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Mapping elemental distributions in submarine hydrothermal sulfide smokers using proton induced X-ray emission

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ABSTRACT

PIXE analysis using a 3 MeV proton beam on the CSIRO Nuclear Microprobe was carried out on samples of four typical undersea sulfide chimneys from the Rogers Ruins and Fenway hydrothermal sites, PACMANUS field, Eastern Manus Basin, Papua New Guinea. The ability of PIXE to map the spatial association of trace elements within the sulfides across multiple mineralogical zones provides important insights into the mode of formation of structures and the nature of interaction between ~250 and 350 °C hydrothermal fluids and 3–4 °C ambient seawater within the chimney walls.

1. Introduction

Hydrothermal vents or fissures on the sea-floor are commonly found associated with submarine volcanic activity [1]. Minerals dissolved within conductively heated hydrothermal fluids reach the cooler sea water causing rapid precipitation forming tall chimneys. These so-called "smokers" may have a white or black hue depending on their plume components. Over time and under the right conditions, these black smokers may form base- and precious-metal rich massive sulfide ore deposits. These deposits potentially form valuable mineral resources as both ancient deposits, now buried on land, and as modern accumulations on the sea-floor, where they host unique chemosynthetic ecosystems [2].

Hydrothermally active polymetallic Cu–Zn–Au–Ag–Pb sulfide mineralisation was first discovered in the Eastern Manus Basin (EMB), Papua New Guinea, by the PACMANUS I (Papua New Guinea – Australia – Canada – Manus Basin; RV Franklin) expedition in October 1991 [3]. The discovery, named PACMANUS, lies on the crest of a 20 km long, NE-trending dacitic volcanic ridge which rises approximately 500 m above the surrounding sea-floor. By virtue of its association with felsic volcanic activity and its location behind an active island arc, the PACMANUS hydrothermal field was initially interpreted to represent a close modern analogue for ancient volcanic hosted massive sulfide (VHMS) mineralisation [3], and has subsequently been the subject of intense research activity, including manned and unmanned submersible dives and Ocean Drilling Program Leg 193 [4]. This research has focused on using the PACMANUS field, and other nearby occurrences, as natural laboratories to study ore forming processes in the submarine environment, including investigating the roles of magmatic fluid and seawater as both sources and transport media for mineralising components and the relative importance of physical effects, such as fluid mixing and phase separation on mineralisation.

In 2006, the MAGELLAN expedition aboard the *RV Melville* comprehensively investigated the hydrothermal systems of the EMB, through a combination of sampling and mapping using the remotely operated submersible vehicle (ROV) Jason, the autonomous underwater vehicle ABE, and ship-based oceanographic work and multi-beam bathymetric mapping [4]. A total of 30 ROV dives (497 operational hours) were completed, collecting 198 samples of vent sulfide, 83 altered volcanic rocks and 43 fresh lava samples.

Proton Induced X-ray Emission (PIXE) analyses using the CSIRO Nuclear Microprobe were carried out on samples of four typical undersea sulfide chimneys collected on the MAGELLAN expedition, although space constraints mean that only a subset of these analyses are reproduced here. The ability of PIXE to map the spatial association of trace elements within the sulfides across multiple mineralogical zones provides a tool to probe the mode of formation of the structures and the nature of interaction between ~250 and 350 °C hydrothermal fluids and 3–4 °C ambient seawater within the chimney walls.

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2. Sample preparation and description

Sea-floor sulfide chimney sections were recovered by ROV from the sea-floor and later cut and polished using standard preparation steps for PIXE on geological specimens [5]. The sample discussed in this paper, 216-16 (Section 16), from the Fenway field, displays two, simple, thin-walled (<6 mm), chalcopyrite-rich, open conduits, each with a 2–3 mm thick massive chalcopyrite conduit wall grading outwards to a more porous zone dominated by barite gangue, with minor disseminated covellite, bornite, sphalerite and pyrite. The area selected for PIXE analysis (Fig. 1) provides a traverse from the inner to the outer wall of one of the conduits (Fig. 2).

