Early Tertiary of Sardinia, Italy

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INTRODUCTION

In Sardinia, the Paleocene-Eocene sediments are confined almost entirely to the central southern part of the island (Fig. 1) and are composed either of marine or continental deposits. Though studied by numerous authors, including La Marmora (1857), Schwarzbach *et al.* (1952), Calvino (1962), Vardabasso (1962), Dieni *et al*. (1979), Cherchi (1983), Murru (1990), Murru & Salvadori (1990), Murru & Ferrara (1999), Matteucci *et al.* (2000), Matteucci & Murru (2002) the Lower Tertiary in Sardinia is still relatively little known. The reason for this is the scattered and sparsely fossiliferous outcrops.

PALEOCENE

Paleocene continental sedimentation is documented in southern Sardinia (Monte Maraconis, Sant'Andrea Frius and Villamassargia) with ironstone deposits (Ferrara *et al.*, 1992; Murru & Ferrara, 1999), that were originally composed of alluvial deposits of clasts (sandstones and conglomerates) interpreted as flood and channel deposits (Fig. 1A). Based on their mineralogic and geochemical properties (significant Al and Fe contents) the continental deposits of central-southern Sardinia can be defined as ultisols with ironstones (Murru & Ferrara, 1999). These paleosoils can be dated to the Paleocene, as they are overlain by carbonate-dolomitic layers with microcodium and Thanetian - Ilerdian sediments containing charophyte and nummulitid-bearing horizons. The climate was probably similar to the present day subhumid, tropical climate.

The clasts of shallow-water marine limestones with *Broeckinella belgica* L. & J. Morellet, *Miscellanea* cf. *miscella* (D'Arch. & Haime), *Elianella elegans* Pfend. & Basse, *Pycnoporidium levantinum* Johnson reported at Orosei, are evidence of a brief and local marine incursion during the Lower-Middle Paleocene (Fig. 1A). These clasts, of Danian-Montian age, were found within the post-Cuisian conglomerate of Cuccuru e' Flores (Dieni *et al.*, 1979; Dieni & Massari, 1985). The presence of microcodium "incrustations" on these clasts, which are missing on clasts of marine limestones referable to the Thanetian-Middle Ilerdian coexisting in the same conglomerate, suggest a continental oscillation occurring in the Early to Late Paleocene (Dieni & Massari, 1985).

Microcodium is commonly observed only in central-southern Sardinia, except for incrustations (Barberi & Cherchi, 1980) on marine carbonate rocks of Upper Cretaceous age in the Nurra region (Fig. 1A). Usually, it occurs within brecciated fine grained limestones (solution breccias) resting on a Paleozoic-Mesozoic carbonate substratum, often karstified, and covered by marine deposits, prevalently of Early Ypresian = (Ilerdian) age. In some places, microcodium has also been found in carbonate-dolomitic layers interbedded in arenaceous argillites with charophyte, of partly Paleocene (Thanetian) age (Matteucci & Murru, 2002). The kaolinite-poor and quartz-rich continental detrital deposits containing microcodium suggest an environment with sparse vegetation cover and presumably microcodium debris formed and deposited in under semiarid climatic conditions.

EOCENE

During the Early Ypresian (= Ilerdian) an extensive and well-documented marine ingression flooded central-south Sardinia (Fig. 1A) persisting up to the Late Ypresian (= Cuisian) in some areas such as central-east Sardinia (Cherchi, 1983; Matteucci, 1985b; Murru & Salvadori, 1990). Nevertheless most of the Eocene marine deposits so far discovered in Sardinia can be attributed to the Ilerdian transgression (Matteucci, 1985a; Murru,1990).

