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INTEGRATED STRATIGRAPHY FROM THE CONTRADA FORNAZZO SECTION, MONTE INICI, WESTERN SICILY, ITALY: PROPOSED G.S.S.P. FOR THE BASAL BOUNDARY OF THE TITHONIAN STAGE

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Abstract. This paper deals with a definition of the lower boundary stratotype of the Tithonian Stage in the Upper Jurassic succession of Monte Inici, Western Sicily. The upper member of the Rosso Ammonitico Fm. is 27 m thick and shows a typical nodular-calcareous lithofacies; its lower beds have been sampled for biostratigraphic and paleomagnetic purposes. Though the succession is affected by high stratigraphic condensation, the resulting hiatuses have been shown to be below biochronological resolution and thus do not hinder any biostratigraphic definition. The biostratigraphic analysis has been based on the rich ammonite assemblages in which the common genus *Hybonoticeras* is the index-key for characterizing the Kimmeridgian-Tithonian boundary. Four ammonite biozones have been identified; the basal Tithonian one is defined by the assemblage of *Hybonoticeras* gr. *hybonotum* and *Haploceras staszycii*. The recorded calcareous nannofossil bioevents allow recognition of the *V. stradneri* and *C. mexicana* Zones, whose boundary is located a little below the identified Tithonian lower boundary. The paleomagnetic record shows normal polarity in the *S. darwini/V. albertinum* Zone and mainly reverse polarity in the *H. beckeri* and *H. hybonotum* Zones, with three minor normal polarity intervals; the lower boundary of the Tithonian falls in the oldest of these intervals. The integrated multidisciplinary stratigraphic information gathered from the Contrada Fornazzo section defines the lower boundary of the *H. hybonotum* Zone at the base of Bed 110, and supplies elements of chrono-correlation sufficient to regard this section as a possible G.S.S.P. of the Tithonian Stage.

Riassunto. Questo lavoro riguarda la possibile definizione dello stratotipo del limite inferiore del Piano Titoniano nel Giurassico Superiore di Monte Inici, in Sicilia Occidentale. Il membro superiore del Rosso Ammonitico è potente 27 metri e presenta una tipica facies calcareo-nodulare; gli strati basali sono stati campionati per analisi biostratigrafiche e paleomagnetiche. Sebbene la successione presenti forte condensazione stratigrafica, le lacune individuate risultano avere estensione inferiore alla risoluzione biocronologica e quindi non influenzano le interpretazioni biostratigrafiche. Lo studio biostratigrafico si è basato sulle ricche associazioni ad ammoniti, in cui il genere *Hybonoticeras* è riccamente rappresentato con specie-indice del limite Kimmeridgiano-Titoniano. Sono state riconosciute quattro biozone ad ammoniti; tra queste, la biozona basale del Titoniano è definita dalla associazione di *Hybonoticeras* gr. *hybonotum* e *Haploceras staszycii*. I bioeventi a nannofossili calcarei hanno permesso di riconoscere le Biozone a *V. stradneri* e *C. mexicana*, il cui limite è localizzato un poco sotto l'inizio del Titoniano. Il record paleomagnetico presenta una polarità normale nella Biozona a *S. darwini/V. albertinum* e una polarità inversa diffusa nelle Biozone a *H. beckeri* e *H. hybonotum*. Sono stati riconosciuti tre eventi minori di polarità normale, nel più antico dei quali cade il limite inferiore del Titoniano. Le analisi multidisciplinari condotte nella sezione di Contrada Fornazzo si integrano nel definire il limite inferiore della Biozona a *H. hybonotum* alla base dello strato 110, che viene quindi considerato come possibile G.S.S.P. del Piano Titoniano.

Introduction

In the last decades the Tithonian Working Group of the International Subcommission on Jurassic Stratigraphy (I.S.J.S.) has been looking for a section which could serve as the Global Stratotype Section and Point (G.S.S.P.: Remane et al. 1996) of the Tithonian Stage (Olóriz & Schweigert 2001). Some proposals have been already discussed which are based on the Ammonite Standard Biozonation established for the Submediterranean Province (Schweigert 2000). Nevertheless, the spreading centres of many Jurassic marine biota point to the Mediterranean Province, whose position within the Tethyan Realm fostered colonisation of the south European shelves. It follows that data from Mediterranean area have high potential as a basis for chonostratigraphic correlation, which is the most important criterion for selecting a bound-

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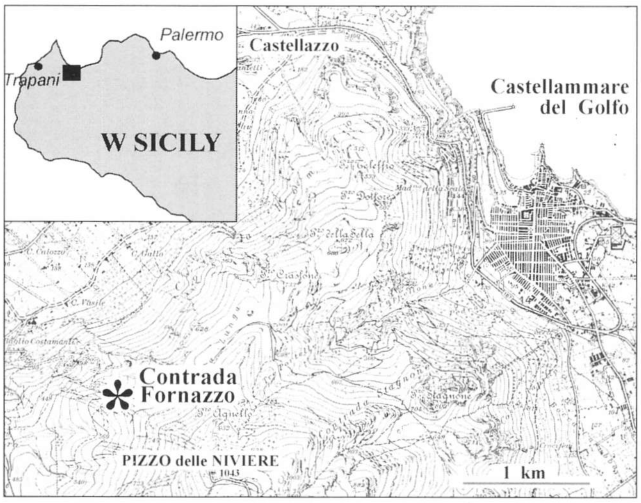

Fig. 1 - Location (star) of the Kimmeridgian to Tithonian studied section, along the service road of Contrada Fornazzo.

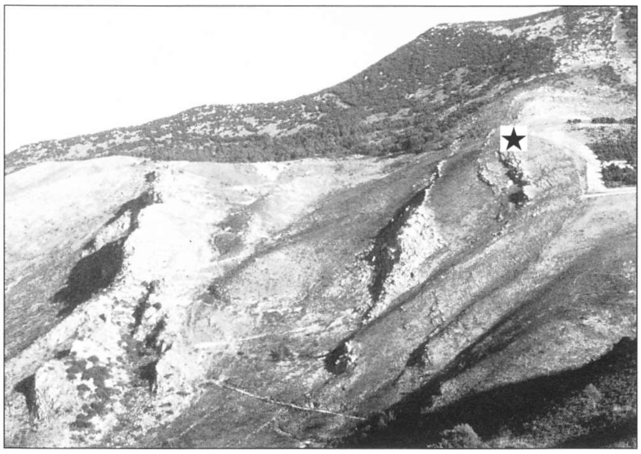

Fig. 2 - The old Fornazzo quarry on the northern side of Monte Inici; the service road is visible at about 700 m of altitude, whereas the old winding road climbs the center of the slope. View from Contrada Fraginesi. The asterisk marks the outcrop described in the text.

ary stratotype. At present, no proposals on Mediterranean successions have been formalized for the Tithonian Stage; the Sicilian Upper Jurassic is promising for this purpose.

The section of Contrada Fornazzo, on the western slope of Monte Inici, exposes the Kimmeridgian/Tithonian boundary interval. The beds are characterized by rich ammonite assemblages which could supply basic biostratigraphic information for the identification of that boundary. Actually, the uppermost Jurassic of Sicily is famous through the ammonite monographs produced by Gemmellaro in the late nineteenth century (see the revision edited by Pavia & Cresta 2002), and the contributions by Floridia (1931) and Christ (1960) with details on Monte Inici fossil assemblages.

