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Gamma-ray facies in marine paleoplacer deposits of the Punta Serpeddì Formation (Ordovician of SE Sardinia, Italy)

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ABSTRACT - This study analyses the variability of the spontaneous gamma-ray signal linked to heavy minerals in various sedimentary facies of shallow-marine placer deposits of the Punta Serpeddì Formation (Upper Ordovician of SE Sardinia, Italy). The heavy minerals assemblages are mainly made up of titaniferous minerals, zircon and monazite. They were deposited in siliciclastic storm-dominated platform environments. This work is based on sedimentological (facies, sequence stratigraphy) and petrographic analyses combined with outcrop gamma-ray logging. Two facies containing heavy minerals were identified: a shoreface facies dominated by titaniferous minerals and a proximal upper offshore facies composed of zircon, monazite and titaniferous minerals. Depending on relative values of the radioactive signals, it is possible to distinguish three gamma-ray facies: high, medium and low. The first two correspond to fine-grained facies of the proximal part of the upper offshore, whereas the low radioactivity values relate to coarse-grained shoreface facies.

Gamma ray signal can then be used in heavy mineral prospection, as well as in well-log analyses, to refine indirect facies interpretation and their stacking pattern.

Keywords: zircon; monazite; rutile; heavy minerals; sequence stratigraphy; Katian; Sandbian.

1. INTRODUCTION

Placers are accumulations of heavy minerals that form by gravity separation during aerodynamic or hydrodynamic processes (Slingerland, 1977; Komar and Wang, 1984; Hughes et al., 2000). In marine environments, placers are located from coastal settings (e.g. beaches, transgressive dunes) to the proximal upper offshore. Recent works showed that they form during episodes of sea-level rise (e.g. Dillenburg, 2004; Dabard et al., 2007; Pistis et al., 2008; Dabard et al., 2015) and result from superposition of several sea-level cycles of different frequencies (Pistis et al., 2016). This superposition leads to an increase of assemblage maturity and an enrichment in more resistant minerals (i.e. titaniferous minerals, tourmaline) and some radioactive species (i.e. zircon, monazite). Measurement of the natural radioactivity can then be a quick way to identify placer deposits, the total radioactivity being well correlated with the relative abundance of the heavy minerals (see in Pistis et al., 2016). However, the repartition of mineral species in placer facies results from complex interactions between the specific density of minerals and the grains size. This feature can lead to segregation between heavy mineral sand. The aim of the present study is to discuss the influence of the size sorting in placer deposits on the gamma ray signal through the study case of the Punta Serpeddì Formation (Fm) in the Variscan basement of Sardinia (Italy, Fig. 1A). This sedimentary succession, deposited during Upper Ordovician in a storm-dominated platform environment, is characterized by a segregation of the heavy mineral species along the depositional profile and consequently shows a variability of the gamma-ray signal in various sedimentary facies. The natural radioactivity was measured using a portable spectrometer RS-230 (Radiation Solutions, Inc., Canada). Measurements were taken with a counting time of 120 seconds and a stratigraphic interval varying between 10 and 50 cm. The counts per minute (cpm) in the selected energy windows were converted automatically into K (%), U (ppm) and Th (ppm) concentrations.

2. GEOLOGICAL SETTING

The lower Palaeozoic successions of Sardinia are mainly made up of terrigenous facies with some carbonate intercalations. In the Sarrabus area, the Upper Ordovician (Sandbian-Katian) Punta Serpeddì Fm (Loi et al., 1992) overlies the "Porfidi Grigi" volcanic rocks (Darriwilian to Sandbian: Oggiano et al., 2010; Pavanetto et al., 2012a, 2012b) and is overlain by the Tuvois Fm (Katian). The Punta Serpeddì Fm (60 to 140 m thick) consists of fine-

