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Invited review

Luminescence dating of interglacial coastal depositional systems: Recent developments and future avenues of research☆

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ABSTRACT

Luminescence dating offers new opportunities to explore the evolution of Quaternary marine coastal facies and landforms. This review highlights the main advances in luminescence geochronology of interglacial coastal sediments through the analysis of 547 luminescence ages, most of which were published during the last decade. The majority of these reported luminescence investigations have been carried out along passive margin coasts. Since the turn of the century, the discovery of a normalization procedure known as Single Aliquot Regeneration (SAR) has drastically reduced data scatter and improved precision, with the consequence that quartz SAR optically-stimulated luminescence OSL has become the dating protocol of choice for the Last Interglacial (LIG) period. A more complex technique, known as thermally-transferred OSL (TT-OSL), is presumably proposed for dating older interglacials of the Mid-Pleistocene and beyond. Feldspar luminescence is increasingly being applied to dating Pleistocene sea level high stands due to a much higher dose saturation level than quartz OSL. The use of feldspar IRSL (Infrared-stimulated luminescence) is limited by the occurrence of variable, but ubiquitous anomalous fading (AF). Following the advent of AF-correction methods, several Middle Pleistocene sites have been amenable to dating, albeit with significant related uncertainties. Recently, new protocols involving the measurement of post-IR IRSL at elevated temperatures have yielded relatively coherent ages for interglacial sediments up to ca. 300 ka.

Quartz OSL/TT-OSL, AF-corrected IRSL, and post-IR IRSL ages are generally correlated with periods of sea level high stands. A few ages are reported from the early and middle part of the Middle Pleistocene, as MIS11, 9 and more commonly MIS7 high stands are documented in strongly uplifting active margin coasts. However, by far the most obvious age peak corresponds to the end of the LIG. The MIS5e shoreline is probably the most studied and luminescence-dated coastal feature of all, as the chronology of the sea level markers is crucial to assess global eustatic sea level variations through the course of the last interglacial. Nevertheless, the observed abundance of young (100–120 ka) luminescence ages for presumed MIS5e sediments may underline methodological issues, and/or reflect the higher preservation potential of late regressive sequences. On the other hand, the occurrence of geographically distant reports of MIS5a high stand might reflect a true eustatic origin for this event.

Age analysis supports the impression of general reliability of luminescence for the timing of former sea level high stands. There is a clear need to address issues in dose rate variability, in the phenomenology of fading in feldspar, and in the behaviour of luminescence growth with dose, both in laboratory and natural conditions. These could be addressed and properly evaluated by dating different minerals, as multiple or single grains, with consequent variable internal dose rates. More robust practices in the application of luminescence dating techniques could eventually constrain the age uncertainties to no better than 2–3%. Therefore, the strength of luminescence as a dating tool is more in terms of its extended age range and the ubiquity of datable material.

1. Introduction

The history of sea level has long been an academic issue, discussed among scholars interested in the stratigraphic and

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geomorphological aspects of this geological record. Heated debates have revolved around the true nature of the global sea level curve, the elevation of former high stands or even on the question of how many high stands there were in the course of the interglacials of the last million years. In the Mediterranean, the marine transgressions of the Last Interglacial (LIG) are known as Tyrrhenian I and II, and their existence and nature have been the subject of intense debate among European geologists. Ages from new dating methods, such as luminescence, have invigorated the debate again (*e.g.* Pascucci et al., 2014).

Sea level is the net result of multiple processes involving the exchange and accommodation of water among surface reservoirs in the global Earth system. Climatic changes impact glaciers and ice sheet mass balance, resulting in high-frequency sea-level variations (periods of a few years to a few thousand years). On the other hand, tectonic activity appears to be the main driving force acting on the global distribution of sea water for periods on the order of millions of years. Accordingly, rates of relative paleo-sea level changes are thought to span four orders of magnitude (Cronin, 2012) from almost stable to possibly 50 mm/year during deglaciation.

Recently, the impact of glacio-hydro-isostasy (including ice, water, and sediment loading) has been invoked to account for the geographical variability of former sea level markers ("fingerprints" of Mitrovica et al., 2009). A maximum eustatic LIG sea level of almost 6–9 m asl (Waelbroeck et al., 2002; Dutton and Lambeck, 2012; Dutton et al., 2015) is now thought to result from the cumulative effect of thermal expansion of seawater, the loss of mountain glaciers, as well as significant contributions from both the Greenland Ice Sheet and West Antarctica. A comprehensive assessment of sea level changes through Quaternary time and a full account of the complexity of this global problem can be found in a recent text book published by Murray-Wallace and Woodroffe (2014).

