

First results regarding the influence of mineralogy on the mechanical properties of seafloor massive sulfide samples



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ABSTRACT

Seafloor Massive Sulfides (SMS) are increasingly accepted as important marine raw material resources for the future, in particular because of their polymetallic character. Many industrial nations are researching not only on the scientific importance of these deposits but also on their economic value. Regarding the current state of the international exploration, mainly two-dimensional surface-close observations are accessible, whereas only some core data and measurements are publicly available to date. In fact, there are few successful drilling campaigns containing information about the size and shape, which also give information on the structure and content of modern massive sulfide ore bodies in their third dimension. Regarding the mechanical properties of SMS samples, only few data are available. Geotechnical data of these deposits are important in order to develop an efficient mining technology for exploitation. In this research, 12 SMS samples from two different locations were investigated. Based on the mineralogical characterization of the studied samples the geotechnical properties were preliminary correlated with the mineralogical results. The comparative study indicates how far the geotechnical data are controlled by mineral type and composition, including the porosity. A regression relation between compressive strength and the porosity based on the mineralogy shows a distinct relation between these parameters. Therefore, the geomechanical and mineralogical features have a strong importance for deep-sea mining applications and this should be kept in mind considering the hyperbaric effects on the rock cutting.

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1. Introduction

In the deep-sea environment, hydrothermal fields are preferentially related to extensional tectonics. These fields are parts of a global energy dissipation system in which mantle heat is transported to the seafloor by a combination of conductive and convective flux; the latter mainly represents the hydrothermal circulation. The preferred locations for the convective energy transport and the related mineral formation processes are the globe-encircling mid-ocean ridges as well as the spreading zones of back-arc basins behind volcanic island arcs. Typical water depths of the modern hydrothermal fields are 1500–4000 m. Seafloor Massive Sulfide (SMS) deposits are considered to be a very important future source for metals such as Cu, Zn, Pb, Au, Ag, Se, Cd and other high-tech elements. However, the necessary techniques and systematic details for mining and processing these minerals have not been tested yet and are still in the development stage (Nautilus Minerals, 2016). For the process of marine excavation the geotechnical properties of the respective sulfidic ores are extremely important, in particular

since these deposits are located in water depths with remarkable hydrostatic pressures (Spagnoli et al., 2015).

More than 100 sites exhibiting more or less recent activity, emanating mineral-bearing hot fluids at temperatures of up to 410 °C, and containing metal-rich solutions, are now known from a variety of tectonic settings, particularly in the Pacific Ocean and its marginal back-arc seas, but also in the Atlantic and Indian Oceans as well as in the Mediterranean Sea. Larger accumulations of polymetallic sulfides are known from about 300 sites (Hannington et al., 2011). They contain groups of chimneys, fragmented chimneys, and hydrothermal mounds that are up to several hundred meters in diameter and tens of meters high within vent fields that can be traced for kilometers. Commonly, the larger occurrences consist of several generations of chimneys, with the older portions generally fragmented, forming mound deposits that are subsequently topped by the youngest (active) chimney generation.

The evolved hydrothermal fluids reach the seafloor where, due to rapid cooling by mixing with cold seawater, most of their mineral content precipitates in the form of chimney structures and stockwork mineralizations in the permeable subsurface. Hot fluid-mineral suspensions emanate as black and white smoke and enter into the near-bottom water layer, since not all the mineral content precipitates immediately on and below the seafloor. The chimney structures are subject to

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cooling, alteration and fragmentation and become eventually incorporated into mound deposits. These mound deposits are primarily the sites for seafloor excavation.

This research provides new information on the influence of the mineralogy on the geotechnical characteristics of the SMS samples. This is an important part of the project development for the mining systems (e.g. Spagnoli et al., 2015; Spagnoli et al., 2016). Many of the results available in the literature regarding deep-sea mining applications are based on tests performed on non-SMS materials (e.g. Waquet et al., 2011; Alvarez Grima et al., 2015). Therefore, the data introduced in this research give a first indication about the geotechnical properties with regard to the mineralogical characteristics of SMS samples. However, it has to be pointed out that further detailed tests are necessary for designing specific mining systems for the marine deep-sea environment.

