The Ironberry Plan: an Electric and Steel-making Way to Build a Science Station on Mars

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This paper introduces the Ironberry Plan. This practical plan leads to the construction of a science station in the iron region of the Meridiani Planum (IRoM), Mars. It also enables the continuation of NASA's Water Strategy, the beginning of astronomy from Mars, the landing of humans at IRoM and the beginning of continuous human habitation there. A focus of the plan is to provide abundant electricity on Mars through an intense use of local resources. The characteristic early steps of the Ironberry Plan are:
1. The robotic harvesting and processing of a superb iron ore at IRoM;
2. The use of Mars-optimized, robot-controlled steel-making and manufacture of steel parts;
3. At least for some years, a deliberate push for mutually feeding exponential growth in electricity generation, steel-making and steel manufacture, where early steel manufacture is focused on making more electrical generation equipment;
4. Using the rapidly growing power capacity and advanced robotics and processing of local sediments, the start of many more foundational activities (i.e., water liberation, sulfur-concrete construction, multi-material manufacture, agriculture and more);
5. Using 1-4, the building of a science station at IRoM while also converting excavated sediment caverns into underground, radiation-protected spaces for the science station.

Keywords: Ironberries, Iron Region of the Meridiani Planum (IRoM), Science Station, Abundant Electricity, Steel-making

1 INTRODUCTION

While the characteristic steps of the Ironberry Plan are written succinctly, demonstrating its practicality cannot be done briefly. There are very many points to consider and some will be new and unfamiliar to most readers. This creates a writing and communication challenge.

To write a good read for one sitting, the author made a selection of points to cover. This selection will cover (a) the plan's broad points and its benefits and features, (b) the exceptional iron and sediment resources at IRoM that are a foundation pillar that makes so many of the plan's activities practicable, (c) an overview of the Mars-optimized iron- and steel-making that can turn IRoM's hematite (Fe_2O_3) iron ore into sheet steel and steel powder, (d) very brief comments on existing robotic manufacturing that is already capable to deliver the needed steel parts, (e) an outline of how IRoM's sediment could be processed to liberate a lot of water and make many valuable intermediate materials for building a science station, (f) a short consideration of the station's scale, also (g) a commentary on details that were not included in this plan outline.

Hopefully, the details left out of this shortened text attract questions that test the plan's practicality. The plan should survive such tests; it could be implemented soon, at least if a spacecraft can land a giant payload on undisturbed, unengineered Martian ground at least once.

2 THE PLAN'S BROAD POINTS

2.1 Flexibility & Options

The strengths of the plan's characteristic parts facilitate a broad range of options and ideas to be carried out. Illustrations appear below. Flexibility is a feature of the Ironberry Plan. This flexibility allows us to change our actions with changing circumstances, deploy newly needed equipment and evolve with the benefit of human ingenuity and new information.

2.2 Contingency on knowledge of the iron region of the Meridiani Planum (IRoM)

The practical formulation of the Ironberry Plan was most contingent on knowledge about IRoM. This knowledge is based on the data collected and the studies made in NASA's early Water Strategy projects, particularly those of the orbiter Mars Global Surveyor (MGS) and the rover *Opportunity* [1-6, 23-28, 30-32].

Sub-region name note: The iron region of the Meridiani Planum (IRoM) is a sub-region of the larger Meridiani Planum, see Fig. 1. This sub-region does not yet have a proper name adopted by the International Astronomical Union (IAU). However, a name request for this sub-region (i.e., "Berry Campus") was recently sent to the IAU for review. In previous Mars literature, this sub-region has been implied by the phrase "the

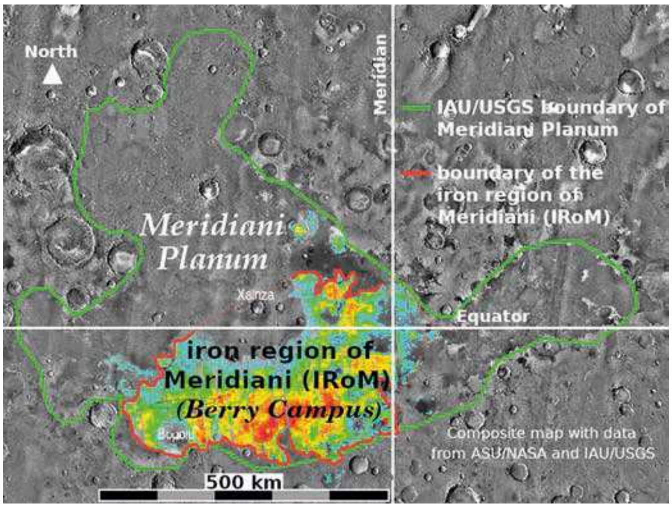

Fig.1 Boundaries of the Meridiani Planum and the iron region of the Meridiani Planum (IRoM). Christensen et al. first mapped IRoM with the thermal emission spectrometer (TES) hematite survey from the MGS orbiter [3,1]. The data source used here to delineate IRoM's boundaries is ref [4]. This data is imperfect since new surface material (such as crater ejecta from Bopulo and Xainza craters) often obscures hematite detection from orbit.