For academia, applied scientists, and policy makers, the short-term future evolution of sea level is considered as one of the most serious threats to highly populated coastal areas in the wake of global warming (Church et al., 2013). Global sea level evolution models predict an increase in sea level of *ca.* 0.5–1 m over the next century. These predictions are to be assessed in coastal areas where several other factors, mostly glacio-isostatic and/or tectonic in origin, may control the evolution of the local shoreline. In some areas, the eustatic sea level increase rate may be cushioned by crustal uplift, hence diminishing the overall contribution of climate-related sea level rise. Conversely, the impact of sea level rise may prove catastrophic in areas where coastal crust is subsiding because of regional subsidence or glacio-isostatic adjustment (GIA). Thus, correct projection of the 2100 sea level in coastal areas will strongly depend on a detailed understanding of the local net balance of geological forces.

An appropriate evaluation of the impact of future sea level variability in any one region requires the assessment of long-term evolution of the local relative sea level. In areas where high LIG levels are recorded by raised beaches and notches, *i.e.* several metres above the current coast, the impact of an accelerated rise of *ca.* 1 m/100 years may be restrained. In subsiding areas, where current sea level is already above the LIG marine limit, the trend in global eustatic rise might be accelerated. Therefore, understanding the local history of sea level is critical and provides the foundation of modern sea level research. Raised beaches must be dated in order to deduce trends in relative sea level, enhancing the interest in the development and application of dating methods to coastal areas where former sea level "fingerprints" are documented.

The chronology of former sea level high stands has been mostly based on the development and application of radiometric U–Th series to corals (see Siddall et al. (2007) for a review and Dutton et al. (2015) for the most recent publication). The level of precision and accuracy of several U–Th dating programs have allowed the understanding of the evolution of sea level during the last interglacial to be detailed at the time scale of centuries. Unfortunately, U–Th ages are limited in number for pre MIS5 sea level high stands due to limited occurrences of unrecrystalized corals and to the upper limit of the method. Therefore, alternative dating techniques have been developed for dating older interglacial periods. Luminescence dating is one such method that was tested for dating former sediments as early as 1985 (Huntley et al., 1985). Over the following 30 years, thermoluminescence (TL) and, more recently, optically-stimulated luminescence (OSL), have been used to date coastal sediments on most continents. The quality and reliability of luminescence is a critical issue, as OSL/IRSL dating results are produced and published in increasingly large numbers every year. This is a result of several years of methodological and hardware development with consequent increase in equipment availability, particularly driven by the relatively low cost of luminescence readers as opposed to mass spectrometers.

Recent reviews of luminescence dating were published by Rhodes (2011) and by Jacobs (2008) for applications specifically to coastal sediments. Recently, some specific applications of OSL to sea level studies have been described and discussed by Bateman (2015). Herein, the examination of modern luminescence chronology research is carried out in the contexts of geodynamic/glacio-isostatic domains. This review focuses on the applications of luminescence dating to interglacials of the last million years. Luminescence ages from the current Holocene Interglacial are not considered. The objectives of this paper are to: a) review the recent luminescence dating applications to coastal depositional systems; b) assess their general reliability and c) propose some guidelines and avenues of research to address the issue of the timing of former sea level high stands over the Mid to Late Pleistocene.

2. Geodynamic and glacio-isostatic domains

First order division of coastal areas is based on their geographical and geological framework with respect to tectonic plate boundaries, identified as convergent (in subduction zones) or divergent (oceanic ridges and nascent oceans *eg.* Red Sea). The current large scale divisions are based on the duality of passive *vs* active margins, corresponding to relatively stable to uplifting/subsiding coasts (Fig. 1). Along modern subduction zones, such as the Andes, the uplift along the Pacific coast is of *ca* 0.5 mm/year. The South African coast, an archetypical stable margin, appears to regain a similar coastal geometry at each recurrence of interglacial conditions, approximately every 100 000 years. Subsiding geodynamic areas are less common, and are known in back-arc contexts, such as the Hong Kong basin or in high deltaic discharge areas (Mississippi or Pô rivers). In each of the geodynamic domains, the architecture of the depositional systems will develop according to the geodetic elevation of local sea level during high stands, as well as to the accommodation space available and to the sediment flux (Catuneanu, 2005). The relationship between sea level high stands and marine isotopic stratigraphy in the different geodynamic and glacio-isostatic contexts is depicted on Fig. 2.

Along passive margins where sediment is readily available and commonly recycled, the coastal geomorphology will be dominated by barrier systems characterized by interfingering aeolian dunes and beach sediments (*e.g.* South Africa: Cawthra et al., 2014). In areas of high carbonate production, coastal facies are dominated by lithified beach rocks and aeolianites (Brooke, 2001). In similar areas, but with slow uplift, systems of raised barrier systems are topographically graded, such as in Southeast Australia (Murray-Wallace, 2002). If sedimentary flux is high, as in the Mississippi