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Invited review

Applications of geochemistry in tsunami research: A review

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ABSTRACT

Much progress has been made since the first published studies of tsunami deposits nearly 30 years ago. Geochemistry is now a much more widely used proxy in tsunami research, mainly due to its increasingly recognised value in the identification of historical and/or prehistorical deposits, at times even providing the conclusive proof when other proxies are missing or equivocal, but also its significance in environmental impact assessments following recent tsunamis. The rapid advance in analytical techniques has also made it a more approachable and popular method, as it is now often faster and cheaper. Here we provide a review of the applications of geochemistry, including the techniques used, as well as a database of studies that used chemical proxies in their investigation of recent and old events, including onshore and offshore tsunami deposits. Chemical signatures are often used as markers of marine inundation, either as salinity indicators, where they can also allow the identification of the limit of tsunami inundation, or tracers of the incorporation of marine-sourced carbonates. Their applications as indicators of source material are nevertheless expanding, thereby potentially providing additional information on the hydrodynamic processes associated with tsunami inundation, although they are largely site-specific. The effects of post-depositional changes in different climatic regimes are examined, with a particular emphasis on water-leachable components and implications for post-event recovery of coastal ecosystems. We demonstrate the usefulness of chemical proxies in studies of the geological record of tsunamis extending back thousands of years, suggest new approaches and discuss limitations and existing knowledge gaps.

Contents

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1. Introduction

Recent devastating tsunamis, in particular the 2004 Indian Ocean Tsunami (2004 IOT) and the 2011 Tohoku-oki Tsunami (2011 TOT), which resulted in a huge human loss, seem to have taken authorities and researchers by surprise (e.g. Normile, 2011). While one cannot predict accurately when and where the next tsunami will hit, preparedness and adequate hazard mitigation measures have proven to reduce the number of casualties and fatalities. Although those are mostly based on the knowledge gained from the geological record, recent events provide the unique opportunity to study modern analogues that can help our understanding and identification of past events.

It is now widely acknowledged that the magnitude and inundation limit of the 869 Jogan tsunami, a predecessor of the 2011 TOT, was underestimated (e.g. Goto et al., 2011; Sawai et al., 2012; Shishikura, 2014). This is mainly because they were based on the extent of the sand deposit on land, the visible layer within the lowland peat sequence that could be identified by researchers in the field. Research carried out shortly after the 2011 TOT revealed that the visible sand deposit (>0.5 cm thickness) extended only about 57–76% of the inundation limit, in particular when the latter was >2.5 km inland (e.g. Goto et al., 2011; Abe et al., 2012). The breakthrough was that geochemical signatures could provide the means to distinguish the mud-dominated tsunami deposit from the terrestrial mud and peat, beyond the extent of the sand (Goto et al., 2011; Chagué-Goff et al., 2012a,e), allow a better estimation of the tsunami inundation limit and thereby provide a more accurate assessment of tsunami magnitude. Ironically, 20 years earlier, Minoura and Nakaya (1991) had reported chemical variations without any associated marked facies changes in sedimentary sequences retrieved from coastal lagoons in northern Japan and suggested that a geochemical signature for tsunami inundation could possibly be found in the absence of any sedimentological (sand) evidence.

Professor Minoura (then at Tohoku University, Japan) can certainly be called the pioneer of tsunami geochemistry. He led the first study presenting tsunami geochemistry data published in Japanese (Minoura et al., 1987), followed by the first one in English four years later (Minoura and Nakaya, 1991). These authors analysed interstitial water from lagoon sediments and reported increases in cations and anions (Na^{+}, K^{+}, Cl^{-}, Ca^{2+}, Mg^{2+}), as well as carbonates, which they attributed to seawater inundation by the 1983 CE tsunami and other historical and prehistorical events. It was at about the same time as the first published study recognising that sandy deposits above buried soils could represent the evidence for tsunamis associated with the earthquakes that had caused the land subsidence (Atwater, 1987). However, while sedimentological features quickly became one of the most widely used criteria to distinguish and identify recent and historical and/or palaeotsunami deposits, closely followed by microfossil assemblages, the application of geochemistry as a proxy appears to have met with some reluctance. It seems surprising, as chemical markers have long been used as palaeosalinity indicators (e.g. Berner, 1970), in studies dealing with sea-level changes (e.g. Meyerson, 1972), or to provide insights in the depositional environment of coals (e.g. Swaine, 1967). Thus, one can only assume that the reluctance by many tsunami researchers to adopt tsunami geochemistry is probably related to the fact that most of them are specialists in sedimentology or geomorphology.

Following the studies by Minoura and co-workers, who focussed on interstitial water, sediment chemistry was then used, sometimes in association with mineralogy, to identify historical and/or palaeotsunami deposits in the geological record (Chagué-Goff and Goff, 1999; Goff and Chagué-Goff, 1999; Kumagai, 1999).

However, it was the 2004 IOT and the resulting ocean-wide devastation that really led to an increased interest in tsunami geochemistry and tsunami in general, with a marked increase in line with the large increase in publications dealing with all aspects of tsunamis (Fig. 1), although the former is at least one order of magnitude lower. Nevertheless, a new field of research was established in the aftermath of the 2004 IOT, namely the assessment of environmental impact due to tsunami inundation, with the first published study on the subject by Szczuciński et al. (2005), followed by the first detailed study dealing with post-depositional changes of tsunami deposits