hematite-bearing unit of Meridiani Planum" [1] and denoted by "the hematite plains of the Terra Meridiani" [2]. Less accurately, the name "Meridiani Planum" was often used in geological writings as a name associated with the hematite-rich sub-region. While this is not incorrect, it is misleading because the boundaries of the Meridiani Planum, as accepted by the IAU (see Fig. 1), are drawn to encompass a much larger region with high levels of surface hydration [5, 6]. This paper often refers to the sub-region with high levels of hematite; using the abbreviation IRoM enhances brevity.

2.3 Contingency on Various Technologies

Plans from 1989 and 1990 [7, 8] to land humans on Mars were thwarted by a lack of demonstrated technology to (a) transport very large payloads to Mars and then (b) successfully protect such payloads through the "7 minutes of terror" [9] of Mars EDL (entry, descent and landing).

Success in implementing the Ironberry Plan is also contingent on the availability of various technologies. Some of these were developed and deployed since 1990, while a few are in the late stages of development but still need to be firmly demonstrated. The already dependable, post-1990 advances include:

- post-1990 improvements to robotics, computers, artificial intelligence and environment sensing;
- Extreme radiation-intensity photovoltaic cells and cell cooling technology [10];
- Concentrating solar power plants that are largely made of steel [10,11];
- recent generations of solid oxide electrolysis cells [12,13];
- CO_2 PEM electrolysis systems (CO_2-splitters) with low start-up temperatures [14];

The most nail-biting technologies the Ironberry Plan still waits on are, as in 1989 and 1990, a spacecraft capable of a 30-100 tonne payload EDL onto Mars. There are demonstrations that such an EDL will likely be successful, they are: (i) the retro-propulsive landings of SpaceX Falcon 9 boosters [15], (ii) the successful 10-km-fall-and-land tests of prototypes of SpaceX's giant Starship [16] and (iii) the soon-to-occur tests of EDL's to Earth from orbit by Starship, also (iv), the superb technology iteration methods of SpaceX. However, the above does not address the final few seconds of Mars EDLs when the descending spacecraft has to fire rockets a few meters above pristine Mars terrain, pound onto the unengineered ground and remain stable and intact. A demonstration of a giant payload EDL onto a rough landscape on Earth should be done.

2.4 Self-Sustainability

The Ironberry Plan should aim to rapidly build a science station that comes close to being self-sustaining by using local resources and robots. Subsequent sections discuss how to turn IRoM's mineral materials and atmosphere into valuable intermediates and the many things that can be done with them. The Ironberry Plan does not need vast transport of supplies and equipment from Earth. It does not emulate The Iliad and dispatch 1,000 Starships from Earth to Mars close to every conjunction (conjunctions recur every 780 days). In the Ironberry Plan, the number of transport spaceships reaching Mars remains small (one or a few every 780-day period).

2.5 Abundant electricity at IRoM via steel-making and the Sun

Electricity enables almost every human activity on Earth. As with Earth so with Mars in the future, this paper gives examples of things that can be accomplished with abundant electricity, capable robots, processing equipment and raw materials such as iron ore. All of these conditions can be available at IRoM. Given this, a core goal of the Ironberry Plan is to provide abundant electricity at IRoM.

Abundant electricity requires a capacious power source, sunlight suffices. Concentrating solar power equipment can harness this power. A detailed discussion of concentrating solar technologies and their applications on Mars is beyond the scope of this paper. However, there are three important, short points to make about concentrated solar technology. One, suitable concentrating solar plants exist and are in action today [10]. Two, all concentrated solar plants can be largely made out of steel. Three, on Mars, using the technology of ref [10], roughly 2,000 m^2 of steel-made heliostats (solar concentrators) will be focused onto just 1 m^2 of extreme radiation-intensity photovoltaic cells. This ~2,000 to 1 concentration, or a smaller 100 to 1 concentration suggested by a reviewer for another technology, hugely increases the productive value of photovoltaics transported from Earth. Large-multiple solar concentration is one of a few factors that make abundant electricity at IRoM a practical goal to strive for.

2.6 Electricity, steel-making, steel-manufacturing, exponential growth

Another factor making abundant electricity at IRoM a practical goal is the power of exponential growth.