3. μ-PIXE data collection

All PIXE analysis was performed using a 3 MeV H^+ beam focused with the CSIRO-GEMOC Nuclear Microprobe based at the School of Physics, University of Melbourne [6]. The MPSYS data collection system incorporating pile-up and dead-time corrections was used throughout. A large area/solid angle Canberra Ge (Li) detector at an

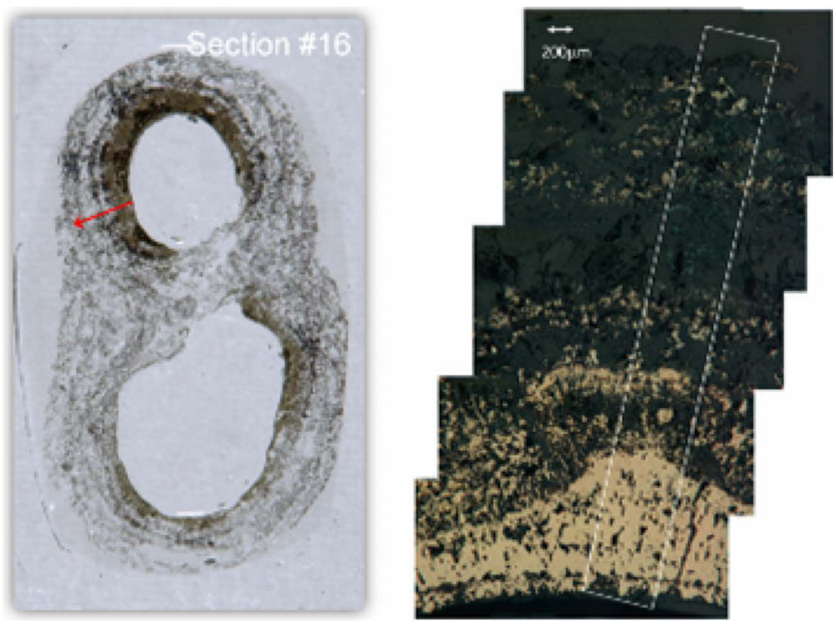

Fig. 1. Section 216-16 with a size of 25 × 50 mm. The red arrow marked on the left images indicates the PIXE traverse (left). A series of photomicrographs indicating a close up of the traverse region scanned. The bottom most region is the inner chimney wall. A scale bar is given at the top left of the image (right) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

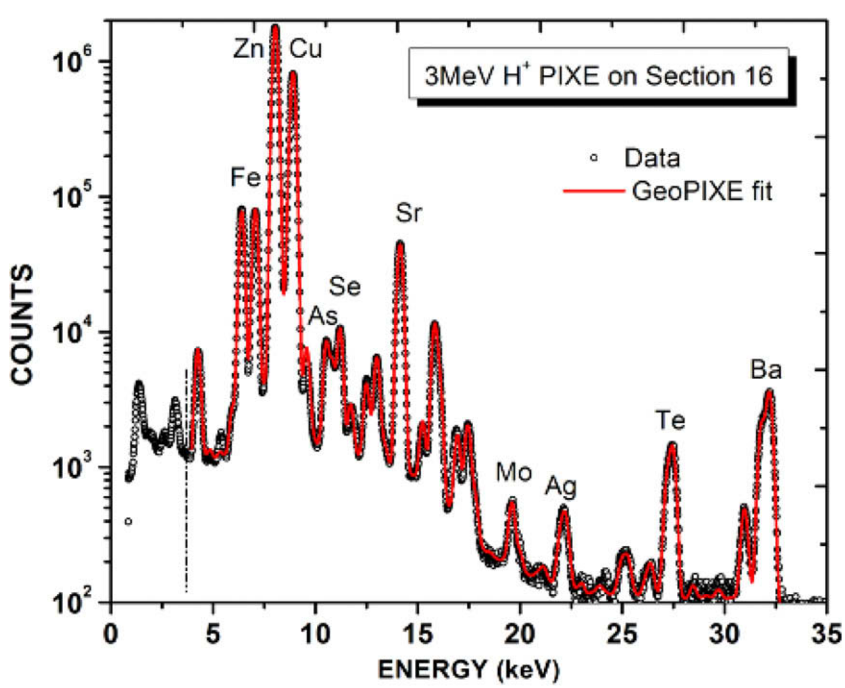

Fig. 2. 3 MeV H^+ PIXE spectrum on section 16 as well as spectrum fitted using GeoPIXE.