**Introduction:** Terrestrial early Archaean crustal materials were formed in a geological context remarkably similar to that of Noachian/Early Hesperian Mars [1,2]. They are dominated by igneous lithologies, including volcanics and their derivatives (sediments, alteration products) as well as hydrothermal precipitates and evaporitic secondary deposits. The sediments were deposited in aqueous basins including littoral environments. Although the early Earth was an ocean covered planet (as opposed to Mars), the few remaining portions of well-preserved Early Archaean crust conserve mostly volcanic and sedimentary sequences formed at relatively shallow water depths or in the coastal environments. These volcanic and sedimentary materials contain traces of primitive life (chemolithotrophic and possibly chemoorganotrophic) of the kind that could have lived on early Mars [2].

The early Archaean terranes occur in the Pilbara (NW. Australia) and the Barberton (E. South Africa) greenstone belts. There are many outcrops in these regions that could serve as useful analogue locations but here we will concentrate our descriptions on one locality from each region as representative examples. The 3.45 Ga-old Kittys Gap Chert (KGC, Fig. 1 [2, 3]) in the Pilbara is located at 20°53′33.56″S, 120°04′22.37″E and includes rhyolytic to maﬁc/ultramafic (basalts, komatiite) volcanics with intercalated sediments derived from these volcanic sequences. Sedimentary structures record deposition in a littoral mud-flat environment [4]. The environment was directly influenced by contemporaneous moderately high temperature hydrothermal activity (~175°C, [5]. The coordinates for the 3.3 Ga-old Josefsdal Chert (JC, Fig. 2) are 25°57′54.71″S, 31°04′41.22″E. This locality records two sedimentary successions between ultramafic pillow basalts flows. Sedimentary structures show that the volcanic sediments were deposited in a relatively shallow basin at depths ranging from sub wave base to the littoral environment [6-8]. There is also evidence for direct and indirect hydrothermal influence on the environment.

**Mission Description:** These analogue locations are of relevance for any Mars missions with the upper crust as a science objective because they touch on the nature (i.e. volcanic, plutonic, sedimentary, hydrothermal, evaporitic) of the crustal materials, depositional environments, habitability, and biosignature preservation. They are thus of relevance to the 2011 MSL, the 2018 Max-C/ExoMars, and the 2022(?) Mars Sample Return missions.

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**Figure 1.** Kittys Gap Chert location in the Pilbara of Australia.

**Figure 2.** Location of the Josefsdal Chert, Barberton, South Africa.

In terms of access for study and/or field testing of instruments, both locations have nearby roads. The KG site is at a distance of 0.5 km from the road and at an elevation of 100 m above it. The terrain is rocky and slopes to the outcrop levels are ~25°. The most accessible portion of the JC outcrop is a short 50 m walk from the road along a small ridge. The terrain is moderately rocky. Portions of the outcrop occur on the
ridge top where there is more or less no slope but other
potsions are on steep slopes of ~30°.

Science Merit Related to Mission Objectives:

(1) The Kittys Gap Chert: The KGC is part of the
Coppin Gap Greenstone Belt. The greenstone belts are
associations of extrusive and intrusive volcanics and
volcaniclastic sediments that have been penecontempo-
raneously intruded by primitive granites (TTGs). The
KGC has been directly dated at 3.46 Ga and is the
stratigraphical equivalent of the Panorama Formation
in the Warrawwona Group. Regionally, the sediments
were deposited on the edge of a large basinal structure
characterized by circum-basinal growth faults [4,9].
Structurally, the growth faults cutting the KGC control
depositional thicknesses with thicker volcanic and
sedimentary deposits towards the hanging wall of the
growth fault. Apart from the syndepositional growth
faults, the deposits have been tilted vertically due to
regional tectonic disturbance related to the granitoid
intrusions. This means that layers of rock exhibiting
compositional, habitability, and biosignature diversity
are readily accessible at the surface. Younging direc-
tion of the various facies is to the north. Metamorphic
alteration is limited to burial metamorphism (prehnite-
pumpellyte facies). A major influence on the sediment-
ary facies was their penecontemporaneous silicification.
Silicon isotopes show that the silicification was
both hydrothermal and due to Si-enriched seawater [5].
Indeed, a number of chert veins penetrate the base of
the chert and represent hydrothermal conduits originat-
ing in the underlying felsic volcanics.

The volcanics and sediments of the KGC form lin-
ear sequences that outcrop laterally over 4 km along an
upstanding ridge. The ridge is formed by the resistant
silicified sedimentary deposits. Three ~2m thick layers
of sediments are interspersed with ~5 m thick layers
basaltic composition. The underlying, intervening and
overlying volcanics are not silicified and are poorly
exposed. The sediments are capped by mafic and ul-
tramafic volcanics including komatitites.