Within the Ironberry Plan, electricity generation, steel-making and steel manufacturing mutually feed each other, see Fig. 2, and provide for a science station. Importantly, steel manufacturing feeds electricity generation by producing steel equipment (such as heliostats) that increase electrical capacity and this extra capacity increases generation. The plan's mutual feeding can be controlled to produce growth or stasis. Exponen-

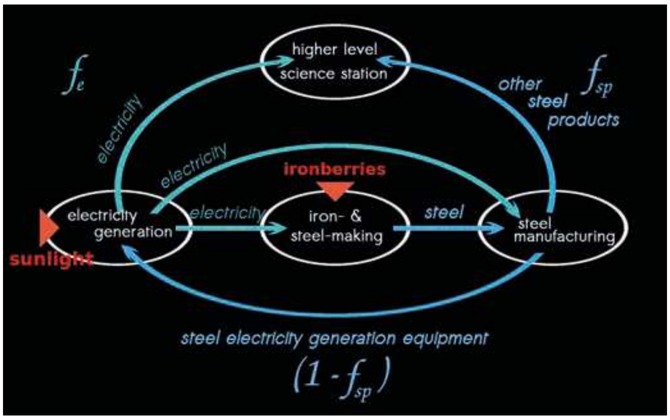

Fig.2 Mutual feeding of electricity generation, steel-making and steel manufacturing to grow each other and provide for a science station.

tial growth is easily produced in this infrastructure-system by holding fixed for extended periods the fraction, $\left(1-f_{sp}\right)$, of steel manufacturing devoted to making new electricity generating equipment and the fraction, f_e, of electricity sent to higher level science station activities ($\left(1-f_{sp}\right)$is used for steel-making and manufacturing together). The doubling time for this exponential growth is shortened or lengthened by, respectively, increasing or decreasing the fraction $\left(1-f_{sp}\right)$.

A sensible way to operate this mutually-feeding infrastructure-system across the history of building a science station is to (a) set $\left(1-f_{sp}\right)$ close to 1 (say 0.95) during the first couple of years of implementing the plan on Mars, then (b) step-by-step, reduce the value of $\left(1-f_{sp}\right)$ until it reaches 0 (when no further growth occurs). Such a regimen concentrates on the building the power/steel infrastructure first with the delayed-satisfaction benefit of building a full, desired science station quicker (in the longer term). The rates of growth and exponential doubling times can also be altered by varying f_e, the fraction of electricity devoted to higher level science station activities.

2.6 Manufacturing & Human Ingenuity

The plan achieves many of its detailed goals using local manufacturing. Humans control this manufacturing with the aid of robotic intermediaries. In its early stages, the Ironberry Plan will focus on making the least complicated parts of a few high-impact systems – primarily concentrated solar sub-systems. However, this manufacturing will progress to make a greater variety of parts and systems and eventually, it will include the production of complicated and high-precision systems. The implementation of the Ironberry Plan will put high value on broadening the scope of Martian manufacturing. As such, many people working from computers on Earth will be exposed to attractive opportunities to advance the capabilities of Martian robotic manufacturing. The implementation of the Ironberry plan needs and benefits from never-ending flows of human ingenuity translated into inputs communicated to the robots and translated into the hardware manufactured on and transported to Mars.

2.7 Continuation of the Water Strategy

In the middle 1990s, Carl Sagan and Daniel Goldin formulated the Water Strategy [17, 18, 19]. It seeks to look for signs of life on Mars at locations with signs of past or present water. As of 2024, the eleven successful missions within the Water Strategy have vastly expanded our knowledge of the geology of Mars and established that it is hard to find signs of life on the planet's surface. However, NASA's rovers have only searched a tiny fraction of the planet's surface. There are many more surface sites to search, while the sub-surface is completely unknown and an excellent place to look; lithotrophs ("rock eaters") are common underground and may be at the root of the Tree of Life of Earth [20].

It is essential to continue the Water Strategy. With a science station at IRoM, the search for signs of life on Mars will become much more thorough than in the past quarter century. It will be more thorough because thousands of sites across the planet will be reached from IRoM at a tiny fraction of the costs of putting today's rovers at their landing sites. Further, the station's scientific instruments will be substantially more various and capable than those on current rovers. Eventually, a lot of the station's electricity should be devoted to making CO/LOX (carbon monoxide/liquid oxygen) ground transport propellant and to store energy (in propellant) for electricity production anytime, anyplace. This mature emphasis will enable many site visits across Mars.

2.8 Humans on Mars

The Ironberry Plan can enable the most discussed Martian goal, landing humans on Mars. The safest plans to put humans on Mars do so with the aid of precursor missions. Zubrin and Baker's 1990 Mars Direct [8] was the first of such plans. That plan advocated for (a) a landing of a precursor spacecraft, (b) use of local carbon dioxide, (c) automated propellant production inside the precursor spacecraft and (d) human landings on Mars with returns to Earth using the locally fuelled precursor craft. The Ironberry Plan has similarities to Mars Direct when it enables humans to travel to Mars and return. However, the Ironberry Plan's precursor missions are more ambitious and offer a wider variety of options. To illustrate these options and the flexibility they provide, a hypothetical mission history is given. It highlights some benefits of Ironberry Plan precursor missions, such as gathering information that affects decisions on when and how to launch humans-to-Mars missions. It also illustrates Water Strategy steps, the push toward self-sustainability, benefits of easy excavation of the soft rock sediments at IRoM and benefits of giant payload transports like the SpaceX Starship. Most of the steps and points made in this hypothetical mission are integral (although not distinguishing) parts of the Ironberry Plan.