In addition to that, the section also bears an interesting record of calcareous nannofossils and clear paleomagnetic signals. Such a combination of stratigraphic tools appears to be very favourable to proposing the section as the reference for the Tithonian basal boundary within the Mediterranean Province in Western Tethys, if not even as the G.S.S.P. of this Stage.

The section of Contrada Fornazzo

The outcrops of the Fornazzo sector (Montagna di Giannuzzo in Gemmellaro 1878; Costa Larga in Floridia 1931, and Christ 1960) are located on the northwestern slope of Monte Inici, some 3 km south-westwards of Castellammare del Golfo (Fig. 1). The best exposures are in the old "marble" quarry of Contrada Fornazzo and along the service road leading to the quarry (Fig. 2). The Fornazzo outcrops were visited during one of the field trips of the 6th International Symposium on the Jurassic System in September 2002 (Martire & Pavia 2002).

In the geodynamic setting, Monte Inici represents a structural unit within the Maghrebian Chain (Catalano et al. 2002, and ref. therein). Its Jurassic succession is typical of the Trapanese Domain, a carbonate platform which subsided in the middle Early Jurassic first as a pelagic swell, and eventually into basin conditions in the Cretaceous.

In the Monte Inici morphotectonic unit the whole Jurassic succession crops out, and is composed of two classic lithostratigraphic complexes: (1) the Inici Fm., hundreds of metres thick, represents the Upper Triassic to Lower Jurassic epicontinental carbonate platform; (2) the Rosso Ammonitico Fm., some tens of metres thick, reflects carbonate sedimentation in a pelagic platform condition that is biochronologically proved to have been active from Toarcian to Middle Tithonian, at least (Di Stefano 2002). At the top, the red-nodular limestones pass to the thick Lattimusa Fm., mainly Early Cretaceous in age. In the western sectors of Monte Inici the Rosso Ammonitico Fm. can be subdivided into three members (Fig. 3): massive-calcareous in the lower part (Rosso Ammonitico Inferiore: RAI), marly-siliceous with radiolarite-like beds in the middle (Rosso Ammonitico Medio: RAM), nodular-calcareous in the upper part (Rosso Ammonitico Superiore: RAS).

The whole RAS succession is exposed in a natural outcrop along the quarry service road, where the massive red-nodular limestones of RAI had been exploited up to the sixties (Wendt 1964). In particular, the Kimmeridgian to Tithonian beds are exposed at the bend of the road (700 m altitude) corresponding to the morphostructural crest that descends from Pizzo delle Niviere to Contrada Fraginesi.

Lithostratigraphy at the Kimmeridgian/Tithonian boundary

The succession exposed in the upper part of the composite section of Contrada Fornazzo consists of several levels which were described in detail by Martire & Pavia (2002). Here we restrict the attention to the beds present at the very base of the RAS; their numbering, from 93 upwards, continues from numbers assigned to the other two members of the Rosso Ammonitico. In particular, Beds 93 to 132 were investigated in detail with a multidisciplinary approach; they can be grouped into three levels which are here described from bottom to top (Figs. 4, 5).

Level 1 (Beds 93-105: 3.45 m)

Nodular limestones with cherts in small nodules and ribbons. This interval is easily weathered because of the thin bedding, well developed nodular structure and thick marly interbeds. Two clay beds, 2-3 cm thick, are continuous and show the typical plasticity of bentonites; X-rays diffractometry indicates a smectite composition (Montagnino, pers. comm.), so their primary origin as ash layers is possible.

Level 2 (Beds 106-123: 5.85 m)

Compared to the underlying interval, this one bears no cherts and is more massive and less easily weathered, forming a small cliff recognizable also in the distance. Beds have different thickness and lithofacies. The most massive ones consist of incipiently nodular to homogenous coarse grainstones with abundant *Saccocoma* debris and subordinate small peloids. Grains are reorganized in a fitted, poorly cemented fabric along dissolution seams. These *Saccocoma*-grainstones grade unevenly to finer grained grainstones with scarce *Saccocoma* and abundant spherical micritic particles interpreted as radiolarian molds. No true nodules can be recognized, although local merging of wavy dissolution seams can produce a nodular effect. These beds may be referred to as the massive bioclastic facies.

Other beds, usually thinner, show the typical knobby aspect of nodular limestones, where nodules and matrix are differently weathered. They can be referred to as the intraclastic nodular facies of Cecca et al. (2001). Two kinds of nodules may be recognized.

Type 1: nodules show gradational boundaries and usually a flattened ellipsoidal shape. They consist of packstones to grainstones with predominant *Saccocoma* and subordinate peloids and *Globochaetae*. The matrix is typically red, crossed by bundles of dissolution seams, and is composed of *Saccocoma* packstones with a fitted fabric. These nodules fit the definition of early diagenetic nodules of Clari et al. (1984).

Type 2: nodules have more irregular, often spheroid shape and sharp boundaries with the matrix. They mainly consist of fine grain-

