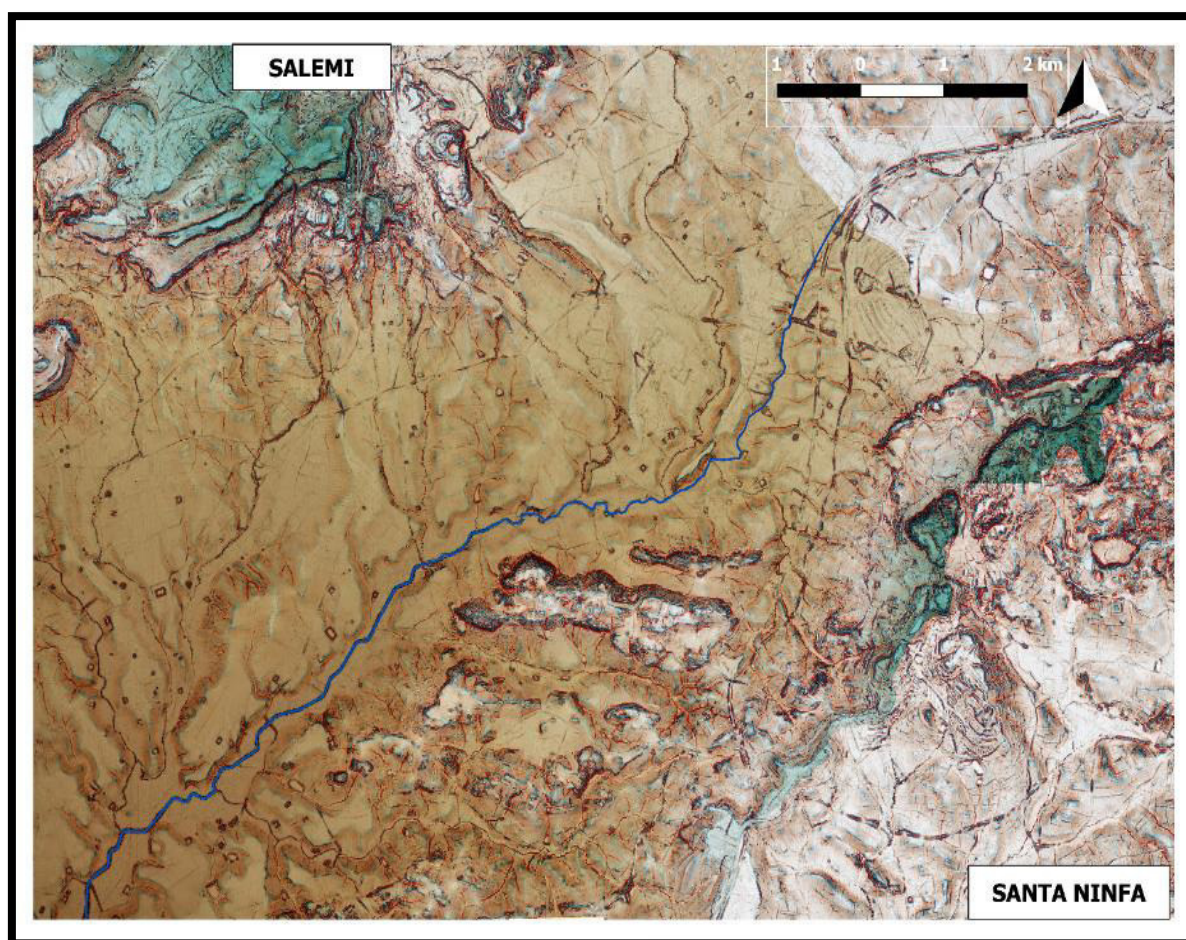


Figure 3.3-2: CS topographic map using CS map Marker plugin. Maps showing break slope and identified three morphostructure: plateau of Salemi; Evaporitic Hills of Santa Ninfa and terraces of Delia\Grande River. The Scale of map is 1:50000.

3.3.1 Terraces Fluvial

This paragraph shows the results of the mapping of river terraces through GIS modelling and fieldwork. Through the manipulation of the dem with appropriate plug-ins in QGIS (Geomorphology Analyses, CsMap Marker, Qprof) it was possible to define the primary geomorphological elements of the area. The CS map marker shaded relief map is useful to identify, correlate and characterise the geometry of river terraces (e.g. slope, incision) an also to analyse the morphologic characteristics of the studied area. Furthermore (Figure 3.3-3), thanks to the Cs map marker plugin, it is possible to reconstruct the slope edge of the river terrace and the subsequent erosion phase with the formation of the current floodplain. The scarps are yellow with angles of 25-30°. Blue and red colour identified breaks slope and have angles of even more than 70°.

The **Errore. L'origine riferimento non è stata trovata.** shows the presence of at least two river terraces. The oldest in some places is on the left of the river, covered by colluvial deposits. While, on the right of the river the scarps are more evident, and they allow to identify the terraces surfaces over incised by the Holocene river system.

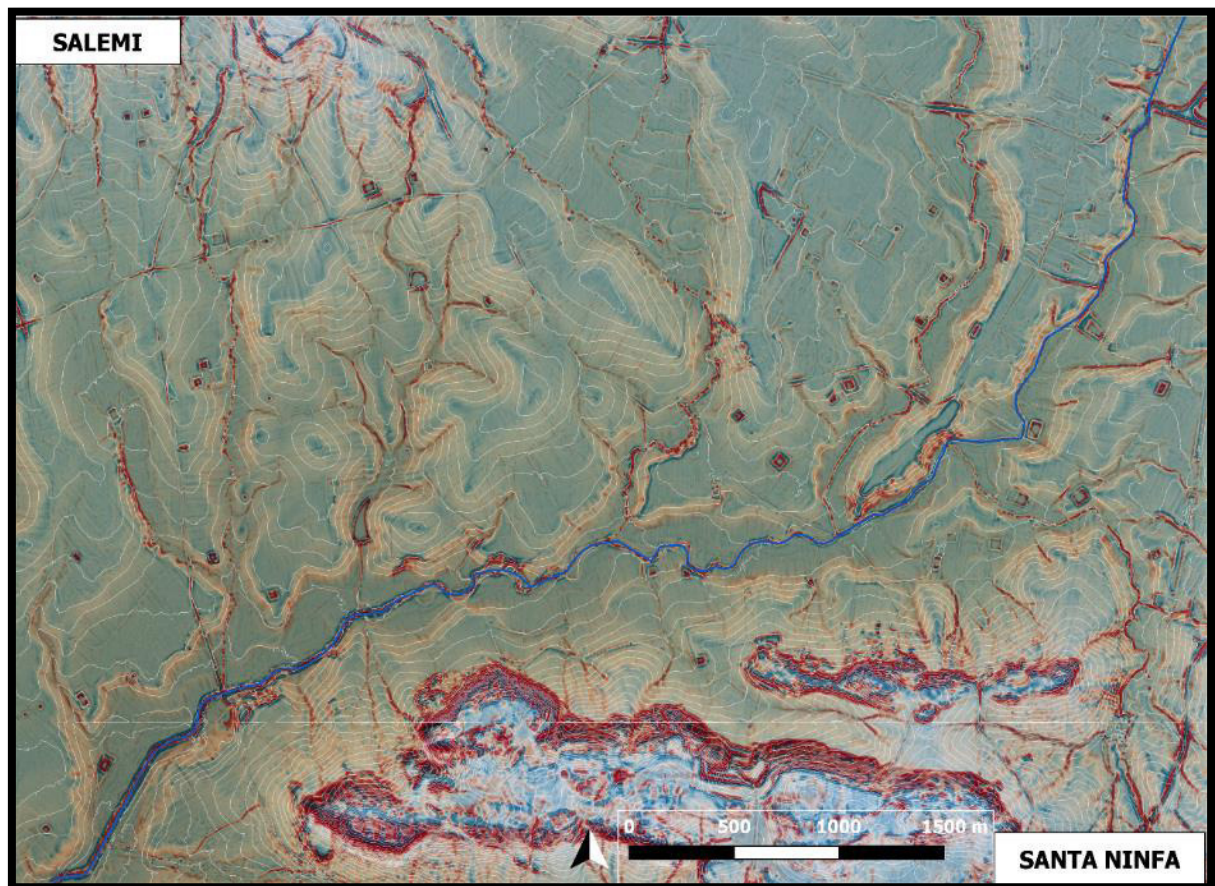


Figure 3.3-3: Zoom to C\Da Bovara where the difference between scarps and surface is most evident. Red colour identified evaporitic hillside relief (map elaborated from CS map)

The Longitudinal profile shows progressive decrease in slope downstream, the profile has a characteristic concave-up shape and reflects both the geological and tectonics of the basin in Figure 3.3-4. Concave-up long profiles commonly are associated with a river in the "graded" condition (Pazzaglia et al., 1998; Zaprowski et al., 2005). This profile could have steps, called knickpoints, which can be originated by differential erosion controlled by lithological parameter (Duvall et al., 2004). knickpoints is a crucial point because show a modification of flow

regime and knickpoint can migrate upstream and lead to the formation of a river terrace (Whipple et al., 2000; Bianca and Caputo, 2003).

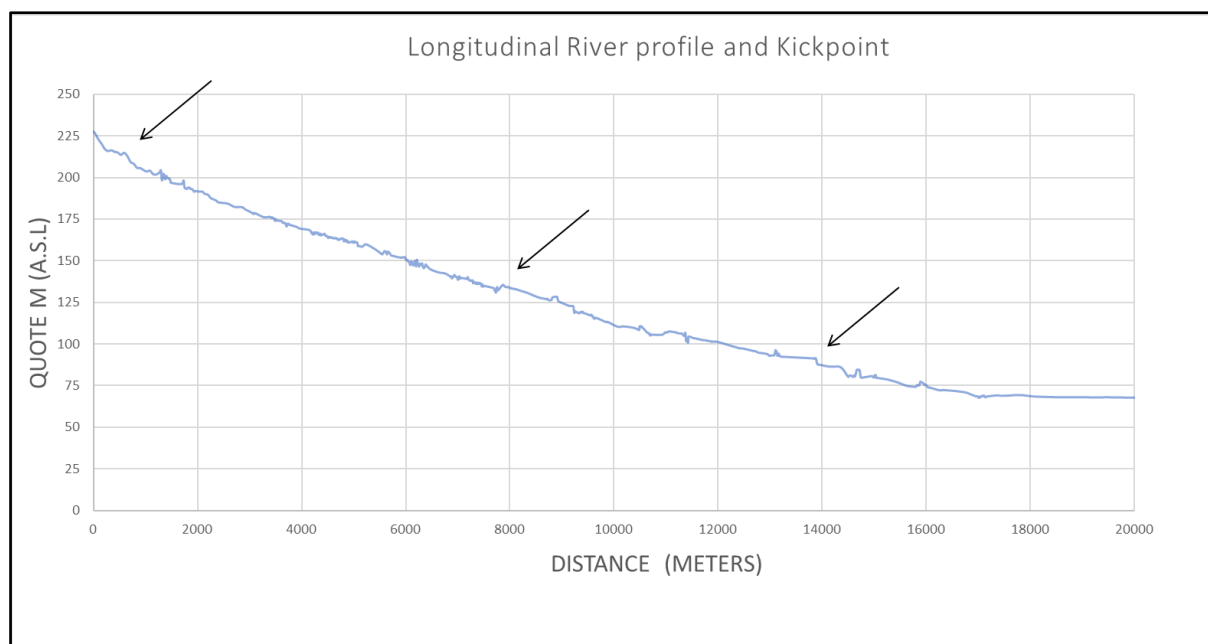


Figure 3.3-4: Longitudinal profile of Grande\Delia River to Trinity dyke. The arrows indicated a Kickpoint and identified a change of level base

Using Qprof plugin ten cross-section across the floodplain with aims to investigate Terraces Fluvial. Qprof is a QGIS plugin for the generation of topographic and geological profiles. Geological data, such as stratification, attitude and geological traces, can be projected on the profile (Alberti et al., 2016). The cross-section is very significant to reconstruct the palaeogeographic development of the study area. The analysis of the cross section identifies at least three orders of terraces (T1-T2-T3) that develop from Gibellina station to the Trinity dyke in Figure 3.3-5. The Figure 3.3-5 Plot graph distance (m) vs Elevation of fluvial terrace with a linear regression that indicates the "mean of trend" of the different quote ranges. The first terrace T1-Bovara extends from 220 to 192 m with a mean elevation of 206 m. Terrace T2 Fiume Grande has an initial elevation from 180 m to 118 m with a mean altitude of 146 m. The terrace Pozzillo T3 has an elevation of 110-74 m, with an average value of 91 m while the terrace GTS 174-138 has an average elevation of 160 m. The graph shows that all four terraces have a constant incli-

nation. This slope is recognised in south-western Sicily and is linked to the orogenetic movements that develop in the basin with a tilt towards the sea (Bonomo et al., 1996; Barreca et al., 2014; Di Stefano et al., 2015; Di Maggio et al., 2017).

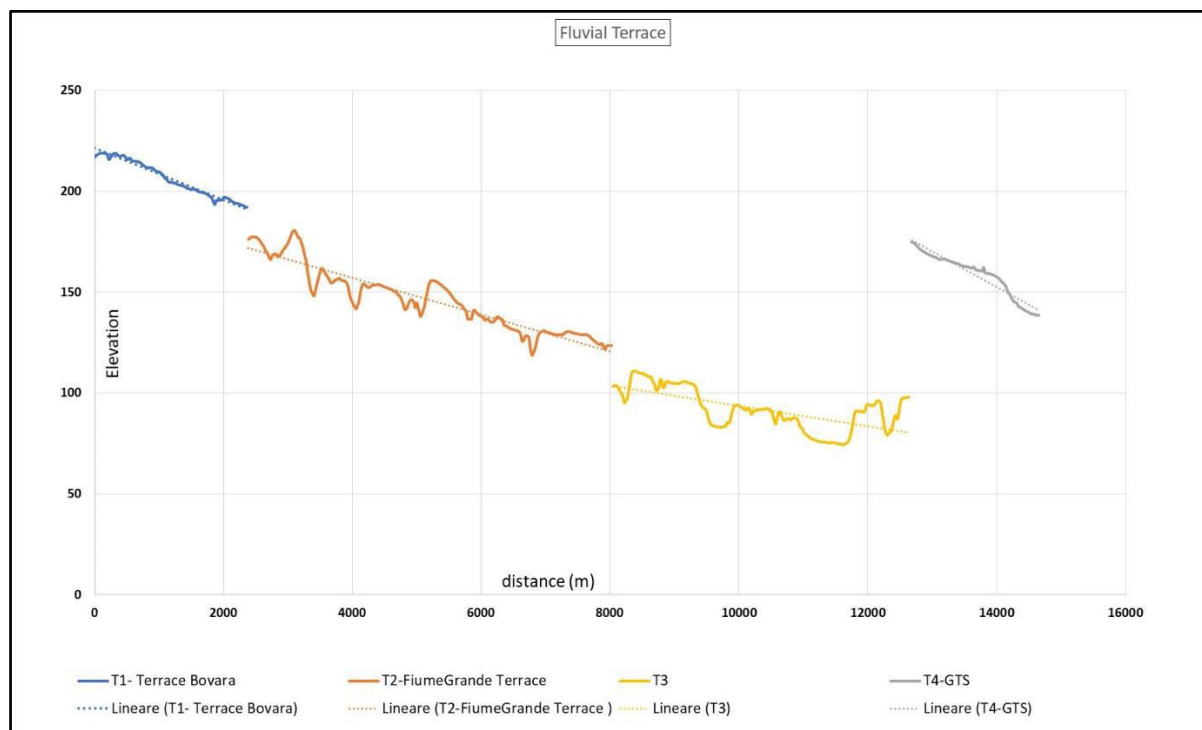


Figure 3.3-5: Plot graph distance (m) vs Elevation of the fluvial terrace. Elevation quote extract from DEM

The sections are shown in Figure 3.3-8 and Figure 3.3-9. The lithological sequence is probably uniform in the cross sections from 1 to 8. In section 8-9 geological survey do not have outcrops evidence of a calcarenite\conglomerates deposit but an overgrowth of fluvial deposits (silt. sand). Usually, the Terravecchia Fm. deposits are overlain by 1- to 2-m thick successions of calcarenite, 1- to 2 m of conglomerate and at top fluvial gravel deposits. The cross-section shows the classic morphology of a river terrace. The flat surface is connected to floodplain with a scarp (Figure 3.3-6, Figure 3.3-7). It is also possible to follow the development of the different orders of the terraces. Also, most of the position of terraces do not coincide in the right and left hydrographic sides. Probably due to the different erosive action developed on the opposite banks: the development of terraces is not symmetrical and is also the response to the tectonic situation of the river Delia-Grande basin (Figure 3.3-9 and Figure 3.3-8). Only terrace II appears

to have been maintained on both sides. The river along its route makes significant changes of direction E-W to N-S (Figure 3.3-10). Change of fluvial pattern corresponds to the structural geological complexity of the area with a system of fold and thrusts and transpressive regional faults (Abate et al., 1998; Nigro and Renda, 2002; Napoli et al., 2012; Barreca et al., 2014). As a result, the sedimentary processes connected with the formation of a river terrace on the side a deposition and formation of large terraces, while on the other side erosive processes created the formation of small terraced surfaces. On the hydrographic left there are also phenomena of "Alluvial Fan" with the formation of olistostromes (Catalano et al., 2002; Festa et al., 2016). Deposits can also be eroded by the fluvial action itself (Blum and Törnqvist, 2000; Garfí et al., 2007; Nesci et al., 2012; Fidolini and Andretta, 2013).

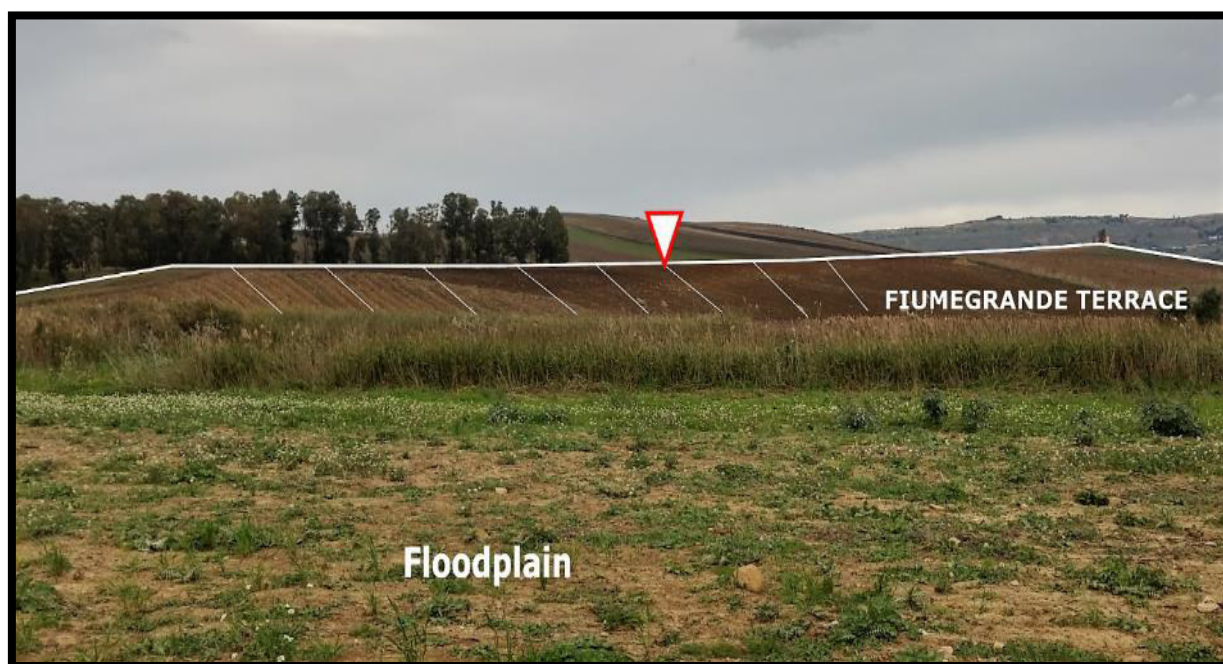


Figure 3.3-6: fluvial terrace in C\da Fiumegrande (blank line), Triangular symbol indicated the location of *P.Maidriensis* fossils.



Figure 3.3-7: Panoramic overview of Grande\Delia River with the result of plio-Pleistocene tectonic and formation of fluvial Terrace (triangular symbol indicates terrace\scarp line) from C\da Bovara airfield to Santa Ninfa

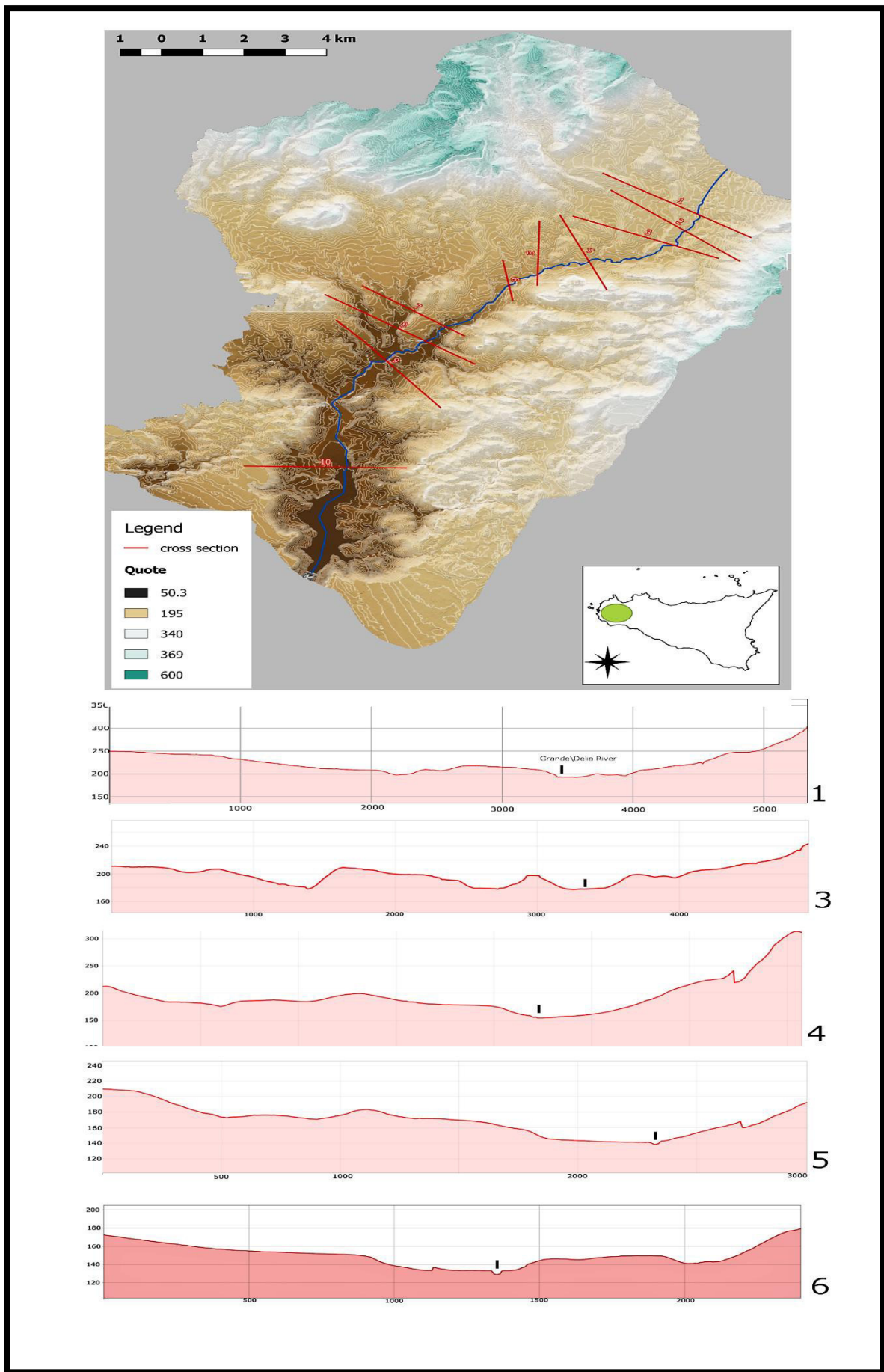


Figure 3.3-8: Topographic cross-section along Grande/Delia River (from 1 to 6).

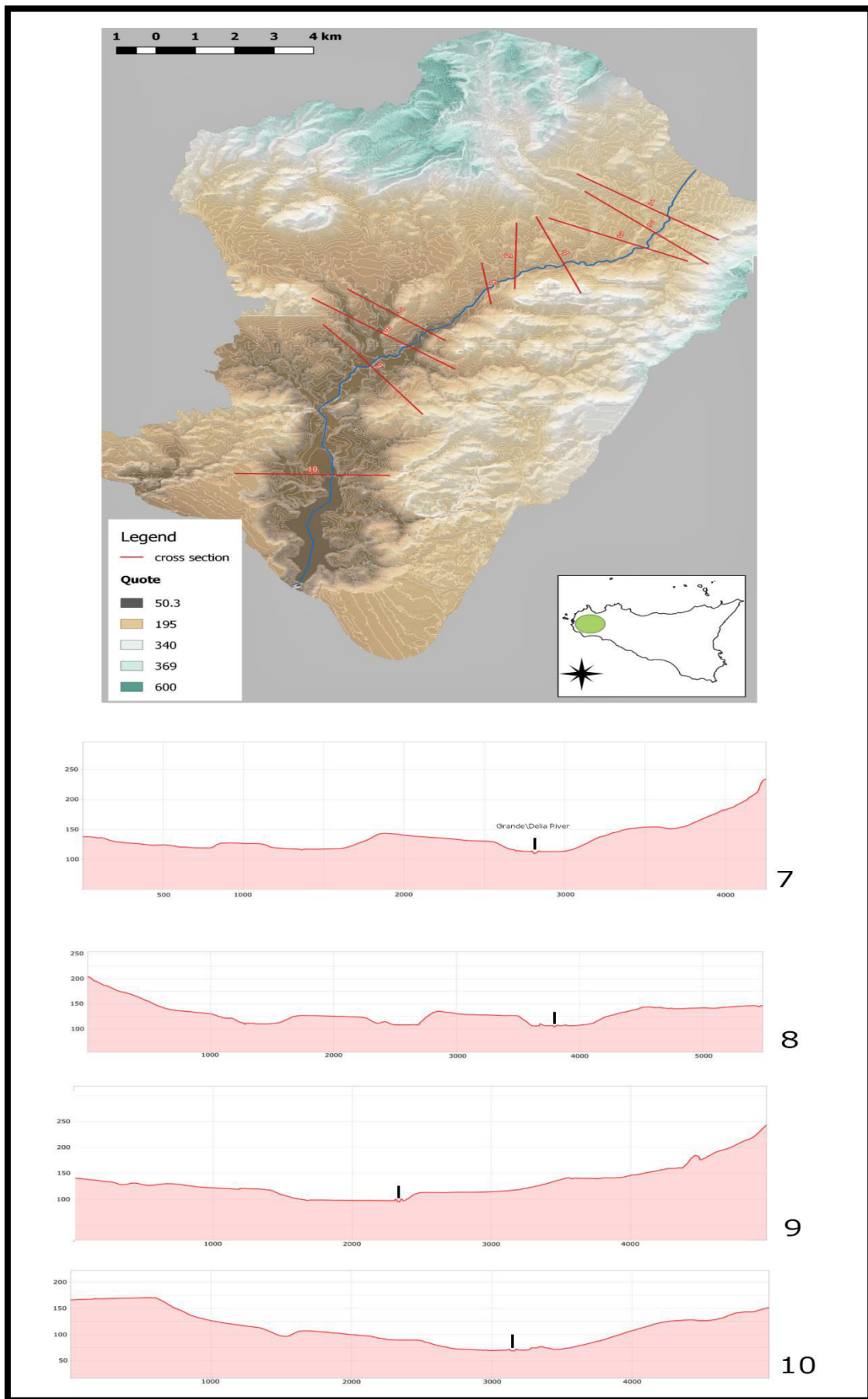


Figure 3.3-9: Topographic cross-section along Grande\Delia River (from 6 to 10).

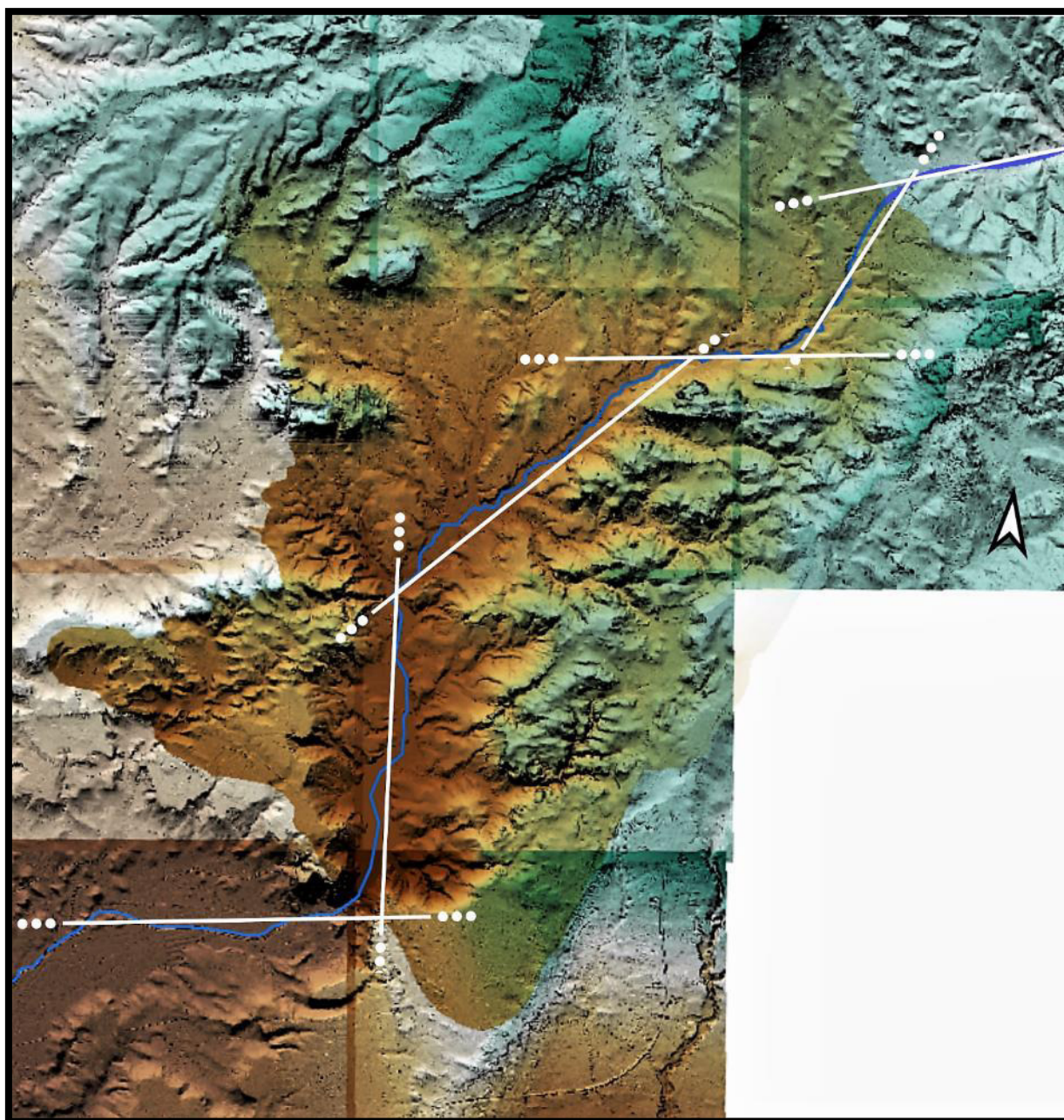


Figure 3.3-10: modification in river flow patterns with the imaginary structural line (blank line).

3.4 Outcrops

The study of the area provided the geological survey of detail on the scale 1:10.000. Besides, to classify and code terrigenous deposits the classification scheme of Miall (Miall, 1978; 2006) has been used. Lithofacies classification is based on bedding, grain size, texture and sedimentary structures. In the research area, there are colluvial coulter, debris conoids and small landslides. Colluvial deposits, if presents, usually are placed in place by different depositional cycles, are formed in precise prevalence by a loamy material with sandy-gravelly structure, more mainly located at the base of the same levels. The two outcrops have different facies thus a result of different sedimentary processes. The outcrops studied have a thickness from 1 to 3 m and the lithology are composed by sand and conglomerates layer. There are different sedimentary structures between two outcrops. The S1\M7 outcrop is interpreted as a paleochannel of an alluvial fan, the S7\M5 is interpreted as a braided channel fluvial style.

Outcrop: S1\M7

Location: FiumeGrandotto.

The S1\M7 site is located on the left side of Grande\Delia river (C\da FiumeGrandotto Figure 3.4-1). A natural cut on the slope allows the observation of a 60 m long section with a thickness of about 3 m with sandy-silty levels at the bottom, a pebble layer and on the top a silt level with organic soil (Figure 3.4-1).

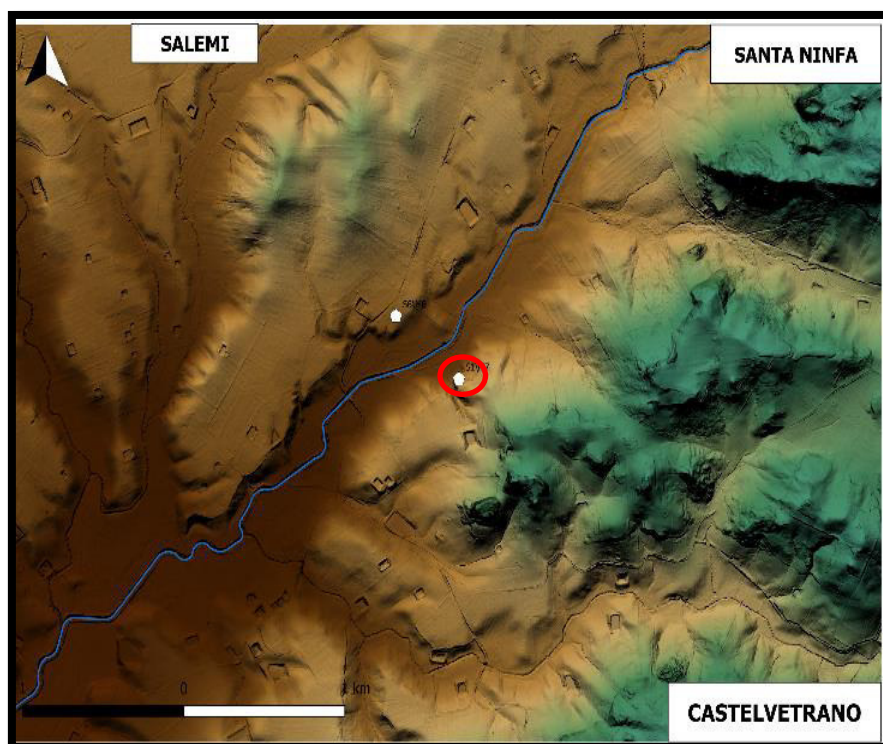


Figure 3.4-1: Location of S1\M7 outcrops sample (in red circle) other symbol is the location of s6\m5 sample.

Sedimentary graphic log drafts the stratigraphic section (Figure 3.4-4). The silty, sandy basal level (thickness of up to 1.5 m), shows well-sorted layers, with a sandy-silt alternation with parallel flat stratification with an E-O strike with dips of about 20° with carbonate concretions. The sand level is cut off from the top by an erosive surface. Above the erosive surface, the conglomerate layer is made up of pebbles of various lithology with a prevalence of Quartzite and Quartzite with a mean grain size of about 61 mm (B-axis). Grain size goes from coarse to very coarse and poorly sorted deposits and plane-parallel lamination. The pebbles have good

roundness and sphericity whit blade shape. The matrix is made up of very coarse sands and pebbles. The pebbles are oriented at the base to the morphology of the paleochannel, in the central section of channel an imbricated orientation, finally are with pebbles cluster structures. Pebbles cluster formed when pebbles in the course of transport are stopped by obstacles such as cobbles or boulders protruding from the river bed (Dal Cin, 1968b). The morphological characteristics are described in the paragraph of the morphometric analysis. In summary, the pebbles have a sphericity index of 0,67 (min 0,38; max 0,86) and flatness index 0,6-0,8. Conglomerate present at the top a sharp planar surface pass up clay-silty layer with massive texture and pedogenic (Figure 3.4-3) forms. Furthermore, using scheme of Miall (Miall, 1978; 2006) the outcrop is debris flow lithofacies clast-supported gravel (Gci). This Lithofacies is typical of Gravel-Bed Braided River with Sediment-Gravity-Flow Deposits (Figure 3.4-3).



Figure 3.4-2: S1\M7 outcrops.



Figure 3.4-3: a particular of the morphology of paleochannel.

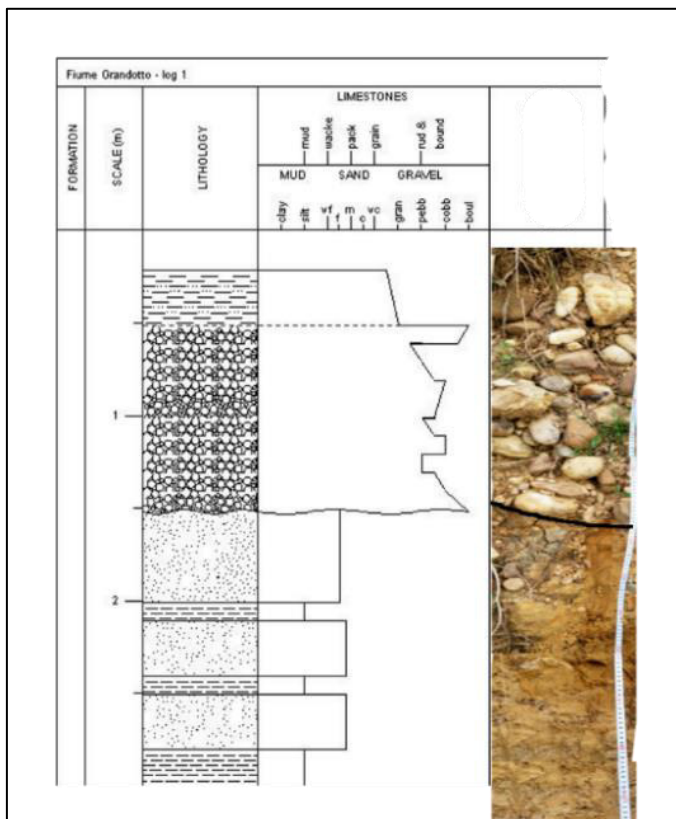


Figure 3.4-4: Graph log of the S1\M7 outcrop.

Outcrop: S7\M5

Location: C\da Bovara, airfield.

The site S7-M5 is located on the right side of the Delia\Grande River in C\da Bovara (Figure 3.4-5). A natural cut with the exposure of a 10 m long section with a thickness of about 1.5 m of a deposit formed by a sand\silty level at the bottom, a pebble layer and at the top there is a colluvial cover with organic soil (Figure 3.4-6).