In this hypothetical humans-to-Mars history, the first human crew landed at IRoM following two rounds of large payload precursor missions that landed before the first crew by one and two 780-day periods. These precursors already started a small science station. They established several structures, including two robotically run factories (made by converting the two previously landed Starships), with one devoted to steel-making and manufacture and the second to a propellant production unit and an early sample-testing laboratory. The other early structures include: a electricity generation facility with 1.8 megawatts peak capacity; deep bores into IRoM's sediments to search for signs of life and test sediment hydration levels; an excavated shelter and repair shop for roving robots; steel storage tanks for fluids; the first rock dehydration facility (running on the waste heat from electricity generation [21]); and also a leveled landing pad for the first crewed Starship. The crewed mission landed on the pad after a fast 201-day transit.

The final decision to make this mission crewed was made after a review of evidence for signs of life found none. The review looked at data from eight sediment bores and surface sampling within 1,200 m of the growing station.

The first crewed Starship landed a full 100-tonne payload after earlier geotechnical tests established a full load was in order. The ship's load contained more than enough food for a planned, 497-day stay, as well as equipment to establish underground, LED-lit agriculture and underground crew living quarters, plus plenty more equipment and parts to expand electricity generation and steel production further. The underground shelter for robots was given over to human habitation and early agriculture. This conversion was expected to take 77 days. Conversion planning benefitted from a laser scan of the excavations and a predictable supply of local sheet steel. The conversion was finished eight days late due to assembly problems that required updated computer instructions. The successful updates were written in under six hours by a Colorado engineer, with the aid of AI, then tested at California's JPL and finally communicated to IRoM.

Later excavation allowed the crew to move into a dedicated habitat. This gave agriculture more space and also excavated rock (a resource). Two crew members ran agriculture experiments, oversaw excavations and prepared to turn some sediment bores into dehydration water wells. The agricultural experiments were successful and provided an option to stay another 780 days. All crew stayed. The other two crew worked on construction, long-distance transport and travel. They oversaw assembly and maintainance of a 3-tonne all-terrain construction robot capable of road-building with sulfur concrete and 60 km/h travel speeds. Locally-made steel parts accounted for 87% of this robot's mass. It sped up solar concentrator deployments, built a mini landing/launch pad in Coimbra Crater (280 km distant) and modifed the science station's initial landing pad to include a flame deflection structure (making it safer for launch). On their penultimate day on Mars, the first crew enjoyed watching a flight of a rocket plane. It flew toward Coimbra Crater with partial success. The second crew to land on Mars organized that test. 1,276 days after landing, the first crew returned to Earth in their refueled, original Starship. When they left, IRoM's electricity capacity had surpassed 6 MW, while the rate of water liberation was determining how many people were going on subsequent missions.

2.9 Astronomy from Mars

For millennia, humans have searched to understand our place and significance in the Cosmos. Astronomy adds new chapters to this quest with each cutting-edge telescope system commissioned. The astronomy of the near future will use telescopes that are off-Earth, in space, or on other bodies like Mars. As the Ironberry Plan persists, it could and should enable new astronomy.

Possibly the most promising project to start at IRoM, in the middle-term future, would be to take advantage of the newly acquired precision Martian manufacturing and build a large, interferometric array of mid-infrared (5-50 μm) telescopes. Such interferometry will involve high-frequency (6-60 THz) detector technology that is nearly available today [22]. The atmosphere is so dry that an array at IRoM will have excellent observing conditions. IRoM's resources and the station's grown manufacturing base will allow an array with a light-collecting area that far exceeds the James Webb Space Telescope's. To see distant rocky exoplanets, mid-infrared observations are best-of-all. A fraction of those exoplanets will have temperatures similar to Earth's. This astronomy will infer the water conditions on such planets. With such an observatory, our children will know how rare Earth-like planets are in our galactic neighborhood.

3. IRoM

NASA's rover *Opportunity* spent years studying the sedimentary rock making up the hematite-bearing unit of IRoM, the cratering of these sediments and the eroded surface deposits on top of the sedimentary rock. Many papers were written about these studies. These papers were crucial for formulating the Ironberry Plan.

