Foraminifera from Restronguet Creek: Monitoring recovery from the Wheal Jane pollution incident

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In 1992, following a period of heavy rainfall, acidic mine water escaped from Wheal Jane tin mine and severely polluted the River Carnon, Restronguet Creek and the Carrick Roads (Fal Estuary). From June 1992, for a period of over four years, a programme of sampling in the inter-tidal sediments of Restronguet Creek was carried out in order to document the disruption to the foraminiferal fauna, the geochemistry of the surficial sediments and the chemistry of the water still entering the estuary. Since that time an extensive water treatment system has been installed that uses a series of "natural" filters. In 2004 this foraminiferal monitoring programme was re-activated using the same sites, the same sampling techniques and the same methodology. It was anticipated that there should be a noticeable recovery of the microfauna. Using samples from February, May and July we sampled across the "spring bloom" and have compared both the species content and abundances with the data generated in the early to mid-1990s. While the balance of taxa has changed slightly the species content remains the same, with no new taxa recorded. The living fauna is dominated by *Haynesina germanica, Elphidium williamsoni* and *Ammonia aberdoveyensis*. Particularly significant is the lack of typical estuarine agglutinated taxa such as *Trochammina inflata, Jadammina macrescens* and *Miliammina fusca*. The geochemistry indicates that the surface muds are now approaching pre-Wheal Jane incident levels, though still containing metals as a result of the natural geological environment of the catchment. Test deformity is reduced, though still present.

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Introduction

In 1992, following a period of heavy rainfall, 50,000 m^3 of acidic mine water and sludge escaped (16th January 1992) from Wheal Jane mine and severely polluted the Carnon River, Restronguet Creek and Carrick Roads (Fal Estuary). From October 1992 until October 1996, a programme of sampling was carried out in the inter-tidal sediments of Restronguet Creek in order to document the disruption to the foraminiferal fauna, the geochemistry of the surficial sediments and the chemistry of the water still entering the estuary. In 2000 an extensive water treatment system was installed and became operational (Younger, 2002). In 2004 this foraminiferal monitoring programme was resumed, using the same locations and methods, in order to assess the level of environmental improvement since the cessation of the original sampling programme.

Prior to this pollution incident there had been no published information on the benthic foraminifera of Restronguet Creek and this has always been a limiting feature of the work on this inter-tidal area. With no data on the distribution of taxa prior to the pollution incident it has been difficult to make firm statements about the impact of the event and the likely time-scale for full recovery. Despite this limitation, Stubbles (1999) reported a recovery in the benthic assemblage towards the end of her studies, probably due to the clean-up measures put in place by the Environment Agency (see later discussion). The immediate post-event clean-up was done using a passive treatment system alongside a conventional lime treatment system previously used in the mine. As this system did not contain the discharge of mine water from Wheal Jane, the establishment of a long term management system involving a passive reed bed storage system was then developed to treat the mine water discharge (Hamilton *et al*., 1999). This has subsequently been replaced with an active treatment plant comprising a high-density sludge alkali dosing plant, which during its first full winter of operation treated a total of 4,400 million litres of water (Younger, 2002).

Foraminifera as indicators of pollution

The response of foraminifera to polluted environments has been studied for over forty years. The first examples of such work came from areas adjacent to sewerage outfalls on the California coast (Zalesny, 1959; Resig, 1960; Watkins, 1961; Bandy *et al*., 1964a,b, 1965a,b). This research was expanded to a range of other locations in the 1970s and 1980s (Schafer, 1970, 1973; Schafer and Cole, 1974; Seiglie, 1971, 1975; Bartlett, 1972; Setty, 1976, 1982; Bates and Spencer, 1979; Setty and Nigam, 1984; Ellison *et al*. 1986). In 1991 two significant publications (Alve, 1991; Sharifi *et al*., 1991) pointed to the impact of heavy metals on the distribution of foraminifera in estuarine environments, as well as introducing the debate on the acquisition of test deformities. The paper by Sharifi *et al*. (1991) was particularly important as it was published in August 1991, just five months before the Wheal Jane pollution incident.

At that time (1991) there was a possibility that:

(1) some foraminifera may be sensitive to pollution;
(2) some foraminifera might be more tolerant of pollution and able to increase in numbers when competition is removed; and
(3) some taxa appear more likely to develop abnormal growth features (misaligned coiling, multiple chambers, etc.) in polluted environments.

In the 1990s there was continued use of foraminifera as indicators of pollution. Yanko *et al*. (1994) linked pollution from heavy metals to changes in the distribution of foraminifera, with Yanko *et al*. (1998) extending this work to the Mediterranean coast of Northern Israel. These authors particularly drew attention to the morphological deformities of