HIGH PRECISION DRILLING AND EXTRACTION OF MICRO-SIZED MATERIAL IN GEOLOGIC SAMPLES: IMPLICATIONS FOR ASTROBIOLOGY.

M. Ivarsson[1], M. Swillo[2], A. Neubeck[3], N.G. Holm[3], C. Broman[3], G. Björk[2]. [1]Dept. of Palaeozoology, Swedish Museum of Natural History, Stockholm, SE-104 05, Sweden. Email: magnus.ivarsson@nrm.se, [2] School of Information and Communication Technology, Royal Institute of Technology (KTH), Kista, SE-164 40, Sweden, Email: marcin@kth.se, [3]Dept. of Geological Sciences, Stockholm University, SE-106 91, Sweden.

Introduction: A branch of astrobiological related research deals with micro-sized geological material like fluid inclusions and fossilized microorganisms, or a limited amount of samples like meteorites or mission returned samples [1,2,3,4]. There is an urgent need for methods and protocols to extract and handle small geological samples considering near future Mars Sample Return missions (MSRs) [5]. The amount of sample will be restricted, and it will have to be shared of and distributed to different research facilities all around the world.

Here we demonstrate a method to drill in geological material using high precision laser ablation and extract samples of micrometer size for further analyses.

Micro-containers of paleo-information: Fluid inclusions are naturally formed micro-containers in minerals that have been sealed and isolated since the formation of the minerals. Fluid inclusions can contain information about temperatures, pressures, depths, atmosphere composition, fluid composition and sometimes organic content from the time of mineral formation. They are invaluable tools in the process of reconstructing the paleoenvironment that prevailed at the time of mineral formation and they have been suggested as interesting targets to analyse in an astrobiological context.

Fossilized microorganisms are another micro-sized feature in geologic material that have been suggested as high priority targets in astrobiological material like meteorites and MSRs. Fossilized microorganisms are obviously an indication of past life, but can also contain information about the paleo-environment in which the microorganisms once lived. Morphology and biomarkers can indicate what type of microorganism the microfossil represent (prokaryote or eukaryote), biominerals can give information on oxygenation in the system or possible energy sources used by the microorganism like Fe or Mn.

Separately, fluid inclusions and fossilized microorganisms are important containers for paleo-information, but it has also been pointed out that they are invaluable tools in combination [6].

Method: Since mechanical drilling or polishing involves a high risk for contamination of the sample, it is suggested to use a laser ablation technique for optical drilling and extracting micro-sized material (Fig. 1). For optimum laser parameters (wavelength 355nm, pulse length 10ps, repetition rate 60 Hz), the energy transfer is so abrupt and concentrated that the mineral forms plasma that is ejected from the focusing spot without transferring much energy to the mineral matrix. The result is a well defined hole without melted edges or cracked surface. For the tested minerals: quartz, apatite and calcite, the ablation rate was ca. 2 μm/sec at energy density 1J/cm^2. Since most of considered minerals are transparent, the drilling technique needs to be modified in order to avoid damage of the inclusion. Therefore, instead of a cylindrical hole, we drill a donut shaped hole. In this way, the inclusion which remains in the central, intact cylinder, is not affected by the laser beam (Fig. 2).

Preliminary results: Cylindrical tubes (Fig. 3A,B) incorporating single inclusions have been successfully ablated and extracted without melting, cracking or modifying the surrounding material.

Fossilized microorganisms in calcite filled veins and vesicles from subseafloor basalts drilled during ODP Leg 197 have also been drilled with laser ablation and analysed in SEM/EDS.

Further analyses: The ambition is to further analyse the extracted material and characterize its content. Fluid inclusions will be analysed with appropriate methods like GC-MS or ToF-SIMS to characterize the organic contents. This method is much more precise than previous extraction studies of fluid inclusions. With this method it is possible to extract one specific fluid inclusion compared to analyzing bulk samples which is standard protocol for extraction of fluid inclusions.

Fossilized microorganisms will be analysed with methods capable of characterization of mineralogy, organic content and oxidation states on a nano-scale like TEM, STXM or nano-SIMS. Extracted parts of microfossils will also be analysed with SRXTM in nano mode which require extracted cylinders with a diameter of approximately 40 μm.

The advantage of our method compared to other micro drilling techniques like Focused Ion Beam-milling (FIB) is that it is not restricted to surficial ablation but it is possible to drill and extract three-dimensional portions of samples containing unaffected and isolated samples for further analyses. It includes optical drilling in mineral sample placed inside the quartz capillary, which is transparent for the laser beam.

Astrobiological implications: In an astrobiological context extraction and treatment of micro sized geological material is of highest priority. MSRs are planned for 2018 and the total amount of returned material will be ~300-400 g [5]. This material will consist of ~50 individual samples of varying composition and origin and it will be distributed to various research facilities around the world for processing and analyses. Partition and analyses of such samples will require extraordinary precision and we are convinced that our method will be very useful and applicable for this purpose.

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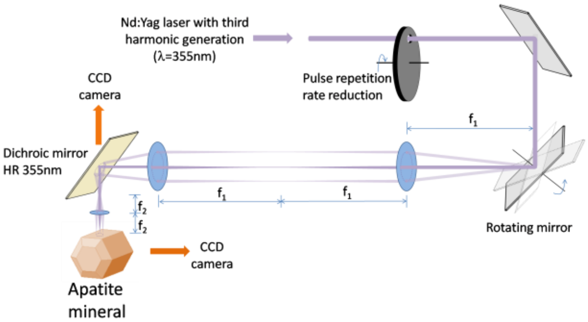

Fig. 1 Scheme for optical drilling using the third harmonic from Q-switched Nd:Yag laser.

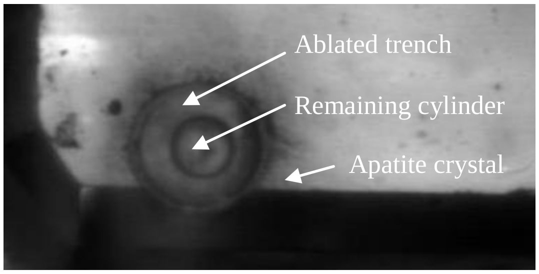

Fig. 2 Top view of the cylinder cut in apatite mineral (trench width 30 µm, trench depth 400 µm and cylinder diameter 60 µm)

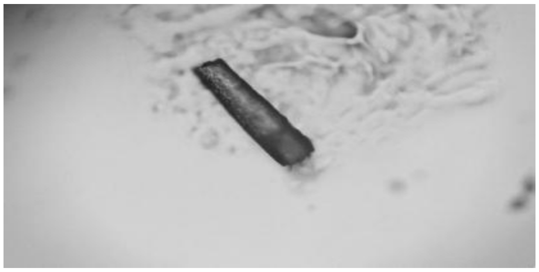

Fig. 3A. Extracted cylinder (60 µm in diameter) from apatite crystal contaning inclusion.

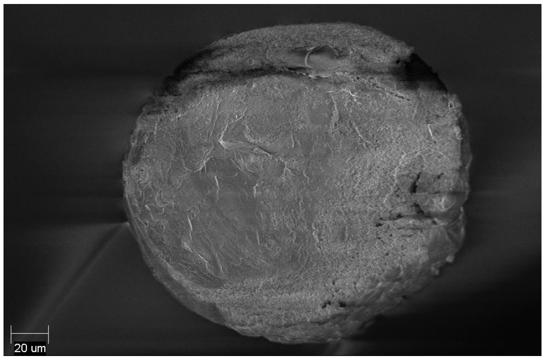

Fig. 3B. SEM picture of calcite cylinder (top view).