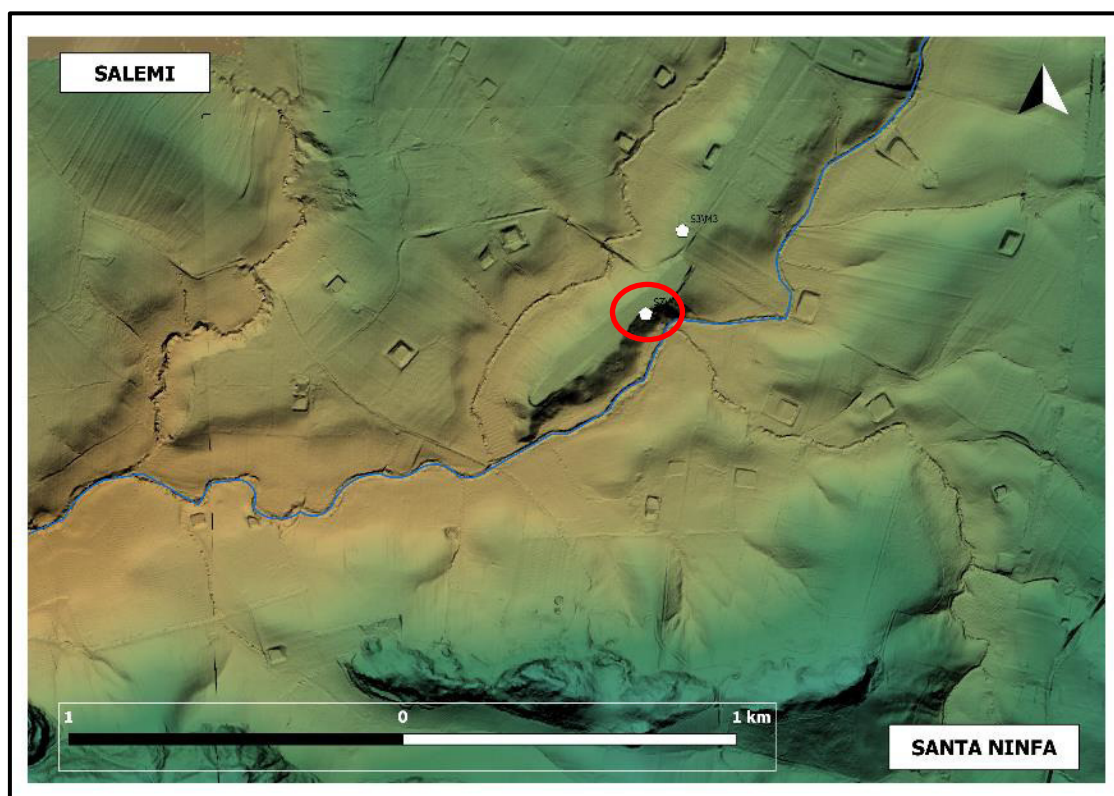


Figure 3.4-5: Location of S7\M5 (in red circle) and S3\m3

The lower sand\silty layer shows a massive texture apparently structureless. Conglomerates layering is made up of pebbles of various lithology with a prevalence of Quartzite and Quartzite with a mean grain size of about 47,91mm (B-axis). Layer Granulometric is from coarse to very coarse pebbles and moderately sorted deposits with a bedding plane-parallel orientation (Figure 3.4-7). The pebbles have good roundness and sphericity with blade shape. The matrix is made up of sand coarse. Conglomerates texture is clast-supported. The sedimentary structure has

pebbles\cobbles imbricated orientation and pebbles cluster structures. Pebbles cluster formed when pebbles in the course of transport have been stopped by obstacles such as cobbles or boulders protruding from the river bed (Dal Cin, 1968b). The morphological characteristics are described in the paragraph of the sedimentological analysis. In summary, the pebbles have a sphericity index 0,72 (min 0,44; max 0,94) and flatness index 0,7-0,9.

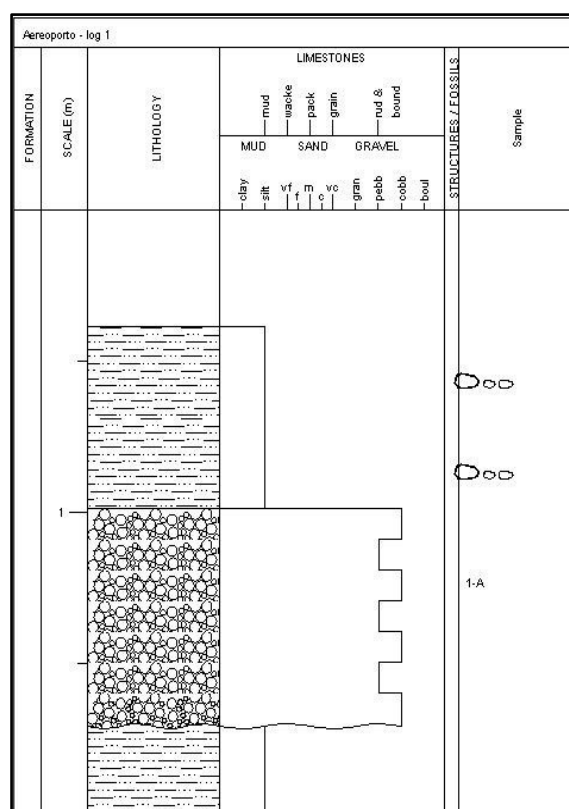


Figure 3.4-6: Graphic log of S7\M5 outcrops.

Furthermore, using the scheme of Miall (Miall, 1978; 2006) described lithological and sedimentary structures characters allow us to consider this deposit as the sedimentary record of a fluvial environment. The environment is dominated by an intermittent flow of variable energy, capable of transporting and depositing sediments with sandy, gravelly and pebbly granulometry. A sedimentation environment is characteristic of alluvial plains produced by coarse water-courses characterised by braided canals Figure 3.4-8.



Figure 3.4-7: conglomerate layers of the S7\M5 outcrop, white line shows the plane-parallel orientation.



Figure 3.4-8: The panoramic overview of c\da Bovara terrace showing main stratigraphic feature. arrows indicate the S7\M5 sampling site.

3.5 Paleontological assemblage

During my research project a preliminary report on fossil large mammal remains found in the study area has been done. These remains are now stored at the the headquarters of “Santa Ninfa Cave Nature Reserve” (Rapinzeri Castle, Santa Ninfa, Trapani). The material is almost unknown, except for some remains (Accardo, 1997; Forgia et al., 2014; Sineo et al., 2015). In this first analysis, species attribution has been possible through the direct study on the sites and thanks to the collaboration of Prof. Benedetto Sala and Dr. Claudio Berto (University of Ferrara, Dipartimento di Studi Umanistici, Sezione di Scienze Preistoriche ed Antropologiche) who have made available the comparison collection stored in the Department. The remains have been determined by means of comparison tables and bibliography data already mentioned in the introductory chapter. *Taxa* recognition was carried out through the application of the methods described and applied by various authors (Schmid, 1972; Pales and Garcia, 1981; Hillson, 1992). For the morphometric study, instead, the methodology described in Von den Driesch (1976) has been applied (see Appendix C). The remains come from different sites distributed along the route of the river bed of FiumeGrande\Delia river and all located on the same flat surface with extensive deposits of gravel at altitudes of 120-140 m (Figure 3.5-1).

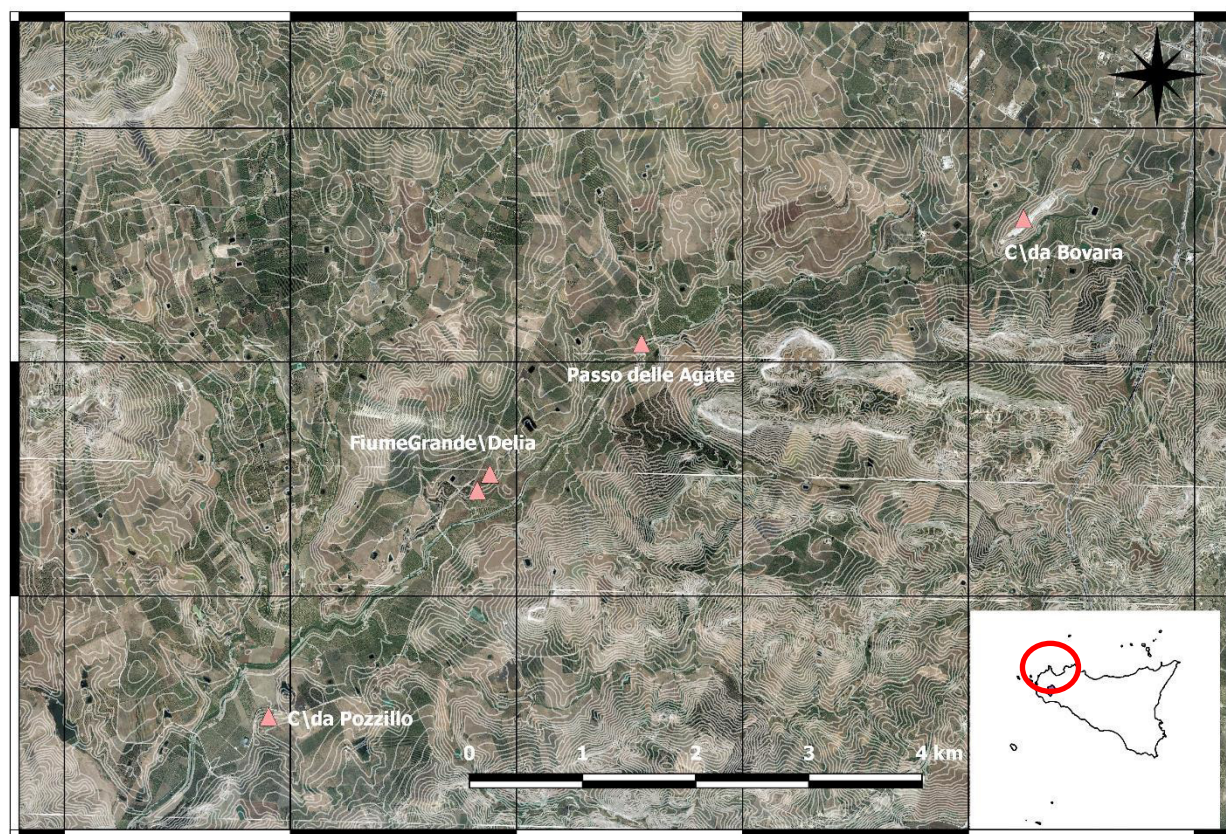


Figure 3.5-1 paleontological site ubication along FiumeGrande\Delia river.

The first site (FiumeGrande\Bovara, FGB) is located on the right side of the river in an area between the district of Bovara (airfield) and the district of FiumeGrande has already been mentioned in literature as indications of the discovery from land collection and recognized as fossils of the *Palaeoloxodon mnaidriensis* taxon (Zampetti et al, 2000; Sineo et al., 2015). The second group of finds comes from the material collected from an emergency excavation carried out during a maintenance work on the river bed of Fiume Grande\Delia River in the area identified as "Passo di Agate". At present, the outcrop is no longer visible because no official documents that identify the exact location of the paleontological material have been produced. However, during the surveys carried out in the area, it has been possible to identify a probable area of origin of these findings thanks to local people cooperation. It is an exposed section of about 3 m thick and 6 m long, which emerges on the right bank of the river. The outcrop is mainly made up of sands and silts which are interspersed by a conglomerate level at about 1 m above the

current elevation of the river. The studied specimens come from two distinct levels: one, placed more superficially, made up of sand and a second level placed lower just above the conglomerate level (Accardo, pers. comm.).

From the area between C\da Bovara and C\da Fiumegrande, fossil material has been attributed to *P. mnaidriensis* (Ferretti, 2008) Sala pers. comm.) and it has been recovered and located. From the Fiumegrande site (130-140 m.) 2 fossil remains have been discovered: an Ind. diaphysis inserted in a cobblestone matrix, previously attributed to a tusk of *P. mnaidriensis* (Zampetti et al., 2000; Sineo et al., 2015) (Figure 3.5-2) and a tusk of *P. mnaidriensis* (Figure 3.5-3).



Figure 3.5-2: Diaphysis of large mammal in zenit and lateral section view.



Figure 3.5-3: Tusk of *P. mnaidriensis* by Fiumegrande site.

From of C\da Bovara site a mandible of *P. mnaidriensis* has been recovered (Figure 3.5-4)

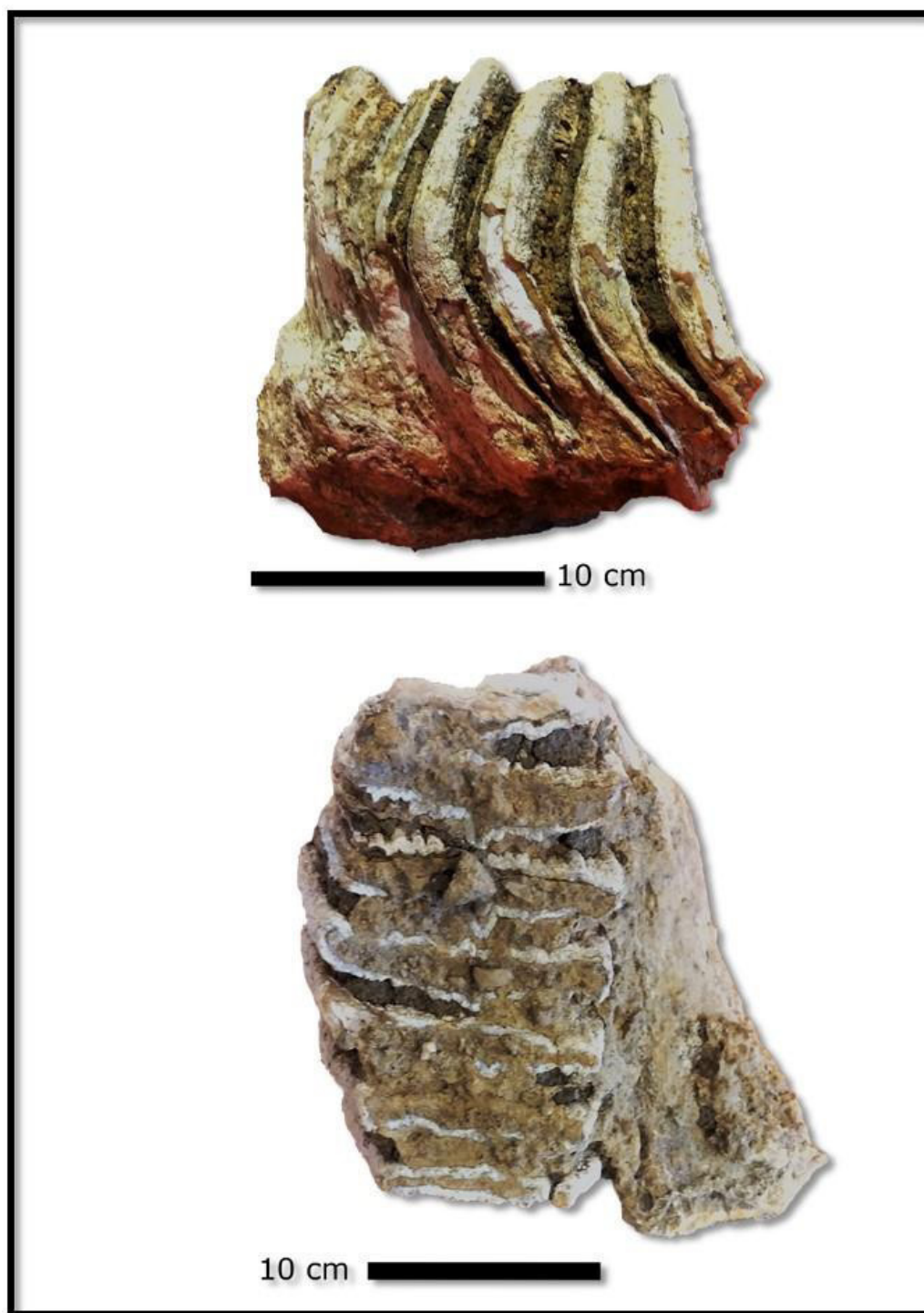


Figure 3.5-4: partial mandible whit tooth of *P.maindriensis* from Bovara site.

Finally, from a flat area on the left side of the river, where a large surface of conglomerates is visible, (Conglomerate sample CC3, described in the petrography paragraph) a fragmented molar of *P. mnaidriensis* in C\da Pozzillo has been discovered.

Preliminary studies over fossil from the second site showing that all the remains are not complete and not well preserved, thus, the measurement of these specimens have not been taken (see Appendix A). A total of 518 large mammal remains, 102 of which has been determinate, comes from the "Passo di Agate" area (Table 3-1). The following *taxa* have been identified: *Bos primigenius siciliae*, *Equus* sp., cf. *Bison*, *Sus* sp., *Cervus elaphus siciliae*, *Ovis* sp., *Canis* sp., *Felis* sp. (Figure 3.5-5). The fossil findings have different conservation state. Within this association, in fact, we find complete and fragmented bones. Even the state of wear is not uniform in all the remains. Several not determinate diaphysis are rounded and these bone modifications are probably due to water transport. Material condition and mammal assemblage with wild and domestic elements, allow us to consider these findings as a "reworked fauna" with almost two complexes, one related to Pleistocene (*Bos primigenius siciliae*, cf. *Bison* and *Cervus elaphus siciliae*) and one related to Holocene with domestic mammals (Figure 3.5-6). In addition, some of these remains show different types of marks which will have to be subsequently analysed to understand the palaeontological and archaeological significance of these traces (Sample 11-A; 12-A; 8B-8B; A9-5A; A9-2).

	Specie	Anatomical element	Side
1-1	<i>Bos</i> sp.	Mandible	RIGHT
1-2	<i>Ovis vel Capra</i>	Mandible	LEFT
1-3	<i>Equus</i> sp.	Palate	LEFT
1-4	<i>Equus</i> sp.	Mandible	
1-5	<i>Equus</i> sp.	Mandible	RIGHT
1-6	<i>Bos</i> sp.	Mandible	RIGHT
1-7	<i>Sus</i> sp.	Pre Maxillar	RIGHT
1-8	<i>Bos</i>	Mandible	RIGHT
1-9	<i>Sus</i> sp.	Mandible	RIGHT
1-s.n.	cf. <i>Equus</i> sp.	tooth	
2-10	<i>Bos primigenius</i>	Horn Core	RIGHT
2-11	<i>Ovis vel Capra</i>	Horn Core	LEFT
2-12	<i>Bos?</i>	Horn Core	
3-13	<i>Bos primigenius</i>	Atlas	
3-14	<i>Bos primigenius</i>	Astragalus	LEFT
3-15	<i>Bos</i> sp.	Astragalus	RIGHT
3-16	<i>Bos</i> sp.	Phalange	LEFT
3-17	<i>Bos</i> sp.	Astragalus	RIGHT
3-18	<i>Bos</i> sp.	Phalanx	LEFT
3-19	<i>Bos</i> sp.	Astragalus	RIGHT
4-20	<i>Bos</i> sp.	metacarpus	RIGHT
4-21	<i>Bos</i> sp.	metacarpus	LEFT
4-22	<i>Bos</i> sp.	metacarpus	RIGHT
4-23	<i>Bos primigenius</i>	metacarpus	RIGHT
4-24	cf. <i>Bison</i>	metacarpus	LEFT
4-25	<i>Bos</i> sp.	Rib	
4-26	<i>Bos</i> sp.	Long bone diaphysis	
8-1	<i>Felis</i> sp.	Humerus	RIGHT
8-2	<i>Bos</i> sp.	Proximal Epiphysis	RIGHT
8-2(b)	<i>Bos</i> sp.	Distal Epiphysis	LEFT
8-7	<i>Equus</i> sp.	Calcaneus	LEFT
8-8	<i>Equus</i> sp.	Ulna	RIGHT
9A-1A	<i>Bos</i> sp.	Femur	RIGHT
9A-2A	cf. <i>Bison</i>	Femur	RIGHT
9A-3A	<i>Bos</i> sp.	Mandibular	LEFT
9A-4A	<i>Bos primigenius</i>	Metatarsus	LEFT
9A-5A	<i>Bos primigenius</i>	Metatarsus	LEFT
9A-6A	<i>Bos</i> sp.	Humerus	IND
9B-1B	<i>Canis</i>	Skull	
9B-2B	<i>Equus</i> sp.	RadioUlna	RIGHT
9B-3B	<i>Bos primigenius</i>	Calcaneus	LEFT
9B-4B	<i>Bos</i> sp.	Calcaneus	LEFT
9B-5B	indet	Rib	IND
9B-6B	<i>Ovis vel Capra</i>	Rib	LEFT
9B-7B	<i>Bos</i> sp.	Metapodial	IND
9B-8B	indet	Femur	IND
9B-9B	<i>Bos</i> sp.	Tibia	RIGHT
9B-10B	<i>Bos primigenius</i>	Metatarsus	LEFT
9B-11B	<i>Sus</i> sp.	Phalange	RIGHT
9B-12B	<i>Bos</i> sp.	Phalange	Left
9B-13B	<i>Bos</i> sp.	Phalange	RIGHT
9B-14B	<i>Bos primigenius</i>	Phalange	RIGHT

9C-1C	<i>Bos</i> sp.	Vertebrae	Thoracic
9C-2C	<i>Bos</i> sp.	Scapula	RIGHT
9C-3C	<i>Equus</i> sp.	Radius	LEFT
9C-4C	<i>Bos</i> sp.	metacarpus	RIGHT
9C-5C	ind	pelvis	LEFT
9C 1D	<i>Bos</i> sp.	Tibia	RIGHT
9C 2D	ind	Rib	IND
9C 3D	<i>Bos</i> sp.	Rib	LEFT
9C 4D	<i>Bos</i> sp.	Femur	RIGHT
9C 5D	<i>Bos</i> sp.	Falange	LEFT
9C 6D	<i>Equus</i> sp.	Radius	RIGHT
9C 7D	<i>Canis</i> sp.	Femur	LEFT
9C 8D	<i>Bos</i> ?	Mandibular	LEFT
10-1	<i>Felis</i> sp.	Tooth	Canino
10-2	<i>Felis</i> sp.	Ulna	RIGHT
10-3	<i>Equus</i> sp.	Incisor	
10-4	<i>Equus</i> sp.	Molar	
10-5	<i>Equus</i> sp.	Molar	
10-6	<i>Equus</i> sp.	Molar	
10-7	<i>Equus</i> sp.	Molar	
10-8	<i>Equus</i> sp.	Molar	
11-A	<i>Ovis vel Capra</i>	Tibia	LEFT
11-B	<i>Ovis vel Capra</i>	Scapula	
11-C	<i>Ovis vel Capra</i>	Humerus	RIGHT
11-D	<i>Ovis vel Capra</i>	Humerus	LEFT
11-E	<i>Ovis vel Capra</i>	<i>Ovis vel Capra</i>	LEFT
12-A	<i>Cervus elaphus siciliae</i>	Calcaneus	RIGHT

Table 3-1: Species, anatomical element and side of remains from "Passo di Agate" site.



Figure 3.5-5: Skull of canis sp. from Passo Agate site

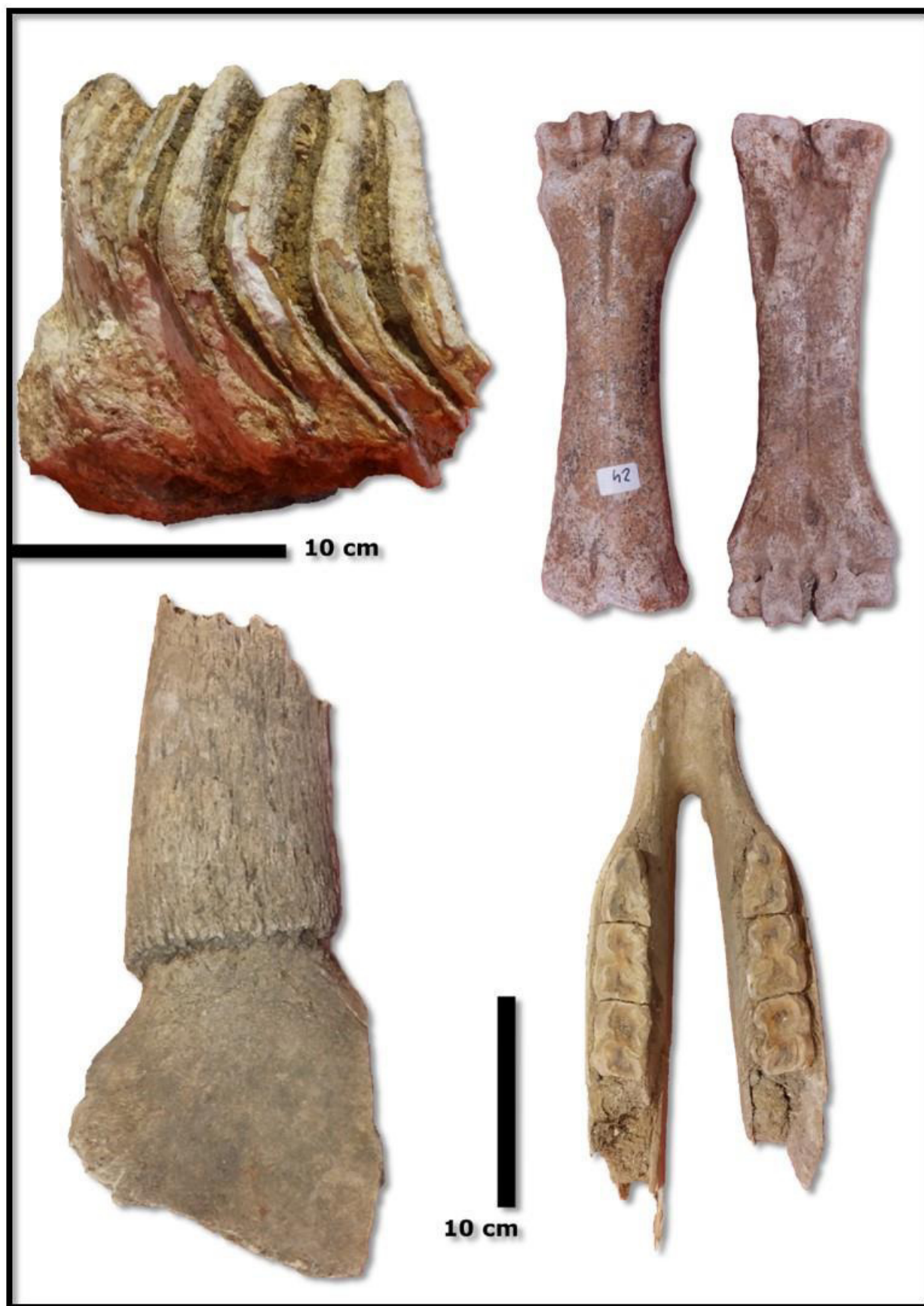


Figure 3.5-6: Plate showing the FGB paleontological remains. Mandible of *P. mnaidirensis* from Bovara site; Metapodial of *cf* Bison, Horn of *Bos primigeius* and mandible of Horse from Passo Agate site.

3.6 Sedimentological Result

3.6.1 Morphometry and Statistical Results

From seven sampling sites were measured 414 pebbles\cobbles. The Dimensional analysis of the pebbles shape is a measure of the relative lengths of the three orthogonal axes of the clast in morphometric studies. The longest axis (a), intermediate (b) and short axes (c) are measured with a digital Vernier calliper. The average b-axis values measured in the pebbles showed very similar percentages. S1, S2, S3, S4, S6 stations have mean values between 61.65 and 66.17 mm, while S5 and S7 stations have values below 54.71 and 47.91 mm, respectively. The measurement of the average value b in the study area shows dimensions between 12 and 133 mm and allows to divide the pebbles into 5-dimensional classes: 16-32 mm; 32-48 mm; 48-64 mm; 64-128 mm; 128-256 mm. The results of the study of the intermediate axis (b) of the pebbles from the seven sites are shown in the following Table 3-2.

axis b (mm)	S1	S2	S3	S4	S5	S6	S7
Mean	61,65	66,17	62,41	59,24	54,71	63,43	47,91
median	56,13	64,65	63,51	59,05	53,19	66,79	45,36

Table 3-2: mean and median values of b-axis from site sampling. Preliminary operation of granulometric classes.

The most typical grain size is composed of values between 48 and 64 mm in S1 (40%), S4 (58,33%), S5 (45,31%) sites (Table 3-3). In S2, S3, S6 sites, the granulometric range of the medium axis b tends to increase and the most represented grain size class has values between 64-128 mm with 52,94% in S2, 48,61% in S3 and 50,98 in S6. Finally, at sites S7 the particle size class 32-48 mm prevails with a percentage of 35,94%. In different sites, gravels lithological is uniform, with prevalence of siliciclastic lithotypes. While particle size class 32-48 mm has values ranging from 7.84% to 35.94%, with similar frequencies between S1, S5, S7 stations.

S7 station, which corresponds to the surface area, has a more heterogeneous particle size distribution in the different classes (Figure 3.6-1).

Axis b of pebbles grain size (mm)	S1	S2	S3	S4	S5	S6	S7
16-32	2,00%	0,00%	0,00%	0,00%	0,00%	1,96%	25,00%
32-48	28,00%	7,84%	18,06%	11,67%	32,81%	23,53%	35,94%
48-64	40,00%	39,22%	33,33%	58,33%	45,31%	23,53%	20,31%
64-128	28,00%	52,94%	48,61%	30,00%	21,88%	50,98%	18,75%
128-256	2,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
tot	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

Table 3-3: Percentage distribution of grain size in the sites

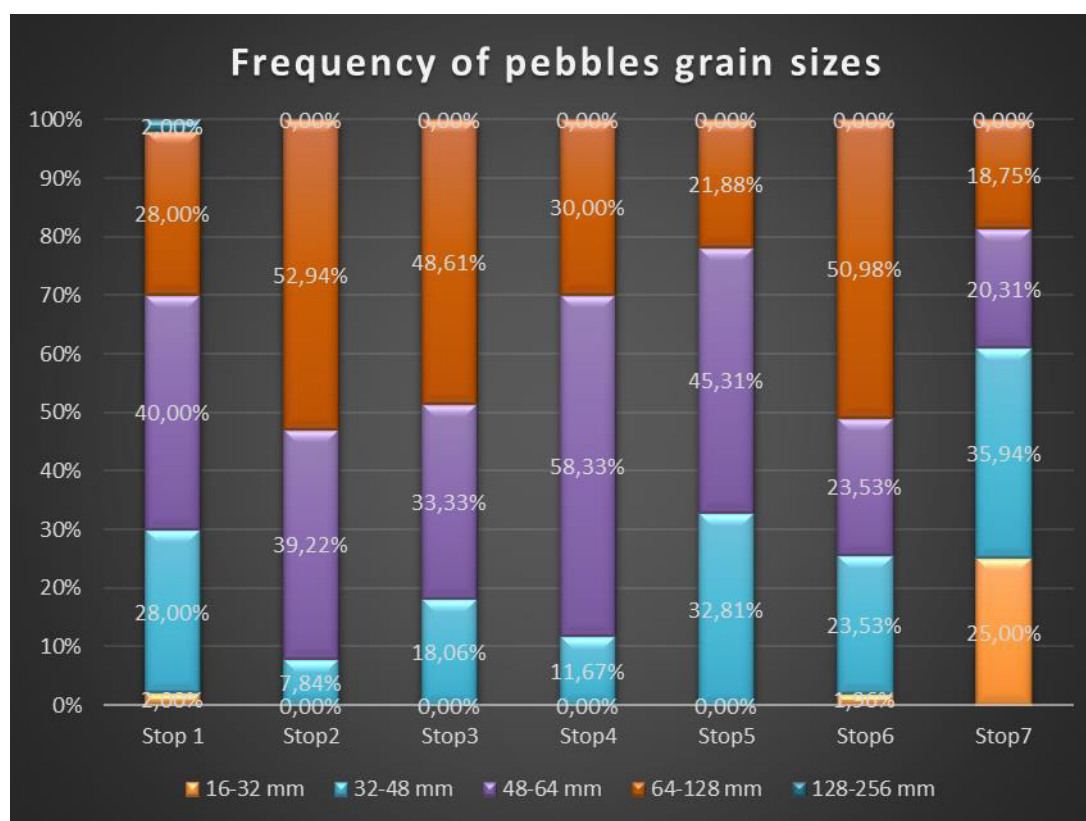


Figure 3.6-1: bar Chart of Percent of grain sizes of the S1, S2, S3, S4, S5, S6 and S7 sites.

Dobkins and Folk (1970) used large particle properties (morphometric indices) of form, sphericity and roundness to characterize pebbles shaped in various sedimentary environments. Index formulas were used are reportated in following Table 3-4.

Table 3-4: summary of morphometric index:

L (a) axis	Long axis
I (b) axis	Intermediate axis
S (c) axis	Short axis
Elongation ratio (Lutig, 1962)	I/L
Flatness ratio (Lutig, 1962)	S/L
Coefficiente flatness	(S/L)*100
Flatness index (Cailleux, 1945)	(L+1)/2+C
sphericity index IS	$\sqrt[3]{c^2/(axb)}$
oblate/prolate index OP index	$\frac{[(a - b)/(a - c) - 0.50] \cdot 10}{c/a}$

Cailleux (1945) developed the flatness index based upon the relationship between the particle dimensions along the three principal axes. An equant particle and becomes progressively larger the flatter the particle index ranges is discriminated from a minimum value of 1. Besides Sneed and Folk (1958) developed sphericity index, the maximum projection sphericity, which they believed represented the hydrodynamic behaviour of particles in a fluid. Moreover, the Oblate-prolate index compares the shape of pebbles because the shape of pebbles is linked to marine or fluvial environment. Also, the use of morphometric index is a useful tool to understanding the formation environments.

Flatness index (IF) (Cailleux, 1945): The lithology, texture and structure of the original rock decisively influence the values of this index (Dal Cin, 1968a). In the seven sites, there is no relation between size and flatness index. For this index, the discriminating value is 2.1 because numerous observations on clasts deposited in different environments (Cailleux, 1945) indicate that the flattening index is higher than 2.1 in beach gravels and less than 2.1 in river gravels (Carrara, 1981). In all the particle size classes of the seven sampling sites, there are higher percentages of pebbles with less than 2.1 IA index (Table 3-5). S1 site show a percentage of 66%, S2, S5, and S6 sites have a percentage of 76-78%, also S3 and S7 sites have a similar percentage of 83% and 86%, and finally S4 site has a high percentage of IF <2.1 equal to 90% (Figure 3.6-2). Site S1 corresponds to the sampling carried out at the outcrop of the Grandotto River, where there are apparently different sedimentary environments.

IA frequency	S1	S2	S3	S4	S5	S6	S7
<2,1	66%	76%	83%	90%	77%	78%	86%
>2,1	32%	24%	17%	10%	23%	22%	14%

Table 3-5: Percentage of pebbles with flatness index larger and smaller than 2.1 in the seven sites.

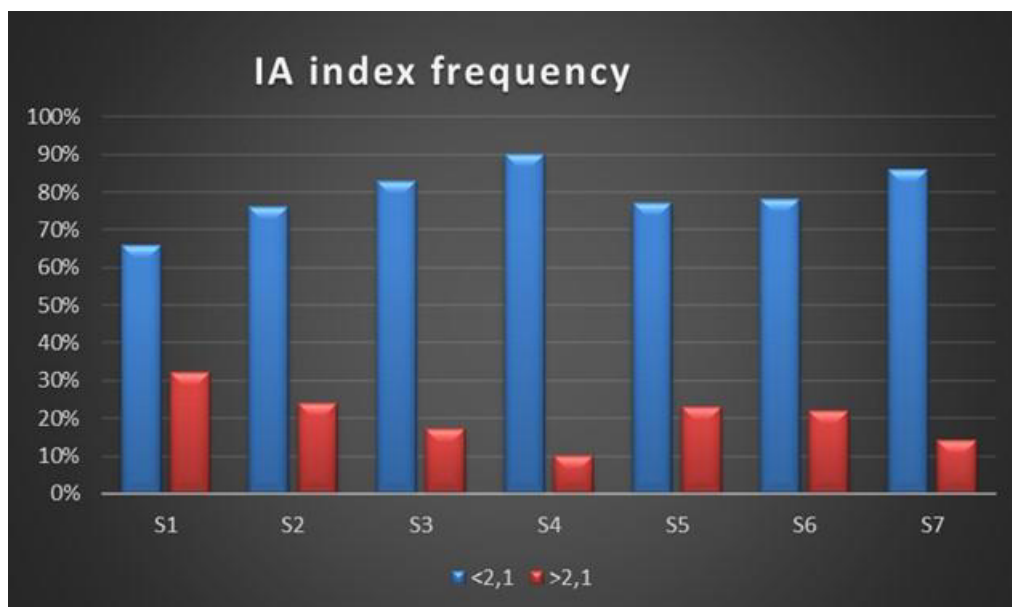


Figure 3.6-2: Histogram distribution of the flatness index.

Index of sphericity: The maximum cross-section ($a \times b$) in the spherical index (IS) formula represents the degree of flatness: higher the product is, flatter a pebble will be and higher its resistance to falling into fluids will be, while values tending towards the spherical shape indicate a lower resistance (Folk, 1954; Chiocchini and Castaldi, 2009). As can be seen from the Table 3-6 and the figure graph, the seven stations have mean and median values of the spherical index between 0.67 and 0.75, corresponding to lamellar and elongated shapes (Sneed and Folk, 1958). The highest mean IS (Figure 3.6-3) index was found in S4, the lowest in S1, while S2 and S6 stations show identical averages (IS=0.68) such as S3, S5, and S7 (IS=0.71-0.75).

sphericity index (IS)							
	S1	S2	S3	S4	S5	S6	S7
Mean IS	0,667	0,682	0,711	0,752	0,717	0,688	0,720
Median IS	0,687	0,683	0,701	0,760	0,700	0,680	0,722

Table 3-6: Mean and median values of the sphericity index (IS)

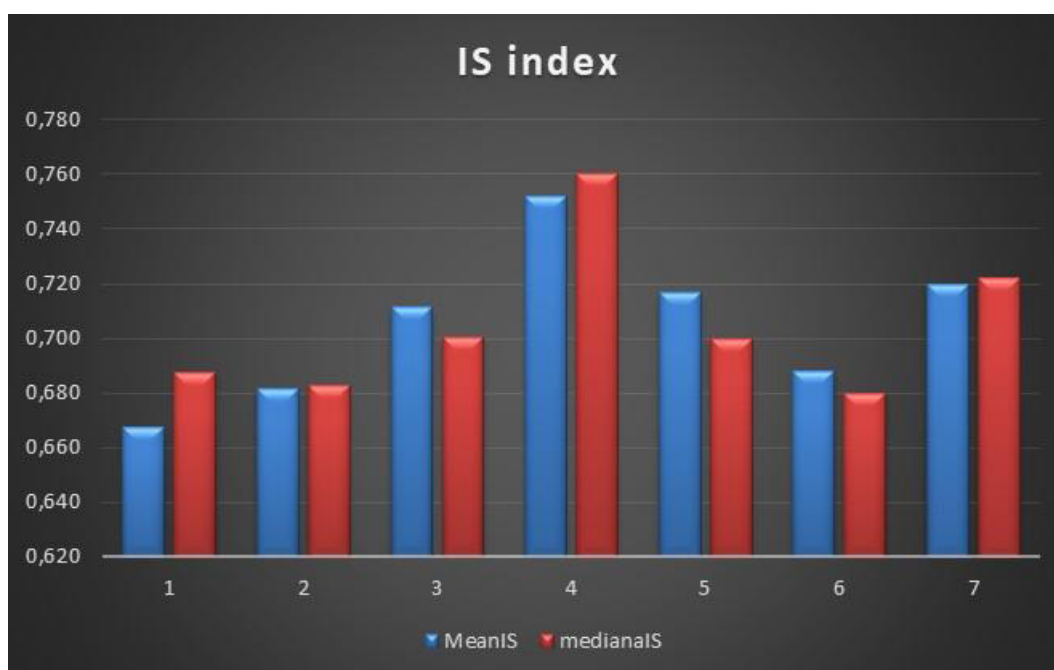


Figure 3.6-3: Frequency of sphericity index of the grain sizes

Oblate-Prolate index (Dobkins and Folk, 1970): clasts which differ in the long (a) and intermediate (b) axes measurements, but the product at equal $a \times b$ have the same spherically index and is not possible describe the clast shape. Therefore, to better define the shapes and differences between the clasts, the Oblate-prolate Index (OP) is calculated. Shapes with b similarly to c will have a negative index and therefore will be *oblated*, conversely shapes with b axis similar to c axis will have a positive index, that is they will be *prolated*. Also, the perfect lamellar shape is evidenced by a numerical equidistance of b from the two extreme axes. The Table 3-7 summarising the average values of the Oblate Prolate (OP) shows a range from -1.15 to 1.64. The percentage of oblate shapes is lower in stations S2 and S6, while in the remaining stations the prolate shapes is higher with a peak in station S7, where a high percentage of prolate shapes are found (Figure 3.6-4). Looking at the change in the OP index, they may note that the values are relatively uniform concerning the limit values dividing marine environments from river environments (Dobkins and Folk, 1970; Carrara, 1981). Differences in shape may be due to the lithology of the pebble or to variations in transport.

