DISCOVERY OF 3.2 BILLION-YEARS-OLD SULFIDIC BLACK SHALES: A PROGRESS REPORT OF THE DIXON ISLAND-CLEAVERVILLE (DXCL) DRILLING PROJECT IN THE PILBARA CRATON, WESTERN AUSTRALIA. K.E. Yamaguchi[1,2,3], S. Kiyokawa[4], T. Ito[5], M. Ikehara[6], [1]Geochemical Laboratory, Department of Chemistry, Toho University, Japan, [2]Precambrian Ecosystem Laboratory, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan, [3]NASA Astrobiology Institute (NAI), [4]Department of Earth and Planetary Sciences, Kyushu University, Japan, [5]Department of Education, Ibaraki University, Japan, [6]Center for Advanced Marine Core Research (CMCR), Kochi University, Japan

Introduction: The Pilbara Craton in NW Australia exposes one of the well-preserved and least metamorphosed greenstone belts in the Archean. Greenstone belts are normally composed of a complex amalgam of meta-basaltic and meta-sedimentary rocks. Sedimentary rocks of the greenstone belts are good targets to search for clues of early Earth's environment and life.

In recent years, several scientific drilling programs (e.g.: Archean Biosphere Drilling Project (ABDP) [1]; Deep Time Drilling Project (DTDP) [2], [3]; and Pilbara Drilling Project (PDP) [4]) were successfully completed in the western Pilbara area, where 3.5, 2.9, 2.7, and 2.5 Ga sedimentary units were drilled. However, there is a huge time gap in the samples drilled by ABDP and DTDP that represents middle Archean time , between 3.5 Ga and 2.9 Ga (i.e., ~600 Ma, equivalent to the duration of the entire Phanerozoic). The Cleaverville-Dixon Island area of the coastal Pilbara terrain is suited to filling in the missing record. It contains well-preserved volcano-sedimentary sequences (Cleaverville Group dated at 3.2 Ga) where hydrothermal vein systems, organic-rich siliceous sedimentary rocks, and iron-rich sedimentary rocks are developed [5]. Such geological materials may be used to reconstruct past submarine hydrothermal activity and its influence on biological activity. Indeed, some attempts have been made to answer the key questions. However, the surface outcrops in this area are generally weathered to variable degrees; thus they are apparently not suitable for geobiological and geochemical studies which require unaltered original chemical/isotopic compositions from the time of their formation in the middle Archean. Consequently, we carried out the "Dixon Island - Cleaverville Drilling Project (DXCL-DP)", to obtain fresh samples from the sedimentary sequences in the Cleaverville—Dixon Island area.

Scientific Objectives and Methods: The most important objective of the DXCL-DP is to understand the nature of the middle Archean (3.2 Ga) marine environment influenced by hydrothermal activity, through detailed systematic study of fresh drill core samples. This objective has been pursued through (a) detailed stratigraphy of the whole section, (b) inorganic geochemistry of sedimentary rocks, (c) organic geochemistry of carbonaceous sedimentary rocks (i.e., characterization of the carbonaceous materials including insoluble macromolecular matter), (d) study of "microfossils", (e) geochemistry (including stable isotopes) of sulfide in sedimentary rocks, and (f) paleomagnetic study on oriented core samples in order to explore the presence and direction of the geomagnetic field in the early Earth. Various geochemical investigations of shales and cherts have been used (e.g., major, minor, trace, and rare earth element geochemistry; C_{org}, N, S, and Fe isotope geochemistry, etc.) to fully extract the information from samples and to understand the influence of submarine hydrothermal activity on the biological and chemical fingerprints. From these data we intend to determine the original environmental information at the time of deposition.

Drilling Results: DXCL-DP was successfully completed in summer 2007. The orientation of the core, being perpendicular to the bedding plane, is 52˚ dip to the SW for the CL1 and CL2 site and 52˚ dip to the NW for the DX site. Orientations of the core samples were taken using "Ezy-Mark" oriented. As a cooling media during drilling, the fresh water was used at CL1 and CL2 sites, and the seawater at DX site; for both "partially hydrolyzed polyacrylamide" lubricant was added.