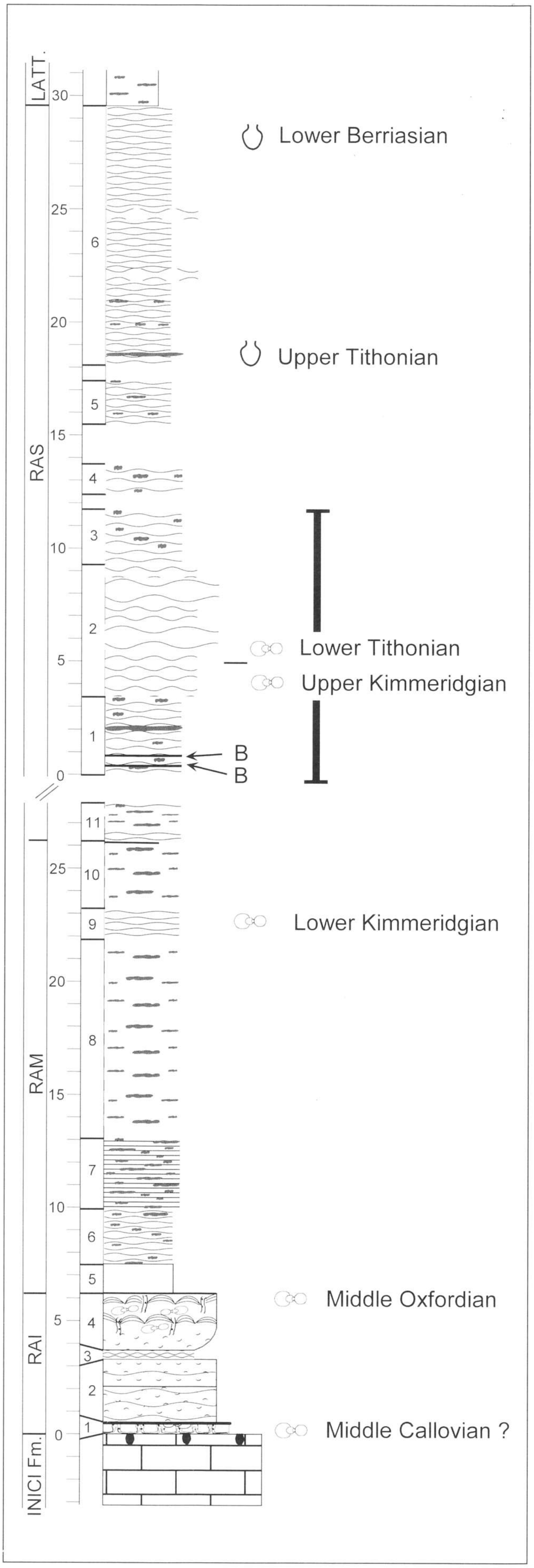

Fig. 3 - Lithostratigraphic log of the Rosso Ammonitico composite section cropping out in the Contrada Fornazzo area (after Martire et al. 2002). The vertical bar indicates the interval described in this work. Symbols: B = bentonite layers; LATT = Lattimusa Formation; RAI = Rosso Ammonitico Inferiore; RAM = Rosso Ammonitico Medio; RAS = Rosso Ammonitico Superiore. Ammonite and calpionellid icons refer to assemblages studied for biostratigraphic purpose.

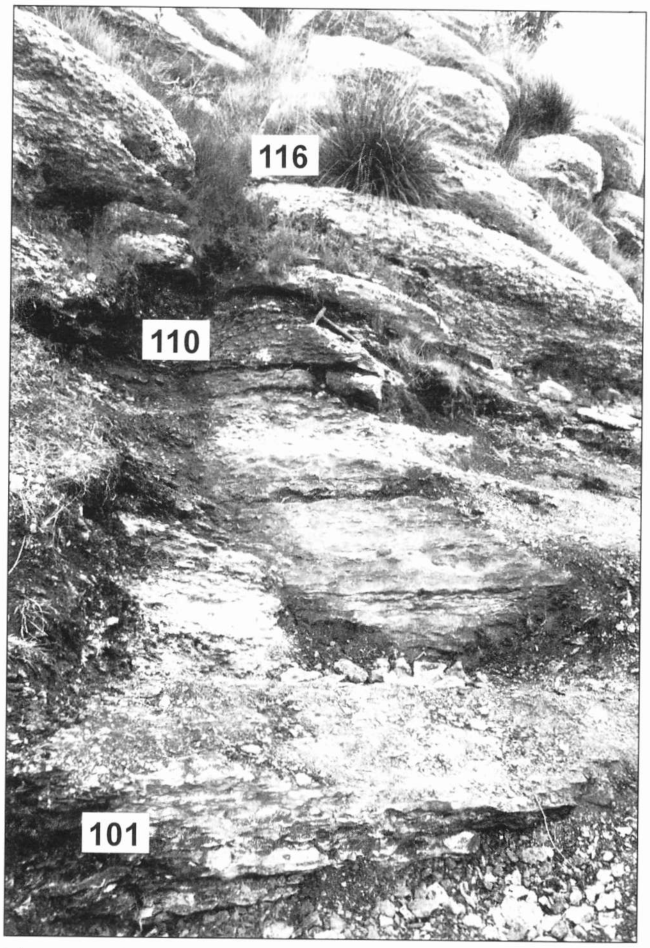

Fig. 4 - Close-up view of the beds at the passage Upper Kimmeridgian (101-109) to Tithonian (110-122). Natural outcrop enlarged for palaeontological sampling. Hammer on the basal part of Bed 110 for scale.

stones with abundant micritic radiolarian molds and subordinate *Saccocoma*, peloids and *Globochaetae*. Some of these sharp-edged nodules show a slightly darker rim that corresponds to the mineralized filling of microborings; they are pre-depositional nodules (sensu Clari et al. 1984), i.e. they are intraclasts exposed on the sea floor, colonized by endolithic organisms and coated by authigenic minerals (Fe-Mn oxides). Interpretation of Type-2 nodules that bear no borings and staining is less obvious; they could be intraclasts produced by current erosion of semi-lithified sediments, or by burrowing and mixing of texturally contrasting uncemented sediments.

Level 3 (Beds 124-132: 2.45 m)

Alternations of massive and nodular limestones as described in the underlying interval, but with chert nodules concentrated in some beds. After a 0.70 cm thick covered tract, a more or less continuous exposure of alternations of nodular and flaser-nodular limestones with sparse pink chert nodules occur. The transition to the white micritic limestones of the Cretaceous Lattimusa Fm. takes place about 29 metres above the base of the RAS.

On the basis of the description above, it appears that the lower part of the RAS (at least Beds 106 to 132) consist of grain-supported limestones where the prevailing grains are *Saccocoma* fragments. This may be interpreted as the result of a winnowing effect by bottom currents. The different facies (massive bioclastic to flaser nodular marly limestones) are consequently to be related mainly to post-depositional processes such as early cementation and pressure dissolution. Some sediments were intensely cemented just below the sediment-water interface and this inhibited the effects of compaction (Clari & Martire 1996); massive beds were produced in this way. Where, on the contrary, early cementation was less intense and affected only limited portions of beds (nodules), a great part of the bed was still unlithified at burial depths where pressure dissolution processes started. Fitted fabrics and dissolution seams were hence generated giving rise to clay-rich, reddish limestones more easily weathered in outcrop, enhancing nodularity. Early cementation is induced by very large amounts of sea water flowing through the pores and precipitating calcium carbonate (e.g. Tucker & Wright 1990). Cementation has been shown to be effective also in pelagic sediments at of hundred or a thousand metres, provided that currents are strong enough to "pump" sea water into the pores (e.g. Mullins et al. 1980; Allouc 1990). The higher the permeability of the sediment and the speed of currents, and the longer the process, the more effective will be cementation. The tops of pervasively cemented beds are likely to correspond to hiatuses during which currents were active and triggered cementation of the underlying sediments. The regular interbedding of nodular and massive beds, clearly shown by the lower part of the RAS, could be interpreted in this light as the result of a cyclicity in hydrodynamic levels where the nodular beds represent more continuous sedimentation with only selective lithification while massive beds, such as 106, 109 and 111, indicate high energy and high sedimentation rate depositional events followed by non-depositional episodes resulting in pervasive cementation.

Ammonite biostratigraphy

Fossil assemblages

Cephalopod remains represent the sole macrofossils of the lower part of the RAS. Ammonites are the most common fossils, whereas belemnites occasionally reach 5%. A detailed sampling has been carried out in levels 1 and 2; it was concentrated in the interval between Beds 95 and 120 from which more than 700 ammonites were gathered bed-by-bed. Though the state of preservation is often poor, 58 species have been identified of which the most significant are listed in Fig. 5. Ammonite assemblages are dominated by Mediterranean taxa; among phylloceratids *Sowerbyceras* gr. *loryi* totals more than 50% of the assemblages. Complementary taxa are aspidoceratids, haploceratids and perisphinctids; the common genus *Hybonoticeras* merits a precise biostratigraphic analysis.