OP Index	S1	S2	S3	S4	S5	S6	S7
Mean OP	0,28	-0,52	0,11	1,07	0,18	-1,15	1,64
Median OP	1,79	-0,43	-0,48	1,18	-0,13	-0,48	2,10

Table 3-7: Mean and median values of oblate-prolate index of the grain sizes



Figure 3.6-4: The graphic shows the distribution of mean and median OP index. The mean value is near to zero value apart S7

Shape, Sneed and Folk Diagram (Graham and Midgley, 2000). The spreadsheet plots triangular (ternary) diagrams for the representation of particle shape following the method recommended by Benn and Ballantyne (1993) and first proposed by Sneed and Folk (Sneed and Folk, 1958). The diagram shows ten shapes represented by 10 classes within the triangle. Both sides of the triangle are graduated from 0 to 1. On one side is the ratio $(a-b)/(a-c)$ and on the other side the ratio c/a . The meeting of the two values will fall on one of the 10 areas: C = Compact; CP = Compact-platy; CB = Compact blade; CE = Compact-elongated; P = Platy; B = Bladed; E = elongated; VP = very platy; VB = very bladed; VE = very elongated (Figure 3.6-6).

The following Table 3-8 collects and compares the different morphometric classes studied in the different collection stations.

Sneed & Folk classes	S1\M7	S2\M1	S3\M3	S4\M4	S5\M2	S6\M6	S7\M5
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Compact		1,96	4,17	15,00	15,63	11,76	7,81
Compact-Platy	4,00	7,84	11,11	11,67	14,06	11,76	9,38
Compact-Bladed	16,00	27,45	15,28	36,67	10,94	21,57	15,63
Compact-Elongate	18,00	13,73	22,22	16,67	15,63		21,88
Platy	12,00	17,65	13,89	1,67	10,94	11,76	6,25
Bladed	28,00	21,57	20,83	10,00	23,44	31,37	18,75
Elongate	14,00	5,88	11,11	3,33	9,38	11,76	17,19
Very-Platy	2,00		1,39				
Very-Bladed	6,00	3,92		3,33			3,13
Very-Elongate				1,67			

Table 3-8: Percent of forms

The general prevalence of bladed and compact-Bladed forms (>20%) can be seen from the table and the observations of the histograms of the different sites. In station S1 the Bladed class is the most abundant, while compact-bladed and compact-elongate shapes are homogeneous with applicable percentages (>15%). Compact-bladed and bladed (>20%) classes prevail in the S2 station, followed by platy (>15%). In the particle size classes of station S3, the most represented forms are bladed and compact-longed (>20%) while the Compact-platy Compact-

elongate, Platy and Elongate classes are comparable (10-15%). In the S4 station, compact-bladed shapes prevail with a percentage > 35% followed by Compact-Elongate shapes. The most prominent class is bladed shapes (s. l.) and compact bladed and elongated shapes (13-15%). Class S6 is characterised by the absence of Compact-Elongate shapes, while the most represented forms are bladed (>25%) and Compact-Bladed (>20%), while the remaining flat and elongated shapes have an equal distribution of 10-11%. Finally, in S7 Station the distribution of shapes is very similar to the one of S3 Station: the most represented class is the Compact-Elongate (>20%) while the most represented family is the bladed-very elongated class (36%). Based on these ten descriptive classes it was made an assessment of the "optimal shape" for gravel riverbed sediments within a river. The results (

Figure 3.6-5) evidenced that the cluster of values displays a strong bimodality among these classes for the entire length of the river that confirms the results reported for other rivers (Ibbeken and Schleyer, 1991; Dumitriu et al., 2011a).

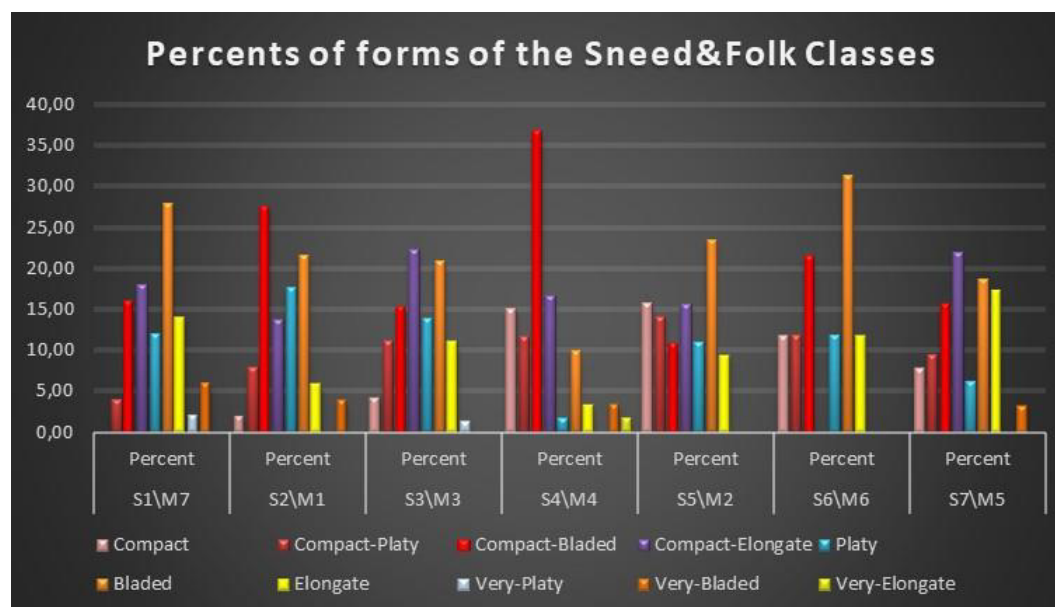


Figure 3.6-5: Histogram of distribution of forms.

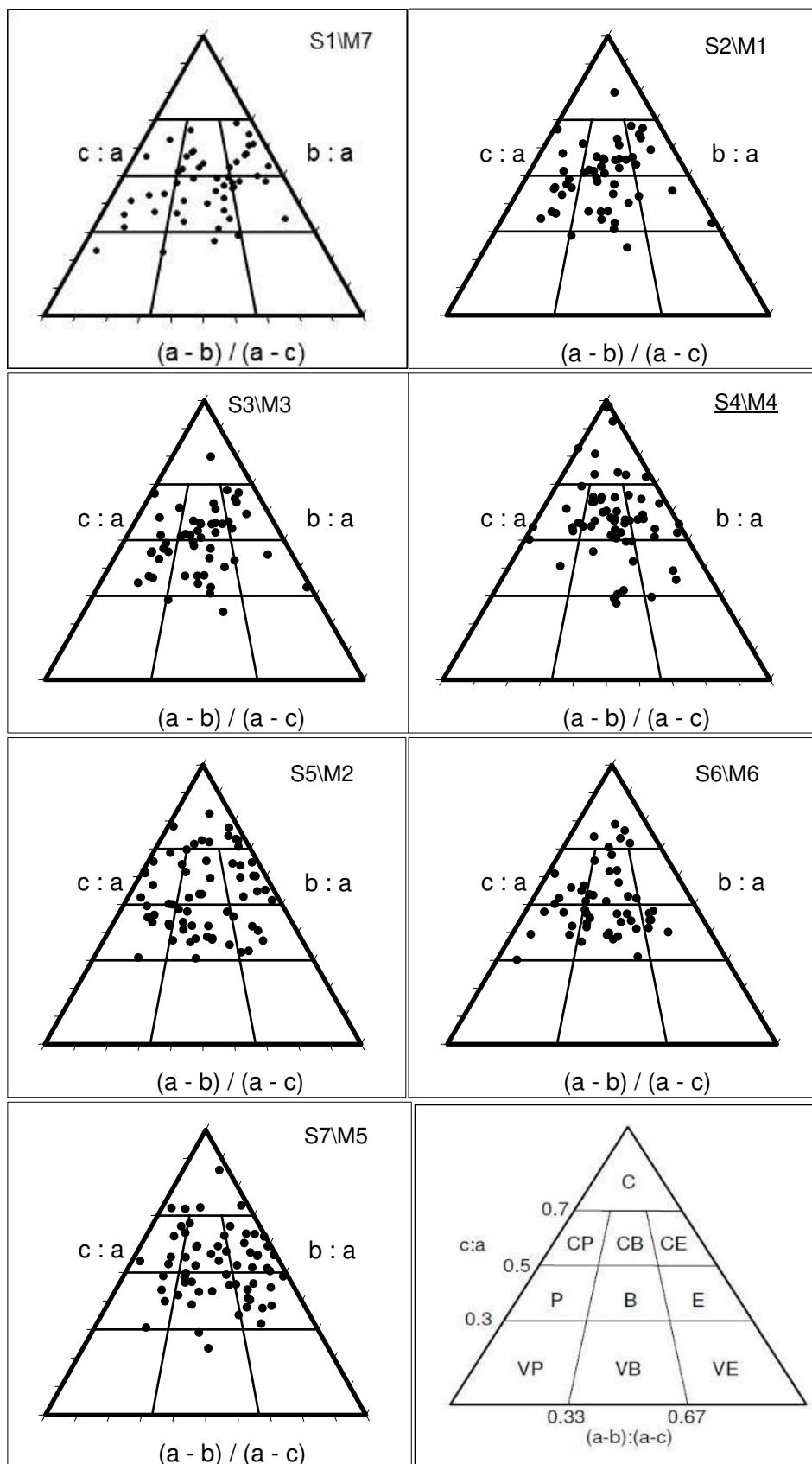


Figure 3.6-6: Ternary Sneed and Folk diagrams: a) long axis; b) intermediate axis; c) short axis of seven sampling sites. The Sneed & Folk diagram where: Compact, Compact-Platy, Compact-Bladed, Compact-Elongate, Platy, Bladed, Elongate, Very-Platy, Very-Bladed, Very-Elongate (Sneed and Folk, 1958).

3.7 Petrographical characters of samples.

The petrographic analysis of thin sections has been carried out in the Department of Geological Sciences of the University of Ferrara. In this context, the collaboration with Prof. Carmela Vaccaro of the University of Ferrara and Prof. Rosolino Cirrincione of Earth Sciences Department of the University of Catania was significant for samples study and interpretation. Twenty-two samples were collected from the study area for the present study. Thin sections have been carried out on pebbles (8 samples) from morphometric study samples and came from both outcrops and stops for the collection of morphometric material. Samples of Calcarenite and Conglomerates found in terraced and outcropping areas were also collected, while samples from Sandstone-Calcarenite were sampled from outcrops at the boundary of the study area to be compared with samples from pebbles.

The petrographic characterisation shows the difference in particle size of quartz arenite. We find samples with a very fine, medium and medium-large size. Some of these cobbles (Quartzite and Quartzarenite) are found within the sampled conglomerates in the study area as evidenced by conglomerates thin sections in the petrographic analysis. Several samples of conglomerate have a particular growth of calcite, forming a lamina, which unevenly covers the larger clasts formed mainly by Quartzarenite.

The petrographic analysis of 22 samples from Grande\Delia River simplified the identification of four petrographic type. The essential characteristics: mineralogical composition, packing, sorting and grain size, have been reported in a scheme and summarized. Moreover Individual petrographic sheet of sample see in Appendix.

Quartzite and Quartzarenite type family: Samples 2\m1; 4\m3; 5\m2; 6\m4; 8\3AG; 9\M2; 10\4CZ (Figure 3.7-1)

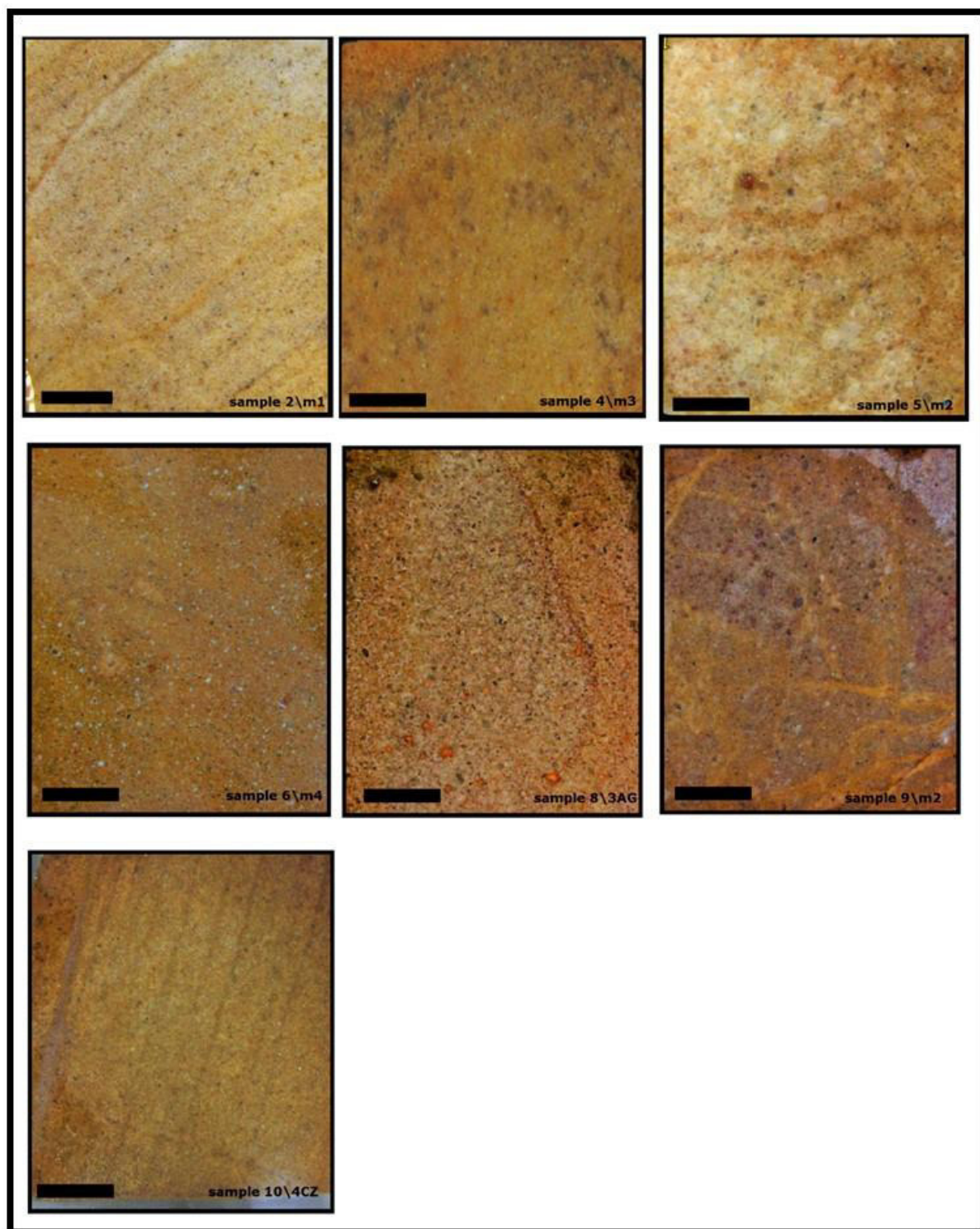


Figure 3.7-1: From right to left Quartzite and Quartzarenite type family: Samples (2\m1; 4\m3; 5\m2; 6\m4; 8\3AG; 9\M2; 10\4CZ). Black line is 1 cm

The quartzite and quartzarenite sampling shows a prevalence towards a sandy Quartz mineral, where the carbonatic member is nearly absent or not significantly represented, like in the case of sample 10\4CZ (Figure 3.7-2).

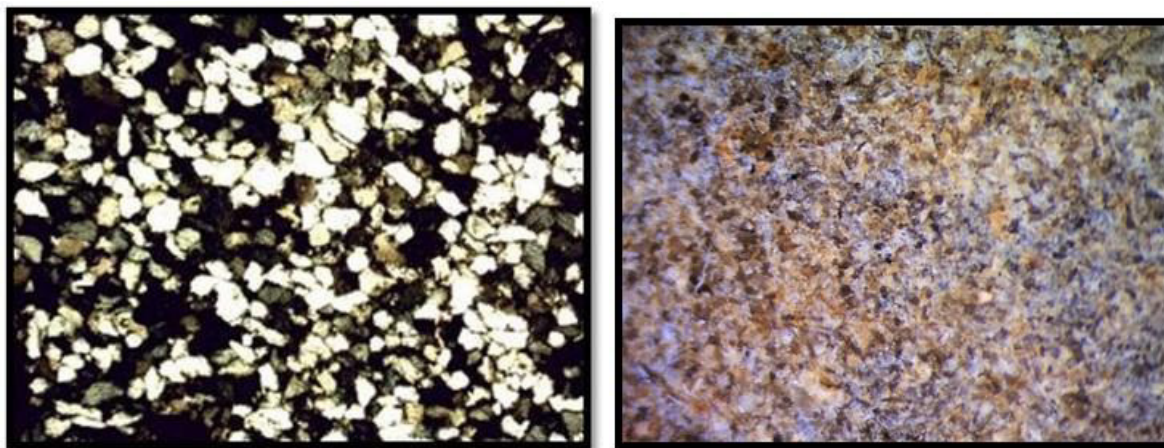


Figure 3.7-2: example of Quartz arenite; very abundant quartz clasts from 10\4CZ, thin section (left) and stereomicroscope (right)

Samples are characterised by a homogeneous texture and a quite high packing. The particle size component consists predominantly of fine sand (0.125-0.25 mm), medium sand (0.250-0.50 mm), coarse (0.50-1 mm) and very coarse sand (1-2 mm). Roundness is the predominant shape of sand grains (samples: 4\m3; 5\m2; 6\m4; 10\4CZ) but also sub-roundness (samples: 8\3AG; 9\M2), sub-angular monocrystalline quartz (samples 9\m2), only sporadically very roundness (sample 6\m4). Samples 2\m1; 4\m3; 5\m2, 8\3AG, 10\4CZ show a sorting parameter from well sorted to very well sorted. However, the samples 6\M4 and 9\M2 show a moderate sorting (Figure 3.7-3) but a similar grain size (Medium-Coarse sand) and shape grain. Moreover, two samples show the same particle size and texture characteristics, suggesting an identical background.

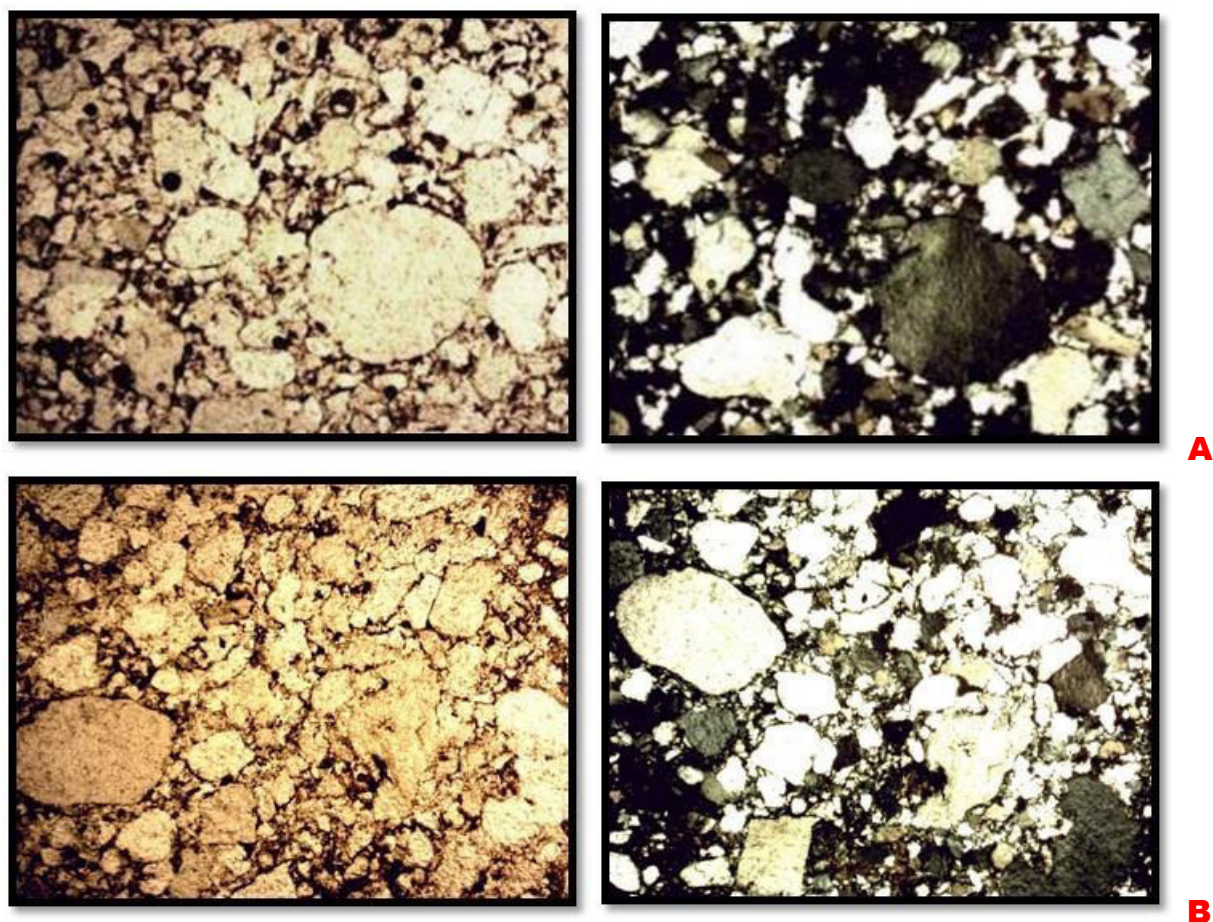


Figure 3.7-3: 6\M4 (A) and 9\M2 (B) sample Quartz arenite is showing a good sorting and roundness grain and similar texture.

The nature of grain to grain contact shows a different typology: tangential contacts, long point, concavo-convex contacts and sutured contacts. Observing thin sections, contact grain nature shows different deformation types occurring in this phase. One type is the deformation through pressure among the long and concavo-convex grain contacts and it causes sutured contacts along the grain borders. This deformation type is perpendicular to compressive forces. The exerted forces during the plastic inter-crystalline deformation provoke grains dislocations and pressure dissolution during chemical compaction. Pressure dissolution is also identified along intergranular contacts. As a result, pressure dissolution creates a thin calcite coatings or causes the presence of mica at the interface along the quartz grain contacts. Recrystallisation processes follow a process from the intercrystalline dislocations to the formation of now grouped generating lines which are the subgrain borders. The result, when the grain edges are deformed, is a creation of new crystals or neoblasts forms.

Biocalcarenite type family: *Sample 11\Calc2; 12\Calc4; 13\Calc3d; 15\Calc3* (Figure 3.7-4)

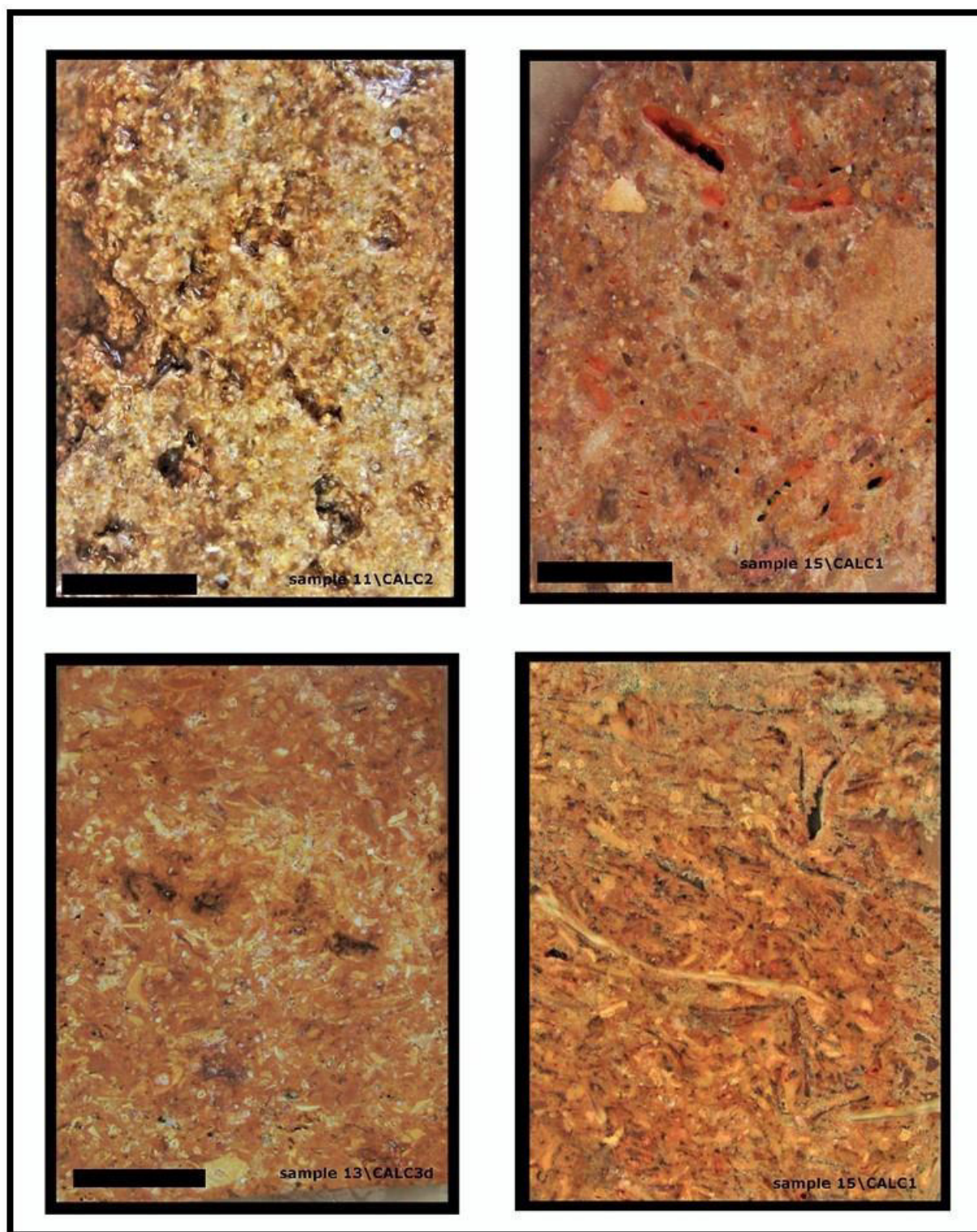


Figure 3.7-4: From right to left Calcarenites type family: *Sample 11\Calc2; 12\Calc4; 13\Calc3d; 15\Calc1* (from right to left).

The samples show a clear prevalence towards sandy/siliciclastic lithoclasts and bioclasts in a similar percentage. However, the sample 13\calc3d shows a lower percentage of lithoclasts and a high percentage of micrite cement. The bioclasts are here presented in decreasing order of percentage: fragments of rhodolites, fragments of mollusc shells and foraminifera. The simultaneous formation of this calcarenite is evident by observing the sample 12\calc4 where the shells of different species have a geopetal filling (Figure 3.7-5). The lithoclasts, made of carbonate rocks fragments, are a low percentage; monocrystalline or polycrystalline quartz grains are present in a good percentage; are also present Quarzarenite clasts. Calcarenite is characterised by uniform texture and is quite packed. The particle size distribution of the grains is well graded: fine sand (0.125-0.25 mm), medium sand (0.250-0.50 mm), coarse sand (0.50-1 mm). The predominant lithoclasts are round-shaped. Usually, Quartz-arenite fragments samples show sub-angular monocrystalline quartz inside. Observing samples sphericity, is noticeable that is good for all the bioclasts and lithoclasts except that fragments of mollusc shells that are flat and elongated and with a medium-high roundness degree in the most cases. Grain contacts are tangential or of flattened at the same frequency and flat grains show an oriented fabric (sample 13\Calc3d).

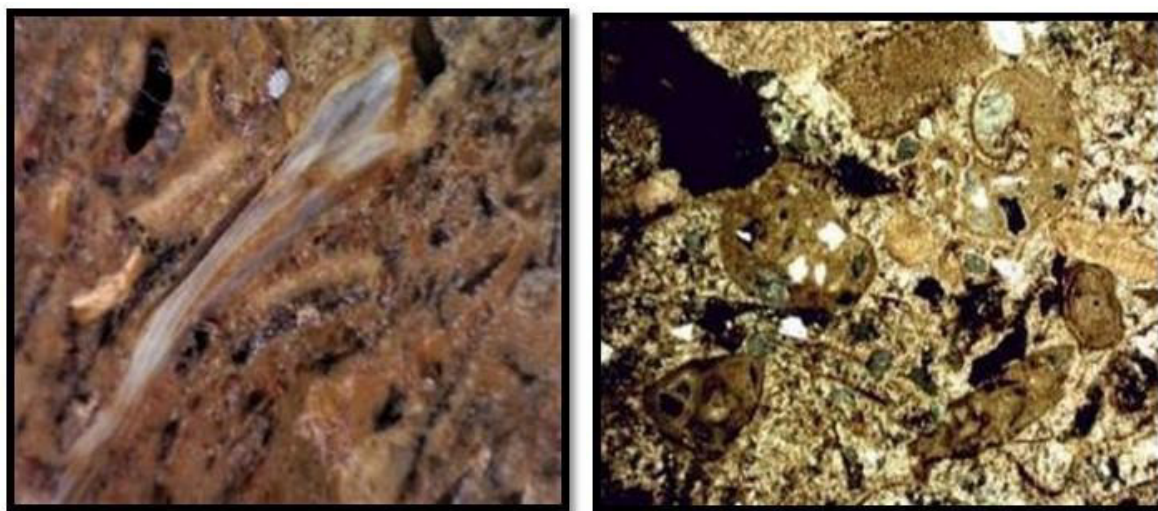


Figure 3.7-5 bioclast grain and geopetal micrite from sample 12\Calc4.

Conglomerate type family: *Sample: 1\Calc_3; 3; 14\CC4b; 16\CC2; 17\CC3; 18\CC10; 19\CC5; 20\CC3; 21\CC1* Figure 3.7-6

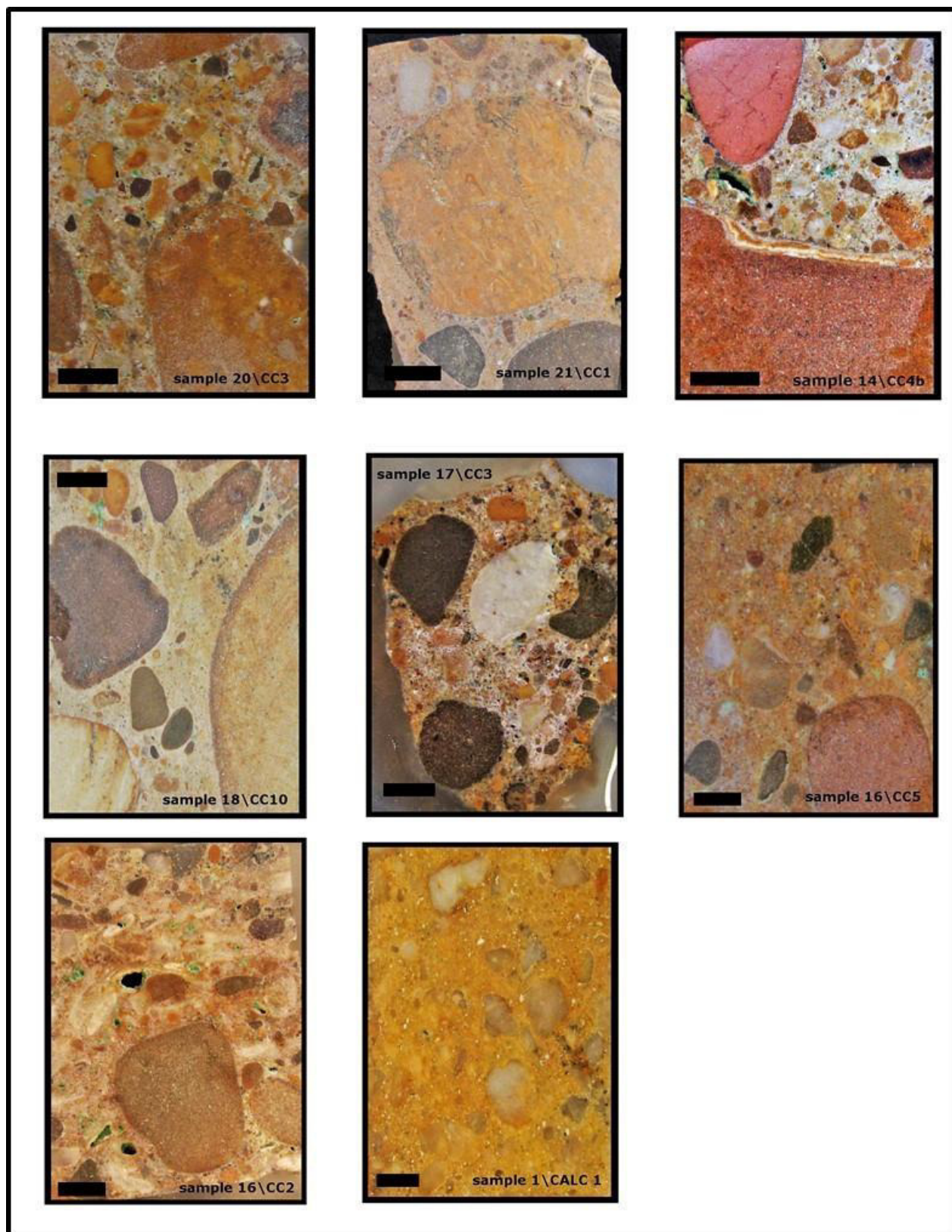


Figure 3.7-6: Conglomerates type family: Sample: 1\Calc_1; 3; 14\CC4b; 16\CC2; 17\CC3; 18\CC10; 19\CC5; 20\CC3; 21\CC1, Black line is 1 cm.

The petrographic characterisation of conglomerates indicates that most of the lithoclasts are mainly quartz sandstone clasts and we can distinguish, in smaller percentage, other lithoclasts made up of -Feldspars alkaline, plagioclase, terrigenous carbonate and siliciclastic clasts, and finally, monocrystalline quartz clasts are located between the different clasts (Figure 3.7-7). Besides, In Figure 3.7-7, thin section, showing a calcite crust between Quartzarenite clast and matrix by Quartz clast very well roundnes.

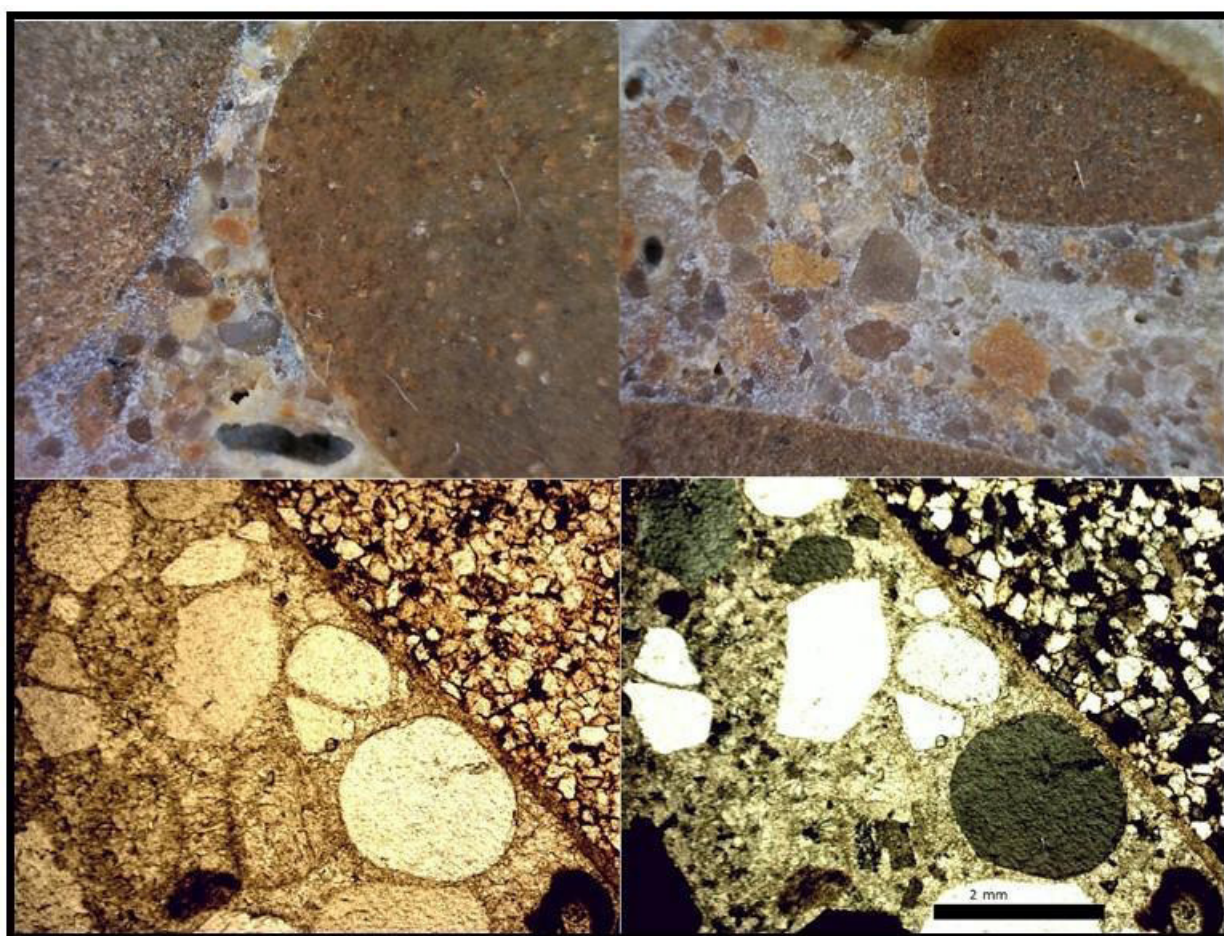


Figure 3.7-7: Sample 16\CC2 shows principal petrographic characteristic of conglomerates samples. A) stereomicroscope vision B) thin section PP and PX nicols.

Sample 1\Calc1 is a sample between Quartzarenite and Conglomerate type, but it's a Conglomerate because the percentage percentage of grains greater than 2 mm is higher. Detrital mineral grains, eroded from pre-existing rocks, and sand-sized pieces of rock it is almost entirely composed of monocrystalline quartz with a angular-roundness (Figure 3.7-8).

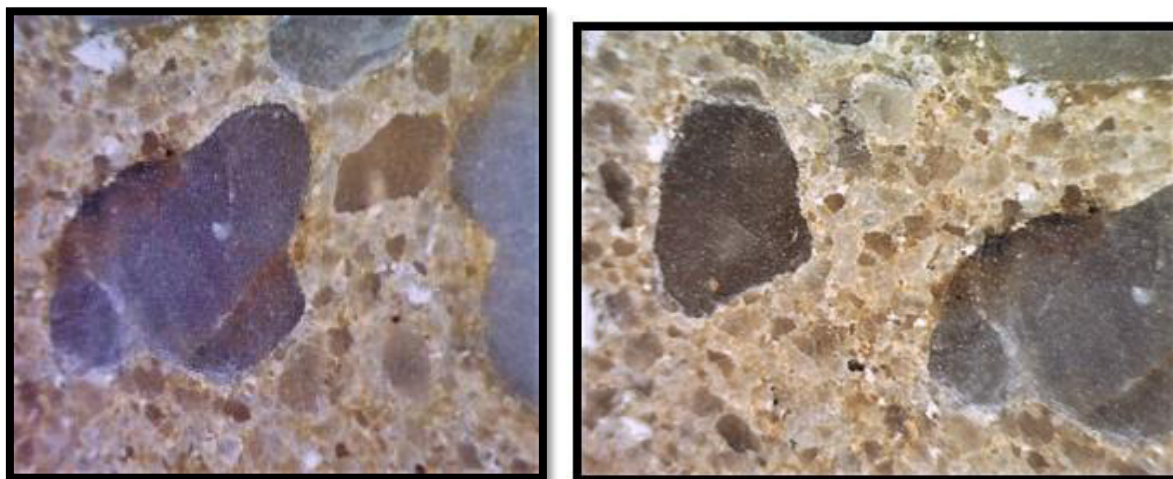


Figure 3.7-8: Stereomicroscope vision of quartz-conglomerates 1\Calc1 showing angular to subangular grains and sutured contacts from 1\Calc_3 sample

Particularly interesting is the presence of alkaline Feldspars and mineral particles of muscovite that both contain inside some pebbles that do not seem to belong to Terravecchia basin of formation (Figure 3.7-9).