3.1 Uniformity & station location

The uniformity of IRoM is remarkable. The composition of the sediments between the rover's landing site and Victoria Crater are largely uniform [23, 24]. Arvidson et al. [2] argued that IRoM's sediments formed through regional-scale changes. With nearly four more years of data, ref [24] reiterated the regional scope of water-induced rock alteration. Ref [24] also found that the details of soil bedforms overlaying most of IRoM's sediments were related to the size of lag-deposited hematite-rich spherules that cover these soil bedforms. The large database of ultra-resolution HiRISE orbiter images [25] show a restricted variety of soil bedforms and sediment outcrop features right across IRoM. This HiRISE data adds weight to the early inference [26] that the region-wide detection of surface hematite from orbit [1, 3] was due to the region-wide covering of soil bedforms by loose, lag-deposited, hematite-rich spherules. These factors, as well as the regional covering of hydrated sulfates and regional flatness suggest the sediments across IRoM have a similar composition [1, 2, 24]. Given this uniformity, a science station could be founded at many IRoM locations using the approach given in this Ironberry Plan outline.

3.2 Ironberries, surfaces, rover mobility and harvesting

After twenty years, the hematite-rich spherules have yet to have a formal name used in major journals covering Martian geology. Although, in informal settings, they were often called "Martian blueberries." They are essential for the Ironberry Plan and need a name. Here, they are called "ironberries."

Ironberries can either be loose and deposited on the top surfaces of IRoM, or they are embedded in the underlying sediments. Fig. 3(a)-3(d) illustrate these loose and embedded contexts. Fig. 3(a) shows ironberries partially embedded in sediments exposed in the walls of Eagle Crater. Loose ironberries started embedded. They were loosened and lag-deposited by (i) meteorite impacts on the sediments, (ii) wind-driven small-particle erosion (saltation) and (iii) size sorting [27, 28]. Fig. 3(b) shows blocks of meteorite impact ejecta and crater walls where the erosion to loosen ironberries happens.

Significantly, loose surface ironberries can be gathered in huge numbers from the surfaces of smooth sheet soil bedforms quite easily. (Fig. 3(d) illustrates such smooth sheet soil surfaces). For example, surface brushing drums on small robotic harvesters could lift thousands of ironberries off the tops of smooth sheet soils every second while separating them from soil particles using sieves and magnets and depositing the harvested ironberries into holding bins on the harvester [29]. Fig. 4 illustrates such ironberry harvesting.