Ammonites are generally preserved as calcareous internal moulds without shell remains. They are represented by phragmocones usually with partial body chamber or by fragments of the last whorl reflecting biostratinomic breakage of the shell before burial. The size of fossils is variable; some fragments indicate shell size up to 200 mm. Horizontal positions are dominant, except for small-sized fossils that could have been reoriented within the substrate by bioturbation or later by the combined effect of pressure solution and compaction. Plastic deformation observed in some specimens depends on differential compaction of the internal infilling of the phragmocone versus body chamber. As to the state of preservation, (1) most internal moulds are covered by argillaceous coatings deriving from pressure-dissolution at the boundary

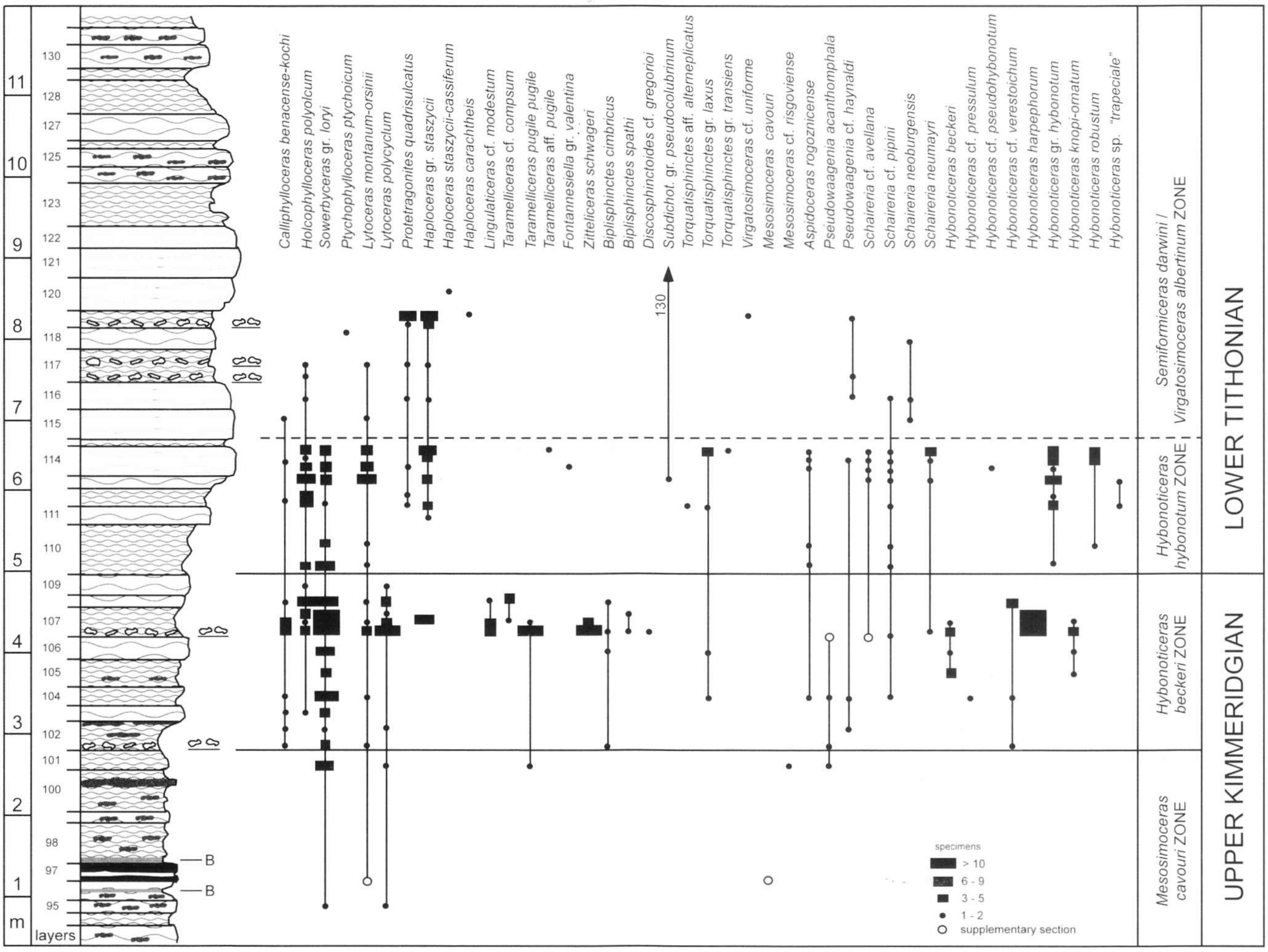

Fig. 5 - Ammonite biostratigraphic log of the basal upper member of the Rosso Ammonitico Fm., at the Kimmeridgian/Tithonian boundary.

between the concretionary mould and the encasing sediment, (2) the texture of the calcareous infilling is the same that observed in surrounding nodules without any adoral discontinuity, (3) internal moulds do not show any mineralized crusts, truncation facets, erosion surfaces or biogenic encrustations. Such characteristics indicate no removal of these fossils from the embedding sediment; they can be defined as resedimented elements "coeval" to the embedding calcareous matrix (Fernández-López 1991; Pavia & Martire 1997).

The only ammonites in which removal from the original sediment has to be admitted, are the molds present as reworked "pebbles" at the base of Beds 102, 107, 117, and upper 119. Nevertheless, in these cases also, traces of bioerosion, bioencrustation or Fe-Mn oxide coatings are missing; the only evidence of taphonomical reworking is the broken internal moulds of single specimens with slight displacement of the separated parts ("uncoupling moulds"). These fossils can thus be regarded as the result of winnowing of early lithified shell infillings, for a presumably short time and with no appreciable displacement on the sea bottom after the first burial episode.

Biozonation

Ammonite biostratigraphy was correlated with the Standard Ammonite Bio-Chronozones proposed for the Mediterranean Province by Cariou & Hantzpergue (1997). Further results and/or reinterpretations by Sarti (1993), Villaseñor et al. (1994, 2000), Schweigert et al. (1996), Caracuel et al. (1998), Caracuel & Olóriz (1999), Olóriz & Villaseñor (1999), Olóriz et al. (1999), as well as unpublished data from the Betic Cordillera by Olóriz & Serna-Barquero (in progress), have also been taken into account. In upper Kimmeridgian and lower Tithonian four biozones have been recognized (Fig. 5).

Mesosimoceras cavouri Zone - This biozone is proved in Beds 95 to 101 based on the joint occurrence of *Mesosimoceras risgoviensis* and *Pseudowaagenia acanthomphala* from layers just below the first occurrence (FO) of the genus *Hybonoticeras*. The index-species *M. cavouri* is known only from a single specimen collected from a correlated section studied in the area, in a layer corresponding to Bed 96.