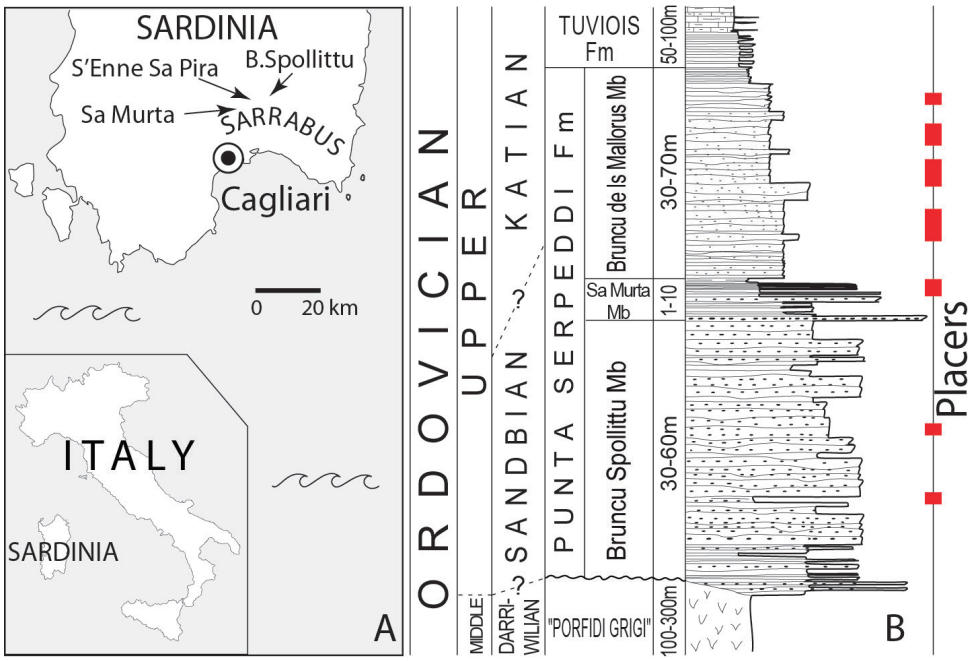

Fig. 1 - (A) Location and (B) lithologic column of the studied sections in the Sarrabus area.

to coarse-grained lithic wackes containing intercalations of conglomerates, microconglomerates and siltstones (Figs. 1B and 2G). It is subdivided into three members (Mb). The Bruncu Spollittu Mb is made up of coarse- to very coarse-grained sandstones, showing swaley cross-stratification and planar and cross lamination, and was deposited in shoreface environment (Pistis et al., 2016). The Sa Murta Mb is represented by siltstones and coarse-grained to conglomeratic sandstones; it was deposited from shoreface to the proximal part of the upper offshore (Pistis et al., 2016). The Bruncu de Is Mallorus Mb, made up of very fine- to fine-grained sandstones with hummocky cross stratification, was laid down in upper offshore environment.

Placers are abundant in the Sa Murta and Bruncu de Is Mallorus Mbs and are scattered in the Bruncu Spollittu Mb (Loi et al., 1992). The main source-areas of the heavy minerals supply are the underlying "Porfidi Grigi" volcanic rocks (Dabard et al., 1994; Loi and Dabard, 1997).

3. RESULTS AND DISCUSSION

Three stratigraphic sections have been studied, the Sa Murta, the Bruncu Spollittu and the S'Enné Sa Pira sections. Only the most complete one is illustrated in Fig. 2G (Pistis et al., 2016). The stacking pattern of the facies along the Punta Serpeddì Fm shows a major retrogradation phase (Loi et al., 1992) known as the "Caradocian transgression Auct". This deepening coincides with a significant rise in the total radioactivity with increases in the U and Th contents (Fig. 2G).

In the Punta Serpeddì Fm, grains of rutile, pseudo-rutile, anatase, zircon and monazite are the main constituents of the placer assemblages; they can account for more than 10% of the clastic components. The titaniferous minerals have a mean size of about 150 µm (maximum 300 µm), while the zircon and monazite are smaller (mean sizes of 100 µm and 60 µm, respectively). A mineralogical segregation of the heavy minerals, according to the host-sediment granulometry, is observed. In the coarse-grained shoreface facies, the population is mainly represented by titaniferous minerals and some zircons (Fig. 2 A,B,E and F) whereas in the finer-grained upper offshore facies, the zircon, monazite and small titaniferous minerals grains constitute the heavy minerals assemblages (Fig. 2 C,D,E and F). This mineralogical segregation explains the natural radioactivity variations between the sedimentary facies and allows us to distinguish three gamma-ray facies depending on relative values of the signals:

- A low radioactive facies: in the coarse-grained sandstones of the Bruncu Spollittu Mb (shoreface), the total radioactivity is relatively low (c.a. 5.000 cpm) in the placers. This feature can be explained by the assemblage composition dominated by titaniferous minerals while zircon and monazite grains are rare. Here, the major contribution of the natural radioactivity is given by the K contained in the K-feldspar and micas (see Fig. 2G in the interval from about 5 to 45 m).