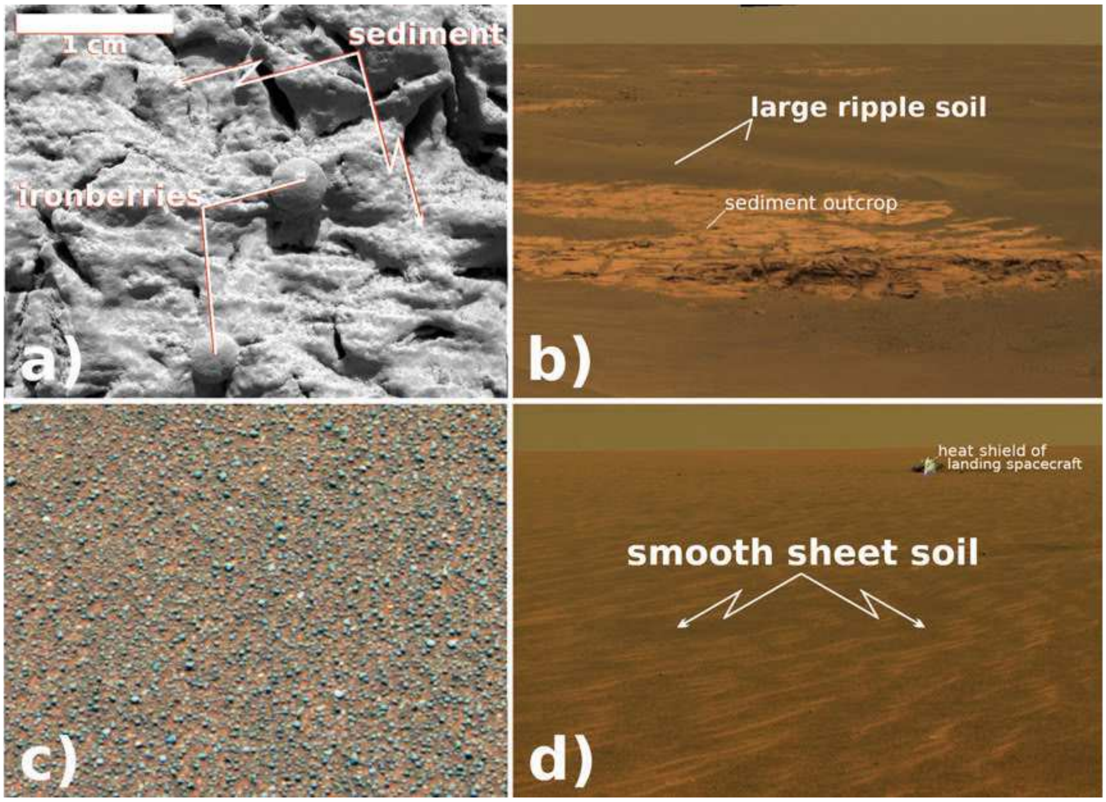

Fig.3 Sediments, ironberries and soil bedforms. (a) close-up view of sediments and ironberries in a near-vertical wall section of Eagle Crater (by Microscopic Imager, on sol 29), (b) long-distance view of ripple soil bedforms and sediment outcrop (by Pancam, on sol 827), (c) false-color, downward-looking view from a height of 1.5 m of the top surface of a soil bedform showing a near-average surface density of ironberries (the blue blobs) (by Pancam, on sol 532), (b) long-distance view across smooth sheet soil bedform (by Pancam, on sol 322).

The typical surface density of ironberries on soil bedforms is very high. Fig. 3(c) (in false color) illustrates this. This photograph was used in the main study of ironberry surface density [30] to show a sampling site with a near-average surface density of ironberries. Although, the depth of ironberries on soil is shallow (less than 1 cm).

Smooth sheet soil bedforms are common but not everywhere [28]. Large parts of the region have surfaces like the one shown in Fig. 3(b), which is characterized by ripple soil bedforms interspersed with outcrops of the underlying IRoM sediments. The ripples shown in Fig. 3(b) are taller and wider than average. In a long expanse between Victoria Crater and Endeavour Crater, ripples mostly have heights under 20 cm and the fraction of the surface area with exposed sediment outcrop is often more extensive than the areas covered by ripples. *Opportunity* found it easy to move over smooth sheet soil and areas with short ripples and large expanses of outcrop. The rover struggled on the tallest ripples, such as Purgatory Ripple, with heights approaching 1 m.

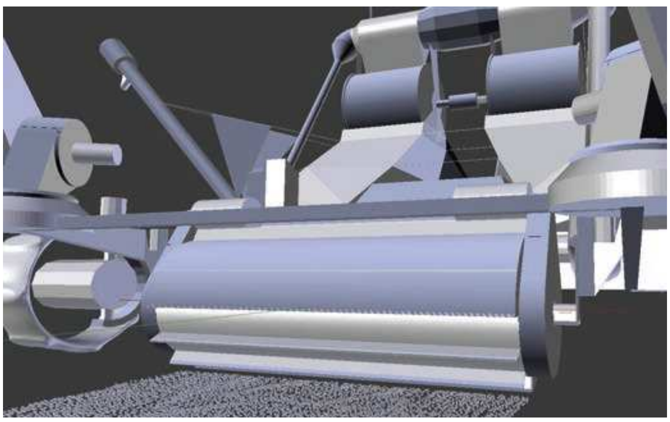

Fig.4 Robot harvester concept for harvesting ironberries from smooth sheet soils..

Opportunity's scientists realized early that ironberries are probably rich in hematite [26], although it proved difficult to fix their hematite levels [31]. However, using a 2008 result that *Opportunity's* thermal emission spectrometer could not detect siliceous material in ironberries [30], a recent data analysis placed a lower bound on ironberry hematite levels at 78 wt% with likely levels well above this [32].

Loose ironberries on smooth sheet soil are a superb iron ore to start steel production with a small complement of equipment transported in a spacecraft. These ironberries have very high hematite levels, while minimal equipment can harvest them and input them to a reduction furnace.

3.3 Steel-making at IRoM

The way that steel is made on Mars will change over time. More techniques will be introduced from Earth's state-of-the-art; however, the initial Martian steel-making should be optimized for constraints due to special conditions.

The initial complement of steel-making equipment transported to Mars should be low-mass and low-volume, also robust to reliably survive strong vibrations during rocket launch and potentially large shocks when the transport craft lands on unengineered Martian ground. Further, the steel-making should not use any consumables or refractories that cannot be obtained locally at IRoM soon after landing. Ideally, the complement of steel-making equipment, solar concentrating and other parts of the Ironberry Plan equipment should be designed in tandem with the landing spacecraft. This will (a) allow high-strength equipment elements to add to the structural strength of the spacecraft that will make the first (and perhaps only) giant payload landing on Mars without an engineered pad and (b) allow conversion and re-purposing of landed spacecraft parts to make steel, drill bores, concentrate sunlight and do early sediment rock dehydration.

In addition, the initial steel-making should make the sort of steel that can construct the planet-opening steel structures, i.e., solar concentrator and receiver structures for electricity generation. Sheet steel is such a steel. State-of-the-art robotic manufacturing can cut, bend, press and weld sheet steel into a wide variety of shapes and structures; for example, automakers make the bodies and doors of cars from sheet steel. It would also be useful to have steel powders for 3D printing small parts that are difficult to make from sheet steel.

