# Natural Fe fertilization mechanisms in the Amundsen Sea Polynya, Antarctica

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The polynya of the Amundsen Sea, West Antarctica, is the most productive region of the Antarctic Shelf (~40 mg/m3 Chl-a in Dec. 2010), and is a test case for natural Fe fertilization, in stark contrast to the Fe-limited Antarctic Circumpolar Current (ACC) that borders this shelf region. ASPIRE (Amundsen Sea Polynya International Research Expedition, field work completed 2010-11), is an multidisciplinary study with a core emphasis on the mechanisms and pathways of bioavailable Fe delivery to the polynya euphotic zone. Candidate Fe sources include atmospheric deposition, upwelling of Modified Circumplar Deep Water, sea ice melting, glacier and iceberg melting, and inputs from shallow sediments. Samples for dissolved and particulate (>0.45um) trace metals and for Nd isotopes were collected at 35 stations in Dec. to early Jan. using a Geotraces-type CTD-rosette and in-situ pumps. Dissolved Fe (dFe) concentrations varying widely, and generally increase with depth. High values (up to 2nM) occur in near-bottom (~700m) waters of the western bathymetric trough and in the outflow from under the Dotson ice shelf (1nM at 150-600m). Lowest values (<0.1nM) are found in surface waters of the most productive central polynya region. Suspended particulate Fe (pFe), ranging 5-60nM, exceeds dissolved Fe throughout. Leachable fractions (LpFe; 25% acetic acid) range 0.2-16nM (2-35% of pFe), are lowest in the euphotic zone and highest in two important regions: at 50-600m where glacial meltwater-influenced flow emanates from under the ice shelf, and at ~300m adjacent to a drifting iceberg encountered in the southern polynya. Euphotic zone leachable Fe/P ratios are generally >10 mmol/mol, suggesting Fe-replete phytoplankton at most stations. Strikingly, Fe/P is very high (>1000 mmol/mol) and nearly identical at 50-150m in both the ice shelf and iceberg stations, suggesting that these are regions of injection of potentially bioavaible glacially-sourced LpFe into the upper water column. Dissolved Nd isotopes (<0.2um), a quasi-conservative tracer of continental sources, support the importance of glacial terrigenous inputs, with values as low as -6.0 at the ice-shelf outflow station (compare to adjacent ACC at ~ -8.0), tracing Fe inputs from radiogenic source rocks to shelf waters.

Inputs of dissolved and especially of labile particulate Fe resulting from flow under glacial ice-shelves are a major source of bioavailable Fe fueling productivity in the Amundsen Sea polynya.

# Network of Terrestrial Subsurface sites in Precambrian Shields: Insights for Early Earth and Mars

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Like the Lost City Hydrothermal Vents or Rainbow field, at depths of 2-3 km below the Earth's surface, saline fracture waters in the Precambrian Shields of Canada, Fennoscandia and South Africa are some of the most $H_2$ –rich on the planet and hence an important setting to investigate the planet's habitability – but significantly under investigated compared to the higher temperature hydrothermal systems and marine analog sites. The deep fracture waters host some of the deepest microbial communities yet identified on the planet: a low biomass, low biodiversity ecosystem subsisting at maintenance rates far from the photosphere – dominated by $H_2$-utilizing sulphate-reducing bacteria and $H_2$ derived from radiolysis and serpentinization [1,2]. These subsurface sites represent a critical environment in which to determine whether the types of chemolithotrophic life recognized at the vents are supported in the much larger segments of the Earth's crust where lower temperatures and hence slower rates of water-rock reaction prevail.

The tectonically quiescent, ancient fractured rock subsurface is directly relevant to single plate planets such as Mars, where surface expressions of volcanism such as hydrothermal vents are unlikely. Many of the investigated sites are located in northern regions in areas of continuous or semi-continuous permafrost, providing the opportunity to investigate psychrophilic life and hence as analogs for potential extinct or extant life on the icy planets and moons. Unlike high temperature seafloor systems like Lost City, where rapid fluid circulation and mixing means that the products of water-rock reaction such as $H_2$ rapidly diffuse away, the hydrogeologically isolated fracture waters in Precambrian Shield rock provide virtual "time capsules" in which, despite the slower rates of reaction, the products of water rock reaction and potential substrates for microbial life can accumulate and build up high concentration gradients over geological long time scales. The deepest and oldest fracture networks have residence time estimates derived from noble gas studies on the order of tens of millions of years [3], preserving a geochemical and microbial environment minimally impacted by hydrogeological mixing with the surface. They may provide a window into a different aspect of the Earth's biodiversity, but most significantly may preserve a more deeply branched and potentially evolutionarily older component of the Earth's life history with important implications for the origin and radiation of life on Earth. The deepest fracture water may even provide the opportunity to investigate controls on the biotic-abiotic transition and limits to life in the deep Earth.

[1] Lin et al. (2006) *Science* **314,** 479-482.
[2] Chivian et al. (2009) *Science* **322,** 275-278.
[3] Lippmann-Pipke et al. (2011) *Chemical Geology* **283,** 287-296.