^{13}C depleted carbon microparticles in >3700 Ma sea floor sediments from the Isua supracrustal belt, West Greenland: implications for Earth's earliest habitats?

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Metamorphic rocks with well preserved sedimentary structures have been found in a low-strain domain in the >3700 Ma Isua supracrustal belt. The sediments are bordered on either side by metabasalts and appear to form a depositional continuum with the basaltic units. The well preserved sedimentary screen can be traced ca 100 m along strike and forms a *c.* 50 m thick succession dominated by Bouma sequence clastic sediments intercalated with banded iron formation. The Bouma sequences range in thickness from *c.* 10–70 cm. They are defined by up to 60 cm thick units of gray fine-grained greywacke displaying a gradation in colour from light gray at the bottom to darker gray at the top separated by slaty black units up to 10 cm in thickness. The gray graded units are interpreted as turbidity current deposits and the black slates as pelagic muds. Near the base of greywacke layers cm-size tabular flakes of the black slate interpreted as rip-up clasts of pelagic shale occur. The depositional environment was most likely in an oceanic environment at a water depth below the wave base, i.e. possibly exceeding 100 m and possibly in the vicinity of volcanic edifices.

The black slates are laminated on a sub-mm scale with alternating lighter and darker layers consisting of varying proportions of quarts, muscovite, biotite, chlorite, pyrrhotite, ilmenite, chalcopyrite and graphite. The darker layers are rich in micas and graphite while the lighter layers are richer in quartz. On a cm-scale packages of such fine layers are interspersed with strictly concordant mm thick feldspar-rich layers of slightly coarser grain size. These layers contain little or no carbon. The layered structure is cross cut by mm-wide carbon-free quartz veins.

In both the graded turbidite deposits and the black slate, carbon is seen as abundant 2–5 μm sized globular grains included in the silicate phases. In some cases strong anisotropy has been observed in the grains, and it is assumed that they are dominantly composed of graphite. The graphite globules are arranged along buckled stringers or surfaces subparallel to the bedding. These stringers and surfaces transgress grain boundaries, such that one string can be found within several consecutive quartz and mica grains. The graphite grains fall within the same limited size-range both within the area of a thin section and between different samples separated by metres in the field. The particle size show no correlation to the abundance of graphite in the layer in which it occurs. The distribution of graphite grains closely follow the sedimentary bedding, and is disrupted by boudinage and quartz veining. Where the rocks have undergone local shear deformation carbon is recrystallized to 10–100 μm size flaky graphite.

The absence of carbon grain size sorting between different parts of the Bouma sequences may indicate that only 2–5 μm particles were available in the sediment source. The laminated slaty sediments deposited in low energy environments have higher total abundance of carbon compared to the sediments deposited by the turbidity current, but both types of sediment have abundant graphite globules. This is in contrast to the coarse grained feldspar-rich layers within the laminated slaty sediments, which are virtually free from graphite globules. This probably indicates that carbon rich pelagic muddy sediments where eroded by the turbidity currents and incorporated into their deposits. The plagioclase-rich interlayers in the pelagic sediments could represent volcaniclastic sediments settled through stagnant water without disruption of the assumed muddy precursor of the laminated slates. The strong stratigraphic control of the abundance of graphite inclusions suggest that graphite or the reduced carbon precursor were emplaced during sedimentation, and not during later fluid migration.

Conventional analysis of the carbon isotopic composition of decarbonated whole rock powders of the metasediments indicate $\delta^{13}C$ values in the range −18.8 to −19.1. These compositions are within

the range of biologically reduced carbon. The limited range in values, and the lack of correlation with total reduced carbon content of the samples suggest that the $\delta^{13}C$ values are not to a first order disturbed by secondary equilibration with a transient carbonic fluid phase.

The carbon particles most probably sedimented from suspension or formed directly in the pelagic mud during sedimentation. The absence of carbon grains from the coarser grained feldspar-rich volcaniclastic layers favour an origin by settling from suspension. The sediments were deposited below the photic zone. If this precursor of the graphite grains included organic detritus, the organisms could have been photoautotrophes that sedimented from the photic zone. If the reduced carbon particles formed in the mud, they could have been formed by heterotrophic or chemoautotrophic organisms.