Fig. 5 gives a flow sheet of an end-to-end steel-making process that accommodates the special condition constraints given above. The process of Fig. 5 features a fast form of a niche process, called carbonylation, with a long history that started with Langer and Mond [33]. Another paper will cover the details of the iron- and steel-making processing outlined in Fig. 5 and a full discussion of why this form of steel-making should initiate steel-making on Mars. Although, briefly touching on that discussion, other end-to-end processes using standard industrial methods (a) use consumables that will not be readily available at IRoM and (b) use higher temperatures that involve molten intermediates that force the (i) use of equipment that is hard to make small for transport, (ii) the use of brittle (easily broken) refractories and (iii) requires extensive use of cooling systems (on Earth these systems use water and are simple, on Mars complicated cooling systems using CO_2 would be needed). There is now active R&D into methods to upgrade standard (slow) iron carbonylation to fast iron carbonylation by this author that is funded by the National Science Foundation of the government of the USA. The Ironberry Plan could be implemented with mature slow iron carbonylation but will be less costly with fast iron carbonylation.

3.4 IRoM' s sediments: building a radiation-safe science station

The first purpose of the very early borehole excavations into IRoM's sediments is to search for signs of life. It is now assumed these searches have resulted in a stop/go decision that favors continuing to build a science station.

Given the go-ahead, boreholes then have other purposes. One is geotechnical, that is, to better understand the structural properties of IRoM's sediments to guide making underground radiation-sheltering spaces for human habitation, laboratories, agriculture, storage, robot shelter, etc.

One of the many reasons to locate a science station at IRoM is that needed radiation-sheltering structures will be readily made inside IRoM's sediments: Simple tests by *Opportunity* found that near-surface sediments are soft, easy-to-abrade and excavate [34], this softness lowers the energy and mechanical force needed to make underground excavations.

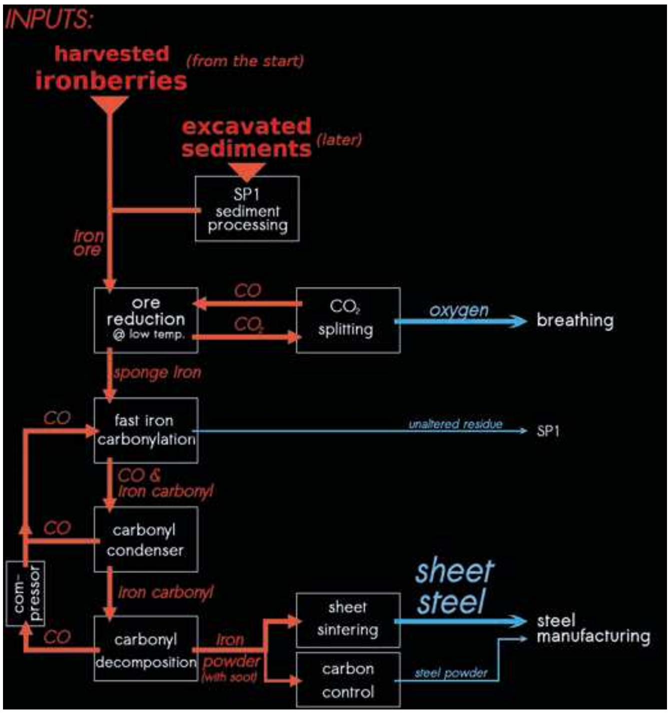

Fig.5 Fast carbonylation-based steel-making.

3.5 IRoM' s sediments: water & mineral mother lode, sediment processing

Underground sediment excavations have a significant, additional synergistic benefit – they produce excavated IRoM sediments, a mineral lode.

This lode can be converted into water and a material trove for building a science station. The conversion involves many steps. They are outlined here; the details will go in separate papers. This outline gives sediment mineralogical information from *Opportunity's* observations and a short discussion of one process that could carry out the conversion from excavated sediments to many valuable intermediates.

Although the instruments on *Opportunity* could not directly measure many of the minerals in the sediments at IRoM, they provided enough elemental and compositional data that Clark et al. [23] could constrain and model the minerals in IRoM's near-surface sediments. Table 1 provides a list ordered on the abundance of the minerals Clark et al. inferred. It is a starting point for how to use these sediments as a multi-component resource.

Fig. 6 outlines, in a flow-sheet overview, one practical processing system, denoted SP1, for IRoM's sediments as characterized by ref [23]. SP1 could have zero tailings.