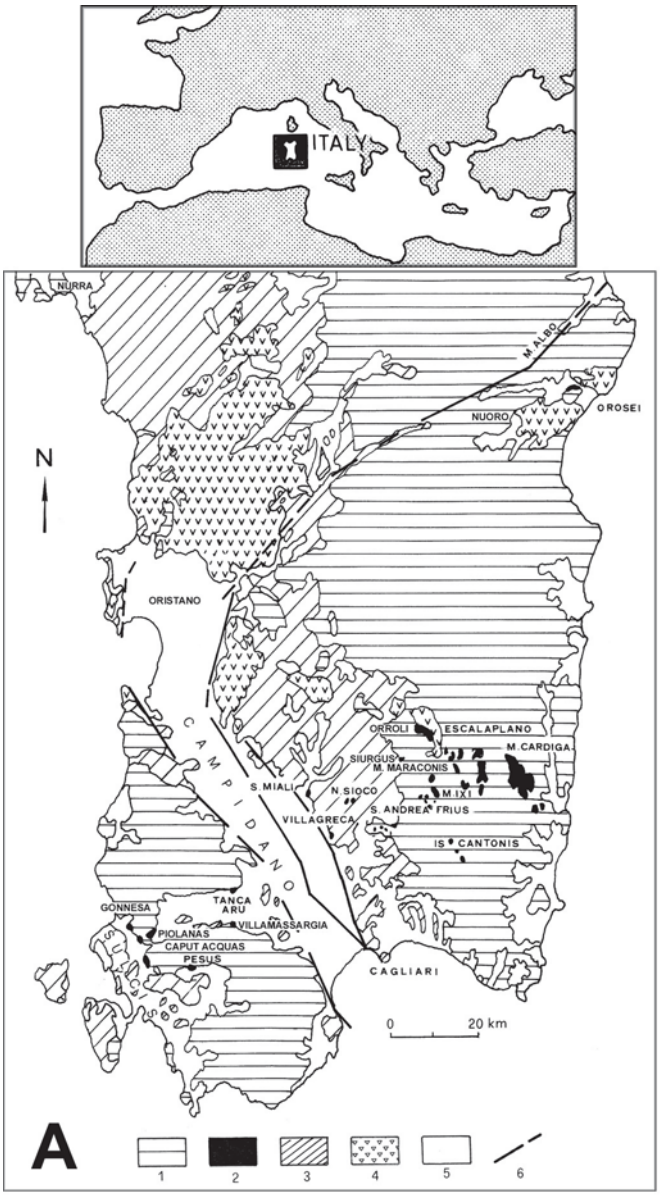
These marine sediments are to be found mostly in the south-east of the island and are characterized by sparse fossil content and substantial facies diversity. They are composed mostly of clastic sediments

(conglomerates, sandstones and argillites), rarely of carbonates. Remnant outcrops of what is believed to have been a single sedimentary blanket are today found in South-East Sardinia at different altitudes, ranging from 539 m at Monte Ixi to 78 m at Santu Miali) usually with sub-horizontal bedding (Fig. 1B). The differences in level are largely the result of the extensional tectonics that took place in the Late Oligocene-Lower Miocene (Cherchi & Montadert, 1982; 1984, Casula *et al.*, 2001), but probably also during the Plio-Pleistocene (Marini & Murru, 1983) that locally produced uplifting or subsidence of the Eocene formations to different.

The most well-known and also the thickest (240 m) outcrop in South-east Sardinia is Monte Cardiga (Fig. 1A) a primarily terrigenous sequence, consisting of sandstones, silty and pebbly sandstones, conglomerates, marls and limestones. Lower layers exhibit predominantly *Assilina*-bearing assemblage (*Assilina* cf. *prisca* Schaub, *Assilina* cf. *yvettae* Schaub) which may be dated to the Lowermost Ilerdian and perhaps also to the Thanetian and which are reworked in *Assilina*-bearing levels of the Lower-Middle Ilerdian. Resedimented forms can be well recognized by their abraded tests and their yellow-red colour due to iron oxide infiltration. Except for one horizon containing abundant *Ranikotalia* and *Operculina, Assilina* dominate the marly strata that contain calcareous nannofossils of the *Discoaster multiradiatus* zone. A first carbonate layer is characterized by *Discocyclina applanata* Gümbel, *Discocyclina archiaci* (Schlumberger) and by *Nummulites atacicus* Leymerie. The upper thick carbonate layer, rich in corals, prevalently poritids, and with small nummulitids and discocyclinids, is abruptly interrupted by a strong terrigenous inflow (Matteucci, 1985b). In this part of the island there are numerous, generally non-fossiliferous outcrops attributed to the Eocene because of facies similarity with the fossil bearing outcrops in this region (Is Cantonis, Orroli, Monte Ixi, Sant'Andrea Frius, Nuraghe Sioco, Villagreca and Santu Miali). The outcrop at Nuraghe Sioco comprises a succession composed chiefly of marls alternating with shales with two organogenic calcareous horizons. In the first calcareous bed a larger foraminifera assemblage has been identified (*Orbitolites* cf. *gracilis* Lehmann, *Orbitolites biplanus* Lehmann, *Orbitolites* cf. *complanatus* Lamarck ed *Alveolina (Alveolina)* cf. *subpyrenaica* Leymerie, *Alveolina (Glomalveolina) lepidula* (Schwager), *Alveolina (Alveolina) decipiens* (Schwager) dated to the Middle Ilerdian (Matteucci *et al.*, 1985), while the underlying marly layers contain charophyte flora with *N.* (*T.*) *thaleri, H. bressoni, H. squarrulosa, M. pachycera, Stephanocara* sp.1 and *L. priscum* (Tambareau *et al.*, 1989).