2. Materials and methods

2.1. Geological background

The samples tested for these geotechnical experiments originate mainly from the North Fiji Basin (Halbach et al., 1996, 1998) and the MESO-site in the Central Indian Ocean (Halbach et al., 2002). The samples were collected with a grab sampler. The sample set comprises black smoker, white smoker and caprock mineralizations. The black smoker chimneys mostly consist of copper minerals (chalcopyrite and subordinately covellite) as well as recrystallized iron sulfides (pyrite and marcasite) and relics of anhydrite (see sample in Fig. 1A). The corresponding chalcopyrite-concentrations vary between 5 and 18%. The Fe-rich “kies-type” sulfides typically form the outer part of the chimney structures; these sulfides are dominated by pyrite and marcasite with one sulfide often replacing the other. All these features indicate that the black smoker chimneys represent high-temperature mineralizations and were formed from emanating vent fluids with temperatures of up to 410 °C. “White smoker” chimneys are characterized by particularly high sphalerite concentrations (between 19 and 52%) and a great variability with respect to interstitial amorphous silica content. Fe-poor sphalerite is the main sulfide phase in the white smoker mineral assemblage. The chimneys begin to grow at temperatures of around 300 °C or less, and get their colour from greyish white particles (amorphous silica, some barite and anhydrite) suspended in the meso-thermal fluids. White smoker chimneys form mainly at a later stage in high-temperature systems (see sample in Fig. 1B). Often, white and black smoker chimneys occur in the same large vent complex indicating that they are supplied from the same high-temperature plumbing system at depth. The succession of chimney formation and their subsequent erosion causes the build-up of a debris mound at the hydrothermal vent site. This porous debris material is also flown

through by reactivated hot solutions and becomes cemented by epigenetic sulfide precipitates which also contribute to the seafloor massive sulfide deposit. Depending on the respective maximum fluid temperature in this process, the massive ore body can be dominated by either Fe- and Cu- sulfides or Zn- sulfides. At the surface contact between the mound and cool surrounding seawater, predominantly amorphous silica (jasper) is precipitated (Halbach et al., 2003), but also Fe-free sphalerite, barite and anhydrite in larger cracks and vugs. The caprock often forms a covering layer above the subjacent mound sulfide material.

From the theoretical point of view, the black smokers are interesting because of the Cu, Au and Ag, whereas the white smokers are for the Zn. However, it can also be that black smokers have larger amounts of pyrite, which is economically irrelevant and also very hard and abrasive. Therefore, for each exploratory drilling the mineralogy plays an important role in order to assess the ore content.

2.2. Geotechnical tests

In the present study, geotechnical properties were measured for 22 cylindrical samples cut from 12 sulfide samples of known origin. Unconfined compressive strength (UCS), Brazilian test strength (BTS), mineral density, porosity, bulk density and Vickers tests were performed. With these geotechnical data, it was possible to provide preliminary information regarding future deep-sea mining cutting projects. UCS tests were performed according to the recommendations of Mutschler (2004) on 10 test cylinders (Table 1). The cylindrical wet core samples (height 100 mm and diameter 50 mm) were drilled and cut with a diamond saw to cylinders with a length-to-diameter ratio of about 2:1. The load was strain controlled and applied with a constant deformation rate of 0.05%/min (i.e. 0.1 mm/min) until no residual strength was reached. BTS tests, an indirect tensile strength test, were performed according to the Brazilian tests on 12 cylinder (Table 1) samples according to the recommendations of Lepique (2008). The disc shape specimens of the rock were loaded by two opposing normal strip loads at the disc periphery. The specimen diameter was 50 mm with a thickness/diameter ratio ranging between 0.5 and 0.6. The load was continuously increased at a constant rate until failure of the sample occurred after a few minutes. The loading rate depending on the material, varied between 10 and 50 kN/min. At the failure, the tensile strength of the rock is calculated as follows:

$$BTS = \frac{2 \cdot F}{\pi \cdot d \cdot l} \quad (1)$$

where BTS is the tensile strength in MPa, F is the applied load, d is the specimen diameter and l is the specimen length. Compression-induced extensional fracturing generated in this test is also more representative of the in situ loading and failure of rocks (Aydin and Basu, 2006). The

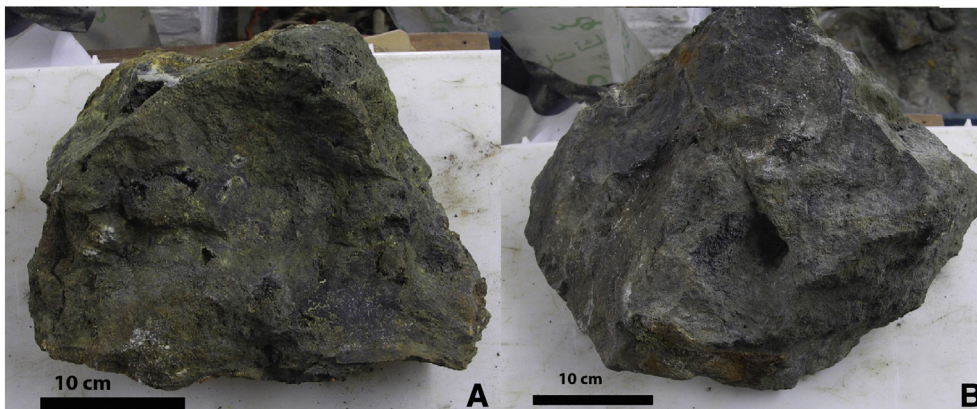


Fig. 1. A: Original sample for the specimen defined as 07 (see Table 3); B: Original sample for the specimen defined as 10 (see Table 3).

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