Hybonoticeras beckeri Zone - This ranges from Bed 102 to Bed 108. Although we are aware there is no gen-

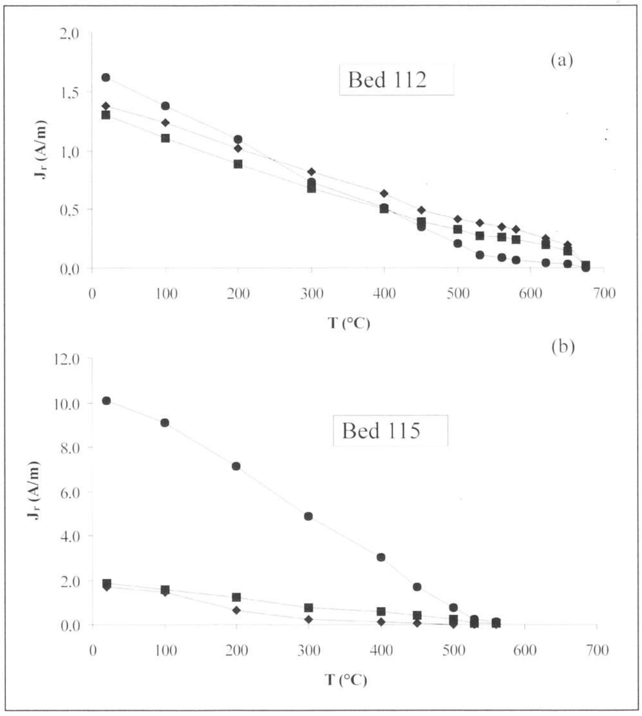

Fig. 6 - Thermal demagnetization of the IRM components. Symbols: dot = low-; square = intermediate-; diamond = high-coercivity component.

chapter. A sort of cyclicity in the lower part of the RAS may be recognized with two superposed orders of cycles: a higher one, developed from bed 101 to bed 116, defined by the upward increasing thickness of massive beds, and a lower cyclicity order, simply defined by alternation of nodular and massive beds. Textural features and degree of cementation allow interpretation of any of the lower order, elemental, cycles, with nodular facies at the base and massive facies at the top, as the result of an upward-increase in hydrodynamic energy ending with a hiatus. In the light of this cyclostratigraphic organisation, it can be concluded that bed 109 represents the upper part of an elemental cycle starting with bed 107 and thus is to be referred to *H. beckeri* Zone.

Semiformiceras darwini/Virgatosimoceras albertinum Zone - Though the index-species are missing, the record of a specimen of *Virgatosimoceras* cf. *uniforme*, coupled with ammonite assemblages lacking in *Hybonoticeras* and largely dominated by haploceratids excluding *Haploceras verruciferum*, have been used as evidence for the *S. darwini/V. albertinum* Zone. The biozone has been interpreted to range from Bed 115 to Bed 120; the boundary with the underlying *H. hybonotum* Zone could not be accurately placed.

eral consensus on this subject, just as in the Betic Cordillera (Olóriz & Serna-Barquero, in progress) here the *H. beckeri* Zone can be subdivided into three parts: lower part (Beds 102-104) characterized by the combined record of *H.* cf. *pressulum* and *H.* cf. *verestoicum*; middle part (Beds 105-106) bounded by the FO of *H. beckeri* below and the FO of *H. harpephorum* and related forms above; upper part (Beds 107-108) embracing the range of the forms related to *H. harpephorum*. The upper boundary of the biozone cannot be accurately interpreted due to scarce ammonite record in Bed 109.

Hybonoticeras hybonotum Zone - In the lowermost Tithonian, from Bed 110 to Bed 114, this biozone is established by the range of the index-species, *H. hybonotum*, and related forms such as *H. robustum* and *Hybonoticeras* sp. "*trapeciale*"; *Haploceras staszycii* is a significant taxon and perisphinctids and haploceratids also give useful information. The upper part of the biozone (Bed 114) is characterized by the onset of the genus *Fontannesiella* as also found in the Betic Cordillera (Olóriz 1978). The lower boundary of the biozone, and thus of the Tithonian Stage, seems to be difficult to locate, due to absence of significant ammonites in Bed 109. Nevertheless, though documented by a single specimen of the index-species, the base of Bed 110 is certainly referable to the *H. hybonotum* Zone. Bed 109 instead can be confidently referred to the top of the *H. beckeri* Zone on the basis of the stratigraphical and sedimentological considerations previously discussed at the end of the lithostratigraphy

Magnetostratigraphy

Sixty-five samples were cored from Beds 100 to 122 across the Kimmeridgian/Tithonian boundary in the Fornazzo section. Magnetic mineralogy was investigated by isothermal remanence (IRM) acquisition curve and thermal demagnetization of IRM components according to Lowrie (1990). In Beds 115 to 122, saturation is approached at field value of 0.2 T and reached at 0.4 T. Most of the IRM is carried by a low-coercivity component, which is completely erased after heating at 530-560 °C (Fig. 6). The intensity of the high- and intermediate-coercivity components is low and they are erased in the same temperature range. Magnetite is thus the only ferromagnetic mineral. From Bed 114 downwards, saturation is not yet reached at field value of 1.6 T; the intensity of the intermediate- and high-coercivity components is high and they persist up to 650 °C. In these beds magnetite occurs together with variable amounts of hematite.

Both thermal and alternating field demagnetization techniques were used to isolate magnetization components. Ten to twelve steps were done either from 120° to 440-520°C or from 4 to 100 mT. A low-temperature, soft magnetization component is often present and erased after the first steps. At higher temperatures or fields, different magnetization components are isolated and three groups of specimens can be recognized on the grounds of their characteristics.

- Group 1 (Fig. 7a). These specimens have two reverse polarity magnetization components whose direc-

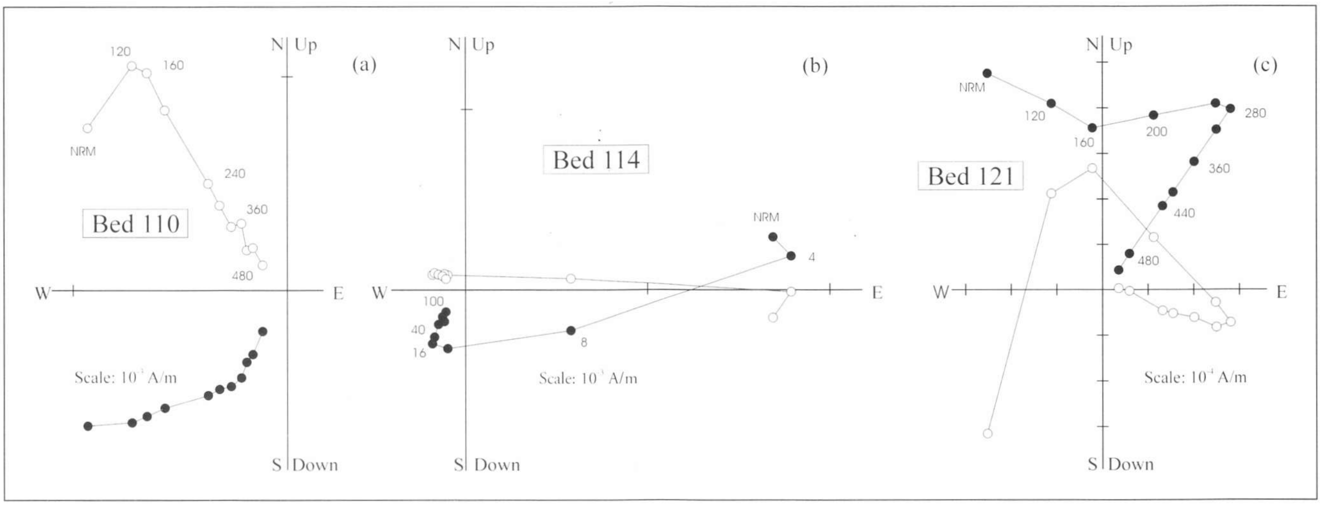

Fig. 7 - Zijderveld diagrams for thermal and alternating field demagnetization. Symbols: full dot = declination; open dot = apparent inclination; figures = temperature (°C) or peak field (mT) value.

tions slightly differ in declination. The first is defined between 160° and 320° to 360°C, the second at higher temperatures.