In the Sulcis region, in the SW of the island, the occurrence of *Glomalveolina* cf. *primaeva* (Reichel) in the basal levels of the Paleogene ingressive carbonate deposits ("Miliolitico" *Auct.*) also indicate that marine sedimentation commenced during the Paleocene (Cherchi, 1983; Murru & Salvadori,1990). In the Sulcis region in particular, the main sequence includes basal limestones (50-60 m thick) containing alveolinids (*Alveolina cucumiformis* Hottinger, *Alveolina ilerdensis* Hottinger) and orbitolitids (*Orbitolites biplanus* Lehmann, *Orbitolites latimarginalis* Lehmann) followed by miliolid limestones. The larger foraminiferal limestones characterised by abundant quartz, low detrital kaolinite content and abundant miliolids, can be interpreted as a marine deposit of tropical arid environment. The appearance in the topmost "Miliolitico" of intercalated layers with abundant rotalinid foraminifers associated with a higher detrital kaolinite content, suggests a wetter tropical climate. A half lower jaw of *Atalanodon monterinii* Dal Piaz, a perissodactyl similar to the modern tapirs was discovered in these layers.

Only in SW Sardinia is this prevalently carbonate marine sequence overlain by a series (100-110 m thick) of marly limestones and marls with freshwater ostracods, including palustrine clays and limestones with charophytes and pollens. Interbedded in the palustrine and/or lagoonal levels are several coal seams which are still mined (the "Produttivo" *Auct.*). A Cuisian (= Upper Ypresian) age has been assigned to this succession on the basis of the microflora assemblages (Pittau, 1977; Salvadori, 1980) observed in the first coal strata that contain *Leiotriletes adriennis* Kr., *Leiotriletes microadriennis* Kr., *Plicapollis pseudoexcelsus minor* Kr., *Plicapollis pseudoexcelsus turgidus* Pf. This dating is confirmed by the presence of the charophyte species *Harrisichara saportae* Feist Castel. The most common plants are palms, myricaceae and tropical ferns. In the uppermost coal strata the pollen assemblage of *Corsinopollenites ichnusae* Pitt. Dem., *Leiotriletes dorogensis* Kds. and *Retriticolpites* cf. *microreticulatus* Brenn. rather suggests an Early Lutetian age (Salvadori, 1980). Two jaw pieces belonging to another perissodactyl similar to modern tapirs, *Lophiodon sardus* (= *Paralophiodon sardus)* Bosco and the teeth of *Amphiperatherium* sp., a large marsupial, have been discovered at the base of the