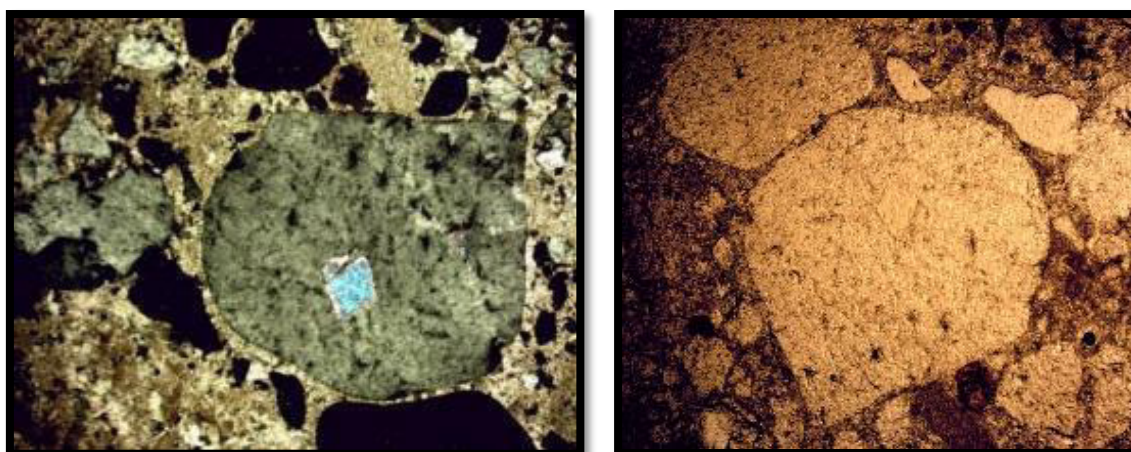


Figure 3.7-9: Nicols XP and PP from 20\CC3 sample show a mica type inside a quartz grain

The particle size component consists predominantly in fine to coarse pebbles (4-32 mm) inside a sample matrix made of sand grains. Sample 1\Calc1 is the exception because the grain size range goes from granules to prevailing very fine pebbles grains (2-4 mm). The predominant shape of pebbles grains is roundness in 16\CC2, 18\CC10, 21\CC1 samples. Moreover, in 14\CC4b, 17\CC3, 19\CC5 samples the prevailing shape of pebbles grain is sub-roundness and in 1\Calc_3 and 20\CC3 samples the predominant form is sub-angular (

Figure 3.7-10). Sphericity degree is low in all sample, and also the sorting is low.

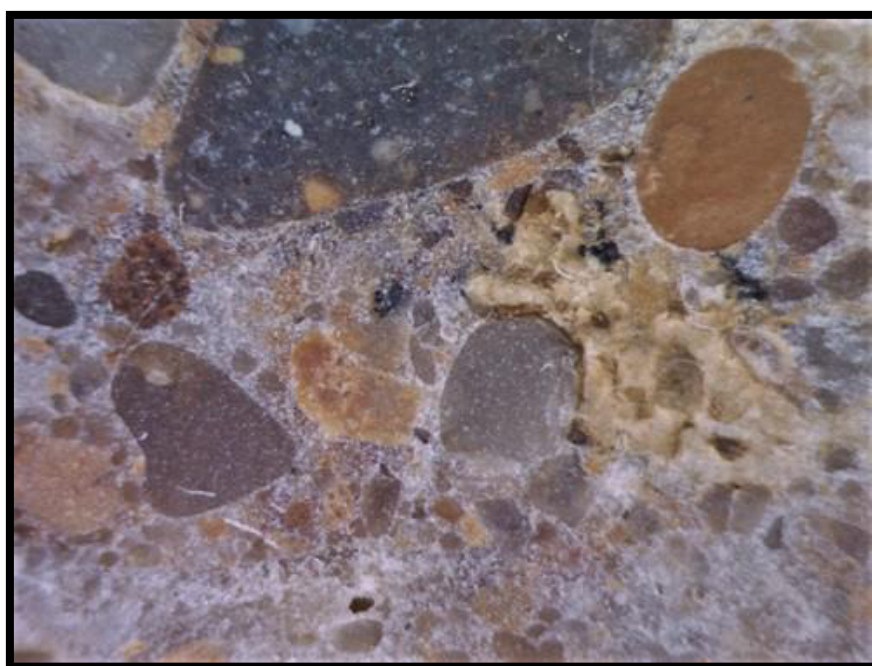


Figure 3.7-10: shape of pebbles grains is roundness in 16\CC2

Initially, a handman description of samples rock texture showed a matrix clast supported but stereomicroscope analysis showed a clast supported with a low percentage of matrix and a different percentage of cement.

The matrix is mostly made of very-fine quartz sand grains (0,74-0,125 mm) in 18\CC10 and 21\CC1 samples. In another sample (19\CC5), the quartz grain size is higher because quartz granulometry is fine sand size (0,125-0.250 mm), leading to matrix supported by clast with

calcite cement Figure 3.7-11. Several samples of conglomerate have been coated from a particular growth of calcite in lamina, which unevenly covers the larger clasts formed mainly by Quartz-arenite (sample 16\cc2; 17\CC3) and occasionally fills the porosity between the clasts (sample 18\CC10); de facto, this cement makes the rock very hard and tenacious at rupture. In the samples, calcite overgrowth is not uniform, and we found both sample areas with an overgrowth of coated clasts and sample areas without overgrowth. In Figure 3.7-12 the stereomicroscope vision also show a excessive growth of calcite that follows pebbles morphology and indicating a passage of saturated carbonate water and its texture (sample 14\CC4b).

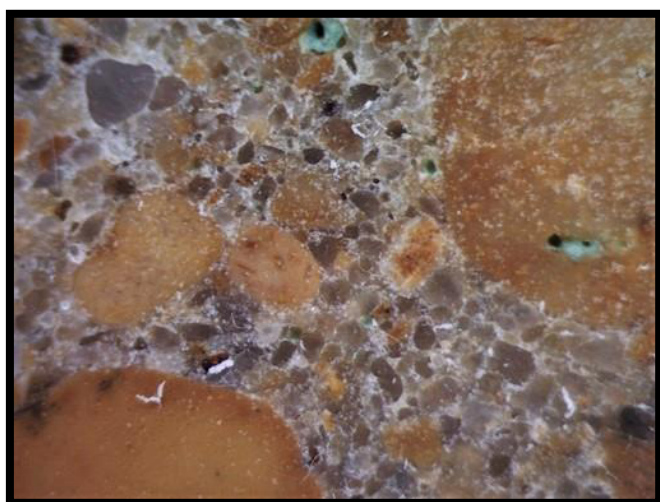


Figure 3.7-11: example of matrix made of very-fine sand quartz grains. 19\cc5 sample.



Figure 3.7-12: a zoom to sedimentary structures of layer that coats Quartzarenite clast (sample 14\CC4b)

Chemical Rock family type: 22\TRAV, 3\M1;(Figure 3.7-13)



Figure 3.7-13: the 22\Trav (right) and 3\M1 (left) samples

Even if the samples belong to the same rocks family, they have a very different origin and evolution (Figure 3.7-13). Sample 3\M1 is a pebble from samples of sedimentological analysis, collected over a terrace flat. Sample 3\M1 is a Calcareous Limestone that shows a white\grey colour and has particle size predominantly of fine silt (0.004-0.008). The identification of grain shape, sorting and nature of grain to grain is not straightforward because the sample shows a texture mostly granular and massive.

The sample 22\Trav is a continental chemical deposit because the sample observing is a Travertine. Travertine is a dense, banded limestone with often containing pores. The sample texture shows the rapid incrustation of macro hemicrophytes already during their development, which has given rise to a rigid support. The sample is composed of calcium carbonate, CaCO_3 and is originated from supersaturated solutions, when a change in the environment (difference of Pressure and Ph) causes rapid chemical precipitation of calcium carbonate in cold or temperate surface or ground waters. Also, the sample shows a texture rich in calcite coated, due to plant and animal remains and then decomposed. Besides The sample shows the radial growth

of calcium layers on vegetales structures that subsequently generated mouldic porosity Figure
3.7-14.

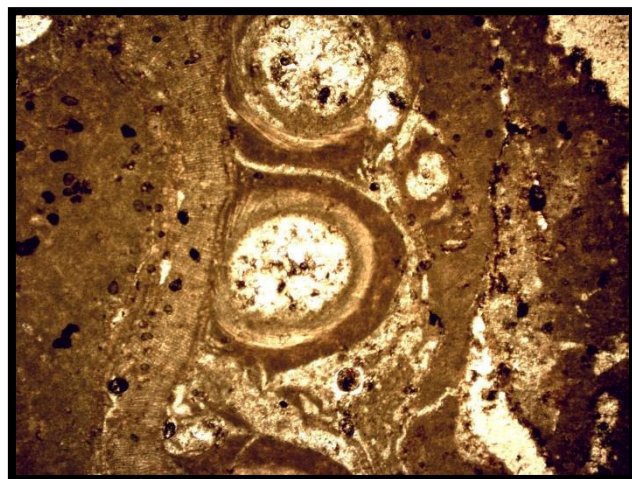


Figure 3.7-14: carbonate structure of 22\Trav sample and radial growth of calcium layers (thin section at NX)

Another Typology: Sample 7\CTR

Finally, sample 7\CTR has a particle size component that consists predominantly of fine sand (0.125-0.25 mm). The predominant shape grains is angular and rarely sub-angular (Figure 3.7-15). common single mineral quartz silt and fine sand sized grains rounded to subrounded and few rounded flinty rock fragments showing a very well sorting parameter. The sample is also very poorly cemented, shows different areas with pores and a characteristic red-brown colour, indicating the presence of paleosol. The fine fraction is reddish finely mixed clay and poorly crystalline.

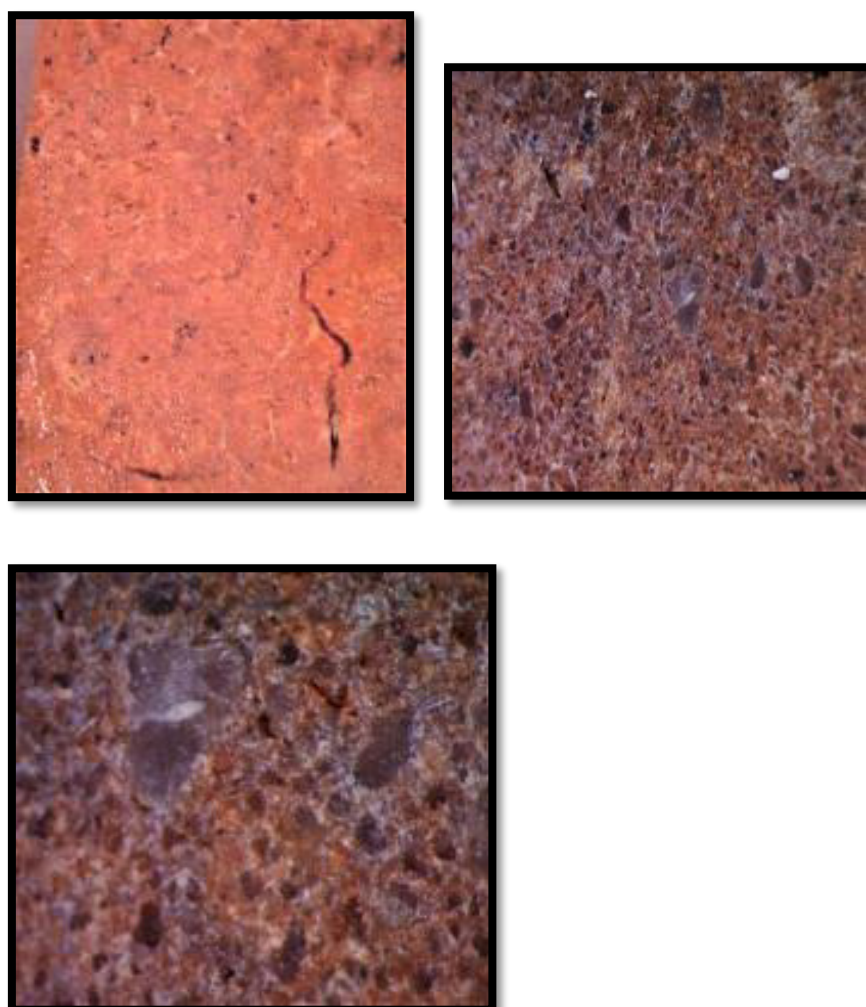


Figure 3.7-15: three figures from 7\CTR: Right figure a macroscopic vision of the sample. Left and bottom a Stereomicroscope vision where quartz clast is the only mineral present.

DISCUSSION

4 Discussion

4.1 Paleontological Context

The fossil fauna found inside the Basin of Grande-Delia River can provide useful information for the study of river terraces and increase the amount of data on Pleistocene in Sicily even if it presents problems for the chronostratigraphic context. The fauna, as described above, is divided into two groups. A first group of FiumeGrande\Bovara assemblage (FGB with *P. mnaidriensis* remains) has been found on the conglomerate level and fluvial pebbles over terrace surface along the Grande\Delia River (130-150 m a.s.l.) while a second fossil assemblage (Passo Di Agate Site, PA) has been found from an outcrop section of the current floodplain. Unfortunately, for PA site there are no bibliographical references about its discovery and the association is reworked with faunas of Late Pleistocene and Holocene. The PA site of Vertebrate fossil assemblage contains probably reworked material from Late Pleistocene cf. *Bison*, *Bos primigenius* (Bonfiglio et al., 2000; 2001a; 2003; Di Patti, 2004). Also, several fossils of *Bos* sp., *Felis* sp., *Canis* sp., and *Equus* sp. are Holocene findings (Burgio et al., 1983; Bonfiglio and Burgio, 1992). The presence of possible *Bison* remains is interesting because is a rare species and it is marked of cold and arid climatic phase (Sala et al., 1993; Marra, 2009; Masini et al., 2013). The chronological collocation of PA site is uncertain, but it is not older than Late Pleistocene.

The FGB fossil assemblage contains only fossils of *P. mnaidriensis* and in Sicily *P. mnaidriensis* is reported in almost the whole Region with over sixty-eight reports (Petrucci et al., 2008). Even if the first appearance is discussed, *P. mnaidriensis* compared in this Region probably before the MIS 8 (Locatelli, 2010; Palombo, 2018) with the last occurrence of *P. mnaidriensis* at MIS 3-4 (32.000 Ky) at San Teodoro Cave (ME) (Bonfiglio et al., 2008). The presence of *P. mnaidriensis* is better recognised from MIS 6 to MIS 3 (Bonfiglio et al., 2003; Palombo and Ferretti, 2005; Ferretti, 2008; Palombo, 2018). At Northwestern of Sicily, there is

a good correlation between marine and fluvial terrace with Pleistocene faunas from the MIS 5 (Di Maggio et al., 1999) and radiometric data (Bada et al., 1991; Rhodes, 1996). Studies of Quaternary eustatic fluctuations shows a stratigraphic relationship between the Sicilian large Vertebrate deposits and marine terraces and continental deposits (Bonfiglio et al., 1996; 1997; 2001b; 2003; Di Maggio et al., 1999; 2009). Also, in Hyblean Plateau remains of *P. mnaidriensis* are contained in terrace deposits overlying Middle Pleistocene marine sand and underlying Tirrenian calcarenites (Bonfiglio et al., 1996; 2002).

Unfortunately, the fossil assemblage studied is, at the moment, without stratigraphic control because the FGB association (*P. mnaidriensis*) comes from the surface collection. The FGB deposit is found, as described above, on a surface fluvial terrace at a higher elevation than PA deposit (floodplain). The terrace is composed from the bottom to top by clays, overlying an erosive contact from sand, conglomerate level and finally by a pebble level. The terrace elevations can be correlated with the eustatic oscillations that occurred in Pleistocene after the formation of the Main Terrace Superior GTS

The chronological collocation of FGB fossil assemblage is uncertain, but it is not older than Late Middle Pleistocene and not younger than PA site. In conclusion, the Paleontological remains studied provides some information about the age of the terraces. The presence of *P. mnaidriensis*, lithics industries and the elevation of terrace assumed that the FGB deposit was created later from the isotopic stages 7 during a marine regression phase, with the creation of several fluvial terraces from Middle Pleistocene (Agate et al., 2017). However, the absence of control data (e.g. Stratigraphic section), radiometric data and the presence of reworked fauna (PA deposits) allows providing some hypotheses concerning chronological collocation. The chronological collocation of deposits probably has a Middle-Upper Pleistocene range and is not older than MIS 7 (Figure 4.1-1).

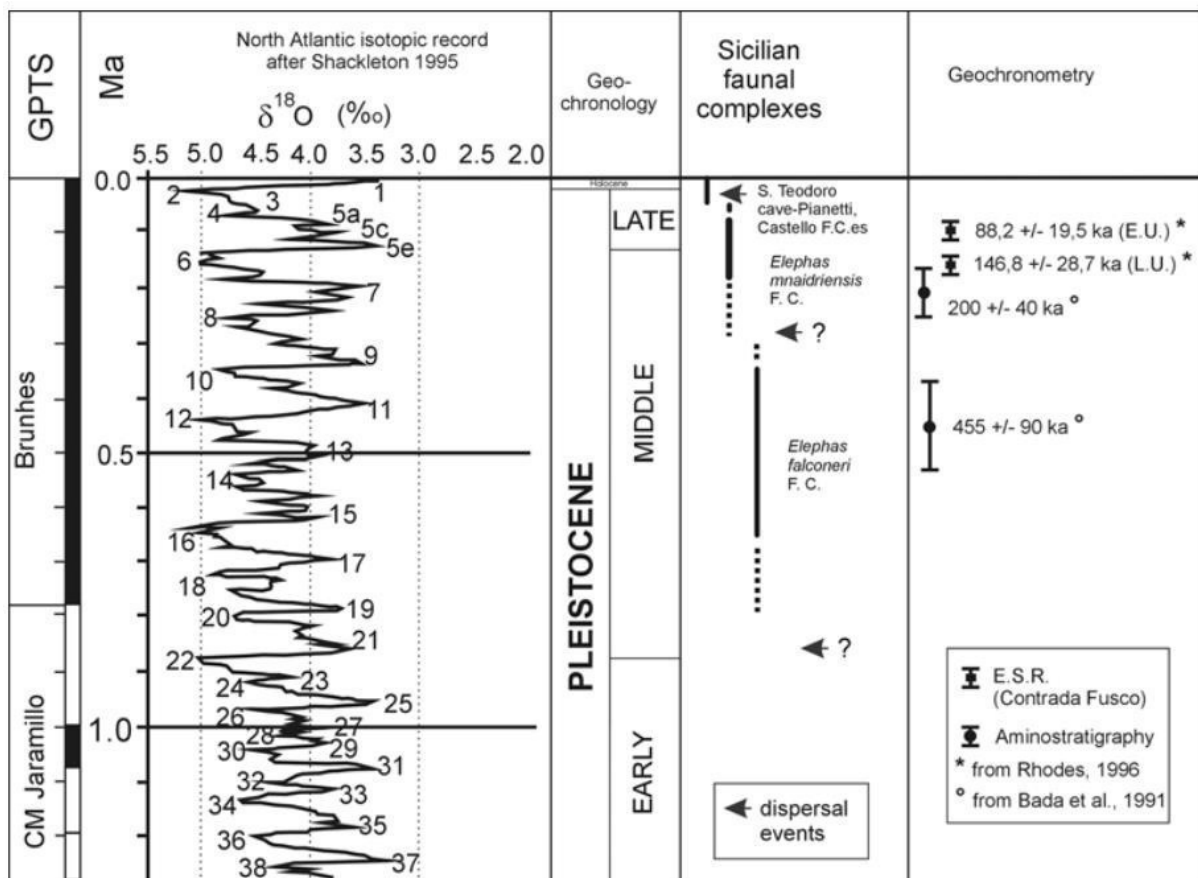


Figure 4.1-1 Chronological correlation frame of the vertebrate-FC complex with marine isotopic stage from Bonfiglio (2003)

4.2 Petrography discussion

Quaternary environmental changes, due to tectonics, climate, and sea-level oscillations are the causes that favoured the development of erosion/deposition processes responsible for the genesis of deposits to Grande\Delia river valley. The study of thin sections made it possible to recognise four types of petrographic families: Quartzite and Quartzarenite (Qz Type), Biocalcarenites; Conglomerates and Chemical rock. Quartzite and Quartzarenite samples come from sampling for the morphometric study. Quartzites are petrographically defined as granoblastic aggregates of allotriomorphic and heterometric quartz crystals, with undulatory extinction and variable preferential orientation depending on whether there is foliation or not (Folk, 1954; Raza et al., 2010; Roy Sunyer et al., 2017). Beginning to analyse the Qz Family's samples, they

seem to belong to the Terravecchia formation, that appears throughout the river basin. Moreover, the basin itself, as described in the previous paragraphs, is the culmination of Plio-Pleistocene orogenic processes (Grasso and Martyn Pedley, 1988; Abate et al., 1998; Gugliotta, 2010; 2012; Puglisi, 2014). In the study area, quartzite and Quartzarenite pebbles are found scattered over several flat surfaces that border and follow the river bed. The comparison between the different samples does not show substantial differences in particle size or texture and represent the testimony of the presence of a single source basin for the develop of these pebbles. Also, the Terravecchia deposits have been accumulated in the inner-to-outer, wedge-top depozone (Gugliotta 2012; Gugliotta et al., 2013) between Late Tortonian and Early Messinian. In short, a full continental-to-shallow-marine wedge-top depozone developed above the growing thrust sheets, characterising the depositional environment of Terravecchia Fm. Orogenic processes caused the formation of several kinds of syn-kinematic basins, localised within this depozone, filled by coarse clastic successions about the Terravecchia Formation (Johansson et al., 1998; Gugliotta, 2010). The quartz clasts in Fm Terravecchia are the result of the erosion of the Magrebide chain and during the Messinian–Lower Pliocene. Syntectonic successions were accommodated as basin fill in progressively narrower localised and laterally discontinuous wedge-top basins bounded by transpressional structures with deposits from different areas (Rosolino et al., 1995; Giunta et al., 2000; Gugliotta et al., 2014; Morticelli et al., 2015). At the moment, it is possible to hypothesise the presence of at least two types of quartzarenite which differ mainly in granulometry and shape: a variety of a reasonable degree of roundness and sorting and a second variety with characteristics that suggest a lower degree of maturity (sub-angular grain, fine and medium grains, moderate sorting). Moreover, quartz grains belong to two distinct categories: undeformed and deformed. The undeformed grains are rounded and can derive from plutonic or high-grade metamorphic rocks (samples: 4\m3; 5\m2; 6\m4; 10\m4CZ); the deformed grains are frequently subangular and probably derive from low- and medium-grade metamorphic rocks (samples 9\m2). This characteristic of rounded grains represents the

result of reworking in a continental and marine environment with a polycyclic origin or may. However, there's the presence of subangular grains that are not affected by such processes or can derive from rounded grains shattered during the final transport.

The sedimentological and petrographic characteristics of Qz type thin sections show some differences inside the clasts. These difference has been interpreted as a change in the formation of numidic successions account for the variability of the sandstone composition in various sectors of the Mediterranean, already indicated by Fornelli (1998) and recently Barbera (2014) and has been also interpreted as a basin of provenance from African plaque. Also, the presence of some minerals belonging to the group of mica may suggest that the feeding of these basins may be different. The samples show same petrographic characteristics that are very similar to Quartzites type present in the Iberian peninsula and utilised as raw material (Pederagnana et al., 2017; Roy Sunyer et al., 2017). The macroscopic analysis of lithic industries (Palma di Cesnola, 1994; Accardo, 1997; Lopez, 2014) present in the area and quartzite samples show similar characteristics such as fine grain and roundness granules. At present, the use of the two types of quartzite present in the area has not been demonstrated. Subsequent analyses will be directed to characterise lithic findings and to compare them with this initial petrographic collection of comparison.

In quartz-pebble conglomerates (QPC), more than 90% of the clasts consist of vein quartz, chert, or quartzite (Boggs, 2009). Current sedimentology textbooks state that they represent tectonically quiescent conditions under which chemical and mechanical weathering were very efficient (Selley, 2000; Collinson, 2005). The thin sections of conglomerate samples have common characteristics. The characteristics are linked to the weaving and mineralogical content such as, for example, the presence of calcitic lamina around some clasts, especially quartzite; the presence of intraclast quartz with very fine sand granulometry; the absence of any stone clast of bandage and a fabric common to all the samples (Figure 4.2-1). The recognition of a fabric common to all samples can lead us to hypothesise how conglomerates can have the same

sedimentary history. The presence of evaporitic rocks in the same catchment area has probably influenced the formation of conglomerates (Forti and Sauro, 1996; Liguori et al., 2008; De Waele et al., 2017). The process of dissolution and re-precipitation of gypsum has been studied by several authors and discussed in the literature (Bellanca and Neri, 1993; Klimchouk et al., 1996; Sauro, 1996; Ferrarese et al., 2003). However, all the chemical-physical processes are not entirely clear; the authors agree about the enrichment of the meteoric waters of these minerals and their subsequent re-precipitation. The variations in pressure and pH, that causes the loss of interstitial water from the exposed rock, are linked to climatic variations that generate geomorphologic forms of both macroscopic and microscopic redeposition (Klimchouk, 1996; Sauro, 1996; Ferrarese et al., 2003). A similar process/forms are present in the eastern Mediterranean where conglomerates showing a process from meteoric water diagenesis include dissolution of sulphurous mineral equant - bladed calcite cement (El-Shahat, 1995; Enzel et al., 2008). The cement was precipitated as rims and filled the intergranular pore space and secondary porosity in a very similar process as that one which led to conglomerate samples (Figure 4.2-1).

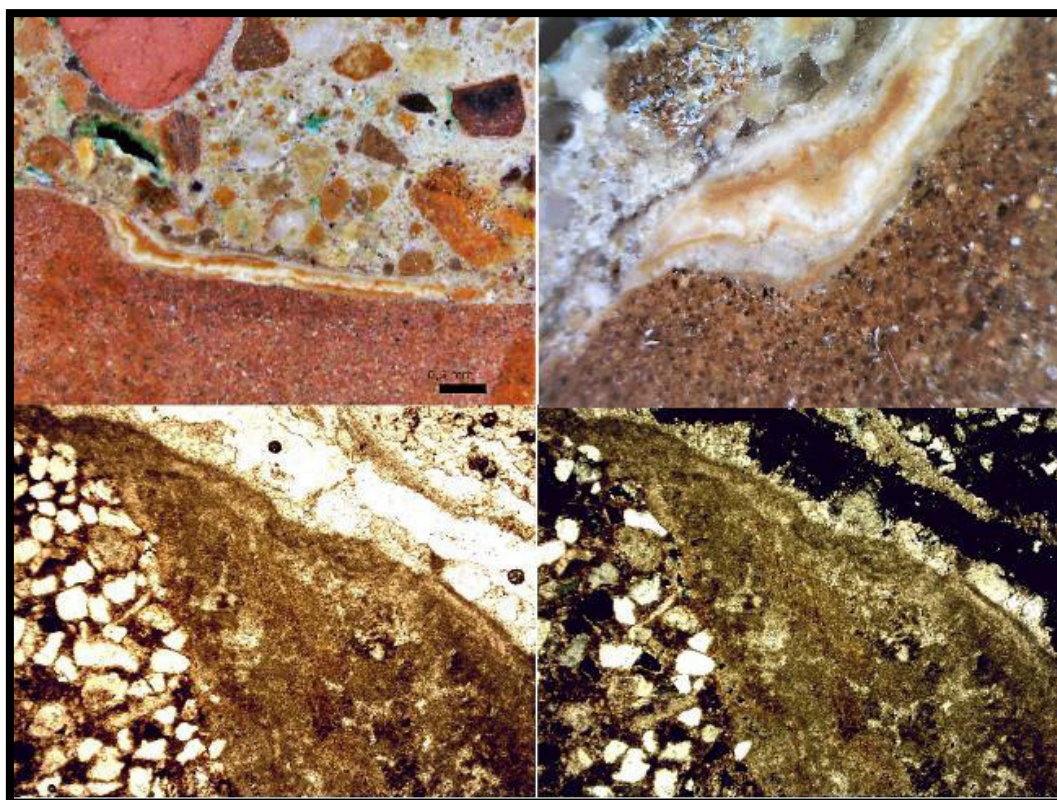


Figure 4.2-1: the carbonate crust from sample 14\CC4b. A macroscopic vision, a Stereomicroscopic vision and with PP and NX vision. The sample shows a characteristic lamine carbonate that covers the clast.

Another process that has probably influenced the formation of cement of these conglomerates is the presence of a soil that increases the carbonate from the dissolution of CaCO_3 (El-Shahat, 1995). Moreover, diagenesis plays a significant role in the compositional evolution of clastic rocks. Chemical alteration coupled with the mass transfer of material can produce sizeable secondary porosity and ultimately diagenetic quartz arenites (Cox et al., 2002). Also, interstitial grain contacts in the conglomerates are actively pressure solved. Cox (2002) indicates that, in many cases, QPC owe their composition to diagenetic processes. In terms of environmental variation, it is probable that clast disintegration and dissolution, followed by porosity collapse and pressure solution along grain boundaries is responsible for the composition and texture of QPC. At the same time, intense weathering and protracted transport can surely produce such deposits. However, the prevalence of QPC in settings where conditions are not optimal for their formation as initial deposits strongly suggests that post depositional modification often plays a significant role. A process is similar to that proposed by Ullyouff et al. (2015) that hypothesised

that shows systematically the micromorphology, geochemistry and mineralogy of cap structures within groundwater silcretes. If we compare the textures of our samples, there is an evident similarity where the texture of a conglomerate, made of mixtures of optically- continuous quartz overgrowth and micro quartz cement, is the typical fabric of river environments (Shaw and Nash, 1998). The presence of overgrowth rings linked to the dissolution-reprecipitation processes and mineralogical composition of the clasts in the conglomerates and the stratigraphic position with the conglomerates are succeeded by sands (in some areas with a discontinuity, in other areas instead of more gradual). We can hypothesise how the formation of these conglomerates is due to a phase of regression of the sea level. Calcarenite samples, on the other hand, come from two distinct areas of the study area. Sample 11\Calc2 was sampled along a road that highlights a stratigraphic section of weakly cemented sands and forms part of the calcareous sandstones on the Great Upper Terrace described by some authors (Ruggieri et al., 1975; Ruggieri and Torre, 1989; D'Angelo and Vernuccio, 1994). Samples 12\Calc4; 13\Calc3d; 15\Calc1 come from small outcrops distributed around the area of the airfields, to the right and left of the Delia river. The samples show uniform texture and slightly packing with the particle size distribution of the grains well graded and similar microfossil assemblage. Moreover, the calcarenite samples show an overgrowth of calcite around some clasts (Figure 4.2-2).

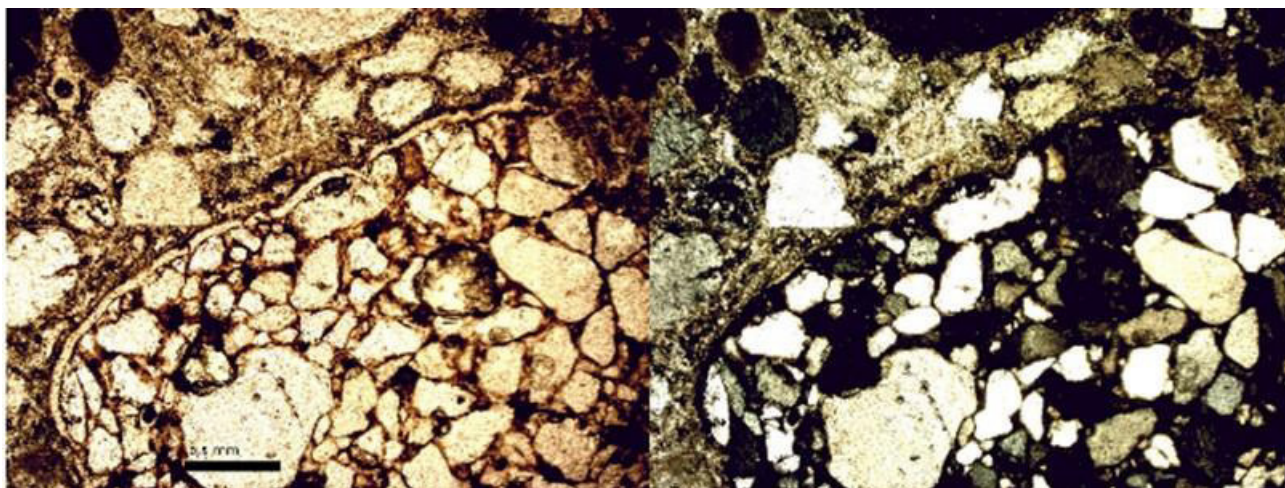


Figure 4.2-2: Quartz clast with an overgrowth of calcite, from 15\calc1

These characteristics lead us to suppose (geographical position, similar textures, microfauna) that these samples belong to the same stratigraphic level as the base in with erosional bottom surface over the clay of Terravecchia Fm. and while on the top there are conglomerates (Figure 4.2-3



Figure 4.2-3: erosive contact between sandstone (bottom) and conglomerate from area study.

The cementation between the two types of samples is also different with granular and microgrunal cement percentage as described by some authors (Arces et al., 2000; Zimbardo et al., 2011; Zimbardo, 2016). In the sample 11\Calc\2 yellowish poorly cemented fossiliferous carbonate sands rather than samples of Grande\Delia River show more marked cementation as evidenced by the thin sections. The presence of remains of foraminiferous remains (still under study), red calcareous, lamellibranchs and gastropods are datable briefly and preliminary to the Middle Pleistocene comparing the samples with other calcarenites present in western Sicily (Alaimo et al., 1998; Bellanca et al., 1999; Arces et al., 2000; Basilone, 2012; Agate et al., 2017). The phenomena of secondary recrystallisation of micritic inside the voids porosity lead to hypothesise how these calcarenites may have had at least two distinct events. The first event was the replacement of these calcarenites and a subsequent phase probably linked to changes in the base level, which led first to the formation of a micritic cement and then to the conglomerate level. We are waiting for a more detailed biostratigraphic analysis for fossil associations to understand the evolution of the paleoenvironment and a more precise stratigraphy placement but it is possible, however, to affirm that the study area has some characteristics that cannot be only attributable to a modelling of the Terravecchia Fm.

4.3 Sedimentological discussion

Several pebble morphometric studies have shown that pebble form indexes are useful tool to split environments (Sneed and Folk, 1958; Dobkins and Folk, 1970; Farabegoli and Ricci Lucchi, 1973; Els, 1988; Gale, 1990; Torre and Ciarcia, 1995; Miall, 2006; Chiocchini and Castaldi, 2009). Several authors compared different morphometric characteristics of river sediments to distinguish index form concerning their geological evolution, transport, and environment (Wadell, 1935; McLean and Kirk, 1969; Farabegoli and Ricci Lucchi, 1973; Chiocchini and Castaldi, 2009; Widera, 2010; Udo and Mode, 2013). Carrara (1981) shows that the pebbles in Italy are characterised by high rounding values, low sphericity values and oblate-prolate negative index in the beach environments. On the other hand, river environments have less rounding, more sphericity and an OP index tending to neutral or negative values. The results of the morphometric analysis on gravels of the different sampling stations are compared with measurements taken on pebbles of the present river environment and beaches from data by Carrara (1981). Moreover, a possible comparison with morphological studies on Pleistocene pebbles in different areas (Farabegoli and Ricci Lucchi, 1973; Torre and Ciarcia, 1995; Chiocchini and Castaldi, 2009; Vitale and Ciarcia, 2013). The discussion takes into account the absence of data collected in the study area and also possible ambiguities on the interpretation of measures and statistical data of particle shape (Barrett, 1980; Benn and Ballantyne, 1993). The means of all the form indices for pebbles from study area are given in Table 4-1. The results lie within limits for fluvial pebbles and are indicative of fluvial environment. Plots of the coefficient of flatness against sphericity show a fluvial depositional environment for the pebbles.

<i>Many values of morphometric indexes</i>							
axis b	S1	S2	S3	S4	S5	S6	S7
Mean	61,65	66,17	62,41	59,24	54,71	63,43	47,91
median	56,13	64,65	63,51	59,05	53,19	66,79	45,36
IF frequency							
<2,1	66%	76%	83%	90%	77%	78%	86%
>2,1	32%	24%	17%	10%	23%	22%	14%
IF mean and Median values							
Mean	1,99	1,88	1,75	1,62	1,75	1,83	1,74
Median	1,79	1,79	1,73	1,52	1,71	1,81	1,68
Coefficient IF*100							
mean	46,44	49,38	52,33	57,71	53,43	50,76	52,09
median	47,61	50,84	50,42	56,90	52,48	47,33	52,13
Sphericity index IS							
MeanIS	0,667	0,682	0,711	0,752	0,717	0,688	0,720
medianaIS	0,687	0,683	0,701	0,760	0,700	0,680	0,722
OP Index							
Mean OP	0,28	-0,52	0,11	1,07	0,18	-1,15	1,64
Median OP	1,79	-0,43	-0,48	1,18	-0,13	-0,48	2,10

Table 4-1: sum up of different index

The following index describes environment which it is possible to discriminate between river and coastal gravel. Also, the use of morphometric index is a useful tool to understanding the formation environments.

Flatness Index (IF): Flatness Index show values less than 2.1, limit value for dividing processing in the marine environment ($IF > 2.1$) from river processing ($IF < 2.1$) (Cailleux, 1945). Also, Stratten (1987) showed that fluvial pebbles have coefficients of flatness of more than 45 and their mean sphericities exceed 0.65 for river environment. The coefficient flatness is the percent of flatness ratio S/L (Lutig, 1962). Thus, the appropriate lower index limits for pebbles shaped in fluvial environments are the following: sphericity = 0.65, the coefficient of flatness = 45 (Sneed and Folk, 1958; Dobkins and Folk, 1970). The mean of IF index from the different sites show a value below <2.1 with a range of values from 1.69 to 1.99 and against the Cailleux (1945) and Carrara (1981) indexes, the IF index mean value is below the environmental limit river-beaches (Dobkins and Folk, 1970; Chiocchini and Castaldi, 2009). The IF index of San-topadre Fm (Latium, Italy) consisting of typical river facies of high energy and uplift movement

(Carrara and Giraudi, 1995) has IF indexes between 1.83 and 1.6 comparable with the IF values of S2 stations at S7, while S1 has an IF 1.99. However, the single stations show a small percentage of pebbles exceeding 2.1 value. The highest value is in the S1 station outcrop of Giandotto ($IA > 2.1$ at 34%), while for the remaining stations the value is constant between 14 and 24%. Following Stratten (1987) the coefficient of IA measured on seven sampling station shows a mean values range between 46,44 (S1) to 57,71 (S4) and the values drop within the fluvial environment. Also, the limit of 2.1 is recognised during Holocene as an environmental limit index in paleo-beaches of Alpine lakes (Baroni, 1985). Values of IF index indicate that these deposits have been formed in the river-sea environment, but the effect of river environmental factors has been more significant over time. This hypothesis is part of a possible general emersion phase during regression of sea level. The textured and morphometric data of the gravel of the Grande\Delia River show a river transport by watercourses and the IF index values indicate high transport energy typical of torrent-like regime watercourses (Lutig, 1962; Carrara, 1981; Chiocchini and Castaldi, 2009).

The spherical index (IS): In general, the values of 0.65–0.66 IS separated the gravels of high-sphericity fluvial abrasion from those of low-sphericity beach abrasion (Dobkins and Folk, 1970). Stratten (1974) and Gale (1990) found mean values for fluvial gravels between 0.67 and 0.77 and beach gravels between 0.53 and 0.64. Quartzite river pebbles have a limit value equal to 0.65 in Southern Africa (Stratten, 1987; Odumodu, 2014). This interval divides marine environments from river environments processing (Dobkins and Folk, 1970). In fact, the sphericity index in Italian rivers shows a range between 0.532 to 0.759 (min 0.532; max 0,759; mean 0,656) (Carrara, 1981).