- Group 2 (Fig. 7b). These specimens have a normal polarity, soft magnetization component, fully erased at peak field of 16 to 20 mT. At higher values, a reverse polarity component is isolated, stable up to 100 mT.

- Group 3 (Fig. 7c). These specimens have intermediate and high temperature components. The first is defined in the range from 160° to 280-320°C and characterized by reverse polarity. The second has normal polarity, appears above 320°C and is stable up to 480±40°C.

These results show that the magnetization history at the Fornazzo section is complex and it is not straightforward to assess which component corresponds to the primary magnetization acquired when the rock formed. Moreover, the contributions of magnetite and hematite cannot be clearly separated, because the coercivity or blocking temperature spectra of the two components of the natural remnant magnetization often partially overlap. We regard the characteristic component (ChRM) isolated at high temperature or peak field values as the primary magnetization, both because it is the most stable and its direction is consistent with those found at other Ammonitico Rosso sites at Mount Inici and in the Trapanese Domain (Channel et al. 1990, and ref. therein). The ChRM directions are shown in Fig. 8: the mean directions of the normal and reverse polarity group are respectively D = 25.4, I = 21.5 (n = 29, α_{95} = 4.3°) and D = 211.7, I = -14.3 (n = 19, α_{95} = 4.9°). Other 9 specimens yielded a definite polarity even if no reliable direction could be calculated.

Comparison between paleomagnetic and palaeontological results (Fig. 9) shows that in the *H. beckeri* and *H. hybonotum* Zones the magnetic polarity is mainly reverse and alternates with three normal polarity intervals. The oldest interval is recorded in Beds 108 to lower 110, at the boundary between the two zones, the second in Bed 111 and the youngest corresponds to a single specimen in the lower part of Bed 115. From the upper part of Bed 115 upwards, the *S. darwini/V. albertinum* Zone is characterized by normal polarity. The polarity succession at the Kimmeridgian/Tithonian boundary at Fornazzo agrees with those from the Subbetic Zone of the Betic Cordillera of southern Spain (Ogg et al. 1984). The main new result is a greater detail at the boundary between the *H. beckeri* and *H. hybonotum* Zones, which is shown to occur within a normal polarity interval.

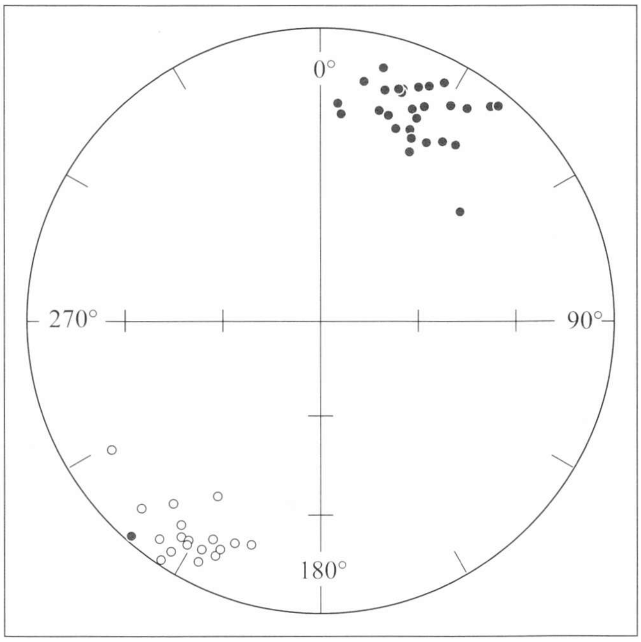

Fig. 8 - Equal-area projection of tilt-corrected magnetization directions. Full/open symbols = positive/negative inclination.

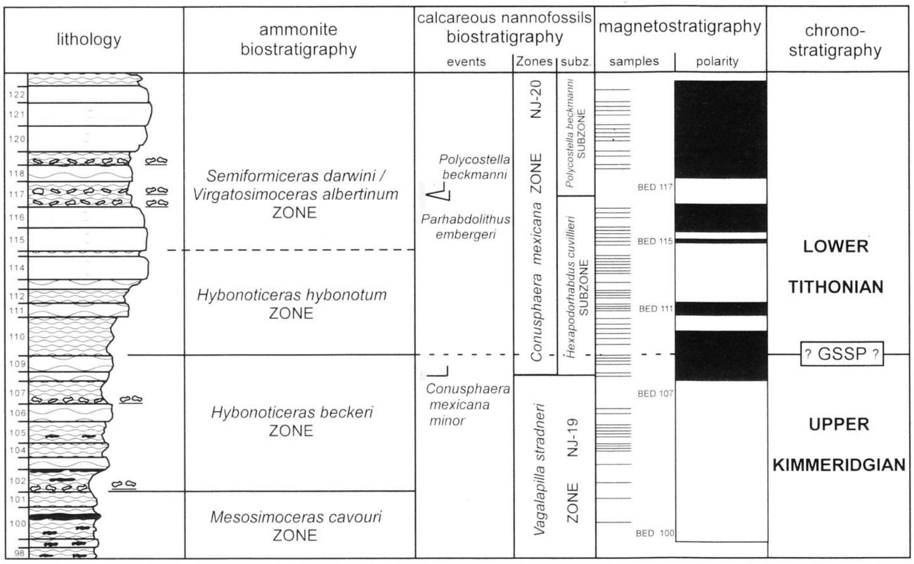

Fig. 9 - Multidisciplinary stratigraphic scheme with correlated position of the lower boundary of the Tithonian Stage. In the paleomagnetic column: left, stratigraphical position of individual specimens; right, black/white = normal/reverse polarity; crossed: not sampled.

Calcareous nannofossil record

Calcareous nannofossil assemblages from 28 samples spanning the Kimmeridgian/Tithonian boundary have been studied (Beds 93-119). The assemblages are mainly dominated by *Watznaueria barnesae*, *W. manivitae*, *W. britannica*, *Cyclagelosphaera margerelii*, *Cy. wiedmannii*, *Cy. deflandrei*, *Diazomatolithus lehmanii*. Despite overall poor preservation of the material studied, and generally poor biostratigraphic resolution for this time interval (de Kaenel et al. 1996; Bown & Cooper 1998), three calcareous nannofossil events have been recorded: the FO of *Conusphaera mexicana minor* in Bed 108 and the FOs of *Parhabdolithus embergeri* and of *Polycostella bekmannii* in Bed 117. Two CN Zones (*Vagalapilla stradneri* and *Conusphaera mexicana* Zones, Bralower et al. 1989) and two subzones (*Hexapodorhabdus cuvillieri* and *P. beckmannii* subzones) are thus identified. It is noteworthy that for the first time these events are directly correlated to the ammonite biozonation, the FO of *C. mexicana minor* occurring in the Upper Kimmeridgian *H. beckeri* Zone and the FO of *Parhabdolithus embergeri* and *P. beckmannii* occurring in the Lower Tithonian *S. darwini/V. albertinum* Zone. The FO of *C. mexicana minor* (recorded in Bed 108) and the FO of *P. beckmannii* (recorded in Bed 117) are both correlative with a normal polarity interval, in agreement with the findings of Bralower et al. (1989) in the Atlantic Ocean and in the Subbetic Zone of the Betic Cordillera of southern Spain. The stratigraphic position of the FO of *P. embergeri* is younger than previously recorded (Bralower et al. 1989), since this species usually appears before the FO of *C. mexicana minor*. The studied samples show a high diagenetic overprint, dominated by dissolution and/or overgrowth; this could account for the obliteration of the main diagnostic features of this species (blocky rim and spines) and suggests that this datum should be regarded as a preservation one. In contrast, the structural features of *C. mexicana minor* and *P. beckmannii* are probably less affected by diagenesis and their diagnostic features are easily detected even in poorly preserved material.