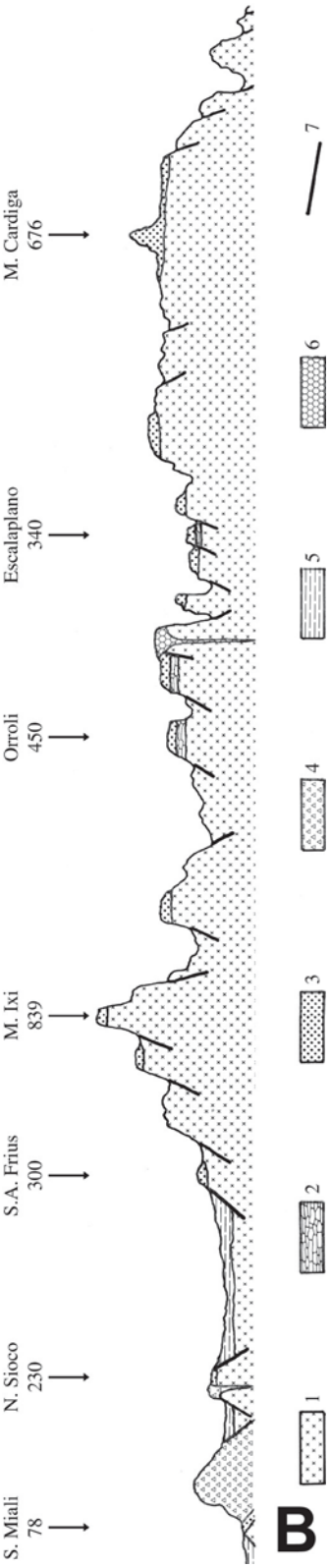


Fig. 1 - A) Simplified geological map of Central-south Sardinia: 1- Palaeozoic-Mesozoic basement; 2- Paleocene-Eocene; 3- Oligocene-Miocene; 4- Pliocene-Pleistocene basalts; 5- Quaternary deposits; 6- Faults. B) Simplified geological cross-section from the East coast to the Plio-Quaternary Campidano Graben: 1- Palaeozoic; 2- Mesozoic; 3- Paleocene-Eocene; 4- Oligocene-Miocene andesits; 5- Miocene sediments; 6- Pliocene-Pleistocene basalts; 7- Faults.

"Produttivo". In this unit, dominating detrital kaolinite combined with the absence of quartz as well as the pollen assemblages confirm the evolution towards a humid-subhumid tropical climate

The marine deposits of Cuisian age occur in East Sardinia at Orosei (Fig. 1A) and are represented by shallow-sea terrigenous and carbonate deposits. Arenaceous limestones alternate with calcareous sandstones, siltstones and sandy-silty marls, often very rich in micaceous minerals. Siliciclastic influx in most cases dominates the depositional environments; less frequently, it is limited to sparse quarz grains and lithoclasts in a micritic carbonate matrix. Red algae nodules and grains are abundant; large amounts of pelecypods, gastropods and echinoids occur in the upper part of the succession. A rich larger foraminifera and nannoplankton fauna has been recognised in these deposits (Dieni *et al.*, 1966; Matteucci & Schiavinotto, 1985) dated to the Lower Cuisian (*Alveolina oblonga* zone; *Assilina placentula* zone and *Discoaster lodoensis* zone) and the Lowermost Middle Cuisian (*Nummulites nitidus* zone and *Discoaster lodoensis* zone).

At Nuraghe Sioco (Fig. 1A), in the second carbonate horizon intercalated into the marly-clayey succession, a larger foraminifera assemblage has been identified (*Alveolina (Alveolina) oblonga* D'Orbigny, *Alveolina (Alveolina)* cf. *rutimeyeri* Hottinger, *Alveolina (Alveolina) boscii* (Defrance), *Nummulites bombitus* Hottinger, and *Nummulites* cf. *soerenbergensis* (Schaub) asssigned to the Lower Cuisian (Matteucci *et al.*, 1985).

Evidence of Middle Eocene marine deposits on the island has only been reported by Dieni *et al*. (1966), who identified Lutetian nummulite-bearing clasts (*Assilina spira* (DeRoissy), *Assilina tenuimarginata* (Heim), *Nummulites gallensis* (Heim) and *Nummulites* cf. *montefriensis* Douvillé) embedded in a continental pre-Pliocene conglomerate in the Osalla creek, near Orosei (Fig. 1A).

During the Middle-Upper Eocene, the Pyrenean tectonic phase affected the island; continental conglomerates and sandstones (Cixerri Formation, Pecorini & Pomesano Cherchi, 1969) unconformably overlie a basement of varying (Paleozoic, Mesozoic and Eocene) age (Agus & Pecorini, 1978; Cherchi, 1985). The presence of charophytes belonging to *Nitellopsis (Tectochara) thaleri thaleri* (Castel & Grambast) at the base of the Cixerri Formation suggests that these fluvio-lacustrine sediments deposited in the Early Lutetian (Agus & Pecorini, 1978; Barberi & Cherchi, 1980).

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