The values of the seven stations have a range between min value 0.67 (S1 station) and max value 0.75 (S4 station) while stations S2 and S6 have a mean value equal to 0.68, the remaining stations S4, S5, S7 have similar values to 0.71-0.72 IS index. Consequentially, the analysis of the spherical index indicates how all seven stations are in the river field. However, frequency

curves of sphericity value in rivers and beaches overlap (Figure 4.3-1). If the IS mean value between 0,6-0,725 there is a 73% of probability that the set is from the river; over 0,725 it is sure. Finally, the value IS index from Grande\Delia River (IS=0,67-0,75) is above the 0.66 line and therefore indicative of a likely fluvial origin. Also, it can help to distinguish fluvial and marine environments the IF (Index of Flatness). Moreover, IS and IF values are in the fluvial field, it is possible to hypothesise the presence of a river with characteristics similar to high energy streams typical of the rivers in southern Italy. (Cailleux and Tricart, 1963; Carrara, 1981; Bartholomae et al., 1998).

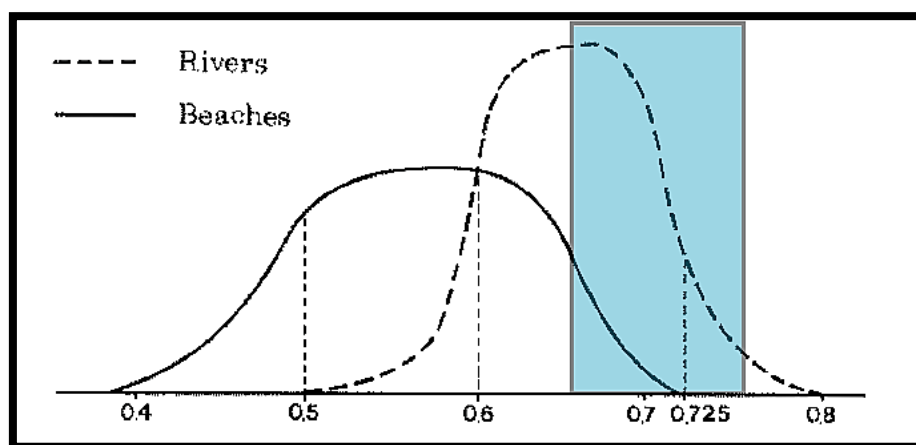


Figure 4.3-1: comparison of the mean values of the spherical index of the pebbles of rivers and beaches from (Carrara, 1981) with the values measured at the sampling stations (blue box)

Oblate-Prolate Index: The Index is used to describe and distinguish better the clast shape and to distinct fluvial and beach environmental. However, the OP index has a different border to separate two environments. In the African context, if the oblate–prolate index is below at -2, it is about 87% certain of a beach environment, and if the values are below, between -1 and +5, it is 69% certain that the environment is fluvial (Okoro et al., 2012; Udo and Mode, 2013; Odumodu, 2014; Itam and Inyang, 2015). However, in Italy the OP index mean values show a limit of – 1,5 between fluvial and beach facies (Carrara, 1981) and Similarly Dobkins and Folk

(1970) confirmed the lower limit value of oblate – prolate index for pebbles as – 1.5 from differentiating fluvial and beach environmental.

The mean values of OP index in Grande\Delia basin show a range from -1,15 to 1,64 values (S6 and S7) and a median value – 0,43 to 1,79 (S1 and S2). The values of OP index suggest that the pebbles from Grande\Delia valley have been formed in a fluvial origin (Dobkins and Folk, 1970). Also, values of -2 and -3 OP index are frequently recorded in upper and mid-course of the river (Dal Cin, 1967; 1968a; Dumitriu et al., 2011b). The difference between mean and median is caused by the flow of the Grande-Delia fluvial system through the conglomerate deposits formed during the passage between the marine and continental environment, re-elaborating pebbles of the Terravecchia Fm.

As described in the results, the ternary diagrams of Sneed and Folk provide a graphical overview of the overall shape of the sampled pebbles. In Italy, rivers are characterised by bladed, compact-bladed shape. Platy-blade (Carrara, 1981) forms characterise beach environments. Diagrams show a non-uniform distribution with a broad distribution curve. Inside the stations, the study of ternary diagrams shows an apparent prevalence of bladed type forms while platy forms are poorly represented. The percentage frequency curve in the ternary diagram classes shows how highest frequencies are in bladed\compact-blade shapes (Figure 4.3-2). Moreover, the distribution is not uniform but distributed in different classes forms. This distribution, however, is part of the action of a river environment with high energy, with the probable replacement of deposits such as debris or a chaotic deposit (Sneed and Folk, 1958; Graham and Midgley, 2000; Miall, 2006; Widera, 2010). Moreover, it is part of the variability highlighted with studies in high energy basins, massive accumulation in limited transport conditions of a colder period of the Pleistocene (Morche and Schmidt, 2005; Morche et al., 2014; Stacke and Tábořík, 2015).

In the sampling stations, the percentage distribution of shape classes is typical of a river type variability. The fluvial action reworked material, even if there are percentage variations between the different classes. (Sneed and Folk, 1958; Carrara, 1981; Benn and Ballantyne, 1993;

Carrara and Giraudi, 1995; Graham and Midgley, 2000). In some stations (e. g. S6) the ruling classes are bladed shapes. The S6 station is located on a terraced surface of a river terrace that has reworked the previous conglomerate deposit. In Station S7 (outcrop airfield) the possibility of re-elaboration of pebbles deposited in beach environment is more evident with a more significant variability within the ternary diagram with nearby of conglomerate levels and sands outcrops.

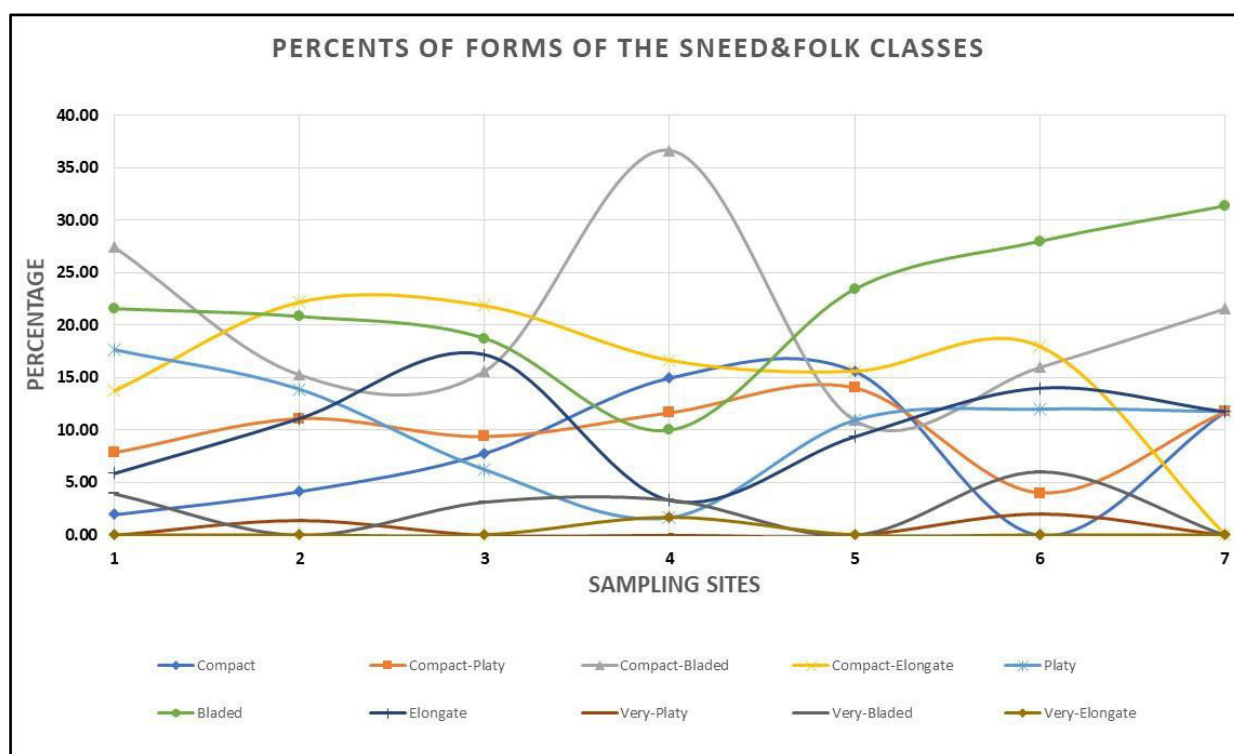


Figure 4.3-2: Distribution percentage of Sneed & Folk classes in sampling sites .1) S2\M1 2) S3\M3 3) S7\M5 4) S4\M4 5) S5\M2 6) S1\M7 7) S6\M6. Station 3) S7\M2 and 6) S1\M7 are outcrop.

The study of single morphological parameters is not sufficient to distinguish the different environments (Sneed and Folk, 1958; Dobkins and Folk, 1970; Carrara, 1981; Stratten, 1987; Gale, 1990; Widera, 2010). Various bivariate plots also agree to consider more diagnostic elements to investigate fluvial depositional environments, like “sphericity against oblate – prolate index” and coefficient of flatness against sphericity.

Results of Plots of sphericity against oblate – prolate index (Figure 4.3-4) using (Dobkins and Folk, 1970) method suggests that the pebbles from Delia\Grande rivers have been formed in a fluvial setting. Besides, the appropriate lower index limits for pebbles shaped in fluvial environments are: sphericity = 0.65, coefficient of flatness = 45, oblate – prolate index = - 1.5 (Dobkins and Folk, 1970; Carrara, 1981; Gale, 1990).

A similar result can be obtained if we plot flatness coefficient against sphericity (Figure 4.3-3) and it shows a fluvial depositional environment for the pebbles. The influence of pebbles deposits in marine environmental, reworked during Pleistocene, is easier to understand if we observe plot in Figure 4.3-5, where all the values of the seven sampling stations are reported. The plot shows a small percentage of values of singular gravel value in “beach” field.

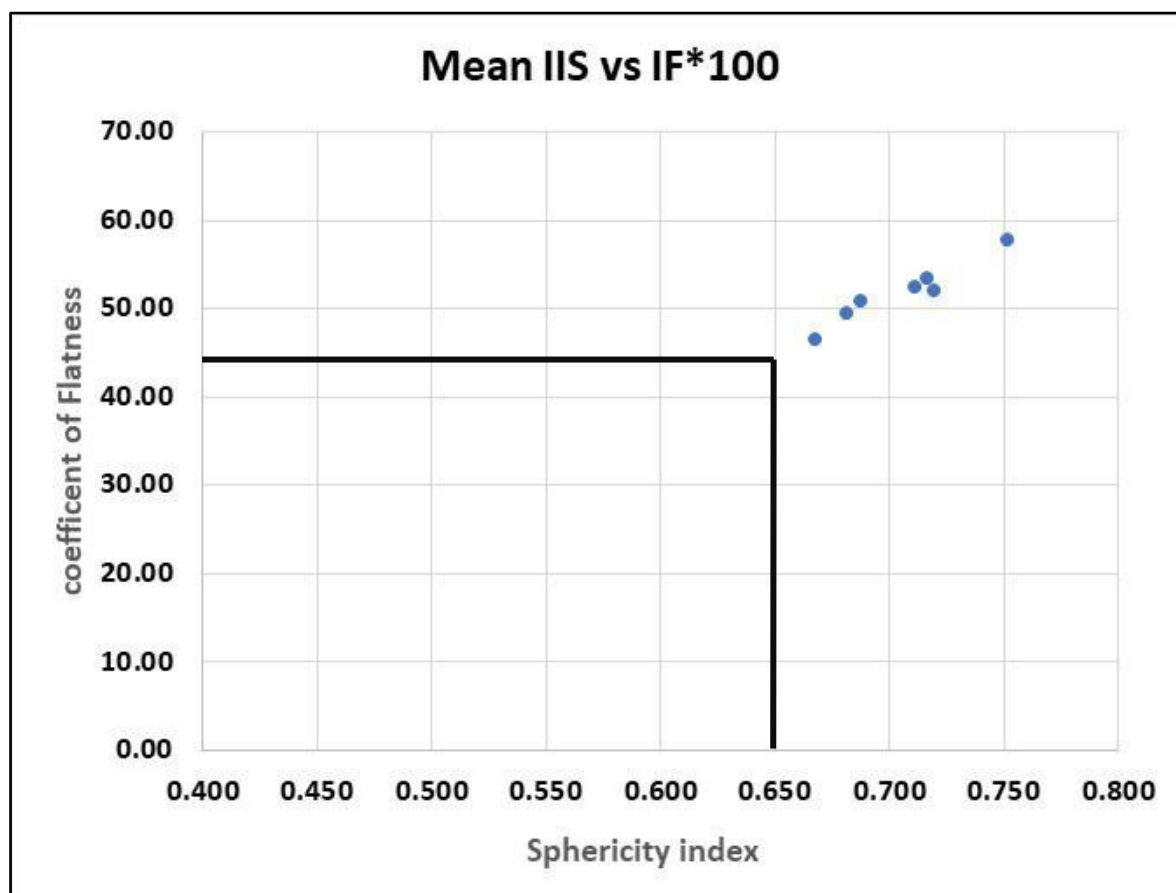


Figure 4.3-3: Bivariate plot of Flatness Index and Sphericity Index for gravels from Grande\Delia valley. Black line shows lower index limits for pebbles shaped in fluvial environments: sphericity = 0.65, coefficient of flatness = 45

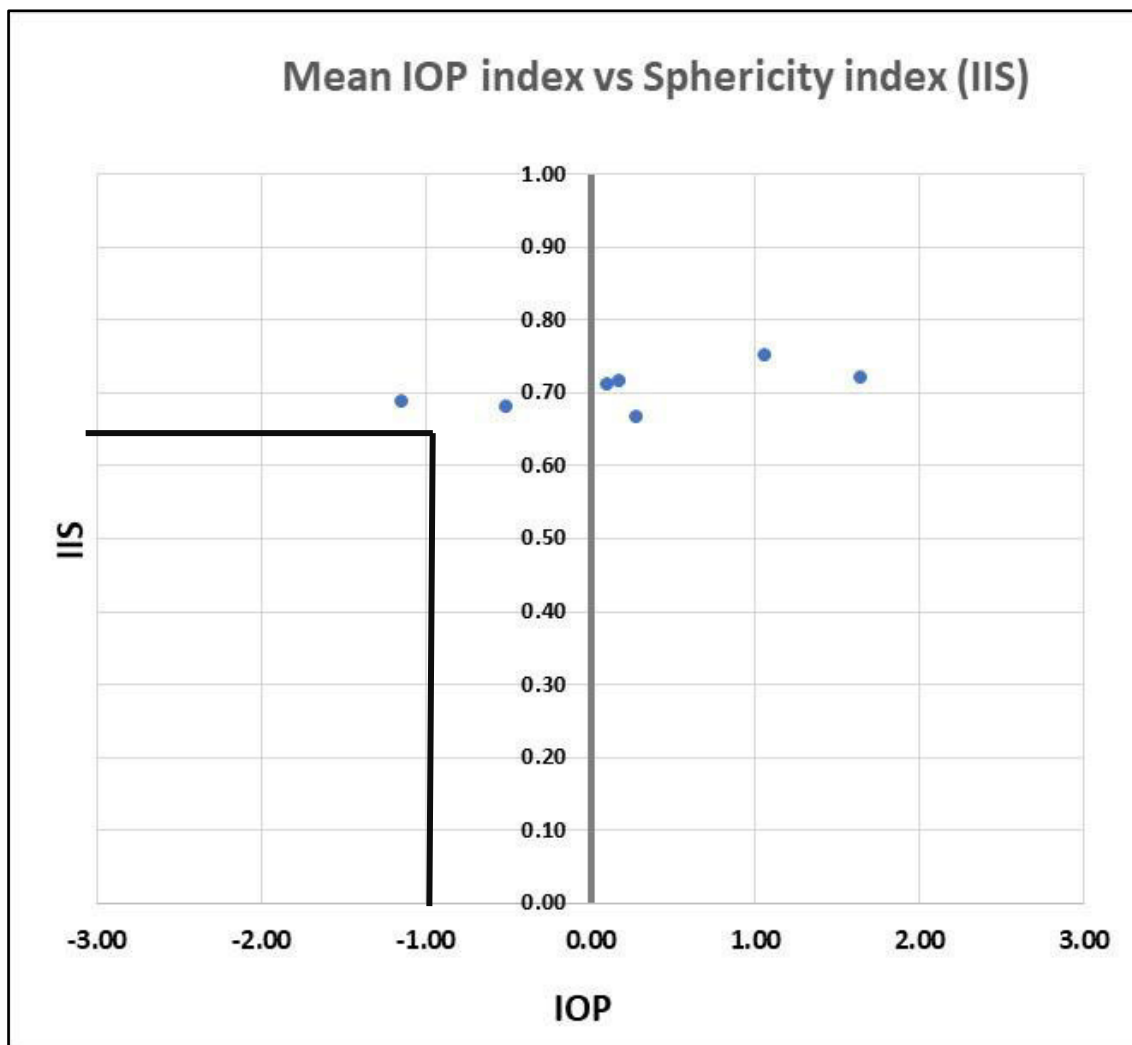


Figure 4.3-4: Plot of sphericity against OP index showing separation of beach field from the river field. Black line separate two environment; beaches shows oblate and lower sphericity; Rivers show prolate and high sphericity.

Finally, the morphometric studies (IS sphericity, IF and coefficient of flatness, oblate – prolate index) to the gravels from Grande\Delia River indicate a fluvial environmental formation. The gravels are from coarse to very coarse pebbles, and the values of morphometric index indicate a probably single Brained torrent that reworked lower conglomerate layer (Chalov and Alexeevsky, 2015). The sites pebble composition indicates a prevailing provenance from areas that correspond to the present-day fluvial catchment (Quarzite and Quartzarenite from Terravecchia Fm, calcarenites and bio-calcarenites). Moreover, the sampling sites are located in elevated areas respect to the current river and they can be interpreted as river terraces. Station S1 can be assumed as a fluvial debris deposit. Debris flows are important depositional processes

on alluvial fans, responsible for many coarse-grained deposits (Costa, 1984; Garfi et al., 2007). The conglomerate layers show a lateral spread at the top of channel. The Conglomerate Layer are about 1 m thick, poorly classed, with well-rounded clasts and granulometric from pebble to boulder at top. The section is formed by a lenticular geometry with a concave erosive base and the top passes to a convex or flat shape. The geometry of the canal seems to be narrow and elongated, like the valley that lies above the outcrop. and interpretable as a ribbon channel (Miall, 1985). The body is the filling of a channel and is the product of a single rapid depositional event. Besides, the conglomerate level seems to be the only one on the slope. Testimony of a single high-energy event with a rapid increase in transport energy. The conglomerate does not have a progressive decrease in granulometric characteristics. Therefore, the depositional of conglomerate debris can possible with a rapid flow variation or lateral movement of the hypothetical alluvial fan.

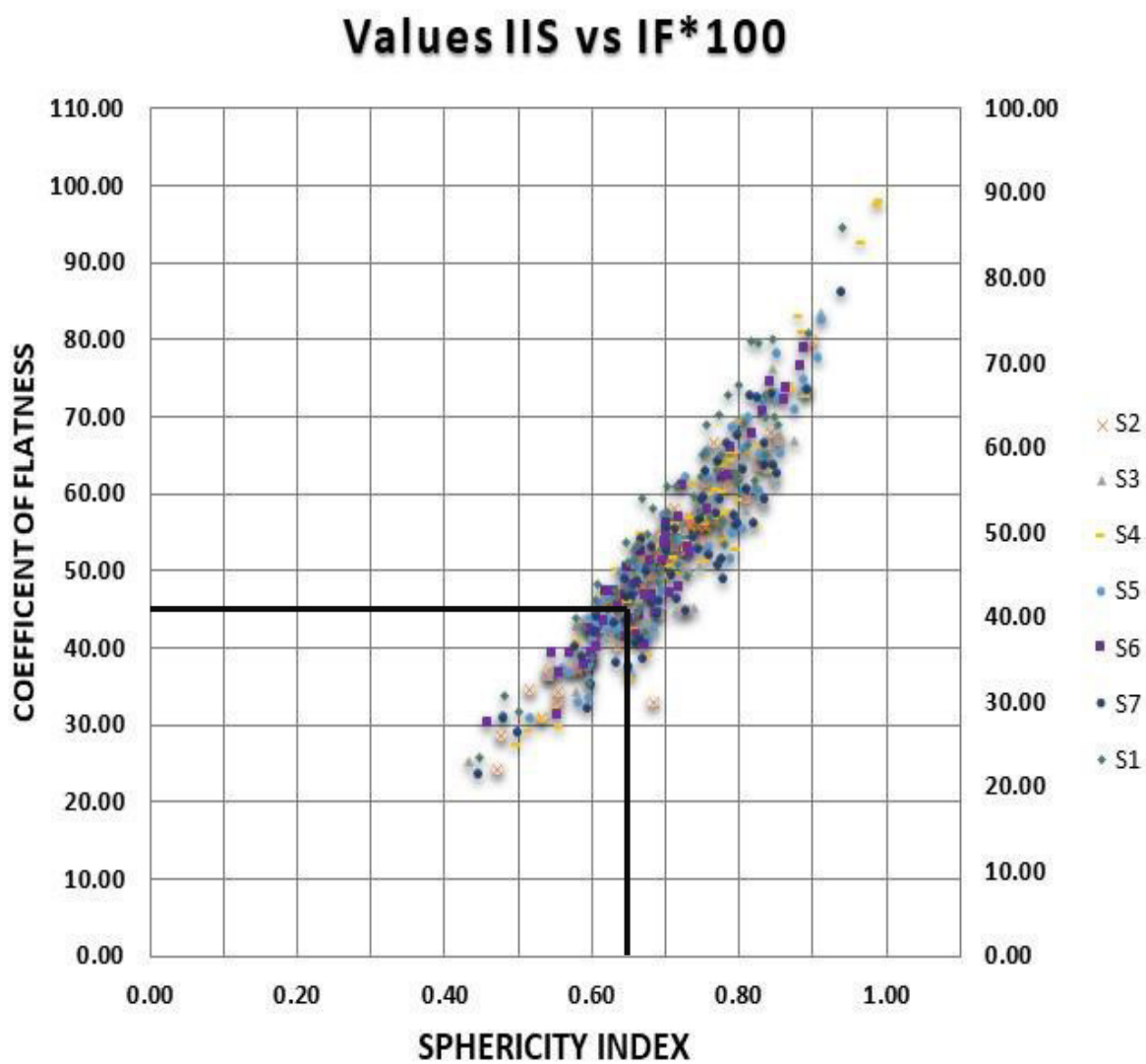


Figure 4.3-5: Bivariate plot of Flatness Index and Sphericity Index of total values gravel from Grande\Delia valley. Black line shows index limits for pebbles shaped in fluvial environments: sphericity = 0.65, coefficient of flatness = 45

4.4 Geological and fluvial Terraces Context

Results of field mapping show Quaternary environmental changes, due to tectonics, climate, and sea-level oscillations that favoured the development of erosion/deposition processes responsible for the genesis of Grande\Delia river valley. Furthermore, using Miall scheme (Miall, 1978; 2006) we are able to distinguish in Grande\Delia Valley two sedimentological and environmental contexts: a braided river depositional system, characterised by fluvial terraces and an “Alluvial Fan” sedimentological environment. The braided channel, the filling of gravelly channels, is sufficient large and little depths to enable forms to migrate, leading gravel during flow periods and depositing it coarsely (Rust, 1972; Miall, 1978). The outcrops with conglomerates facies are all compatible with a canalized braided context. The gravels facies can be indicative of a transport leading to high concentration of sediments. Besides, the “Alluvial Fan” is characterised by debris and/or mud flow active in small catchment areas, made up of poorly coherent terrain, active especially at certain times with intense rainfall (Todd, 1989). A sedimentation environment with these characteristics is indicative of alluvial plains produced by high-energy watercourses and braided channels. The architectural elements are mainly gravel bars and a small proportion of sandy bedforms forming lenses and wedges as abandoned filled channels. The gravel longitudinal bars have been originated in between the incised channels and generally have a diamond shape in low relief. The presence of reverse grading can arise from an increasing strength of flow during sedimentation, caused by a change in basal level (Tucker, 1991). The reverse grading of some conglomerates layers are interpreted as the results of grain flow transporter from rapid increase of high-energy channel-floor sedimentation as gravelly traction (Dal Cin, 1968a; Todd, 1989; Milan et al., 1999; Lewin and Gibbard, 2010) up to the highest level; the remaining portion of the sediment is successively deposited with normal gradation due to the progressive decrease in energy. *Pebble cluster* structure and emblicated pebbles have been recognised in the geological mapping and confirm the fluvial environment system (Miall, 1978; Reading, 1996). The most distinctive components of alluvial fan

environments are debris-flow deposits with a ribbon shaped erosion at the bottom. The conglomerate layers show a lateral spread. The body is the filling of a channel and is the product of a single rapid depositional event. The geometry of the canal seems to be narrow and elongated, like the valley that lies above the outcrop and interpretable as a ribbon channel (Miall, 1985).

The geomorphological evolution of Grande\Delia valley and terraces can be correlated with morphologies studied by Nesci (2012). Stream terraces and the overall pattern of main valleys was already delineated in the Early Pleistocene-Early Middle Pleistocene, thus allowing initial almost-flat surfaces to be gradually furrowed by valleys where stream terraces could develop. Alluvial Fan cycles of downcutting and stream terrace are linked by 100-ka climatic cycles (Fanucci et al., 1996; Nesci et al., 2012). The geological survey showed the presence of river terraces. The main problem is to define the terraces dating and their relationship with sea terraces in Sicily. Quaternary marine terraces are generally the result of the action between tectonic uplift and cyclic sea-level changes (Mauz et al., 1997; 2015; Macklin et al., 2002). The study of Sicilian marine terraces has been developed by several authors (Ruggieri et al., 1968; 1975; Ruggieri, 1978; Di Maggio et al., 1999; 2009; Agate et al., 2017) in Western-Southern Sicily (Ruggieri et al., 1968; Ruggieri, 1978) and Northern Western Sicily (Di Maggio et al., 1999; 2014b), while in Eastern Sicily studies also involved the dating of river terraces in Simeto Valley (Ristuccia et al., 2013). Besides, Sicilian large Vertebrates are a marker tool for the history of marine and continental sedimentary processes (Bonfiglio et al., 1996; 2010). These authors agree that climatic variations and eustatic variations played a fundamental role in the formation of terraces (Westaway, 1993; Trenhaile, 2002; Wegmann and Pazzaglia, 2002). Furthermore, the regional tectonic during Africa–Europe convergence has roles to uplift (Catalano and De Guidi, 2003; Goes et al., 2004; Fedorik et al., 2018). These movements follow a slow but prolonged uplift that involves the continental shelf, coast and even the most internal areas, along the whole North-Western Sicily. (Mauz et al., 1997; Di Maggio et al., 1999; Sulli et al.,

2012). The last 0,5 Ma involved strong vertical tectonics (Catalano et al., 1996). The two main extensional events are linked to opening of the Tyrrhenian basin with strike and transpressive faults, deforming Pleistocene and Tyrrhenian marine and continental deposits (Abate et al., 1998). Tectonic control also found a reliable collocation as responsible for altimetrical terraces distribution (Fanucci et al., 1996). Numerical age dating have been carried out in some different areas of Sicily. The Optically Stimulated luminescence (OSL) age determinations of Pleistocene alluvial–coastal terrace deposits cropping out between Mt. Etna volcano and the Catania Plain provided new constraints for correlating seven orders (from 330 Ka to 60 Ka) of terraces with sea-level high-stands, each corresponding to a distinct phase of the global eustatic curve (Ristuccia et al., 2013). Mauz et al. (1997) dated fluvial conglomerates, sampled along a river valley crossing the Castellammare plain, indicating 227 ± 40 ka age. In contrast, Dutton (2009) proposed different models of formation of terraces and uplift rates from speleotheme dating in the area of Syracuse.

Uplift rates are not uniform in Southern Italy and Sicily (Westaway, 1993). Antonioli et al. (Antonioli et al., 2006) shows uplift rates by 222 mm\1Ky to Southern Western Sicily coast, Hybelan plateau 85 mm\ky and North Sicily 924/ka. Also Antonioli (2006) explains that South coast does not preserve evidence of uncertain uplift remains, although there are at least two different interpretations: (1) the relatively weak bedrock has been easily eroded and possible terrace features and recent sediments have not been preserved, (2) there was a tectonic subsidence. Eight orders of marine terraces can be distinguish in Southern Sicily: GTS (Grande Terrazzo Superiore) from 115 e 214 m, and later seven terraces (90-114; 70-88; 55-69; 25-53; 23-24; 9-10; 3), and linked to Isotpic Stage: 15, 13, 11c, 11a, 9, 7, 5c (D'Angelo and Vernuccio, 1996; D'Angelo et al., 2001). The “Grande Terrazzo Superiore” (GTS), studied by Ruggieri and Unti (1974), is a very wide terrace (probably polygenic in origin) well developed on W and SW coasts of Sicily. The correlation between marine and terraces uplifts has been established with the use of MIS 5.5 outcrops marker. The marker displacement is a response to both surface

and deep crustal processes, and, in absence of more recent indicators, the MIS 5.5 highstand marker is an useful tool (Antonioli et al., 2006; Ferranti et al., 2006). On the basis of palaeontological remains, it has been considered younger than the Marsala Calcarene (of Sicilian age, about 930 ka) and older than the first Middle Pleistocene terraces that are visible in Marsala area above the MIS 5.5 terrace (Ruggieri and Unti, 1974; Ruggieri et al., 1975; Antonioli et al., 2006).

In Grande\Delia Valley the presence of fluvial terrace is linked to three events at least, that led to the formation of the three river terraces orders after the GTS. Fluvial aggradation occurred during Quaternary, generally is considered to have occurred during glacial periods (Starkel, 2003). The formation of fluvial terraces is a result of high levels of marine level stationing, which corresponds to the river baseline level during Middle Pleistocene, while base level lowering occurred and resulted in incision during interglacial (Trenhaile, 2002; Vandenberghe, 2015) or during glacial–interglacial phases (e.g., Bridgland and Westaway, 2008). The result of this model is the distribution of older fluvial terraces at higher altitudes than more recent fluvial terraces (Di Maggio et al., 2009). Comparison between fluvial terraces with global eustatic variations related to isotopic stages has been conducted through data of Spratt and Lisiecky (2016a). Besides, during the last 300,000 Ky there have been three high levels of sea events related to the formation of fluvial terraces (Figure 4.4-1). The comparison between the data collected on the terraces of Grande\Delia river valley with river terraces already recognized in North-Western Sicily have a link with the eustatic variations of Pleistocene (Di Maggio et al., 1999; 2009; Agnesi et al., 2000).

In addition, the compressive tectonics of the area controls the development of terraces as it can affect lifting rates in internal areas (Catalano et al., 1996; 2017). Lifting rates during the Middle Pleistocene can be different, as previously described due to a progressive shift of the orogenic front with the formation of Trusht. This can cause a different response between river terraces and marine terraces (Westaway, 1993).

In the study area fluvial terraces have been formed after the formation of the GTS because the terraces have topographical elevations equal to or lower than the GTS and are correlated with marine terraces at 70m altitudes. Terrace marine (70 m) becomes the basic level of the river and therefore are to be correlated with the lower order terrace. In addition, in the adjacent valleys different orders of fluvial terraces have been mapped, starting from 400 metres above sea level and developing to 200 and 150 m and they have been dated Middle Pleistocene (Di Stefano et al., 2013).

Terraces	TF	2-TF	3-TF	GTS	GTS	6TM	5TM	4TM	3TM	2TM	1TM
Q.te Max	219	180	110	174	170	114	88	69	53	24	10
Q.te min	192	118	74	138	125	90	70	55	25	23	9
Mean	206	149	92	156	148	102	79	62	39	24	10
Va di Quote	27	62	36	36	45	24	18	14	28	1	1
Va terr (T-Tn)	57	57	-64	9	46	23	17	23	16	14	-1
mis					15	13	11c	11	9	7	5c

Table 4-2: Summary of Terraces: maximum, minimum and mean values of elevation, difference in quote of terrace and comparison of following terraces (T-Tn)

Unfortunately, the absence of absolute and isotopic dates in Southern West Sicily, strongly limits the interpretation of data since isotopic variations may not have been recorded in Quaternary deposits. Missing dates can allow a comparison of the variations of the marine terraces and can lead to an incorrect chronological interpretation. In Southern Italy chronostratigraphic data constraints a revision and reconsideration of the age of formation and models on the relations between marine and fluvial terraces (Filocamo et al., 2009; Giano and Giannandrea, 2014). The absence of dating influence a correct reading of frequency and amplitude of glacially controlled cycles, and interglacial forcing (Nesci et al., 2012; Palamakumbura and Robertson, 2016). Besides, the unique correlation between terraces, Isotopic stage, is the presence of *Strombus bubonius* molluscan fauna of MIS 5 at 3-4 m above sea (Bonomo et al., 1996; D'Angelo and Vernuccio, 1996). In addition to problems related to a correct chronological context, fluvial terraces in Grande\Delia valley should not be older than MIS 9-7 (upper-Middle

Pleistocene). This hypothesis is supported by the three events of high sea level appened before MIS 5 and by the correlation with fluvial terraces of North-Western Sicily (Agate et al., 2017). Finally, in the context of a multidisciplinary approach to the topic of fluvial terraces, in addition to the application of dating techniques (OSL, ESR quartz) other techniques may be used as three-dimensional electrical resistivity (3D ERT), for detection of thickness of terraces deposits and bedrock depth (Chambers et al., 2012).

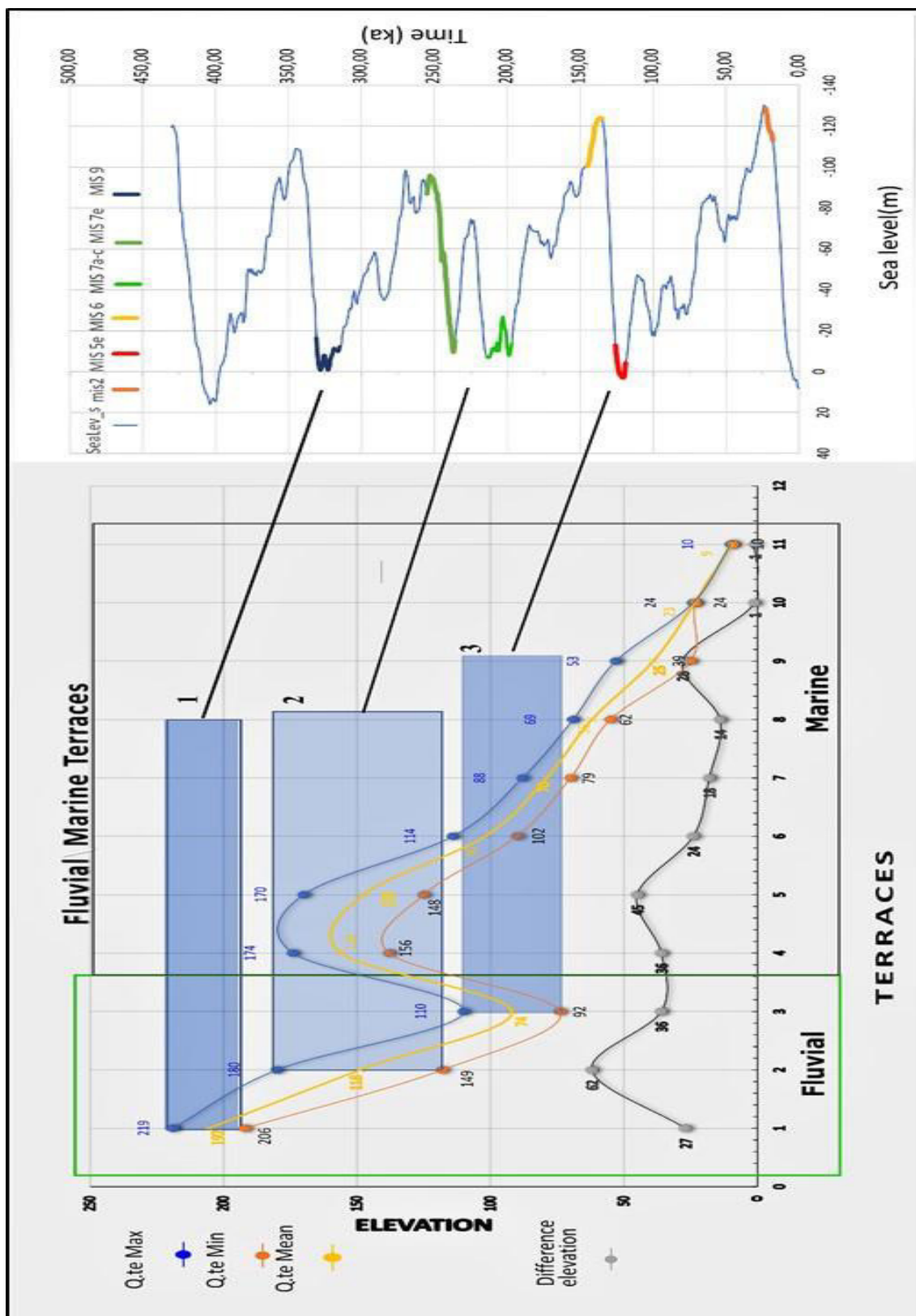


Figure 4.4-1: The diagram shows the principal Fluvial Terraces (1-2-3) compare to Marine Terraces and sea Level stack. Hypothetical correlation between High sea level and Fluvial Terrace. Sea level curve from Spratt and Lisicki (2016a; 2016b); Marine Terrace quote from (D'Angelo and Vernuccio, 1994; Bonomo et al., 1996; Antonioli et al., 2006).

CONCLUSIONS

5 Conclusion

This thesis has attempted to provide a framework to the issue of the early population of Sicily. The achieved results have to be considered as preliminary but will have important implications in the future studies. The debate about first peopling in Sicily is still actual. In addition, the study is further complicated because of the complex geology of Sicily, with deposits of marine origin mainly. The active orogenesis till Pleistocene and the Sicily spread surfacing in the last 0.7\0.5 Ma do not allow us to interpret Continental Quaternary Geology easily.

To date, lithic industries findings come from surface sampling. Nevertheless, in lithic industries, we can found Middle Palaeolithic typical knapping methods (especially Levallois, but also discoid and SSDA).

The objective of this thesis was to fill the geological gap concerning the absence of information about the territory.

For this purpose, research has been carried out with a multidisciplinary approach, For instance, field activities, morphometric, petrographic and paleontological studies have been conducted as parts of the whole geological study. Numerous field activities allowed to map about 170 Km² of GD river valley, corresponding to river basin up to Trinità dam.

Extensive field mapping (1:10.000 scale) and detailed sedimentological analyses of outcropping sections have shown that a complex stratigraphic organisation characterised the studied successions. In the Grande\Delia valley, mapping showed that Quaternary succession consists of continental and marine deposits at the same time. These deposits, gravity-driven deposits, alluvial and colluvial clastics, have been considered as ubiquitous units. The underlying substratum displays a pile of south-verging thrust sheets that consist of three different stratigraphic successions. The marine deposits are mostly Lower Pleistocene calcarenites and clays, Miocene terrigenous clastics and evaporites. They represent the fill of a foredeep basin (Terravec-

chia formation) converted during the Maghrebian contraction into thrust-top basins. The Messinian evaporites are mostly selenitic and clastic gypsum associated to marls. They are sealed by lower Pliocene marls (trubi). From Pleistocene “sandstone of marnoso arenacea of Belice” and Quaternary marine and continental deposits cover the previous deposits.

Mapped fluvial terraces have a stratigraphic succession of quartz sands that pass through an erosive or net surface to some well-cemented conglomerates of the fluvial environment and finally to the gravels.