Integrated stratigraphy discussion

Correlation with the marine anomaly M-sequence is not direct at Fornazzo, since the studied section corresponds to a relatively short time span. The correlation of palaeontological findings with magnetic polarities does agree with the literature data. The FOs of *C. mexicana minor* and *P. beckmannii* occur in normal polarity intervals (Bralower et al. 1989) and the *Virgatosimoceras albertinum* and *Hybonoticeras beckeri* Zones respectively correspond to normal and reverse polarity intervals, as observed in the Carcabuey section (Ogg et al. 1984). We therefore advance the hypothesis that the lower part of the Fornazzo section (*H. beckeri* Zone) falls in the M23r Chron and the upper part (*S. darwini/V. albertinum* Zone) in the M22n Chron. The Kimmeridgian/Tithonian boundary, identified as the boundary between the *H. beckeri* and *H. hybonotum* zones, accordingly falls in the M23n Chron.

Proposal for the Tithonian basal boundary

The present paper is a partial summary of the work done on the whole section of Contrada Fornazzo at Monte Inici by Bovero (2001). After his master thesis, a further large amount of ammonites was collected, and research on the calcareous nannofossils and the paleomagnetic record was completed. Nevertheless, field research is in progress both on the Fornazzo outcrops (e.g. for biostratigraphic allocation of Bed 109) and on other sections around Monte Inici, like Balata di Baida (Christ

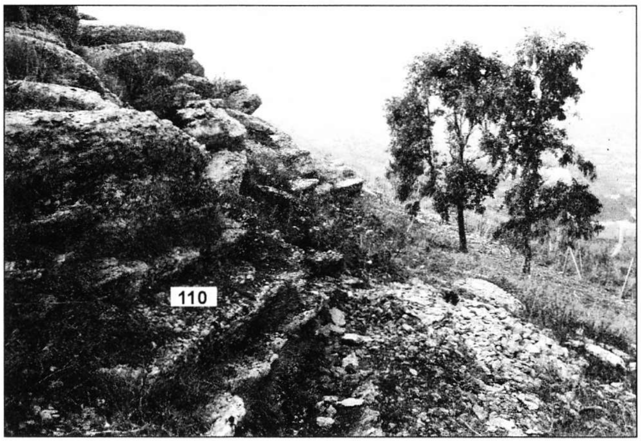

Fig. 10 - Nodular limestones of the basal upper Rosso Ammonitico Fm.; section below the Fornazzo road. The Kimmeridgian-Tithonian boundary is located at the base of Bed 110. Hammer for scale to the right of label of Bed 110.

1960) so that the lower boundary of the Tithonian Stage of Western Sicily could be described more accurately in the near future.

However, the data obtained appear to be sufficient to justify proposing the Contrada Fornazzo section as the possible boundary stratotype (G.S.S.P.) of the Tithonian Stage (Fig. 9). It meets the requirements repeatedly emphasized by the International Subcommission on the Jurassic Stratigraphy according to the guidelines summarized by Remane et al. (1996).

Summary of proposal for the Tithonian Stage G.S.S.P.
Name of the boundary: base of Tithonian.
Rank of the boundary: (chronostratigraphy) Stage; (geochronology) Age.
Geographical location: Europe, Southern Italy, Western Sicily, some 3 km south-west of Castellammare del Golfo, Trapani Province. Topographic map: Sheet 256, Alcamo (1:50.000), UTM coordinates UC10730955.
Accessibility: The outcrop, at 700 m altitude, on the north-western slope of Monte Inici, is easily accessible by the service road leading to the old "marble" quarry of Contrada Fornazzo.
Position of the boundary stratotype: Meter 30.5 from the base of the Rosso Ammonitico Fm. measured in the succession of Contrada Fornazzo. The boundary is fixed at the base of Bed 110 (Fig. 10), some 5 meters above the beginning of the upper R. A., in alternating calcareous and marly nodular facies located at the bend corresponding to the morphostructural crest that goes down from Pizzo delle Niviere to Contrada Fraginesi.
Ammonite biostratigraphy: The boundary is defined by the first occurrence of specimens of *Hybonoticeras* gr. *hybonotum*, which classically marks the base of the Tithonian; significant allied taxa are *Hybonoticeras robustum* and *Haploceras staszycii*.
Multidisciplinary correlation: The first occurrence of the assemblage with *Hybonoticeras* gr. *hybonotum* is easily correlatable through the Tethyan Realm. Further correlation tools derive from calcareous nannofossil biostratigraphy and magnetostratigraphy, according to which the proposed G.S.S.P. lies respectively a little above the lower boundary of the *Conusphaera mexicana* Zone, and within the M23n Chron.
Geoconservation: The outcrop FZ4 is located in the Monte Inici protected area, where no development is allowed. The site is very attractive for the spectacular view on the bay of Castellammare del Golfo.

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REFERENCES

Allouc J. (1990) - Quaternary crusts of the Mediterranean Sea: a tentative explanation for their genesis. *Marine Geology*, 94: 205-238, Amsterdam.

Bovero A. (2001) - Analisi paleontologica e stratigrafica del Rosso Ammonitico (Giurassico medio-superiore) nella sezione Fornazzo di Monte Inici, Sicilia occidentale. Master Thesis, Univ. Torino, unpublished, Torino.

Bown P.R. & Cooper M.K.E. (1998) - Jurassic. In Bown P.R. (ed.), Calcareous Nannofossil Biostratigraphy. Chapman & Hall: 34-85, Cambridge.

Bralower T.J., Monechi S. & Thierstein H.R. (1989) - Calcareous nannofossil zonation of the Jurassic-Cretaceous boundary interval and correlation with the geomagnetic polarity time scale. *Marine Micropaleont.*, 14: 153-235, Amsterdam.

Caracuel J.E & Olóriz F. (1999) - Recent data on the Kimmeridgian-Tithonian boundary in the Sierra Norte of Mallorca (Spain), with notes on the genus *Hybonoticeras* Breistroffer. *Geobios*, 32: 575-591, Lyon.

Caracuel J. E., Olóriz F. & Sarti C. (1998) - Updated biostratigraphy of the Kimmeridgian and Lower Tithonian at Lavarone (Trento Plateau, Italy). Correlation for epioceanic western Tethys. *Geologica et Palaeontologica*, 32 : 235-251, Marburg.

