STRAY FIELD MAGENTIC RESONANCE IMAGING: A NON-DESTRUCTIVE MEANS FOR INTERNAL IMAGING OF PLANETARY ROCK SAMPLES. J.A. Bonetti [1], H. Manohara [1] and W.A. Holmes[1] Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Dr, M/S 302-205, Pasadena CA 91109, joseph.bonetti@jpl.nasa.gov)

Introduction: X-ray tomography is currently the only common technique capable of deep internal imaging of rock samples. However, it suffers from poor image contrast and slow imaging times. Confocal and Raman microscopy are impressive, but can only penetrate about 50 µm below the surface and require the cutting of thin slices. These techniques are superb for studying features known to exist in specific locations within a sample. But, they are not suited to a full, detailed scan of an entire sample. What is needed is a deeply penetrating, non-destructive method that can quickly image an entire rock sample all while providing good spatial resolution and image contrast. Stray field magnetic resonance imaging (STRAFI) meets these requirements. The expected spatial resolution is ~ 30-50 microns. The nuclear magnetic resonance line widths in rigid solids are orders of magnitude larger than those in soft tissue and liquid samples. As a result, medical magnetic resonance imaging (MRI) cannot be used to image rigid solids. In order to image rocks or other rigid materials, a magnetic field gradient that's orders of magnitude larger is required to resolve the much broader line widths. It should be noted that a larger field **gradient** is needed, and **not** a larger field.

Science: The STRAFI instrument can provide important information for three major types of scientific endeavors. 1) It can be used to study and image the structure and makeup of the rocks themselves. For instance, it may image the pore structure, or find striations, crystal vugs, or pockets of varying mineral type. 2) It can detect and image water-ice that may be trapped in the pore structure. Likewise it could image hydrous minerals which may have formed from water once being trapped in the rocks. And finally 3) The instrument could aid in the search for evidence of biological activity such as stromatolites or areas of magnetite biomineralization.

Innovation: The large gradient required for imaging rocks exists naturally above a high strength permanent magnetic with shaped pole pieces. With conventional MRI, the sample is in the sweet spot a very homogeneous (zero gradient) magnet. Separate rapidly pulsed coils are used to generate a gradient and encode spatial information. With STRAFI, the sample is instead slowly translated through the strong, static gradient using a motion controlled sample holder. A thin slice of the sample is excited and an NMR signal is recorded. As the sample is translated through the gradient, a profile is built up slice by slice. 2D and 3D imaging is achieved by obtaining a profile through the sample in one direction, and then rotating the sample about the other two axes and repeating the profile with the sample in different orientations. Ultimately, an adequate number of profiles will be acquired and 2D and 3D images can be constructed using back projection. Even a 1D scan or trace could provide valuable information, especially in determining which samples to choose for a sample return. The STRAFI technique was first performed in the late 1980s [1], and since then has attracted the attention of only a handful of niche researchers [2].

Due to the sample being in a large gradient, a relatively small number of nuclei are on resonance. This results in a lower signal to noise ratio (SNR) compared to that of standard NMR. Superconducting receivers have been incorporated into many conventional NMR systems with great success [3], and incorporating them into a STRAFI system will boost the SNR by roughly a factor of 30. This would constitute the world's first STRAFI system using superconducting receivers. Further gains in SNR can be achieved by cooling the sample, something not possible with medical MRI.

Putting It All Together: The power consumption, mass, and volume requirements for such an instrument are all reasonable for large lander missions. Low mass cryocoolers that can fit into the palm of one's hand exist and provide adequate cooling power at the temperatures needed for the superconducting receivers (60K). [4]. An example of such a cryocooler is shown in figure 1.

Figure 1: Mini cryocooler from NGST [4]

Miniature NMR electronics have also been developed at JPL [5]. These are shown in figure 2.

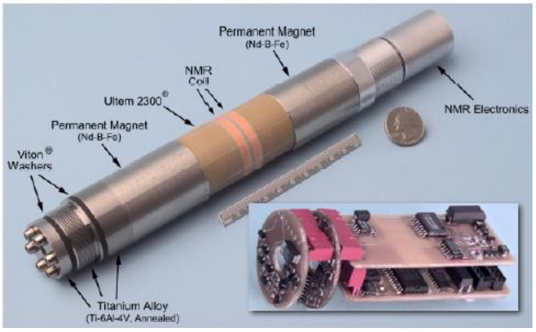

Figure 2: Miniature NMR electronics developed at JPL [5].

Finally, the shaped pole piece magnets which generate the large field gradient (~ 20T/m) have been developed and depicted in figure 3. [6].

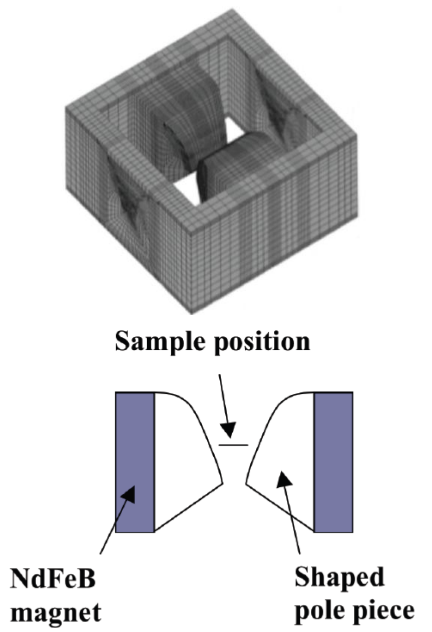

Figure 3 : High strength (~ 1T) permanent magnetic with shaped pole pieces. Shaped pole pieces generate large field gradient (~20T/m).

By combining mature developments in the miniaturization of cyrocoolers, NMR electronics, and that of shaped-pole-piece, high gradient NdFeB magnets, a flight STRAFI system can be built. An artist conception of the instrument is shown in figure 4.

It should also be noted that a ground-based STRAFI system could be employed to study returned samples. The non-destructive nature of the technique would be ideal for imaging returned samples prior to cutting or slicing. Getting an internal picture of a returned rock sample would aid researchers in determining where to slice or cut the sample for further investigation using other techniques.

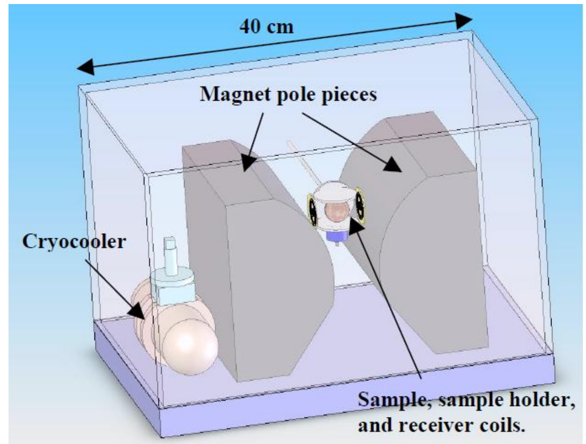

Figure 4: Artist conception of flight STRAFI instrument.

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