The gravels reworking to pebbles of Pleistocene conglomerates. Besides, in both the studied outcrops, named S1\M7 and S7\M5 was possible to distinguish two fluvial depositional systems. S7\M5 crop represents a typical fluvial depositional environment, with braided channels (miall 2006), while S1\M7 shows a different context of fluvial depositional environment. In fact, the observed depositional environment is alluvial fan type, with a debris type facies fed by a small and young fluvial basin.

Collected data have been analysed trough Gis (Qgis software). Data processing starts from DEM, provided by Sicily Region and with a 2x2 m pixel definition. It allowed obtaining a detailed geological map with 1:10000 scale. Appropriate plugin (Csmarker e qProf) allowed to distinguish the morphologies of fluvial terraces from the territory and other morphologies obtained from different geomorphological processes.

In addition, the study of shadow maps shows that the fluvial system flow is under active structural control. The study also allowed to recognise at least three orders of terraces, where two of them belong to fluvial type orders (200 and 100 m). The comparison, between the orders of fluvial terrace and global eustatic variations, showing a linked of three high levels of sea events with formation of fluvial terraces.

The sedimentological morphometric study showed how the sampled strands have typically fluvial environmental formation characteristics. The studied morphometric indexes (flatness, sphericity, roundness, oblate- prolate) have been studied according to the different surveys and

plotted for the depositional context. Plotting the flatness coefficient against sphericity and Oblate-Prolate index against Sphericity show a fluvial depositional environment for the pebbles. Also, The Sneed and Folk ternary diagrams show how the oblate compact blade morphologies are the most typical ones in a fluvial environment. Besides, morphometric study suggests that pebbles did not undergo a high elaboration and a small percentage of pebbles has beach environment characteristics, which suggests an influence of pebbles deposits in the marine environment reworked during Pleistocene.

The study of thin sections made it possible to recognise four types of petrographic families: Quartzite and Quartzarenite (Qz Type), Biocalcarenes; Conglomerates and Chemical rocks. The petrographic study confirms the existence of a fluvial environment, with the formation of recemented conglomerate deposits that indicate waterways carbonate-rich inside.

This process makes a carbonatic crust that covers Quartzarenite pebbles. Besides, this carbonatic surface is not uniform, as shown in thin sections, producing pebbles with and without crust.

This aspect is also present in lithic industries, where sometimes it is possible to find tools with crust and without crust.

The comparison between the different samples does not show substantial differences in particle size or texture and represents the testimony of the presence of a single source basin and demonstrated similar characteristics between quartzite samples and lithics. The origin of lithics tools raw material are pebbles of Terravecchia Fm, that extensively surfaces. The preliminary palaeontological studies show Large Vertebrates fauna of *P. Mnaidriensis* FC and provides information about the age of the terraces. The presence of *P. mnaidriensis*, lithics industries and the elevation of the terrace was created later from the isotopic stages 7-9 during a marine regression phase.

In a nutshell, research covered different research field, allowing to collect much information useful to contextualise lithic industries of Grande\Delia river valley from a geological point of view.

The sedimentological, petrographic, palaeontological and survey analysis on territory show how there was the possibility of a favourable environment for human presence inside the valley and during the Late-Middle Pleistocene, with a rapid transition from marine to the continental environment and formation of fluvial Terraces.

This research was aimed to fill the geological data gap and to contextualise, in general, the topic of Paleolithic in Sicily. The future research will be a focused on variously aspects (Paleontological, Petrographical, Sedimentological and Lithic industries) of the topic, with a unique objective: to enhance the available information about Paleolithic in Sicily.

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7 APPENDIXES

A) APPENDIX A

PAPER PUBLISHER \SUBMITT

Geological context of lithic industries in Delia- FiumeGrande valley, Santa Ninfa (TP):
Hypothetic early human population in Sicily?
Sandro Caracausi

Publisher Impact Factor:

- 1) Gabriele Luigi Francesco Berruti, Davide Bertè, Sandro Caracausi, Sara Daffara, Cristiana Ferreira, Francesca Garanzini; Francesco Rubat Borel; Luca Scoz. (2016). **New evidences of human frequentations in the western Alps: the project "Survey Alta Valsessera (Piedmont - Italy)".** Quaternary International vol. 402: 15-25

Submitt Impact Factor Journals

- A) PONE-D-18-05602.

PLOS ONE

Human behaviour and Homo-mammals interaction at the first European peopling: new evidences from the Pirro Nord 13 site (Apricena, southern Italy).

Gabriele Luigi Francesco Berruti, Razika Chelli Cheheba; Julie Arnaud; Marta Arzarello; Claudio Berto; Isabel Cáceres; Sandro Caracausi; Francesco Colopi; Sara Daffara; Rosa Huguet; Theodora Karampatsou; Guido Montanari Canini; Benedetto Sala; Maurizio Zambaldi; Gabriele Luigi Francesco Berruti, Ph.D. Student

- B) L'Anthropologie

The use of "second rate" raw materials during Middle Palaeolithic. Technological and functional analysis of two sites in north-eastern Iberia. L'utilisation de matières premières "mauvais" au Paléolithique moyen. Analyse technologique et fonctionnelle de deux sites dans le nord-est de l'Ibérie.

Sara Daffara, Gabriele Luigi Francesco Berruti; Sandro Caracausi; Xosé Pedro Rodríguez-Álvarez ; Robert Sala Ramos

- C) QUATINT_2017_907 under review

Quaternary International -

Use of a GIS predictive model for the identification of high altitude prehistoric human frequentations. Results of the Sessera valley project (Piedmont, Italy).

Sandro Caracausi, Gabriele L.F. Berruti, Sara Daffara, Davide Bertè, Francesco Rubat Borel

Corrisponding author

- D) **BSPI Bollettino della Società Paleontologica Italiana**

First report on the Upper Pleistocene paleontological deposits from the Morgana Cave (Mt. Fenera, Borgosesia, Piedmont, Italy).

D.F. Bertè, S. Caracausi, G. Berruti, S. Daffara, M. Zambaldi, G. Montanari, M. Arzarello, W. Albini, V. Miola, A. Riboldazzi, G. Siega, G. Sellaro, E. Panero

Corrisponding author.

Publisher no Impact Factor:

A) S. Caracausi, G. L. F. Berruti, S. Daffara, D. Bertè, F. Rubat Borel (2017)

GIS e siti preistorici d'alta quota: l'applicazione di un Modello Predittivo GIS in Alta Valsessera

(Piemonte, Italia). Annali di Museologia scientifica e naturalistica dell'Università di Ferrara. Vol 13

<http://dx.doi.org/10.15160/1824-2707/13/0>

B) E. Panero - W. Albini - M. Arzarello - G. L. F. Berruti - D. Berté - S. Caracausi - V. Miola - G. Montanari

Canini - A. Riboldazzi - G. Siega - G. Sellaro - M. Zambaldi, (2016) **Borgosesia, Monte Fenera. Nuovi dati**

sul deposito paleontologico della Grotta della Morgana. Quaderni della Soprintendenza archeologica del Piemonte. vol 31: pp.320-323.

C) D. E. Angelucci - J. Arnaud - M. Arzarello - G. L.F. Berruti - D. Berté - C. Berto - R. Calandra - S. Caracausi

- C. Boggio - S. Daffara - E. Luzi - G. Montanari Canini - M. Zambaldi, (2016) **Borgosesia, Monte Fenera.**

Nuovi dati sull'occupazioni della Grotta della Ciota Ciara. Quaderni della Soprintendenza archeologica del Piemonte. vol 31: pp.323-326

D) F. Rubat Borel - G. L. F. Berruti - D. Berté - S. Caracausi - S. Daffara - L. Scoz - A. Vietti. (2016) **Bioglio -**

Veglio - Mosso Santa Maria - Quittengo - Campiglia Cervo - Valle Mosso - Valle San Nicolao -

Camandona, località alta Valsessera. Risultati della terza campagna di survey. Quaderni della Soprintendenza archeologica del Piemonte. vol 31: pp. 214-217

E) F. Rubat Borel, G. L. F. Berruti, J. Arnaud, M. Arzarello, J. Belo, G. Berruto, D. Bertè, S. Caracausi, S. Daffara,

C. Ferreira, C. H. Reis, P. Rosina. (2016). **PROVINCIA DI BIELLA: Candelo, Massazza, Verrone, loc.**

Baragge. Nuovi dati sul Paleolitico medio piemontese. Prospezioni geo-archeologiche nelle Baragge biellesi. Quaderni della Soprintendenza archeologica del Piemonte. vol 31: pp. 219-223

F) F. Rubat Borel, F. Garanzini, G. L. F. Berruti, D. Bertè, S. Caracausi, S. Daffara, L. Scoz (2016). Bioglio-

Veglio-Mosso Santa Maria-Quittengo-Campiglia Cervo-Valle Mosso-Valle San Nicolao-Camandona, località

Valsessera. **Attività di ricognizione con individuazione di siti preistorici e altomedievali.** Quaderni della Soprintendenza Archeologica del Piemonte n. 30, pp. 277-281.

Book Section

- A) G.L.F. Berruti, D. Bertè, S. Caracausi, S. Daffara, C. Ferreira, F. Garanzini, F. Rubat Borel, L. Scoz, A. Vietti, S. Vindrola. Capitolo. (2016) **Il Progetto Survey Alta Valsessera: Primi Dati Sul Piu' Antico Popolamento Delle Alpi Biellesi.** in: Studi e ricerche sull'Alta Valsessera - vol. III, DocBi

Conference:

Oral Presentation

- A) **IAPP IV ANNUALE DI PREISTORIA E PROTOSTORIA** Applicazioni tecnologiche allo studio di contesti paleolitici e mesolitici italiani *The Application of emerging technologies to Italian Palaeolithic and Mesolithic case-studies.* 7-8 febbraio Ferrara

S. Caracausi, G. L. F. Berruti, S. Daffara, D. Bertè, F. Rubat Borel

GIS e siti preistorici d'alta quota: l'applicazione di un Modello Predittivo GIS in Alta Valsessera (Piemonte, Italia) – GIS and high altitude prehistoric sites: use of a GIS predictive model in the Sessera valley (Piedmont, Italy)

Poster:

- A) **IIPP LII RIUNIONE SCIENTIFICA** Preistoria e Protostoria in Lombardia e Canton Ticino Milano - Como, 17-21 ottobre 2017

"Difficoltà nell'identificazione del Paleolitico medio. Il Piemonte settentrionale alla luce delle ultime scoperte"

- B) **IIPP** First Annual Meeting of Prehistory and Protohistory- 2016. IIPP. 4-5 Febbraio Genova

"Geo-archaeological survey in the Baragge Biellesi area. New data on the Middle Palaeolithic in Piedmont."

- C) 10th International Symposium on Knappable Materials University of Barcelona, 7-11 Settembre 2015.

"Live without chert. The use of vein quartz in the Prehistory of Piedmont (North-western Italy)"

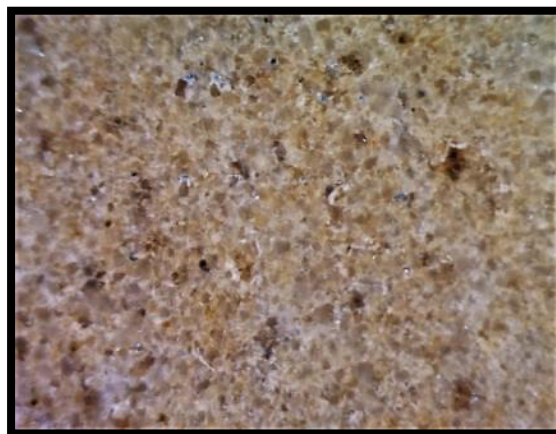
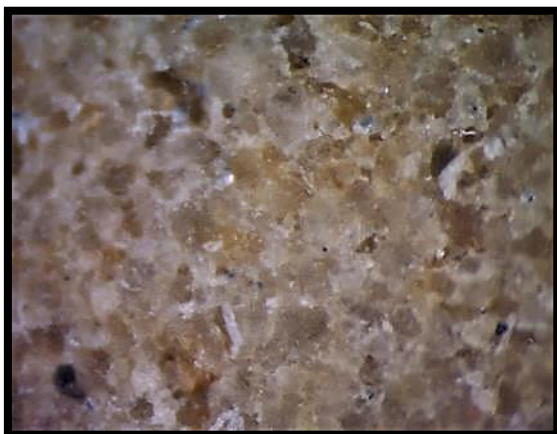
B) APPENDIX B

PETROGRAPHIC IDENTIFICATION SHEET

Quartz-arenite type family:

Sample: _2M1

Sample macroscopy description



Colour: the sample show a moderate yellow (5Y 7\6 munsell)

Rock Texture: clastic Grain supported

grain size: the sample shows fine to medium sand grains size.

sorting: very well sorted

Description of the clasts

Mineral component: Quartz is very abundant, very low percentage of Feldspar and other minerals.

grain shape\roundness of grains: grain show a rounded.

fabric: the sample shows a blande lamine layers

Cement\ Matrix: the sample has no matrix and grains is very well cemented with carbonate cement

Textural maturity: the sample show a high mature

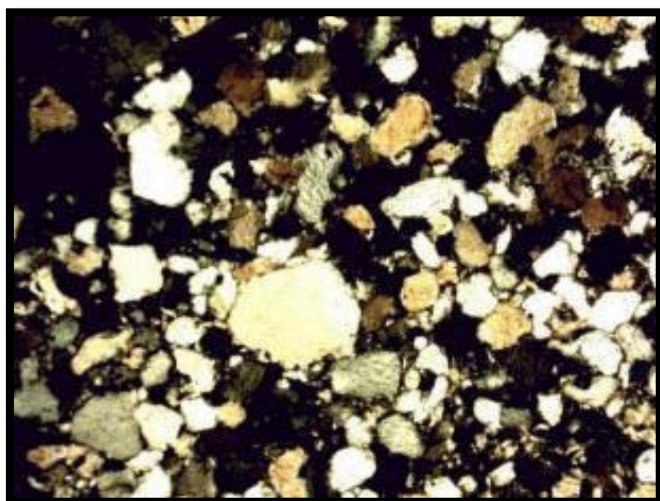
Classification: Quartz arenite sandstone (folk, 1980)

Thin section descriptions:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984, Pettijohn et al., 1987)

Rock Texture:

Grain supported

grain size: medium, fine grain size consisting of common quartz

sorting: well sorted

grain shape\roundness of grains: rounded and some grains sub roundness by sutured contacts

fabric: no orientation of grain.

nature of grain-grain contacts: Grain contacts start off as tangential contacts, long point and concavo-convex contacts and sutured contacts

Cement\ Matrix: A film of cement

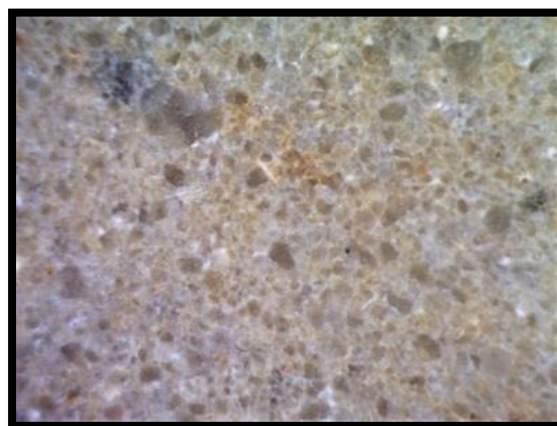
Minerals: the main mineral in this section is quartz (>50%) derived from detrital mineral grains, eroded from pre-existing rocks

Textural maturity: mature

Name: Quartz arenite

4)Sample: _4M3

sample macroscopy description:



Colour: the sample show a Grayish Yellow (5Y 8/4 munsell)

Rock Texture: clastic Grain supported

grain size: the sample shows medium to coarse sand grains size.

sorting: very well sorted

Description of the clasts

Mineral component: Quartz is very abundant, very low percentage of Feldspar and other mineral.

grain shape\roundness of grains: grain show a rounded.

fabric: the sample shows a concave lamine layers

Cement\ Matrix: the sample has no matrix and grains is very well cemented with carbonate cement

Textural maturity: the sample show a high mature

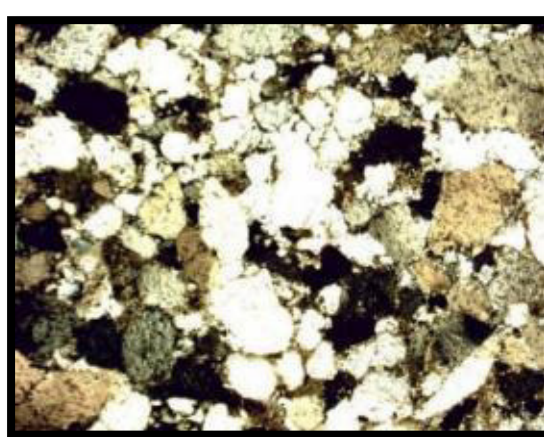
Classification: Quartz arenite sandstone (folk, 1980)

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Grain supported

Grain size: fine, medium grain size consisting of common quartz

Sorting: well sorted

Grain shape\Roundness of grains: rounded and some grains sub roundness by sutured contacts

Fabric: no evidence orientation of grain.

Nature of grain-grain contacts: Grain contacts start off as tangential contacts, long point and concavo-convex contacts and sutured contacts

Cement\ Matrix: A film of limonite cement

Minerals\Grain type: detrital mineral grains, eroded from pre-existing rocks, and sand-sized pieces of rock, the main mineral in this section is Quartz (50%)

Textural maturity: mature

Name: Quartz arenite

5)Sample: _5\M2

sample macroscopy description (5)



Colour: the sample show a moderate yellow (5Y 7/6 munsell)

Rock Texture: clastic Grain supported

grain size: the sample shows coarse to very coarse sand grains size.

sorting: well sorted

Description of the clasts

Mineral component: Quartz is very abundant, very low percentage of Feldspar and other minerals.

grain shape\roundness of grains: grain show a rounded and Quartz clast showing a different grain size

fabric: the sample shows a blande lamine layers

Cement\ Matrix: the sample has no matrix and grains is very well cemented with carbonate cement

Textural maturity: the sample showing absent of mud and rounded grain indicate a mature textural degree.

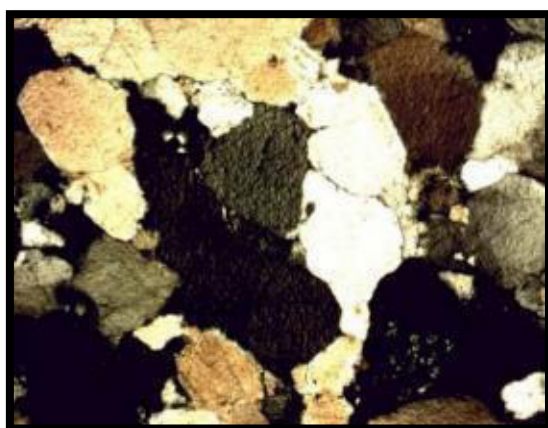
Classification: Quartz arenite sandstone (folk, 1980).

Thin section photos:

plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Grain supported

Grain size: coarse, very coarse grain size consisting of common quartz and high sphericity.

Sorting: well sorted

Grain shape\Roundness of grains: rounded and some grains sub roundness by sutured contacts

Fabric: no evidence orientation of grain.

Nature of grain-grain contacts: Grain contacts start off as tangential contacts, long point contacts and sutured contacts.

Cement\ Matrix: A film of quartz cement

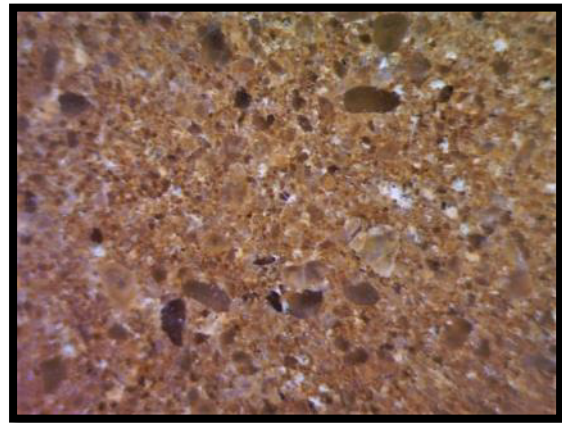
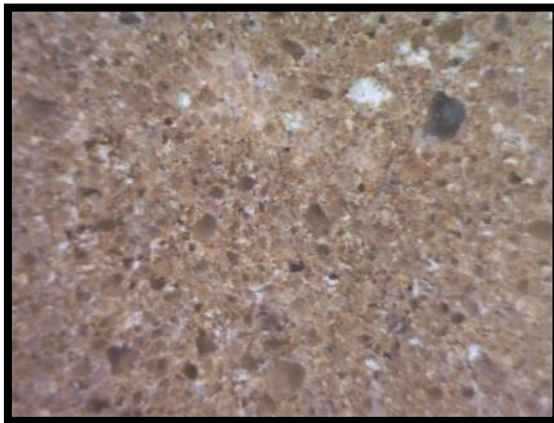
Minerals\Grain type: detrital mineral grains, eroded from pre-existing rocks. The main mineral is monocrystalline Quartz (>50%) in this section.

Textural maturity: Mature

Name: Quartzite

6)Sample: _6M4

sample macroscopy description (6)



Colour: the sample show Moderate Brown Yellowish (10YR 5/4 munsell)

Rock Texture: matrix Grain supported

grain size: the sample shows fine to medium sand grains size.

sorting: well sorted

Description of the clasts

Mineral component: Quartz is very abundant, very low percentage of Lithic clast and Feldspars.

grain shape\roundness of grains: visible grains show a rounded form.

fabric: the sample shows a massive structure

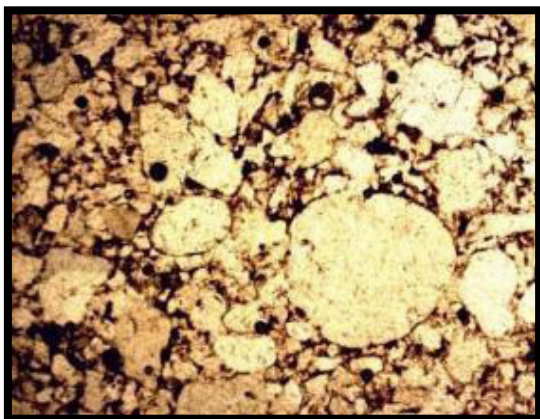
Cement\ Matrix: the sample shows matrix made of carbonate mud and the rock is very well cemented.

Textural maturity: the sample show mature textural

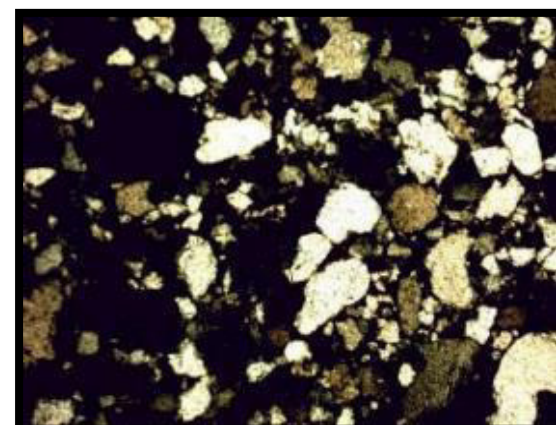
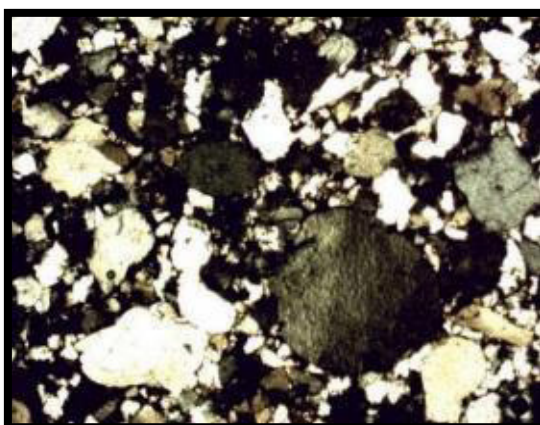
Classification: Quartz arenite sandstone (folk, 1980)

Thin section photos:

plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Grain supported

Grain size: medium, coarse grain size consisting of common quartz.

Sorting: moderate sorted

Grain shape\Roundness of grains: rounded\very roundness with high sphericity

Fabric: no evidence orientation of grain.

Nature of grain-grain contacts: Grain contacts start off tangential to long point contact

Cement\ Matrix: A film of quartz cement

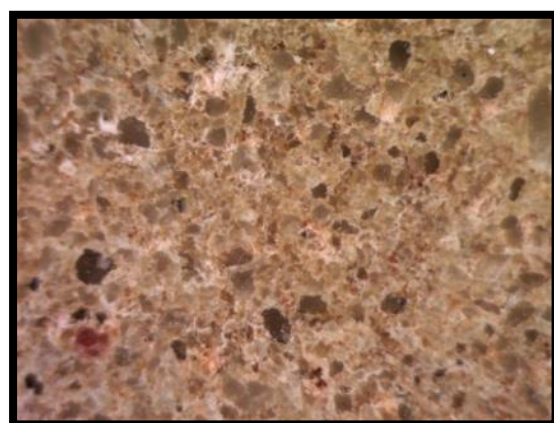
Minerals\Grain type: the main mineral is monocrystalline Quartz and monocrystalline Quartz with Undulose extinction (>50%) in this section. Detrital mineral grains, eroded from pre-existing rocks, and sand-sized pieces of rock

Textural maturity: Mature

Name: Quartz arenite

8)Sample: 8\3AG

sample macroscopy description:



Colour: the sample show Grayish Yellow 5Y (5Y 8/4 munsell)

Rock Texture: Grain supported

grain size: the sample shows medium to coarse sand grains size.

sorting: very well sorted

Description of the clasts

Mineral component: Quartz is very abundant, low percentage of Feldspar and other lithic clasts.

grain shape\roundness of grains: grain show a rounded grain shape.

fabric: the sample shows a bland concave layer stratification

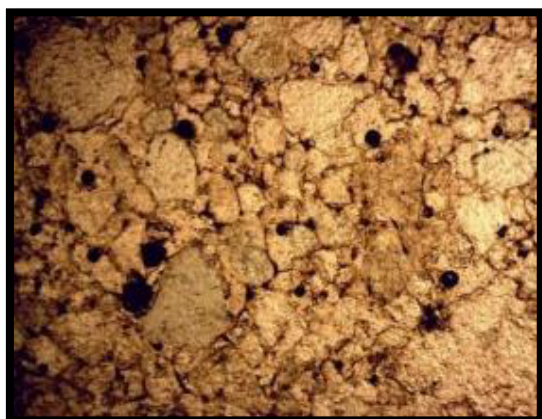
Cement\ Matrix: the sample has no matrix and grains is well cemented with quartz cement.

Textural maturity: the sample show a good mature textural degree.

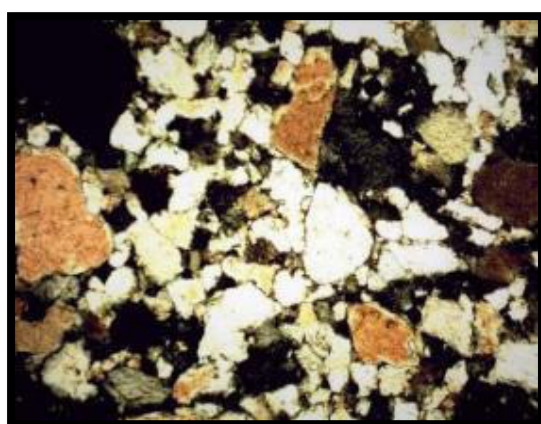
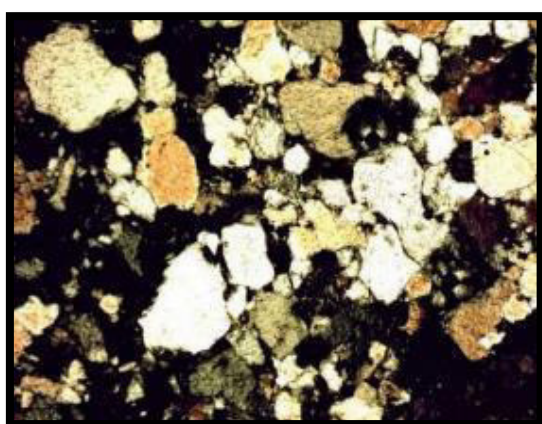
Classification: sandstone Quartz arenite (folk, 1980).

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Grain supported

Grain size: medium, coarse grain size consisting of common quartz.

Sorting: well sorted

Grain shape\Roundness of grains: sub\rounded-roundness

Fabric: no evidence orientation of grain.

Nature of grain–grain contacts: Grain contacts start off long point and concavo-convex contacts

Cement\ Matrix: A film of quartz cement

Minerals\Grain type: the main mineral is monocrystalline Quartz and monocrystalline Quartz with Undulose extinction (>50%) in this section. Detrital mineral grains, eroded from pre-existing rocks, and sand-sized pieces of rock

Textural maturity: Mature

Name: Quartz arenite

9)Sample: 9M2

sample macroscopy description (9)



Colour: the sample show a Moderate Brown (5YR 3/4 munsell)

Rock Texture: matrix Grain supported

grain size: clasts visible showing a fine-medium sand grains size.

sorting: very well sorted

Description of the clasts

Mineral component: Quartz is very abundant and Feldspar clasts have a very low percentage

grain shape\roundness of grains: visible grains shows a rounded shape.

fabric: the clasts don't show a favourite orientation.

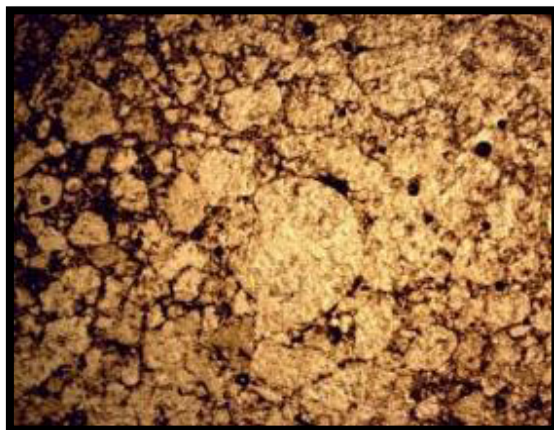
Cement\ Matrix: the sample has no matrix and grains is very well cemented with carbonate cement

Textural maturity: the sample show a high mature

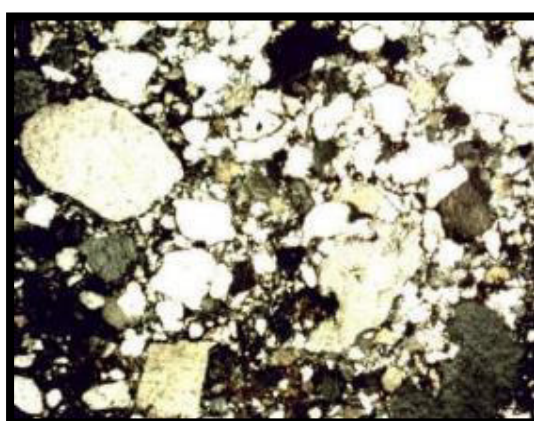
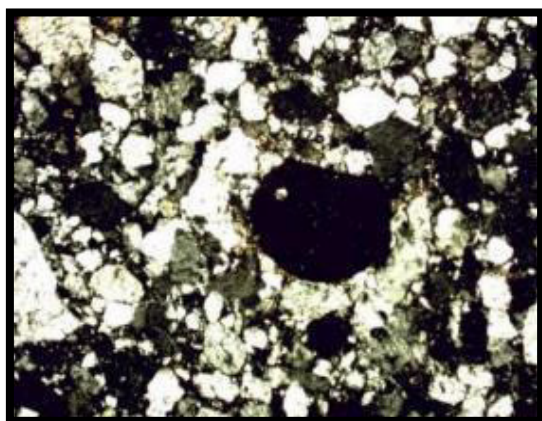
Classification: Quartz arenite sandstone (folk, 1980)

Thin section photos:

plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Grain supported

Grain size: medium, coarse grain size consisting of common quartz.

Sorting: moderate sorted

Grain shape\Roundness of grains: rounded and sub\ angular

Fabric: no evidence orientation of grain.

Nature of grain-grain contacts: Grain contacts start off long point and concavo-convex contacts probably for weathering

Cement\ Matrix: A film of quartz cement

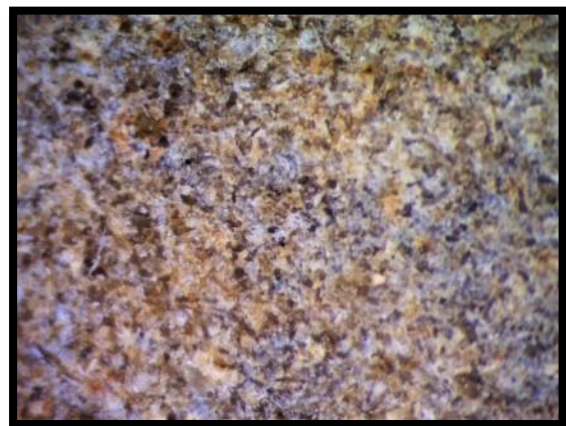
Minerals\Grain type: the main mineral is monocrystalline Quartz and monocrystalline Quartz with Undulose extinction (>50%) in this section. Detrital mineral grains, eroded from pre-existing rocks, and sand-sized pieces of rock.

Textural maturity: Mature

Name: Quartz arenite

10)Sample: 10\4CZ

sample macroscopy description



Colour: the sample show a Moderate Brown Yellowish (10YR 5/4 munsell)

grain size: the sample shows silt grains size.

sorting: very well sorted

Description of the clasts

Mineral component: Quartz is very abundant, very low percentage of Feldspar and other mineral.

grain shape\roundness of grains: not visible.

fabric: the sample shows a lamine layers stratification.

Cement\ Matrix: the sample has no matrix and grains is very well cemented with quartzcement

Textural maturity: the sample show a high mature textural degree

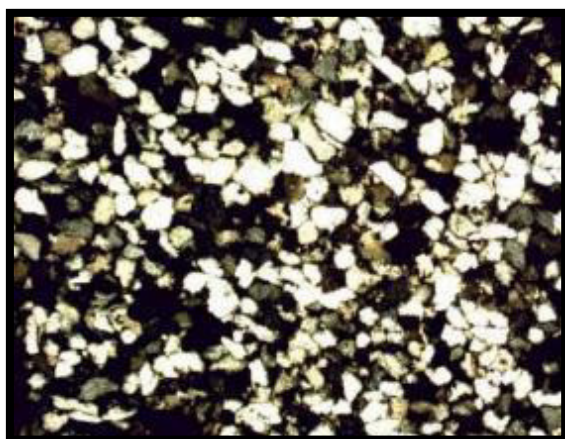
Classification: Quartz laminate siltstone (folk, 1980)

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Grain supported

Grain size: fine grain size consisting of common quartz.

Sorting: very well sorted

Grain shape\Roundness of grains: Lower Sphericity and rounded grain

Fabric: no evidence orientation of grain.

Nature of grain-grain contacts: Grain contacts start off as tangential contacts, long point contacts sometimes triple contacts sutured (red square)

Cement\ Matrix: A film of quartz cement

Minerals\Grain type: the main mineral is monocrystalline Quartz (>50%) in this section. Detrital mineral grains, eroded from pre-existing rocks, and sand-sized pieces of rock.

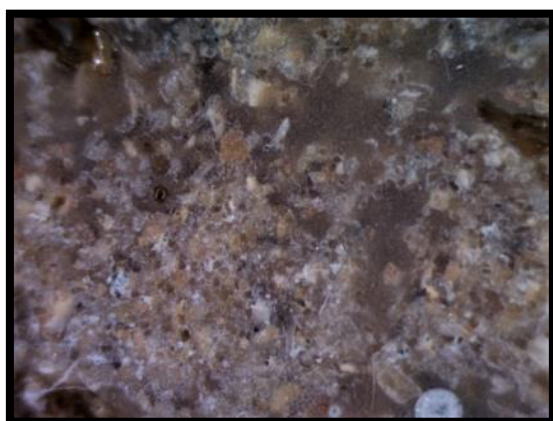
Textural maturity: High Mature

Name: Quartzite

Calcarenite Family type:

11)Sample: 11\calc2

sample macroscopy description (11)



Colour: the sample show a Pale Yellowish orange (10YR 8/6 munsell)

Rock Texture: clastic Grain supported

grain size: the sample shows medium to coarse sand grains size.

sorting: well sorted

Description of the clasts

Mineral component: Clasts of Quartz and bioclast are abundant.

grain shape\roundness of grains: grain show a rounded.

fabric: the sample shows a blande lamine layers

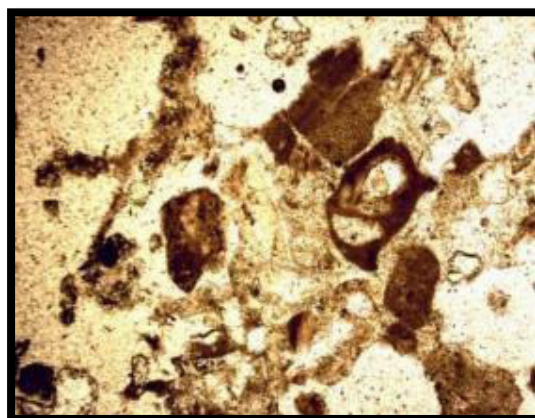
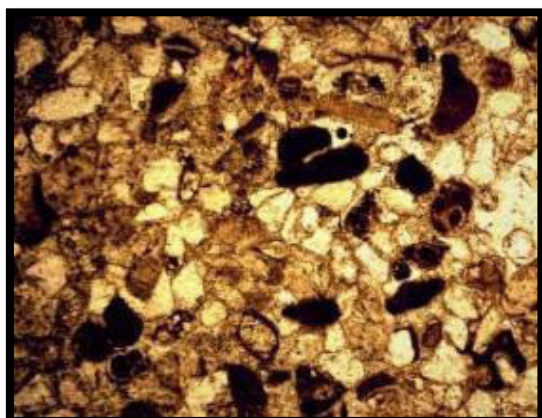
Cement\ Matrix: the sample has no matrix and grains are poorly cemented with calcite cement

Textural maturity: the sample show a lower textural mature degree

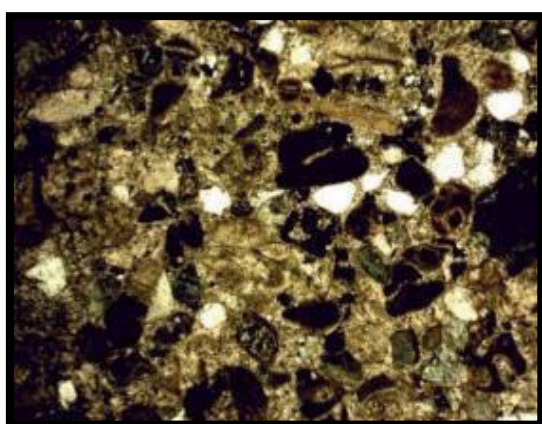
Classification: biocalcarenite sandstone (folk, 1980)

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Grain supported\Packstone

Grain size: coarse to medium sand grain size

Sorting: well sorted

Grain shape\Roundness of grains: Grain roundness index is high although the sphericity is low due to the presence of bioclastic fragments

Fabric: no evidence orientation of grain.

Nature of grain-grain contacts: Grain contacts start off as tangential contacts

Cement\ Matrix: The microgranular calcite cement fills the interparticle pores

Minerals\Grain type: Detrital mineral grains, eroded from pre-existing rocks. Bioclastic (calcareous algae and foraminifera) and clastic terrigenous grains. The grains are mainly limestone fragments although siliceous and monocrystalline quartz

Textural maturity: High Mature

Name: Bioclastic calcareous sandstone, calcarenite

12)Sample: 12\calc4

sample macroscopy description (12)



Colour: the sample show a moderate yellow (5Y 7\6 munsell)

Rock Texture: bioclastic matrix supported\ wackstone

grain size: the sample shows fine sand grains size.

sorting: very poorly sorted

Description of the clasts

Mineral component: High percent of Bioclasts, presence of lithic fragments, quartz arenite and Quartz

grain shape\roundness of grains: grain show a rounded shape.

fabric: the sample shows a favourite orientation.