Cariou E. & Hantzpergue P., eds. (1997) - Biostratigraphie du Jurassique ouest-européen et méditerranéen: zonations parallèles et distribution des invertébrés et microfossiles. *Bull. Centre Rech. Elf Explor. Prod. Mém.*, 17: 440 pp., Pau.

Catalano R., Lo Cicero G. & Sulli A. (2002) - Geology of Sicily: an introduction. In: Santantonio M. (ed.) - General

Field Guide Book, 6th International Symposium on the Jurassic System: 5-20, Geda, Torino.

Cecca F., Savary B., Bartolini A., Remane J. & Cordey F. (2001) - The Middle Jurassic - Lower Cretaceous succession of Monte Inici (Trapanese domain, Western Sicily): sedimentology, biostratigraphy and isotope stratigraphy. *Bull. Soc. géol. France*, 172: 647-659, Paris.

Channel J.E.T., Oldow J.S., Catalano R. & D'Argenio B. (1990) - Palaeomagnetically determined rotations in the western Sicilian fold and thrust belt. *Tectonics*, 9: 641-660, Washington.

Christ H.A. (1960) - Beiträge zur Stratigraphie and Paläontologie des Malm von Westsizilien. *Schweiz. Paläont. Abh.*, 77: 141 pp., Basel.

Clari P.A., Marini P., Pastorini M. & Pavia G. (1984) - Il Rosso Ammonitico Inferiore (Baiociano-Calloviano) nei Monti Lessini settentrionali. *Riv. Ital. Paleont. Strat.*, 90: 15-86, Milano.

Clari P.A. & Martire L. (1996) - Interplay of sedimentation, mechanical and chemical compaction in nodular limestones of the Rosso Ammonitico Veronese (Middle-Upper Jurassic, NE Italy). *Journ. Sed. Petrol.*, 66: 447-458, Tulsa.

Di Stefano P. (2002) - An outline of the Jurassic stratigraphy and paleogeography of Western Sicily. In: Santantonio M. (ed.) - General Field Guide Book, 6th International Symposium on the Jurassic System: 21-27, Geda, Torino.

Fernández-López S. (1991) - Taphonomic concepts for a theoretical biochronology. *Rev. Espan. Paleont.*, 6: 37-49, Oviedo.

Floridia G.B. (1931) - Osservazioni geologiche sul Monte Inici. *Boll. Soc. Geol. Ital.*, 50: 37-49, Roma.

Gemmellaro G.G. (1878) - Sopra i cefalopodi della zona inferiore degli strati con *Aspidoceras acanthicum* di Sicilia. *Atti Accad. Gioenia Sc. Natur.*, 12: 153-250, Catania.

Kaenel de E., Bergen J.A. & von Salis K. (1996) - Jurassic calcareous nannofossil biostratigraphy of Western Europe. Compilation of recent studies and calibration of bioevents. *Bull. Soc. géol. France*, 1996: 15-28, Paris.

Lowrie W. (1990) - Identification of ferromagnetic minerals in a rock by coercivity and unblocking properties. *Geophys. Res. Lett.*, 17: 159-162, Washington.

Martire L. & Pavia G. (2002) - Post-Symposium Field Trip B1: the Trapanese Domain. In: Santantonio M. (ed.) - General Field Guide Book, 6th International Symposium on the Jurassic System: 123-166, Geda, Torino.

Mullins H.T., Neumann A.C., Wilber R.J. & Boardman M.R. (1980) - Nodular carbonate sediment on Bahamian slopes: possible precursors to nodular limestones. *J. Sed. Petr.*, 50: 117-131, Tulsa.

Ogg J. G., Steiner M. B., Olóriz F. & Tavera J. M. (1984) - Jurassic magnetostratigraphy, 1. Kimmeridgian-Tithonian of Sierra Gorda and Carcabuey, southern Spain. *Earth Planet. Sci. Lett.*, 71: 147-162, Amsterdam.

Olóriz F. (1978) - Kimmeridgiense-Tithonico inferior en el sector central de la Zona Subbética. Paleontología. Bioestratigrafía. PhD thesis, Univ. Granada, 184 (1976): 758 pp., Granada.

Olóriz F., Molina-Morales, J.M. & Serna-Barquero, A. (1999) - Revisión estratigráfica del intervalo Kimmeridgiense medio - Tithonico basal en el perfil G_{10} del sector de Venta Quesada (Sierra Gorda, provincia de Granada). *Geogaceta*, 26: 71-74, Madrid.

Olóriz F. & Schweigert G. (2001) - Tithonian Working Group. In: Morton N. & Bown P. (eds.): *Intern. Subcomm. Jurassic Strat., Newsletter*, 28: 10-11, London.

Olóriz F. & Villaseñor A.B. (1999) - New microconchiate *Hybonoticeras* from Mexico. *Geobios*, 32: 561-573, Lyon.

Pavia G. & Cresta S., coord. (2002) - Revision of Jurassic ammonites of the Gemmellaro collections. *Quad. Museo G.G. Gemmellaro*, 6: 408 pp., Palermo.

Pavia G. & Martire L. (1997) - The importance of taphonomic studies on biochronology: examples from the European Middle Jurassic. *Cuad. Geol. Iberica*, 23: 153-181, Madrid.

Remane J., Basset M.G., Cowie J.W., Gohrbandt K.H., Lane H.R., Michelsen O. & Naiwen W. (1996) - Revised guidelines for establishment of global chronostratigraphic standards by the International Commission on Stratigraphy (ICS). *Episodes*, 19, 3: 77-81, Beijng.

Sarti C. (1993) - Il Kimmeridgiano delle Prealpi veneto-trentine: fauna e biostratigrafia. *Museo Civ. St. Natur., Mem.* 5: 154 pp., Verona.

Schweigert G. (2000) - New biostratigraphic data from the Kimmeridgian/Tithonian boundary beds of SW Germany. GeoResearch Forum, Trans. Tech. Publ. Switzerland, 6: 195-202. Uetikon-Zurich.

Schweigert G., Krishna J., Pandey B. & Pathak D.B. (1996) - A new approach to the correlation of the Upper Kimmeridgian Beckeri Zone across the Tethyan Sea. *N. Jb. Geol. Paläont. Abh.*, 202: 345-373, Stuttgart.

Tucker M.E. & Wright V.P. (1990) - Carbonate sedimentology. Blackwell, 482 pp., Oxford.

Villaseñor A.B., Olóriz F. & González-Arreola C. (2000) - Recent advances in Upper Jurassic (Kimmeridgian-Tithonian) ammonite biostratigraphy from north-central Mexico based on new collected ammonite assemblages. GeoResearch Forum, Trans. Tech. Publ. Switzerland, 6: 249-261, Uetikon-Zürich.

Villaseñor A.B., Olóriz F., Lara. L, González-Arreola C. & De La Mora A. (1994) - Homotaxy and the Kimmeridgian/Tithonian boundary in north-central Mexico. 4th International Congress on Jurassic Geology and Stratigraphy, Abstracts: 46, Mendoza.

Wendt J. (1964) - Stratigraphisch-paläontologische Untersuchungen im Dogger Westsiziliens. *Boll. Soc. Paleont. Ital.*, 2 (1963): 57-145, Modena.