- A medium radioactive facies: in the fine-grained sandstones of the Sa Murta and Bruncu de Is Mallorus members (lower shoreface and proximal part of the upper offshore), the radioactivity in the placers shows a moderate increase due to zircon and monazite, present in small amounts (see the intervals in Fig. 2G more or less at 60-65m, 75-80m and 95-105 m respectively).

- A high radioactive facies: in the fine-grained sandstones of the Bruncu de Is Mallorus Mb (upper offshore), the radioactivity reaches values up to 71.000 cpm with high U and Th contents (up to 80 ppm and 450 ppm, respectively) in the placers due to the abundance of zircon and monazite. These enriched levels (see the intervals in figure 2G more or less at 65-75 m, 80-95 m and 105-115 m respectively) are produced during phases of sea-level rise of very high

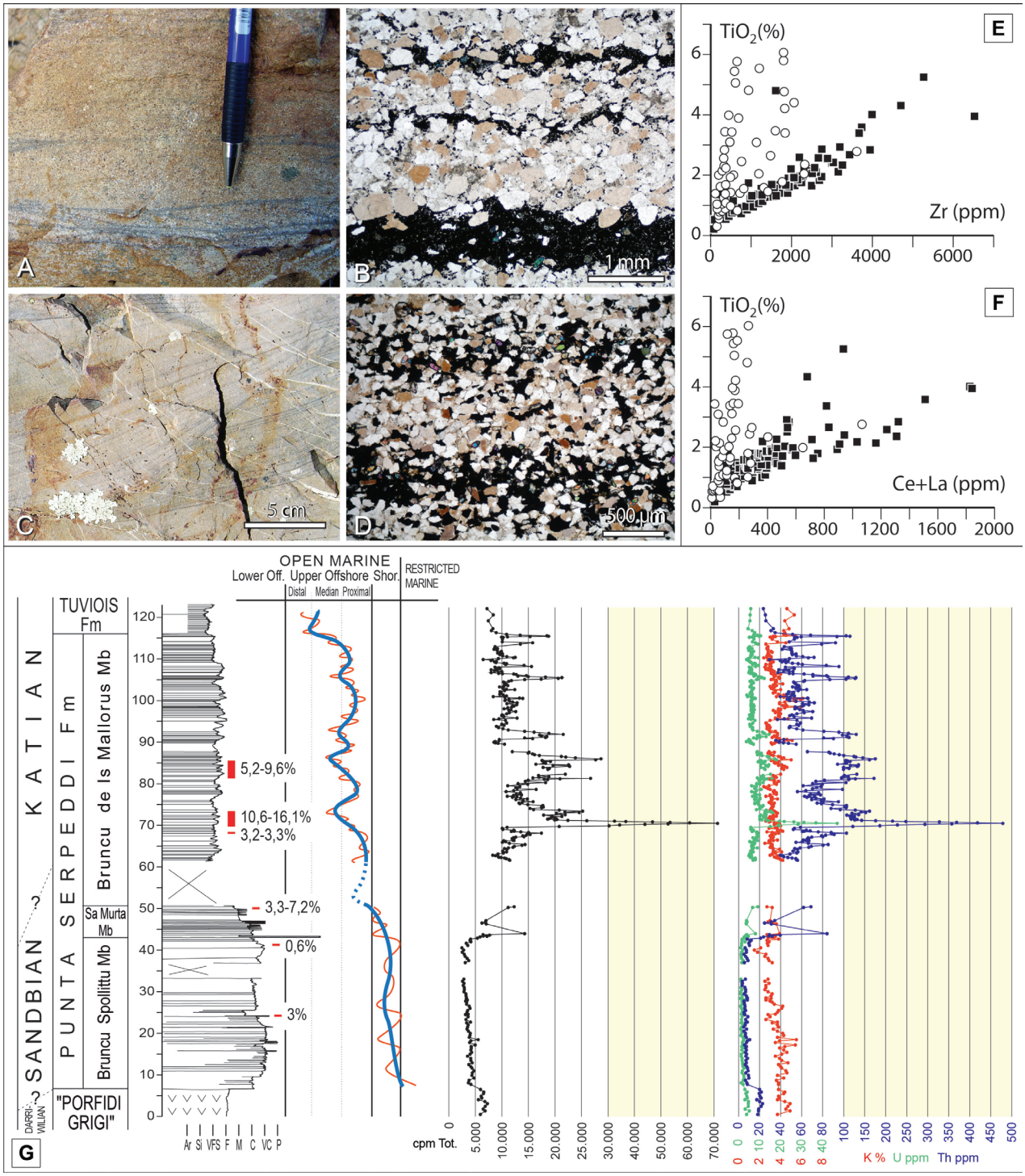

Fig. 2 - Heavy mineral laminations in the shoreface facies (A, B) and in the proximal upper offshore facies (C, D). TiO_2 (%), Zr (ppm) and Ce+La (ppm) distributions in coarse-grained (circles) and fine-grained (squares) sandstones (E,F). Facies interpretation and evolution of the environments in the Punta Serpeddì Fm (S'Enne Sa Pira section). Heavy mineral contents of samples from different sections (vertical red line); gamma-ray spectral logs: total counts (cpm), K (%), U and Th (ppm).

frequency cycles in high energy environments and they represent major condensation facies (Dabard et al., 2007, 2015; Pistis et al., 2008, 2016).

Marine placers being generally enriched in radioactive minerals such as zircon (e.g. de Meijer, 1998; Dillenburg, 2004), measurements of the natural radioactivity is a powerful approach to detect episodes of sea-level rise (e.g. Dabard et al., 2015; Pistis et al., 2016). However