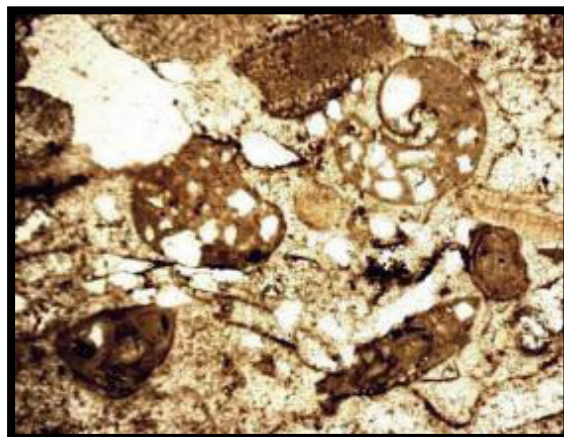
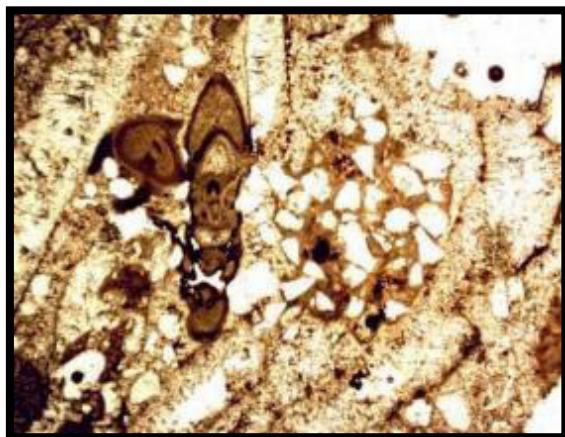
Cement\ Matrix: the sample show a micrite matrix, high porosity and is not well cemented.

Textural maturity: the sample show a poorly mature degree

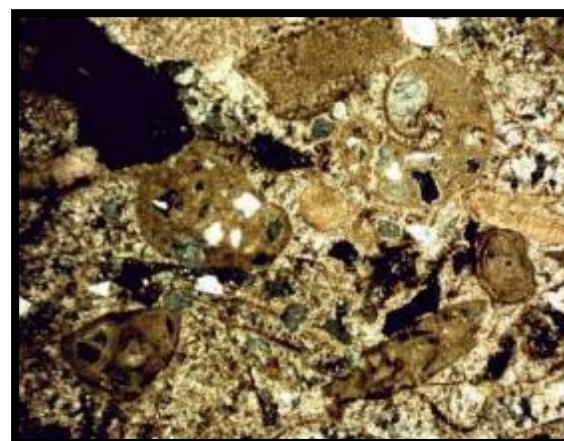
Classification: biocalcarenite, biomicrite (folk, 1980)

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Grain supported\Packstone

Grain size: coarse to medium grain size

Sorting: poorly sorted

Grain shape\Roundness of grains: Grain roundness index is high although the sphericity is low due to the presence of bioclastic fragments.

Fabric: no evidence orientation of grain.

Nature of grain-grain contacts: Grain contacts start off as tangential contacts

Cement\ Matrix: The micrite fills the interparticle pores, also there are a arenite matrix

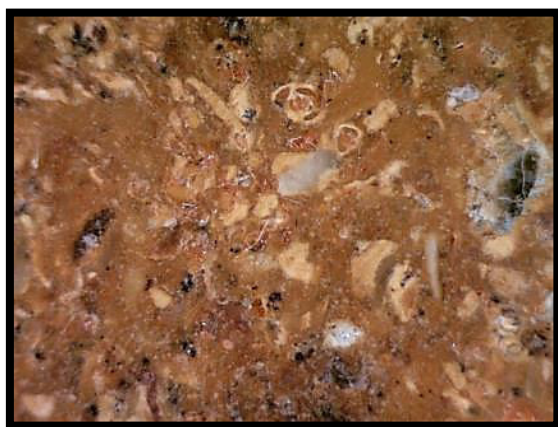
Minerals\Grain type: Bioclastic (calcareous algae and foraminifera and Gastropods in long- and cross-section,) and clastic terrigenous grains. The grains are mainly limestone fragments although siliceous and monocrystalline quartz. Detrital terrigenous made of Quartz arenite\ Quartzite clast.

Textural maturity: sub Mature

Name: Bioclastic calcareous sandstone, calcarenite.

13)Sample: 13\Calc3d

sample macroscopy description



Colour: the sample show a moderate yellow (5Y 7\6 munsell)

Rock Texture: bioclastic matrix supported\ wackstone

grain size: the sample shows fine sand grains size.

sorting: very poorly sorted

Description of the clasts

Mineral component: High percent of Bioclast, presence of lithic fragment of quartz arenite and Quartz

grain shape\roundness of grains: grain show a rounded shape.

fabric: the sample shows a favourite orientation and a vertical gradation from bottom with a low percentage of bioclasts to the top with a higher percentage of bioclasts.

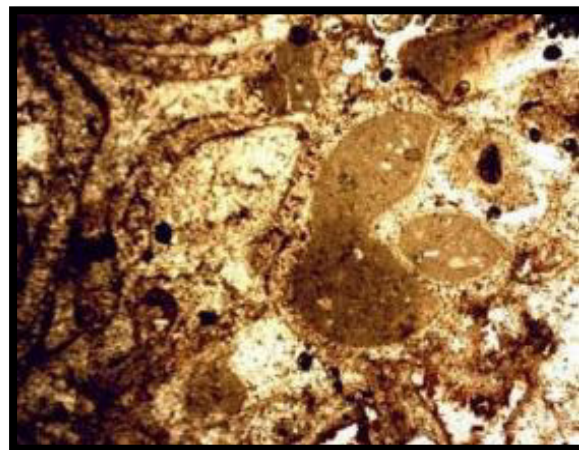
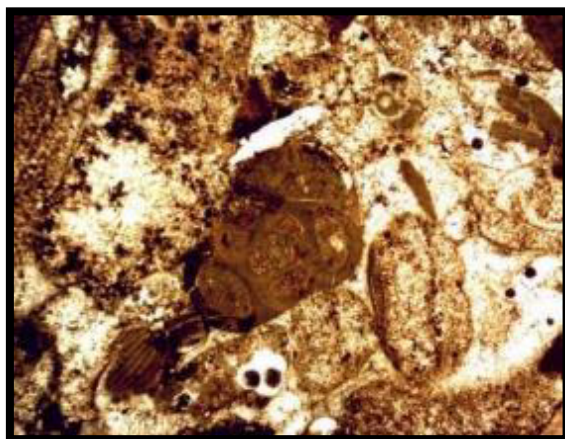
Cement\ Matrix: the sample show a micrite matrix, high porosity and is not well cemented.

Textural maturity: the sample show a poorly mature degree

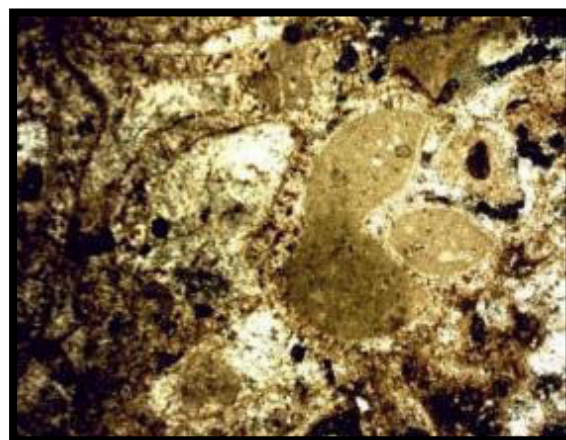
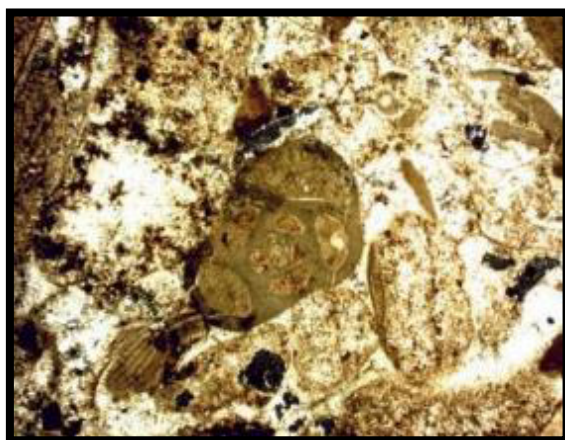
Classification: biocalcarenite, biomicrite (folk, 1980).

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Matrix supported\Wackestone

Grain size: coarse to medium grain size

Sorting: moderately sorted

Grain shape\Roundness of grains: Grain are sub rounded although the sphericity is low due to the presence of bioclastic fragments.

Fabric: no evidence orientation of grain.

Nature of grain–grain contacts: Grain contacts start off as tangential contacts

Cement\ Matrix: The micrite cement fills the interparticle pores, also there are arenite matrix

Minerals\Grain type: Bioclastic (calcareous algae and foraminifera, Gastropods in long-and cross-section and bivalve) and clastic terrigenous grains. The grains are mainly limestone fragments rarely siliceous and monocrystalline quartz.

Textural maturity: Mature

Name: Bioclastic sandstone

15)Sample:15\Calc1

sample macroscopy description.



Colour: the sample show a moderate yellow (5Y 7\6 munsell)

Rock Texture: bioclastic matrix supported\ wackstone

grain size: the sample shows fine sand grains size.

sorting: good sorted

Description of the clasts

Mineral component: High percent of Bioclasts, presence of lithic fragments, quartz arenite and Quartz

grain shape\roundness of grains: grain show a rounded shape.

fabric: the sample shows a favourite orientation.

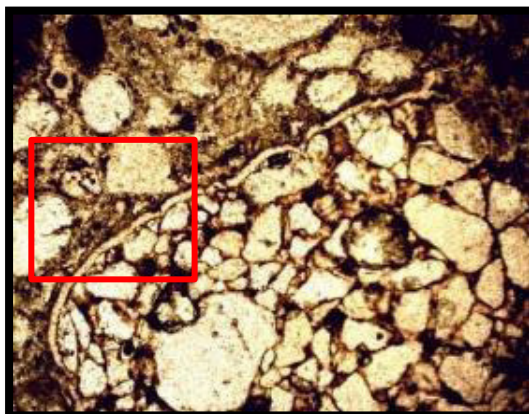
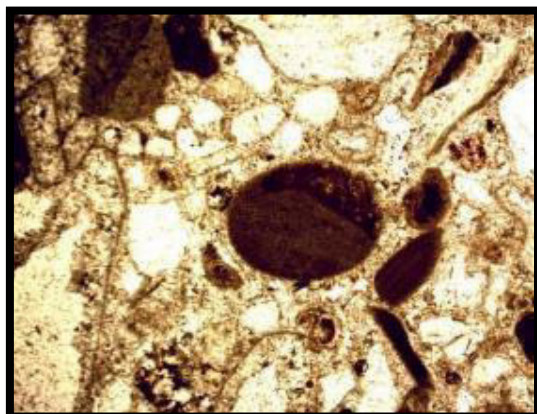
Cement\ Matrix: the sample show a micrite matrix, a high porosity and is not well cemented.

Textural maturity: the sample show a poorly mature degree

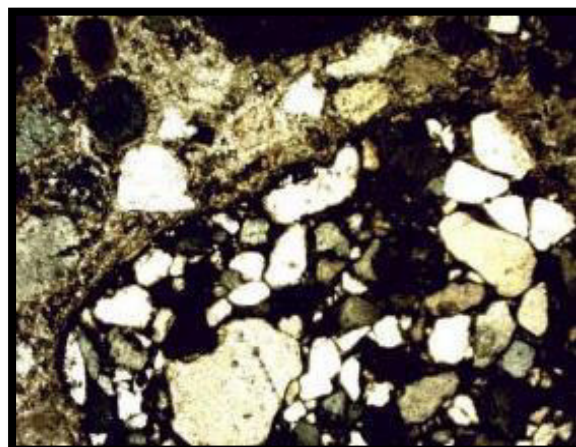
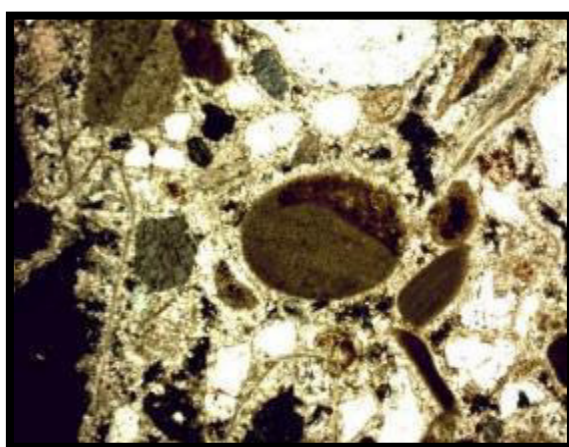
Classification: biocalcarenite, biomicrite (folk, 1980)

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Matrix supported\Wackestone

Grain size: coarse to medium grain size

Sorting: moderate sorted

Grain shape\Roundness of grains: Grain are sub rounded although the sphericity is low due to the presence of bioclastic fragments.

Fabric: no evidence orientation of grain.

Nature of grain–grain contacts: Grain contacts start off as tangential contacts

Cement\ Matrix: The microgranular calcite cement fills the interparticle pores, also there are arenite matrix

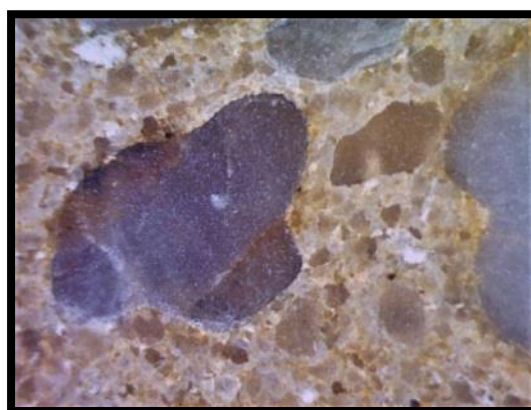
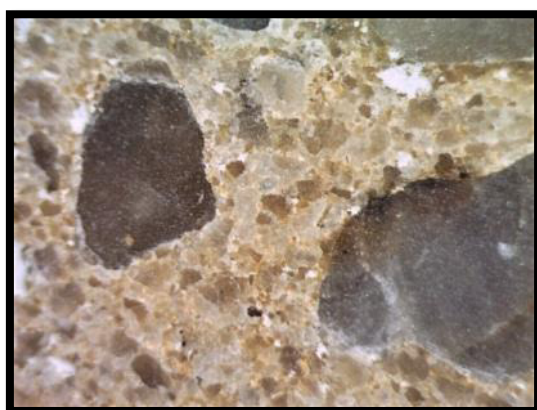
Minerals\Grain type: Bioclastic (calcareous algae and foraminifera, Gastropods in long-and cross-section and bivalve) and clastic terrigenous grains. The grains are mainly limestone fragments rarely siliceous and monocrystalline quartz. Qzarenite clasts show a ring that coat yourself (in red square)

Textural maturity: Mature

Name: Bioclastic sandstone

Conglomerate type family: Sample:

1) Sample: _1\CALC_3 sample macroscopy description



Colour: the sample show a moderate yellow (5Y 7\6 munsell)

Rock Texture: clastic Grain supported

grain size: Fine-grained conglomerate pebble with quartz clasts and fine sand grain size.

sorting: moderate sorted

Description of the clasts

Mineral component Quartz

grain shape\roundness of grains: grain show a subrounded\rounded and a lower sphericity propriety.

fabric: no orientation of grain

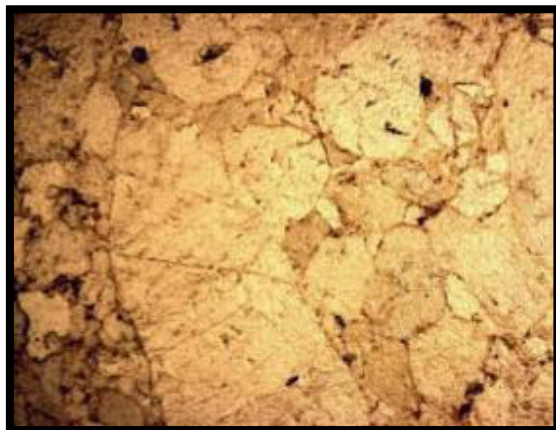
Cement\ Matrix: rock shows a low percentage of matrix

Textural maturity: the sample show a high mature

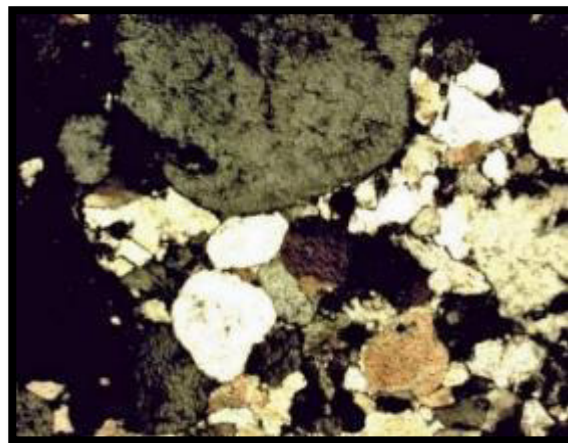
Classification: ortoconglomerate oligomictic sandy conglomerate.

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

grain size: coarse, very coarse grain size consisting of common quartz

sorting: moderately sorted

grain shape\roundness of grains: sub rounded\rounded

fabric: no orientation of grain

nature of grain-grain contacts: Grain contacts start off as tangential contacts, long point and concavo-convex contacts

Cement\ Matrix: A thin film of cement

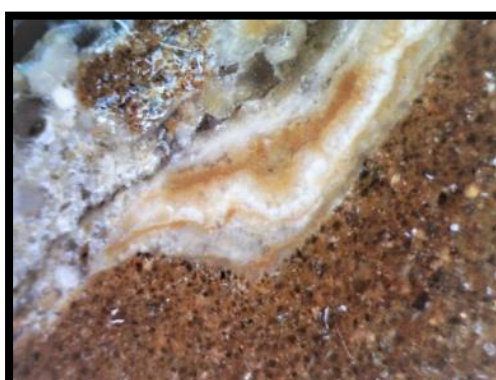
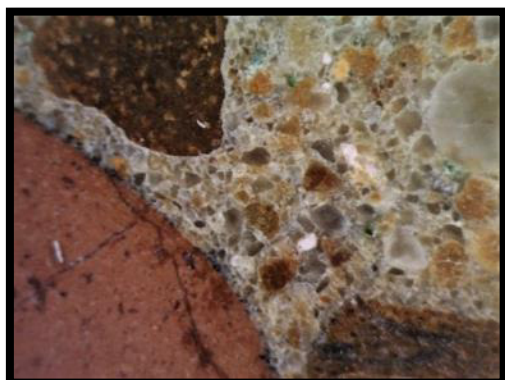
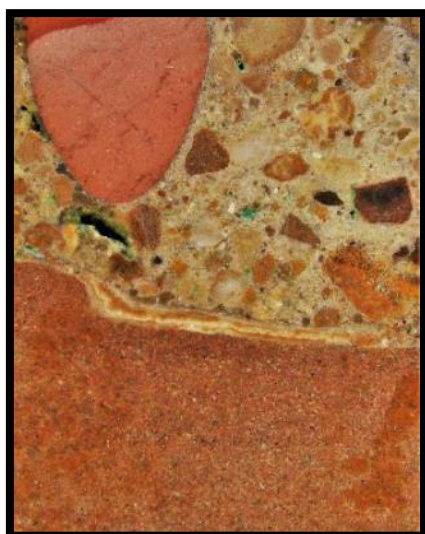
Minerals: the sample is composed from detrital mineral grains, eroded from pre-existing rocks, and sand-sized pieces of rock the main mineral in the section is quartz (over 50%)

Textural maturity: very mature

Name: orthoconglomerate

14)Sample: 14\CC4b

sample macroscopy description



Rock Texture: clastic Matrix supported

grain size: the sample shows different grain size assemblage, from sand to pebble. Principal grain size is coarse-grained

sorting: poorly sorted

Description of the clasts

Mineral component: the sample is composed by different clasts nature. We found a siliciclastic fragment rock, pre-existing quartz arenite sandstone and Quartz.

grain shape\roundness of grains: sample show a two different grain shape pebbles grains show a rounded\well rounded shape and a lower sphericity degree. Clasts with sand grain size show a subangular\rounded to roundness degrees and a lower sphericity but quartz clast show a high sphericity and well roundness.

fabric: the sample don't show a favourite orientation.

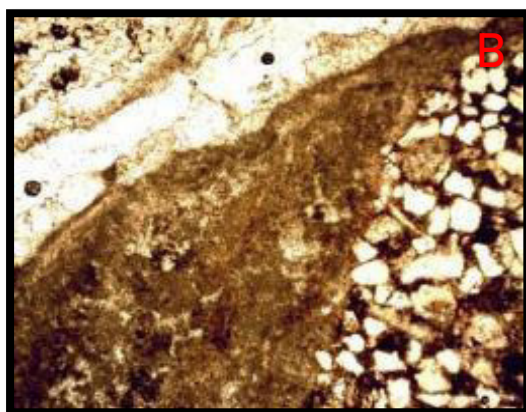
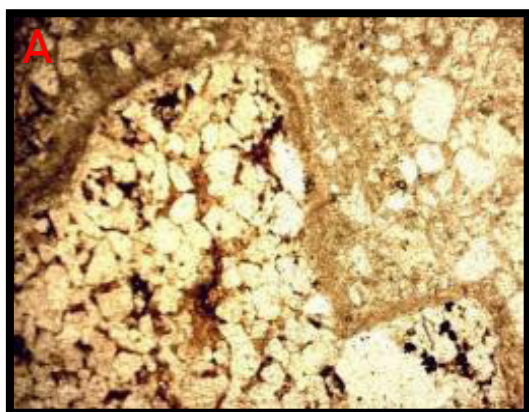
Cement\ Matrix: sample show a carbonate matrix (micirite) and an interesting calcite layer that coated some clasts. Calcite has been formed following the morphology of pebbles.

Textural maturity: the sample show good mature degrees.

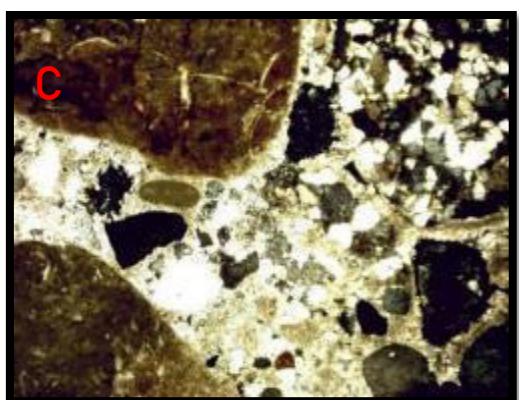
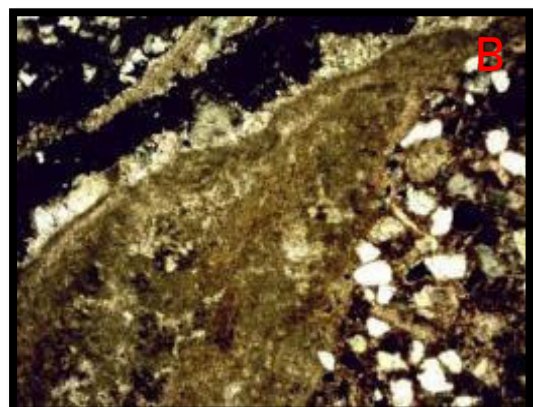
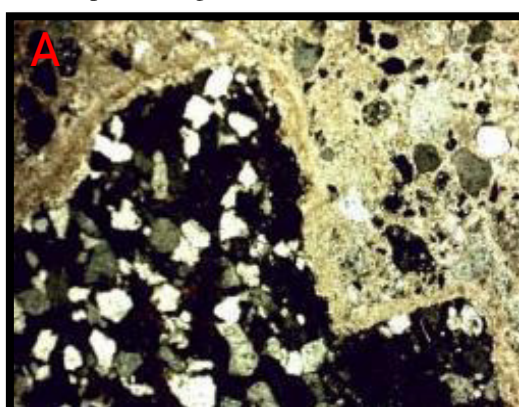
Classification: Quartzose Orthoconglomerate.

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Matrix supported\Wackstone

Grain size: coarse to very coarse grain size, intraclasts show fine medium gran size

Sorting: poorly sorted

Grain shape\Roundness of grains: lithic clasts shows rounded or subangular (see fig.A) with lower sphericity, Quartz clasts show rounded\well-roundness and high sphericity

Fabric: no evidence orientation of grain.

Nature of grain-grain contacts: no Grain contacts

Cement\ Matrix: The microgranular calcite cement several showing a calcite ring that envelops some clast (red square)

Minerals\Grain type: Bioclastic (calcareous algae and foraminifera) and clastic terrigenous grains. The grains are mainly limestone fragments although siliceous and monocrystalline quartz. Quartz grains are well-rounded monocrystalline, with unit and undulose extinction. Detrital terrigenous clast made of Quartz arenite\ Quarzite clast with different granulometric. The calcite ring that envelops some clast ring following convexity of Quartzarenite Clast (see fig. B).

Textural maturity: poorly Mature

Name: quartzose conglomerates (Boggs, 2006)

16)Sample: 16\CC2

sample macroscopy description



Rock Texture: clastic grain supported

grain size: the sample shows different grain size assemblage, from sand to pebble size. Principal grain size is coarse-grained.

sorting: moderately sorted

Description of the clasts

Mineral component: the sample is composed by different clasts nature. We found a siliciclastic fragment rock, pre-existing quartz arenite sandstone and Quartz.

grain shape\roundness of grains: sample show a two different grain shape pebbles grains show a rounded\well rounded shape and a high sphericity degree. Clasts with sand grain size show a rounded\well rounded shape of grain and a lower sphericity and quartz clast show a lower sphericity and well roundness.

fabric: the sample showing a favourite orientation plano parallel.

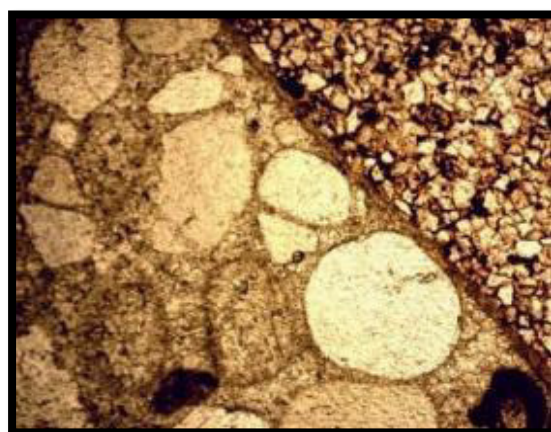
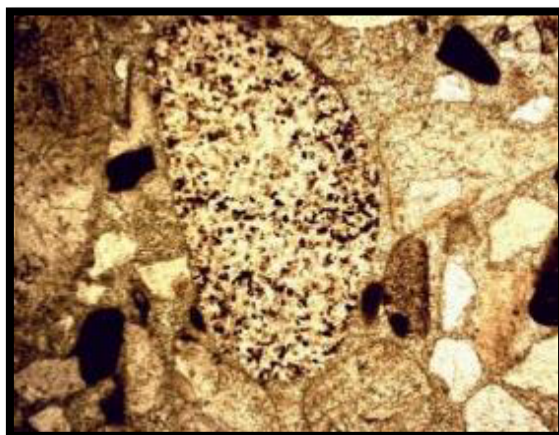
Cement\ Matrix: sample show a carbonate matrix (micirite) and an overgrowth Quartz layer that coated some Quarzarenite clasts.

Textural maturity: the sample show good mature degrees.

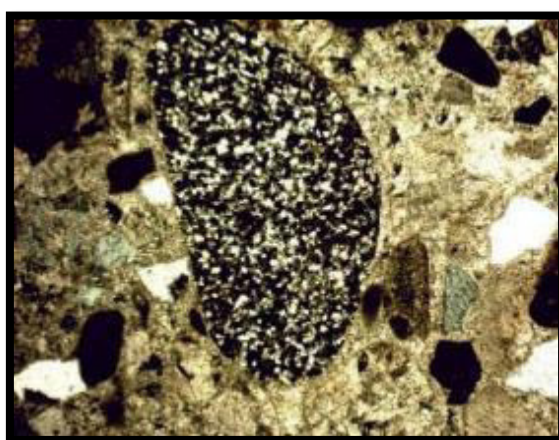
Classification: Polimict Orthoconglomerate.

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Grain supported\Grainstone

Grain size: coarse to very coarse grain size

Sorting: poorly sorted

Grain shape\Roundness of grains: lithic clasts shows rounded\well-roundness with lower sphericity, Quartz clasts show rounded\well-roundness and high sphericity

Fabric: no evidence orientation of grain.

Nature of grain-grain contacts: Grain contacts start off as tangential contacts

Cement\ Matrix: The microgranular calcite cement several showing a calcite ring that envelops some clast (red square)

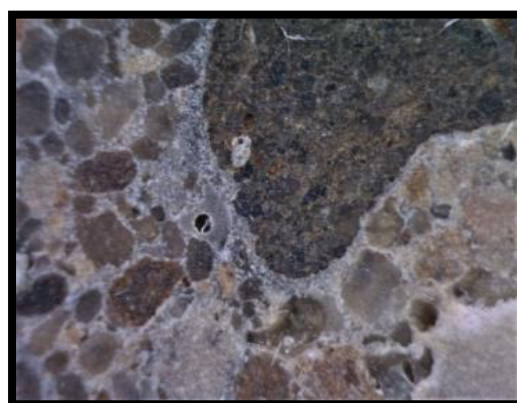
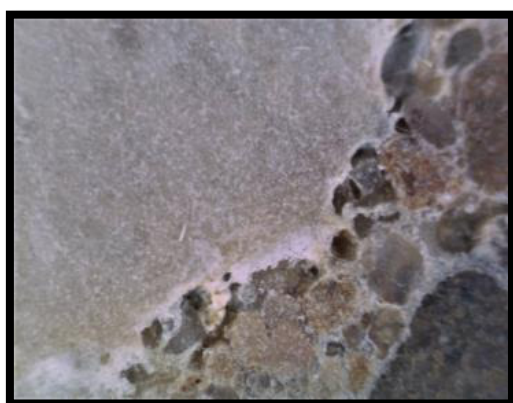
Minerals\Grain type: Bioclastic (calcareous algae and foraminifera and Gastropods in long- and cross-section,) and clastic terrigenous grains. The grains are mainly limestone fragments although siliceous and monocrystalline quartz. Quartz grains are well-rounded monocrystalline, with unit and undulose extinction Detrital terrigenous clast made of Quartz arenite clast. The calcite ring that envelops some clast ring is explained as recirculation by hydrothermal fluids.

Textural maturity: moderately mature

Name: polymictic quartzose conglomerates (Boggs, 2006)

17) Sample: 17ACC3

sample macroscopy description



Rock Texture: clastic Matrix supported

grain size: the sample shows different grain size assemblage, from sand to pebble. Principal grain size is coarse-grained

sorting: poorly sorted

Description of the clasts

Mineral component: the sample is composed by different clasts nature. We found a siliciclastic fragment rock, pre-existing quartz arenite sandstone, Quartz and Micrite limestone Clasts.

grain shape\roundness of grains: sample show a two different grain shape pebbles grains show a rounded\well rounded shape and a lower sphericity degree. Clasts with sand grain size show a subangular\rounded to roundness degrees and a lower sphericity.

fabric: the sample don't show a favourite orientation.

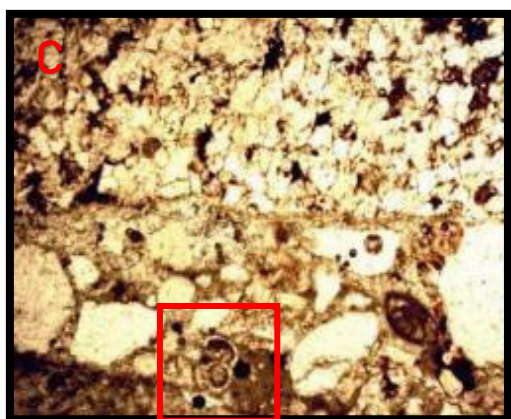
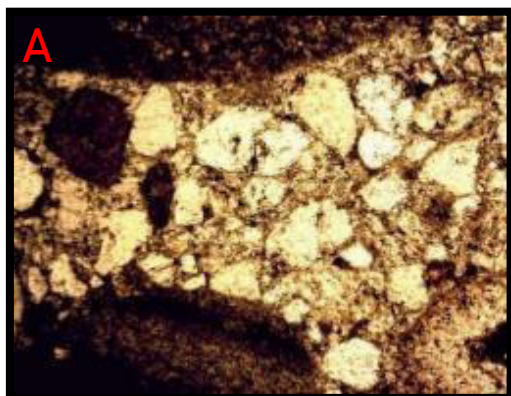
Cement\ Matrix: sample show a carbonate matrix (micrite) and an interesting calcite layer that coated some clasts. Calcite has been formed following the morphology of pebbles.

Textural maturity: the sample show good mature degrees.

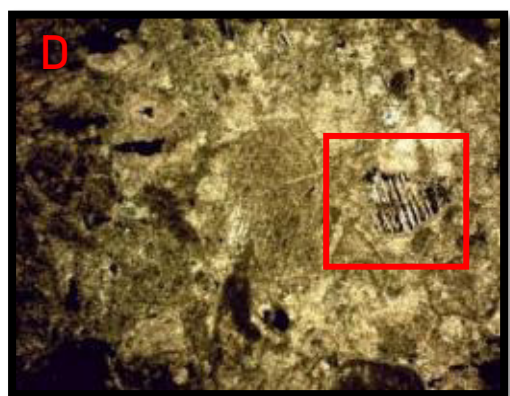
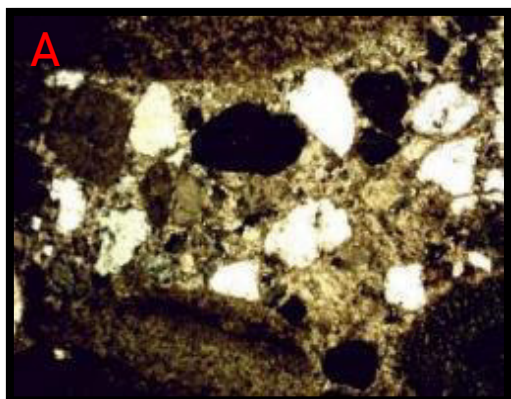
Classification: Orthoconglomerate.

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Grain supported

Grain size: coarse to very coarse grain size with some clast in pebbles field

Sorting: poorly sorted

Grain shape\Roundness of grains: clasts shows rounded\well-roundness with lower sphericity

Fabric: no evidence orientation of grain.

Nature of grain–grain contacts: Grain contacts start off as tangential contacts

Cement\ Matrix: The microgranular calcite cement intra clast and sometimes showing a calcite ring that envelops some clast (red square in Figure B)

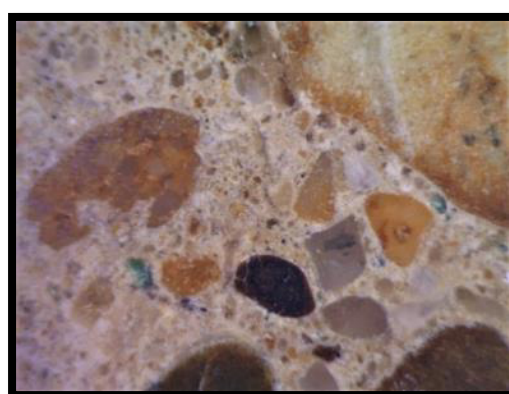
Minerals\Grain type: fossil (calcareous algae and foraminifera in red square figure C) and clastic terrigenous grains. The grains are mainly quartz sandstone fragments, monocrystalline quartz and plagioclase (red square, figure D). Quartz grains are well-rounded monocrystalline. Detrital terrigenous clast made of Quartz arenite and Quarzite clast and calcite cement ring that envelops some clast ring is explained as recirculation by hydrothermal fluids.

Textural maturity: SubMature

Name: quartzose conglomerate (Boggs, 2006)

18)Sample: 18\CC10

sample macroscopy description



Rock Texture: clastic Matrix supported

grain size: the sample shows different grain size assemblage, from very fine sand to pebble.

Principal grain size is coarse-grained

sorting: poorly sorted

Description of the clasts

Mineral component: the sample is composed by different clasts nature. We found a siliciclastic fragment rock, pre-existing quartz arenite sandstone and Quartz.

grain shape\roundness of grains: sample show a uniformity grain shape. Pebbles grains show a rounded\well rounded shape and a good sphericity degree. Clasts with a sand grain size show a subangular\rounded to roundness degrees and a lower sphericity.

fabric: the sample don't show a favourite orientation.

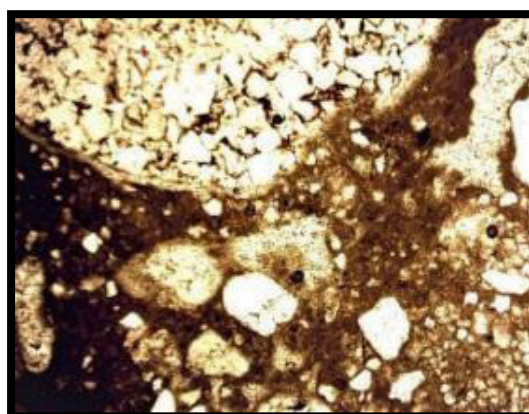
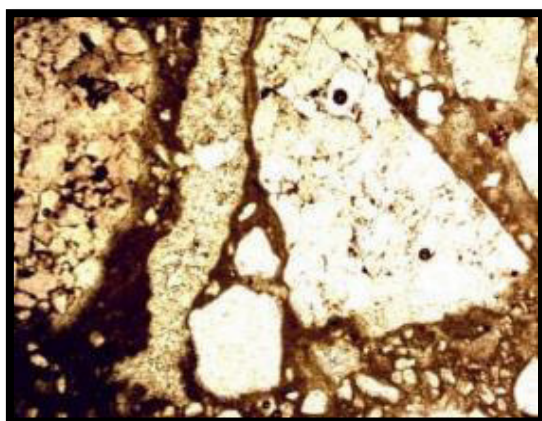
Cement\ Matrix: sample show a carbonate matrix and an interesting calcite layer that coated some clasts. Calcite has been formed following the morphology of pebbles.

Textural maturity: the sample show good mature degrees.

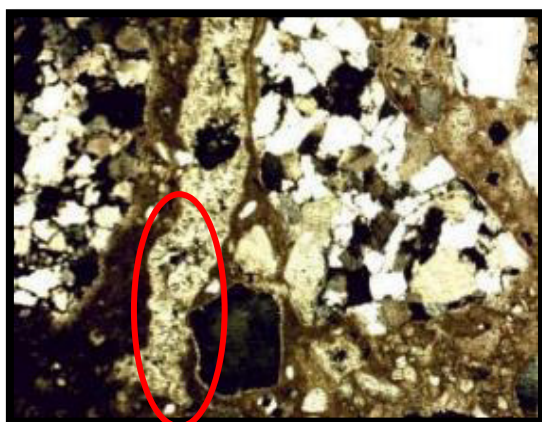
Classification: oligomict Orthoconglomerate.

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Matrix supported\Wackstone

Grain size: from medium to coarse grain size with some clast in pebbles field grain size

Sorting: poorly sorted

Grain shape\Roundness of grains: lithic clasts shows rounded\sub-roundness with moderate sphericity, Quartz clasts show rounded\well-roundness and high sphericity

Fabric: no evidence orientation of grain.

Nature of grain–grain contacts: Grain contacts start off as tangential contacts.

Cement\ Matrix: the sample show a calcite mud matrix. The microgranular calcite cement several showing a calcite ring that coated some clasts. The sample show a secondary fill of the porosity by microgranular calcite cement.