The sedimentary sequences are of particular interest
as analogues of volcanioclastics deposited in shallow
environments on Mars because (1) of their sedimentary
structures and the story they tell about an evolving
coastal sedimentary regime; (2) the information con-
cerning the environmental habitability; (3) the biosig-
natures of primitive life forms living in/on the sedi-
ments; and (4) the influence of penecontemporaneous
hydrothermal activity on sedimentation, habitability,
and preservation of the biosignatures.

Sedimentary structures are clearly observable on
the weathered outcrop surfaces (Fig. 3A). Indeed, dif-
ferential responses to weathering have highlighted the
sedimentary structures, thus aiding environmental in-
terpretation. The outcrop consists of mm-cm thick al-
ternating black and white layers, the black layers con-
sisting of fine grained volcanic clasts (silt-sized) and
the white layers of coarser, sand-sized clasts. Sedimen-
tary structures include parallel, cross, flaser and chan-
nel bedding. These have been interpreted to indicate
sedimentation in an infilling tidal channel [4]. There is
at least one horizon containing 0.5 cm-sized embedded
pumice fragments that has characteristics suggestive of
brief subaerial exposure [2, 3]. Rapid silicification of
the sediments is indicated by in situ brecciation of al-
ready lithified lower layers of the sediment pile. The
silica is of seawater and hydrothermal origin.

The sediment is a heavily silicified (>85%) vol-
caniclastic protolith [10]. The volcanic particles now
consist of illite/muscovite but were originally Ti-
bearing mica, K-feldspar, amphibole, glass shards or
mineral debris. The diagenetic aqueous alteration
pathway would have been: conversion of the volcanic
protolith via (bio?)chemical processes to montmorillon-
ite, conversion of the montmorillonite via hydrother-
mal alteration and burial metamorphism to il-
lite/muscovite. The particles are angular, indicating
local provenance.

Figure 3. KGC. (A) Field view of sedimentary structures
and (B) close-up view of the microhabitats.

These sediments contain morphological, organic
and isotopic biosignatures [2, 3]. Different microhabi-
tats in the sediment (Fig. 3B) contain different types of
microbial remains. Silicified (probable) chemolithotrophic coccoidal microorganisms colonised the surfaces of the volcanic clasts, pumice and dust (fine silt layers). The exposed sediment surface was coated with a fine multispecies biofilm as well as the torn remains of local microbial mats. The layers containing these remnants have a total carbon concentration of 0.01-0.05% and carbon isotopic values between -26 and -28‰.

Summary: The KGC is an accessible outcrop showing well developed tectonic, volcanic, sedimentological and hydrothermal structures. It consists of a variety of lithologies (ultramafic to acidic volcanics, volcaniclastic sediments and hydrothermal chert). The volcanic clasts have been altered to phyllosilicates (illite/muscovite) and are associated with morphological, organic and isotopic traces of life. The volcano-sedimentological sequence was formed 3.45 Ga at a time when similar volcanoclastic deposits were being deposited in shallow water basinal environments on Mars, possibly influenced by hydrothermal activity.

(2) The Josefsdal Chert: There are many similarities in terms of geological context and environmental setting between the JC and the KGC [7]. The JC consists of sediment layers sandwiched between mafic lava flows [11]. Occurring at the top of the Kromberg Formation of the Onverwacht Group, the JC has an estimated age of 3.3 Ga [8]. It was subjected to lowermost greenschist metamorphism and has been faulted and tilted by tectonic activity resulting in almost vertical strata. The sediments were initially deposited in a littoral environment (a beach sand is preserved) which deepened with time such that later sediments were possibly even deposited below wave base. Sedimentary structures include parallel, ripple, flaser and channel bedding. This outcrop has not been exposed as long as the KGC and the sedimentary structures tend to be more cryptic but are nevertheless visible at outcrop level. As with the KGC, the clasts are volcanic protoliths, now replaced by fuchsite, a Cr-rich muscovite [7]. One major difference between the JC and the KGC is that carbon is concentrated into distinct horizons in the black and white layered JC (Fig. 4A). The black layers may contain up to 0.1% organic carbon (Fig. 5). Microscopic observations show that, where deposited in shallow water, the layers represent microbial mats formed on sediment surfaces, whereas in the deeper deposits they simply represent sedimented carbonaceous remains. Isotopic analysis of the carbon results in a -26.8‰ signature [7]. Morphological remains of microbial mats and other colony-forming organisms occur in this sediment [6-8]. Hydrothermal influence was pervasive and contemporaneous in this environment [6,7,11]. [7] even observed a microbial mat that appears to have formed in a hydrothermal outflow channel (Fig. 4B) and was probably killed by an outpouring of hot, silica-rich fluids.

Summary: The 3.3 Ga-old JC is a very accessible outcrop showing well developed volcanic, sedimentological, hydrothermal, and tectonic structures. It consists of a variety of well exposed lithologies (mafic volcanics, volcaniclastic sediments and hydrothermal chert). The volcanic clasts have been altered to phyllosilicates (illite/muscovite) and the sediments are associated with morphological, organic and isotopic traces of life. The JC also formed in a shallow water environment and at a period when similar sediments were being deposited in basinal settings on Mars.