Lithology of CL1 drillcore: The CL1 drillcore (66.1 m long) consists of two units: black shale and reddish shale. The black shale unit is subdivided into five subunits (BS1 to BS5). BS1 (39.4–45m) consists of highly fragmented but organic-rich massive and laminated black shales. BS2 (49–62m) and BS3 (71–88m) subunits consist of massive and partly laminated black shales. BS4 (92–94m) and BS5 (99–105m) subunits consist of organic-rich massive black shale with some fine sandstone layers. The laminated black shales with pyrite nodules occur at the deepest (but stratigraphically the uppermost) part. This unit partly contains graded thin sandstone beds with cross lamination. The reddish shale unit is either mostly fragmented laminated red-brown-black shale (44–49m and 62–71m) or well-laminated reddish to black shale (86–88m and 95–99m). The uppermost section down to 53 m depth is strongly fragmented. Changes of the bedding orientation occurred at 54–57m, 60–62m, 72–75m, 80–84m, and 89–92m depth ranges that are accompanied by fragmentation of the rocks.

Lithology of CL2 drillcore: The CL2 drillcore (44.4m long) consists of three units: weathered yellowish-brown rock (highly weathered white chert), black shale, and reddish shale units. Boundaries between each unit are highly fragmented. The black shale unit is subdivided into five subunits. Each unit mainly consists of massive black shale with well-laminated black and silt bed, and contains some fine sandstone with cross lamination. The reddish shale unit is also subdivided into five subunits, which consist of reddish massive shale, white chert, and massive and well-laminated black-gray-red shale. The color changes between red and brown are gradual. The CL2 drillcore is generally more fragmented than CL1 and DX drillcores. Bedding orientation slightly changes at 75–76 m depth and 81–82 m depth.

Lithology of DX drillcore: The DX drillcore (100.15 m long) consists of four units: highly fragmented/deformed and well-laminated black shale (69–88m, with disturbance at 85–88m); well-laminated black shale with pyrite laminar (88–149m; a partly yet highly deformed section at 101–110m) with several cm-thick pyrite veins and 10–50-cm-thick massive sulfides at 138–139m and 144–149m depth ranges; massive and finely-laminated black shale; and reddish shale (110–118m) units associated with deformed/fragmented zones. The normal dip of the DX drillcore is approximately 50˚. Gradual changes in the dip orientation are observed at the 110–123m depth range that exhibits a few meter-scale open folds. The uppermost ~70m of the drillcore DX is generally highly weathered. Its upper part (47.9–59m) is massive and reddish, the middle part (59–63m) contains bleached materials, and the lower part (63–69m) is red but preserves a chilled margin structure of pillow basalt.

Report: Because a preliminary report of the DXCL-DP, focusing on its stratigraphy and geologic setting, has been recently published in [6], in this presentation we aim to report our current progress on the geochemistry of black shales from the DXCL samples.

Acknowledgements: We thank A.H. Hickman, H. Ohmoto, M. Nedachi, T. Urabe, M. Doepel, K. North, K. McLeod, G. McLeod, and J. Williamson for their suggestions and help throughout the course of the drilling project. We thank GSWA Shire of Roebourne for permission for drilling in the Pilbara coast. This research was financially supported by grants-in-aid from the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT, Grants#14340153 and 18253006) and by the Nippon Steel Corporation.

References: [1] Ohmoto, H. et al. (2006) *Nature, 442,* 873–876. [2] Anbar, A. D. et al. (2007) *Science, 317,* 1903–1906. [3] Kaufman, A. J. et al. (2007) *Science, 317,* 1900–1903. [4] Philippot, P. et al. (2007) *Science, 317,* 1534–1537. [5] Kiyokawa, S. et al. (2006) *Geol. Soc. Amer. Bull.*, *118*, 3–22. [6] Yamaguchi, K.E. et al. (2009) *Scientific Drilling, 7*, 34–37.