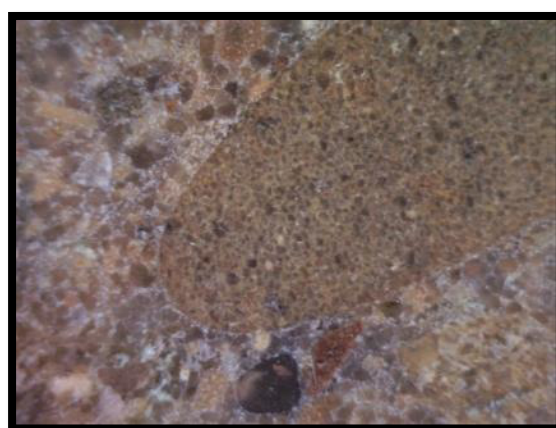
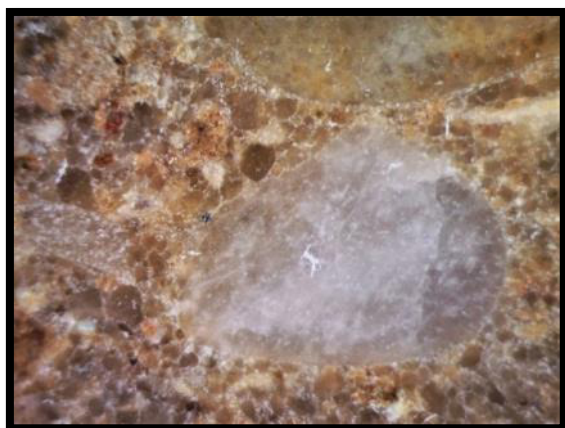
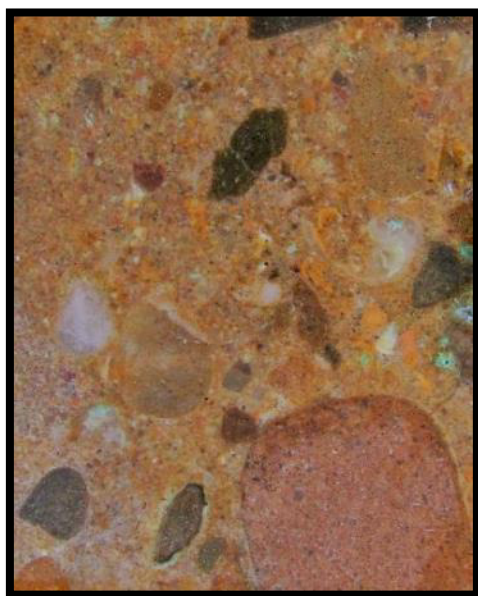
Minerals\Grain type: Bioclastic (calcareous algae and foraminifera) and clastic terrigenous grains. The grains are mainly fragment lithic clast made of Quartz arenite\ Quarzite although siliceous and monocrystalline quartz. Quartz grains are rounded monocrystalline, with unit and undulose extinction. The overgrowth quartz ring that coated some clast is explain with a dissolution and of reworked quartz from previous sandstone.

Textural maturity: Mature

Name: quartzose conglomerate (Boggs, 2006)

19)Sample: 19\CC5

sample macroscopy description



Rock Texture: clastic Matrix supported

grain size: the sample shows different grain size assemblage, from very fine sand to pebble.

Principal grain size is coarse-grained sand

sorting: poorly sorted

Description of the clasts

Mineral component: the sample is composed by different clasts nature but the siliciclastic fragment rock (quartz arenite and quartz) are very abundant.

grain shape\roundness of grains: sample show a uniformity grain shape. Pebbles grains show a rounded\well rounded shape and a lower sphericity degree. Clasts with a sand grain size show a subangular\rounded to roundness degrees and a lower sphericity.

fabric: the sample show a favourite orientation.

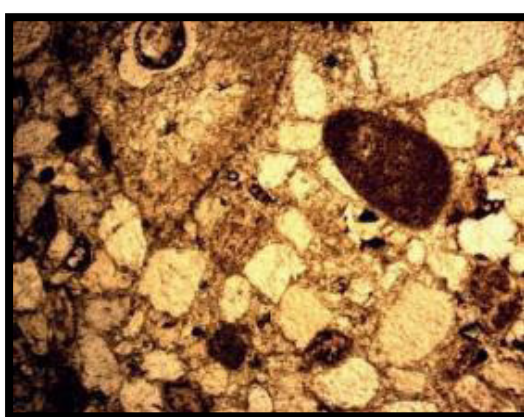
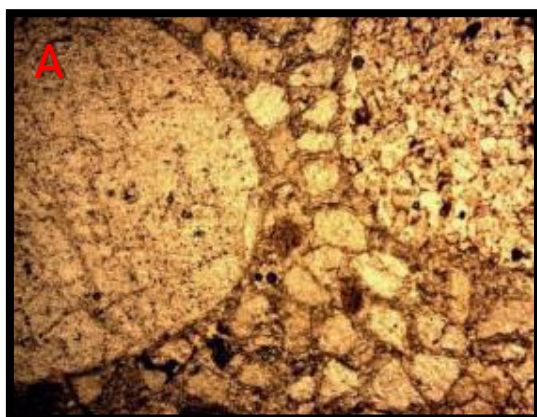
Cement\ Matrix: sample show a carbonate matrix and some clasts are coated by interesting overgrowth of Quartz.

Textural maturity: the sample show good mature degrees.

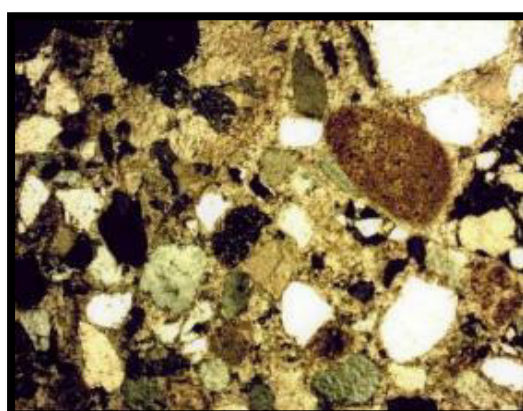
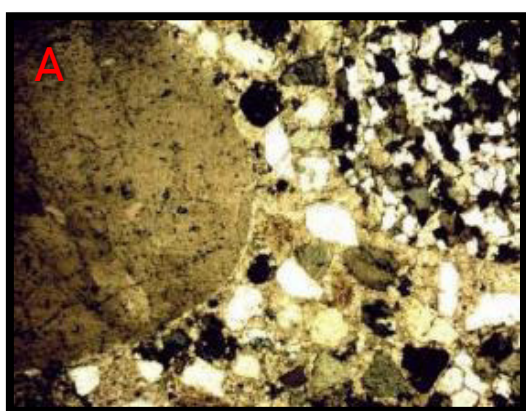
Classification: quartzose Orthoconglomerate.

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Matrix supported\Wackstone

Grain size: from fine to medium grain size with some clast in pebbles field grain size

Sorting: poorly sorted

Grain shape\Roundness of grains: lithic clasts shows rounded with high sphericity, Quartz clasts show angular\subrounded grains and high sphericity

Fabric: evidence orientation of grains (monocrystalline Quartz, Calcite) positioned among fragment lithic clasts.

Nature of grain–grain contacts: Grain contacts start off as tangential contacts.

Cement\ Matrix: the sample show a calcite mud matrix that coated the large clasts. The microgranular calcite cement several showing a calcite ring that coated some clasts.

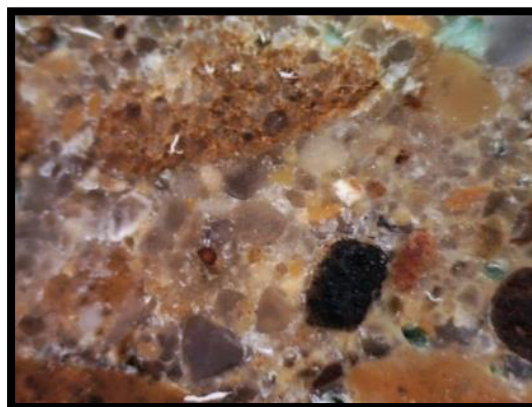
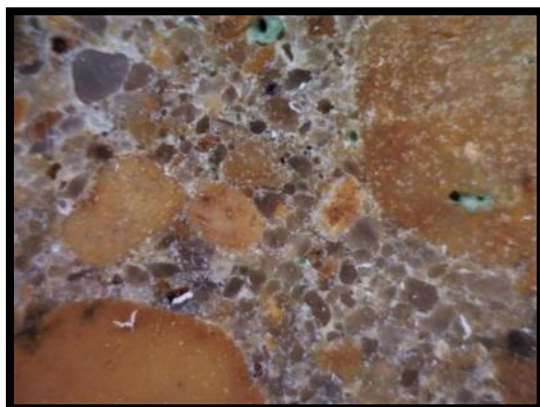
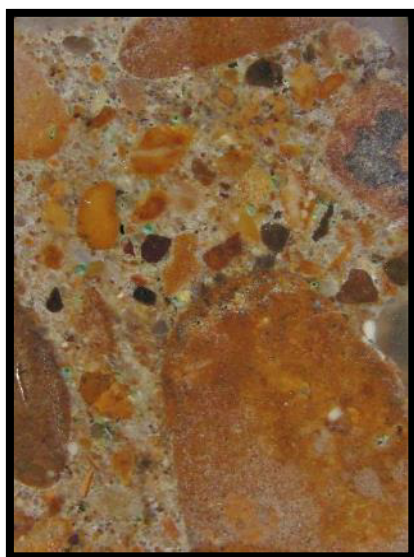
Minerals\Grain type: Bioclastic (calcareous algae and foraminifera) and clastic terrigenous grains. The grains are mainly fragment lithic clast made of Quartz arenite\Quarzite and fine size clast are on calcite and monocrystalline quartz. Quartz grains are subrounded monocrystalline, with unit extinction. The overgrowth quartz ring that coated some clast is explain with a dissolution and of reworked quartz from previous sandstone.

Textural maturity: Mature

Name: quartzose conglomerate (Boggs, 2006).

20) Sample: 20\CC3

sample macroscopy description



Rock Texture: clastic grain supported

grain size: the sample shows different grain size assemblage, from sand to pebble. Principal grain size is coarse-grained sand

sorting: poorly sorted

Description of the clasts

Mineral component: the sample is composed by different clasts nature but the siliciclastic fragment rock (quartz arenite and quartz) are very abundant.

grain shape\roundness of grains: sample show a two different grain shape pebbles grains show a rounded\well rounded shape and a lower sphericity degree. Clasts with sand grain size show a subangular\rounded roundness degree and a lower sphericity.

fabric: the sample show a favourite orientation.

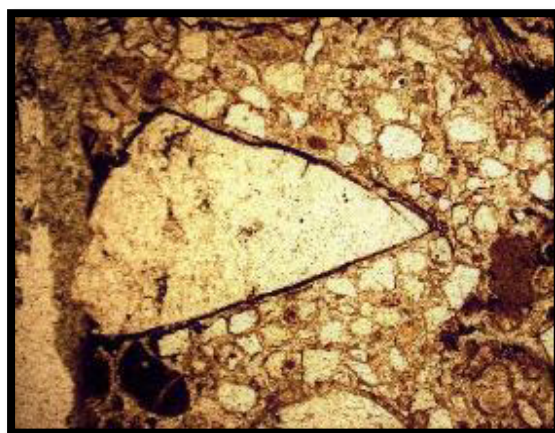
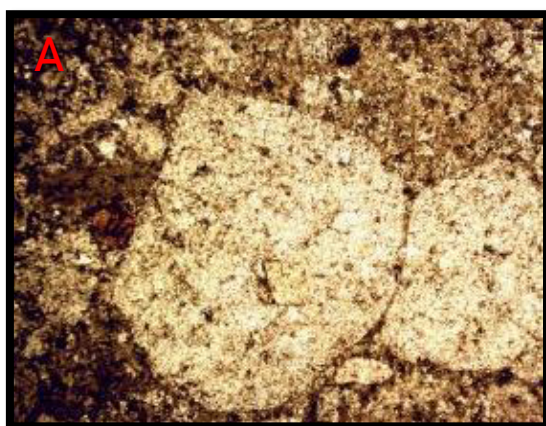
Cement\ Matrix: sample show a carbonate matrix intraclasts and some clasts are coated by interesting overgrowth of Quartz.

Textural maturity: the sample show good mature degrees.

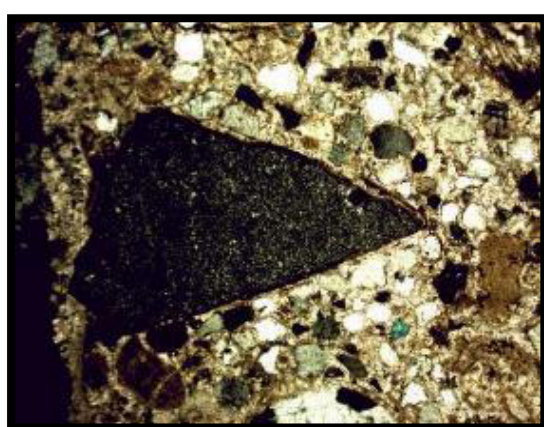
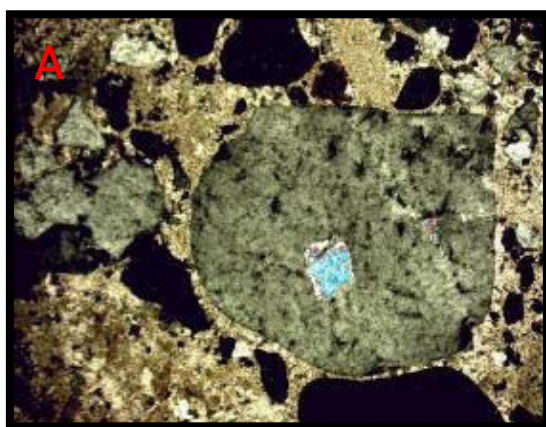
Classification: quartzose Orthoconglomerate.

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Matrix supported\Wackstone

Grain size: from fine to medium grain size with some clast in pebbles field grain size

Sorting: poorly sorted

Grain shape\Roundness of grains: lithic clasts shows rounded\very well rounder with low sphericity; Quartz clasts show angular\subrounded grains and lower sphericity

Fabric: evidence orientation of grains (monocrystalline Quartz, Calcite) positioned among fragment lithic clasts.

Nature of grain–grain contacts: no Grain contacts are identified.

Cement\ Matrix: the sample show a calcite mud matrix that coated the large clasts. The microgranular calcite cement not show a calcite ring that coated some clasts.

Minerals\Grain type: Bioclastic (calcareous algae and foraminifera) and clastic terrigenous grains (gypsum). The grains are mainly fragment lithic clast made of Quartz arenite\Quartzite and fine size clast are on calcite and monocrystalline quartz. The thin section sample showing an interesting Quartz clast (figure A) that has inside it a mineral of muscovite

Textural maturity: submature

Name: quartzose conglomerate (Boggs, 2006)

Sample: 21CCI

sample macroscopy description



Rock Texture: clastic grain supported

grain size: the sample shows different grain size assemblage, from sand to pebble. Principal grain size is coarse-grained sand

sorting: poorly sorted

Description of the clasts

Mineral component: the sample is composed by different clasts nature but the siliciclastic fragment rock (quartz arenite and quartz) and some coarse organogenic clast well rounded.

grain shape\roundness of grains: sample show a two different grain shape pebbles grains show a rounded\well rounded shape and a good sphericity degree. Clasts with sand grain size show a rounded roundness shape degree and a lower sphericity.

fabric: the sample show doesn't a favourite orientation, but very fine sand size clasts are orientated around the morphology of pebbles.

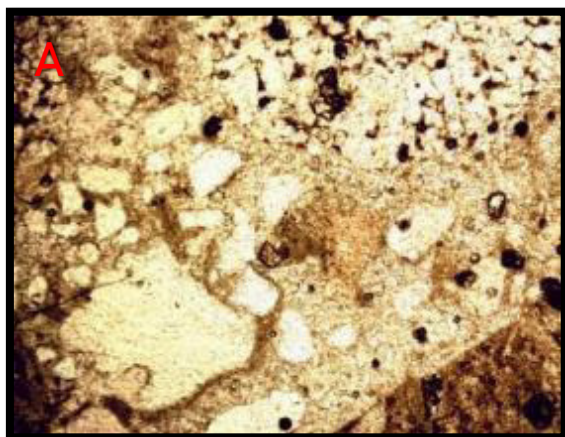
Cement\ Matrix: sample show a carbonate matrix intraclasts and some clasts are coated by interesting overgrowth of Quartz.

Textural maturity: the sample show good mature degrees.

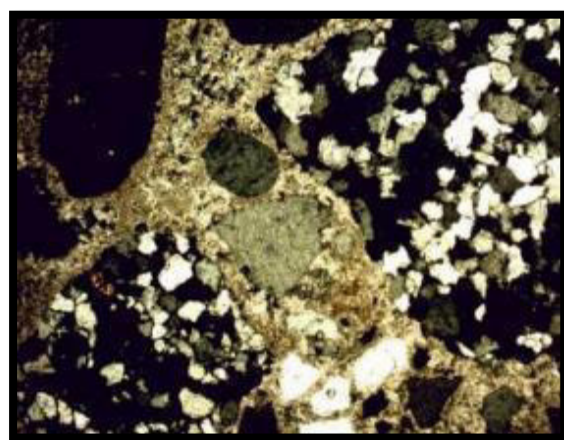
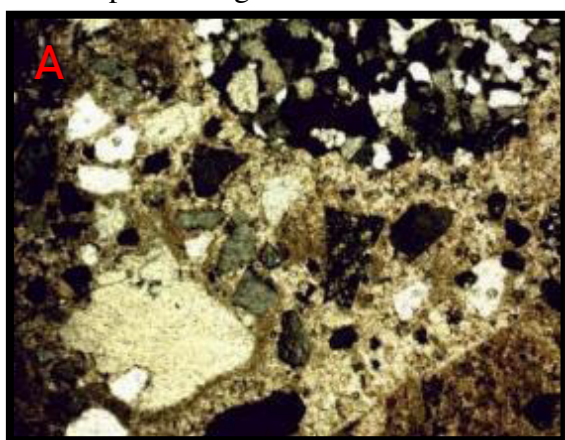
Classification: Orthoconglomerate.

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Matrix supported\Wackstone

Grain size: from fine to medium grain size with some clast in pebbles field grain size

Sorting: poorly sorted

Grain shape\Roundness of grains: lithic clasts shows rounded with high sphericity, Quartz clasts show subrounded grains and high sphericity

Fabric: no evidence orientation of grains.

Nature of grain–grain contacts: Grain contacts start off as tangential contacts.

Cement\ Matrix: the sample show a calcite mud matrix that coated the large clasts. The microgranular calcite cement several showing a calcite ring that coated some large clasts.

Minerals\Grain type: Bioclastic (calcareous algae and foraminifera) and clastic terrigenous grains. The grains are mainly fragment lithic clast made of Quartz arenite\Quartzite some of these show very angular margins (figure A). The clasts show fine-medium grain size are on calcite and monocrystalline quartz. Quartz grains are subrounded monocrystalline with unit extinction and no show a coated ring. The overgrowth quartz ring that coated some clast is explain with a dissolution and of reworked quartz from previous sandstone. The sample show rarely terrigenous extraclast of muscovite.

Textural maturity: Mature **Name:** conglomerate (Boggs, 2006)

Chemical Rock family type: 3\M1; 22\TRAV.

2) **Sample: _3\M1**

sample macroscopy description



Colour: the sample show a Yellowish Gray color (5Y 7/2 Munsell)

Rock Texture: uniform texture, matrix grain supported

grain size: fine grained

sorting:

Description of the clasts

Mineral component: the sample is composed by calcium carbonate

grain shape\roundness of grains: not visible

fabric: massive

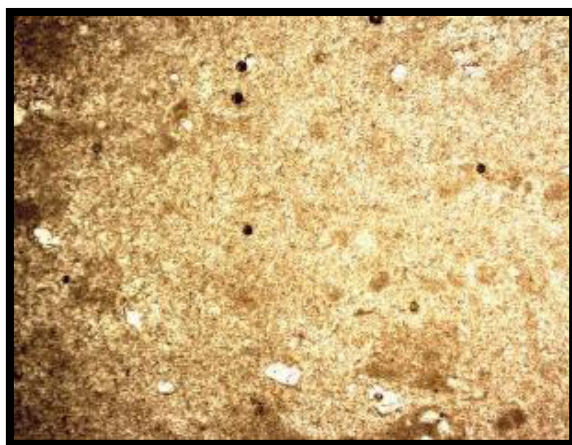
Cement\ Matrix: the sample show a calcite mud

Textural maturity:

Classification: calcite limestone, micrite

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 Folk and duham., 1970, Harrell, 1984, Pettijohn et al., 1987)

Rock Texture:

Grain supported

grain size: clay very fine grain size

sorting: well sorted

The grain shape\roundness of grains and the nature of grain-grain contacts is not possible identified original depositional texture is not recognizable.

Cement\ Matrix: in the sample there is a calcite cement.

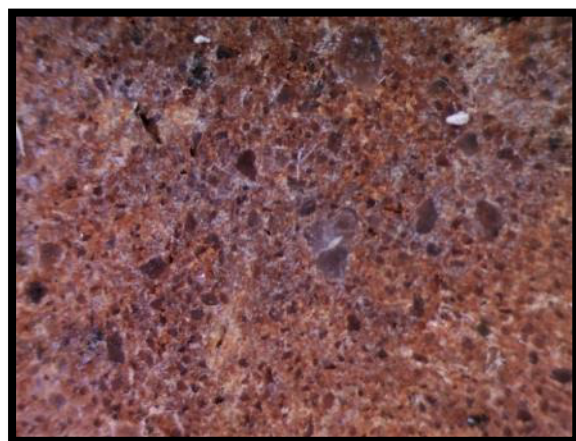
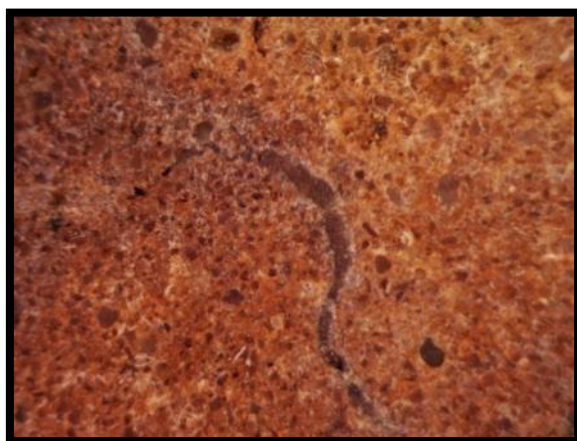
Minerals: the main mineral in this section is calcite (>50%)

Textural maturity: very mature

Name: Calcilutite\ carbonate mudstone

7)Sample: 7\CTRA

sample macroscopy description



Colour: the sample show a red color (10R 4\8 munsell)

Rock Texture: clastic matrix supported

grain size: the sample shows from silt to very fine sand grains size.

sorting: very well sorted

Description of the clasts

Mineral component: the sample show a sand grain size with high percentage of Quartz clast

grain shape\roundness of grains: grain show a angular to sub angular grain shape.

fabric: the sample don't show a favourite grain orientation but a massive fabric.

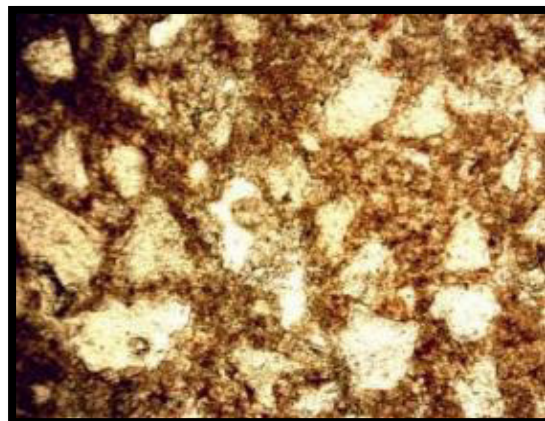
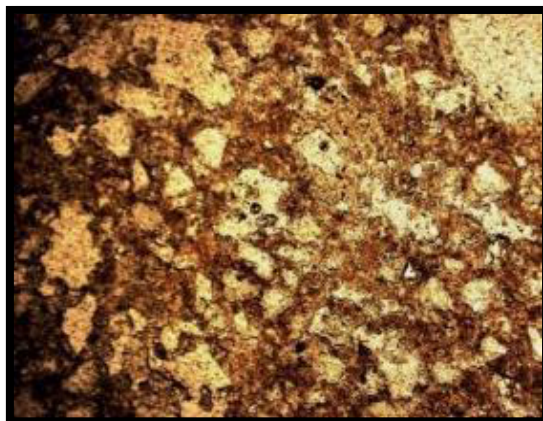
Cement\ Matrix: the sample is poorly cemented and rich of a calcite mud matrix

Textural maturity: the present of a high percentage of matrix indicate a poorly mature textural.

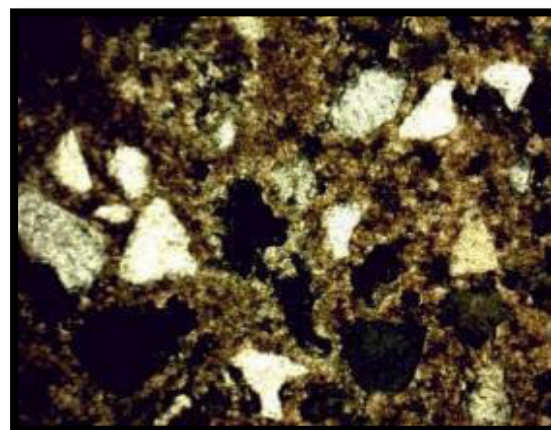
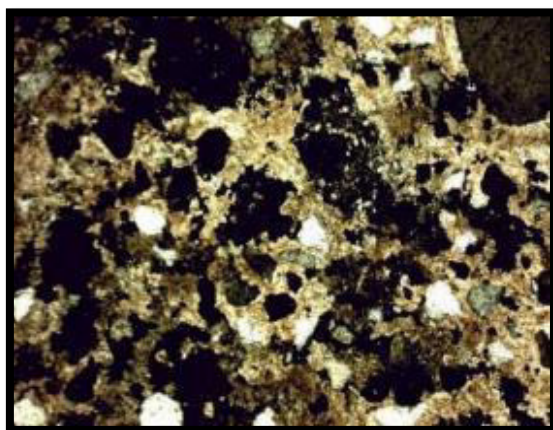
Classification: Quartz siltstone (folk, 1980)

Thin section photos:

Plane-polarized light (PPL), magnification 5X (left) and 10X (Right):



Crossed polars magnification 5X (left) and 10X (Right):



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Matrix supported

Grain size: fine, medium grain size consisting of common quartz.

Sorting: well sorted

Grain shape\Roundness of grains: sub\rounded and sub angular with lower sphericity

Fabric: no evidence orientation of grain.

Nature of grain–grain contacts: no Grain contacts

Cement\ Matrix: A mud matrix

Minerals\Grain type: detrital mineral grains, eroded from pre-existing rocks, and sand-sized pieces of rock, the main mineral is monocrystalline Quartz and monocrystalline Quartz with Undulose extinction (>50%) in this section.

Textural maturity: poorly Mature

Name: quartz mudrock

Sample: 22\TRAV

sample macroscopy description



Colour: the sample show a Yellowish Gray 5YR (5Y 8/1 munsell)

Rock Texture: clastic matrix supported\Boundstone

grain size: the sample shows clay grains size.

sorting: not detection because the sample is chemical sedimentary rock

Description of the clasts

Mineral component: the sample shows two minerals group, bioclasts enclose by carbonate mud and chemical clasts (ooidi).

fabric: the sample shows a horizontal favourite orientation.

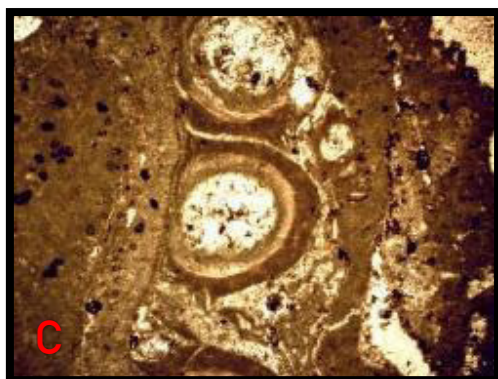
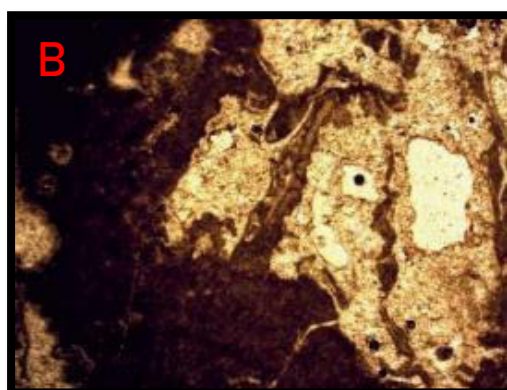
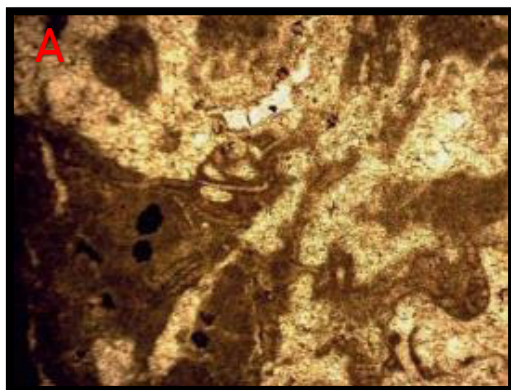
Cement\ Matrix: Carbonate mud that forms rapid precipitation of calcium carbonate which for causes a pH change and changes the solution chemistry so that CaCO_3 precipitates in continental environmental that coated pre-existing lithic clast and structure (e.g. plant). The sample show a high porosity by rapid diagenetic processes.

Textural maturity: poorly mature

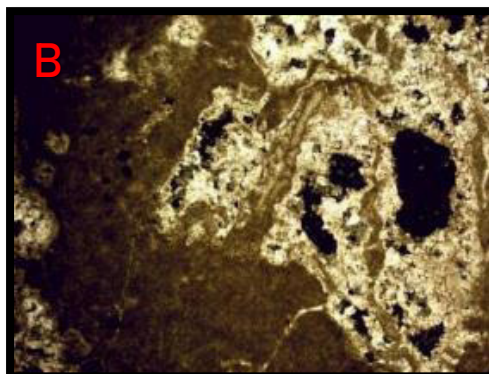
Classification: Travertine, chemical sedimentary rock, calcite limestone (folk, 1980)

Thin section photos:

Plane-polarized light (PPL), magnification 5X:



Crossed polars magnification 5X:



Description: (after Wentworth, 1922; Terry and Chilingar, 1955 and Folk et al., 1970, Harrell, 1984; Pettijohn et al., 1987)

Rock Texture:

Matrix grain supported\ Boundstone

Grain size: coarse to medium grain size

Sorting: poorly sorted

Fabric: no evidence orientation of grain.

Nature of grain–grain contacts: rarely grain contacts start off as tangential contacts

Cement\ Matrix: The microgranular calcite cement fills the interparticle pores and coated clasts (figure A). An oversaturation of carbonate Calcium by rapid chemical precipitation of calcium carbonate (Calcite or Aragonite) from supersaturated solutions (figure B).

Minerals\Grain type: Detrital mineral grains, Bioclastic (calcareous algae) and clastic terrigenous grains and oolids (figure C).

Textural maturity: sub sub Mature

Name: calcite limestone (Travertine)

C) APPENDIX C

TABLES OF PALEONTOLOGICAL MORPHOMETRIC DATA

This appendix contains the values of the measures taken on fossil remains found in the Great Delia River. The values are expressed in mm and have been taken following the indications of Von Den Driesch (1976).

Mandible								
Sample	1	2	3	4	5	6	9	8D
Specie	Bos	Ovis	Equus	Equus	Equus	Bos	Sus	Bos?
length from the angle: Gonion caudale - infradentale	338	153.74						119.3
length from the condyle: aboral border of the condyle process\ infradentale	IND	174.83						
length: Gonion caudale - aboral border of the alveolus of M3	100	43.2			120			
Length of the horizontal ramus: aboralborder of the alveolus of M3-infradentale	225.37	105.62						
Length: Gonion caudale - oral border of the alveolus of P2	230	115.25						
Length: Gonion caudale - the most aboral indentation of mental foramen	308	141						
Length of the cheektooth row, measured along the alveoli on the buccal side	123	79.84						
Length of molar row, measured along the alveoli on the buccal side	103.37	55.67						
Length of the premolar row, measured along the alveoli on the buccal side	32.38	24.3						
Length and breadth of Me, measrude near the biting surface	m3 rotto	26,13\9						
Length of the diastema:oral border of the alveolus of P2 - aboral border of the alveolus of I4	91.42	31.9				86.44		62.4
Aboral height of the vertical ramus: Gonion ventrale - highest pointof the condyle process	IND	66						
Middle height of the vertical ramus: Gonion ventrale - deepest point of the mandibular notch	IND	74.26						
Oral height of vertical ramus: Gonion ventrale - Coronion	IND	IND						
Heigth of the mandible behind M3 from the most aboral point of the alveolus on the buccal side	67.58	34.41						32.2
Heigth of the mandible in front of M1	46.2	24.32						
Height of the mandible n front of P2	37.3	18.21						
Oral height of vertical ramus: Gonion ventrale - Coronion							10.02	
Heigth of the mandible in front of M1				65,46 dx\ 61,07 sx				
Height of the mandible n front of P2				52,13 dx\50,39 sx				

SKULL				
Sample	1B	11	10	7
Specie	Canis	Ovis	Bos	Sus
Total length: akrokranium - Prosthion	198			
Condylbasal length: aboral border of the occipital condyles - Prosthion	171			
Basifacial axis: Synsphenion - Prosthion	127			
Frontal breadth: Ectorbitale - Ectorbitale	57.29			
Least breadth between the orbits: Entorbitale - entorbitale	43.3			
Upper neurocranium length: Akrokranium - Frontal midpoint	95.55			
Viscerocranium length: nasion - Prosthion	94.13			
Facial length: Frontal midpoint - Prosthion	110.15			
Median palatal length: Staphylion - Prosthion	105.62			
Length of cheektooth row (Mesured along the alveoli on the buccal side)	68.46			
Length of the molar row (Mesured along the alveoli in the buccal side)	34.64			
Length of premolar row (Mesured along the alveoli in the buccal side)	34			
Greatest breadth of the carnassial	L18,47\B 7,02\GB 9,91			
Greatest neurocranium breadth=greatest breadth of the braincase: Euryon-Euryon	59			
Least breadth of skull= least breadth aboral of the supraorbital processes = breadth at the postorbital constriction	41.66			
Greatest inner height of the orbit	31.3			
Height (length) of the canine	L10,63\ 5,50			
Length from aboral border of the alveolus of M3 - aboral border of the alveolus of Canine				113.15
length of the cheektooth row (measured along alveoli)				99.86
Length of the cheektooth row, M3-P2 (measured along alveoli)				92.6
Length of the molar row (Mesured along the alveoli in the buccal side)				60.76
Length of the premolar row P2-P4 (measured along alveoli on buccal side)				38.84
Greatest diameter of the canine alveolus				14.61
Horncore basal circumference		137		
Greatest (oro-aboral) diameter of the horncore base		50.84		
Least (Latero-medial) diameter of the horncore base		42.47		
Horncore basal circumference			200	
Greatest (oro-aboral) diameter of the horncore base			73.93	
Least (Latero-medial) diameter of the horncore base			60.2	

Teeth																
Sample	3	7	5	8	TE1	TE2	TE3	TE4	TE5	TE6	TE7	TE8	TE9	TE10	TE11	TE12
Specie	Equus	Sus	Equus	Bos	Equus	Equus	Equus	Equus	Equus	Equus	Equus	Equus	Equus	Equus	Equus	Equus
Upper																
P1																
P2	43,82\24,63															
P3	30,32\27,86															
P4	27\28,90															23,20/ 24,70
M1	24,60\26,95															
M2	25,35\27,35															
M3		28,53\17,46					24,6\14,20	23,5\14,6	23,3\12,3							
Lower																
M1				25,22\14,36											24,40 25,20	
M2				29,73\14,30						28,8\17,9	28,6\14,4	29\18	23,8\16,6	24,70\15,80		
M3			28,91\ 13,66							36,7\24,25	30,56\20,10					
Atlas																
Sample	13															
Specie	bos															
Greatest breadth over the wings	119.98															
Greatest length	88.55															
Greatest breadth of the Facies articularis cranialis	91.91															
Greatest breadth of the Facies articulari caudalis	79.83															
Greatest length from the facies articularis cranialis to the Facies articularis caudalis	68.45															
Length of the arcus dorsalis, median																
Height	72															

Vertebrae	
Sample	9C-1C
Specie	Bos
Physiological length of the body. Measured between the centers of the Facies terminalis caudalis	39.76
Height	170
Greatest breadth across the Processus articulares craniales	76.9
Greatest breadth across the Processus articulares caudales	60.47
Greatest breadth of the Facies terminalis cranialis/caudalis	32,70\34,73
Greatest height of the Facies terminalis cranialis/caudalis	29,25\29,30

Humerus				
Sample	08-gen	11-C	11-D	11-E
Specie	Felix	ovis\capra	ovis\capra	ovis\capra
Greatest Length		51.2	55.9	49.1
Greatest Length caput	82.3			
Breadth of the proximal end				
Breadth of the distal end	18.7	29	32.6	28.8
Breadth of the trochlea	15.2	26.8	31	27
Smallest breadth of diaphysis	6.96			
Radius				
Sample	6D			
Specie	Equus			
Breadth of the proximal end	56.3			
Breadth of the proximal of the facies articularis proximalis	47.1			
Ulna				
Sample	08-ago			
Specie	Equus			
Greatest Length		68		
Length of Olecranon	58.66	12.3		
Depth across the processus Anconeus	55.68	7.7		
Smallest depth of the olecranon	50	10.8		
Breadth across the coronoid process		8.86		

Femour								
Sample	9A-1A	7D						
Specie	bos	Canis						
Greatest Length		207						
Greatest Length caput								
Breadth of the proximal end		40.2						
Depth of the caput femoris	37.72	20						
Smallest breadth of diaphysis	145	12.5						
circumference of diaphysis		43						
Tiba								
Sample	11-A	C9-1C	B9-9B					
Specie	Ovis\Capra	Bos	Bos					
Greatest Length	67.3							
lateral length on the outer side								
Breadth of the proximal end								
Smallest breadth of diaphysis								
circumference of diaphysis								
Breadth of the distal end	26.1	77.5	71.11					
depth of the distal end	19.9	55.6	42.3					
Metapodial								
Sample	4C-22	4C-23	4C-24	8C-2	8c-2B	9A-4A	9B-9B	9C-4C
Specie	Bos	Bos	Bison	Bos	Bos	Bos	Bos	Bos
Greatest breadth of the distal end		62.1	64.63				58.2	
Greatest length			198					174
Lateral length on the outer side								
Greatest breadth of the proximal end				59	59.3	49.27		
Greatest depth of the proximal end								
Smallest breadth of the diaphysis			39.1					35.6
Smallest circumference of the diaphysis			113					113
Smallest depth of the diaphysis		27.45	24.21				27.15	30
Greatest depth of the distal end								
Greatest thickness	32.26	28,7 S \ 30,10	30,70\29,25		28.1		25,46\25,90	27\26
Greatest width	30.37	24 s \ 25,80	d \ 25,60\25,85		25.58			

Astragalus						
Sample	3_14	3_15	3_17	3_19		
Specie	bos	bos	bos	bos		
Greatest length of the lateral half	94.86	70.1	67.62	64.22		
Greatest length of the medial half	84.75	37.05	60.63	57.92		
Greatest depth of the lateral half	53.91		34.43	35.44		
Greatest depth of the medial half	48.02		33.67	31.12		
Greatest breadth of the distal end	62.25	45	44.05	41.06		
Calcaneus						
Sample	11C-12A	9B-3B	8_7			
Specie	Cervus?	Bos	Equus			
Greatest length	120.6	141.77	75			
Greatest breadth	33.2	43	43			
Phalanges						
Sample	3_16	3_18	9B-11B	9B-12B	9B-13B	9B-14B
Specie	bos	bos	Sus	Bos	Bos	Bos
Greatest length	64.69	61.38	56.33	63.82	64.68	62
Greatest breadth of the proximal end	32.29	31.66	25	32.85	29.54	35
Smallest breadth of the diaphysis	29.46	27.3	21.68	29	25.56	30
Greatest breadth of the distal end	30.75	29.38	22.6	31	27.15	32.72