when there is a heavy minerals segregation along the depositional profile, some placers, devoid of radioactive minerals, cannot be highlighted. It is the case of the Punta Serpeddi Fm where the placers associated to shoreface environment, enriched in titaniferous-minerals, show a low radioactivity while those associated to upper offshore environment,

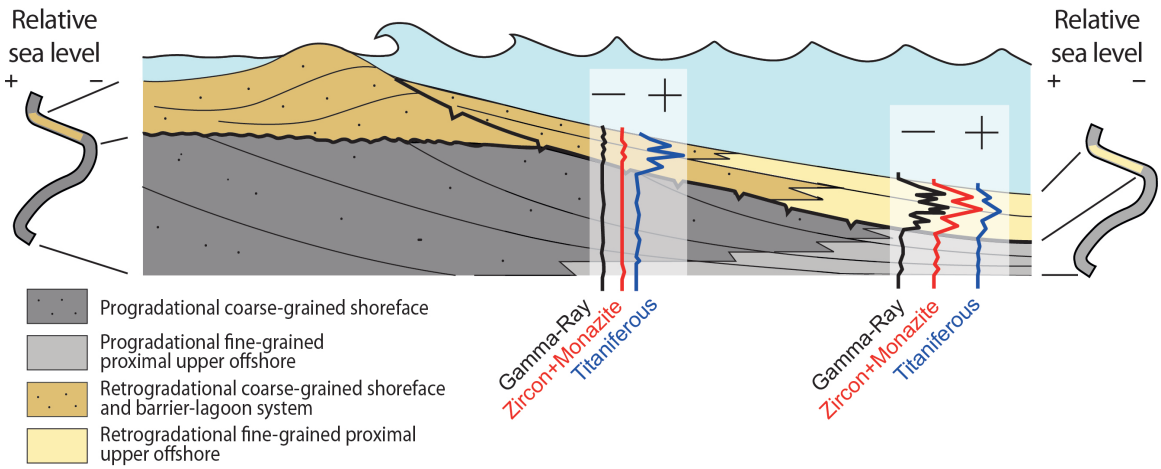

Fig.3 - Diagram illustrating a 2D simplified prograding-retrograding sequence showing the distribution of the heavy minerals within the different facies and their relative gamma-ray response. Two hypothetical well logs are represented: to the left the complete sea-level cycle occurs mainly in shoreface facies, zircon and monazite are negligible, titaniferous minerals prevailing and are abundant in the retrogradation phase and the gamma-ray signal is low; to the right are shown from the base to the bottom, progradational proximal upper offshore facies (medium relative gamma-ray signal, containing some zircon and monazite plus titaniferous minerals) passing to retrogradational proximal upper offshore facies (high relative gamma-ray signal containing high concentration of zircon, monazite and taniferous minerals).

enriched in monazite and zircon, are characterized by a high radioactivity. Therefore the stratigraphic position of the beginning of the condensation (of low frequency cycle) can be located in the shoreface facies (low radioactive coarse-grained titaniferous rich shoreface facies), below the peaks of the high radioactivity. This feature implies that, in the gamma ray interpretation of well log analyses, some placers can be masked leading to a misunderstanding for interpretation of the sequential analysis.

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