SP1 requires a substantial complement of equipment at IRoM. This equipment is in addition to the initial steel-making equipment. SP1 would start at least one 780-day period after beginning steel-making. Starting SP1 could dovetail with a human-to-Mars mission by landing two Starships with the first humans at IRoM. The second spacecraft would have plenty

TABLE 1: Modeled Mineralogical Components of IRoM Sediments*

Mineralogical Components
Silica (probably amorphous, hydrated opalline silica)
Hydrated magnesium sulfates
Rock materials (some mixture of basaltic material, feldspar and pyroxenes)
Jarosite
Hydrated kaolinite or similar minerals
Hydrated calcium sulfates
Hematite
Np-Ox (Nano-particle ferric oxides)
Chlorides
Phosphates
Oxides of Titanium and Manganese
Other minor sulfates + calcium carbonate (?)

*This table is simplified from one in ref [23]. The components are ordered from the most abundant (top) to the least.

of payload space to land SP1's required equipment, plus more supplies and other equipment.

Sediment processing at IRoM will be energy-intensive. Processing at a scale large enough to impact building a science station will require an ample (> 1 MW) power supply. Precursor missions to sediment processing should focus on building power capacity. The energy inputs to SP1 are principally electricity to drive the electrolysis in CO_2-splitting and waste process heat (from electricity generation) for dehydration [21].

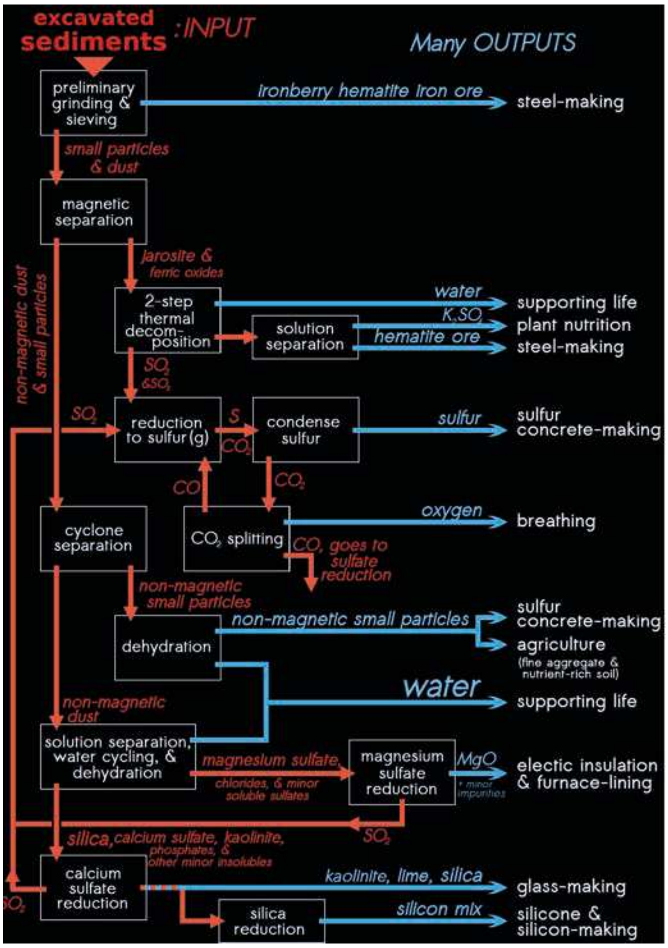

Fig.6 **SP1. A flow-sheet to process IRoM's sediments.**

SP1 provides many outputs with enormous benefits for building a science station. For example, SP1 liberates liquid water, the most valuable substance on Mars. The amounts of water liberated at IRoM can be considerable; the greater the available process heat generation from electricity generation, the larger the flows of liberated water can be [21]. However, the rates of water liberation are also limited by the sediments' levels of hydration well below the surface. These hydration levels at deep depths are mostly unknown, although they are likely significantly higher than orbiters have detected at the surface. Boreholes should be drilled to understand sediment hydration levels across surface locations and depths. In some scenarios, as an alternative to SP1, such bores become forced dehydration water wells (forced by piped process heat) that maximize the amount of water liberated relative to the sediment excavated.

Beyond water, SP1 processing will also produce a nutrient-rich inorganic soil that can become a foundation for Martian agriculture, as well as several important intermediates that can be processed into beneficial construction materials (i.e., a strong [35], water-free concrete called sulfur concrete, glass and silicone sealant), a much-needed electrical insulator and furnace refractory (i.e., MgO), as well as more iron ore and oxygen for breathing. Extracting the sediment's iron ore will reduce, perhaps end, the surface ironberry harvesting. Water-free sulfur concrete will have various uses, including building long-lasting and safe landing and launch pads and constructing better foundations for heliostats, road surfaces and many other surface architectural projects. The science station will need at-surface windows and glass domes for the mental well-being of its inhabitants, the visual interest of spectators and dreamers on Earth and, perhaps, for botanical gardens.

3.6 The station's scale

How big should a science station at IRoM become? Antarctica's McMurdo Station supports science expeditions across that continent. McMurdo gives an idea of the scale to aim toward for the coming generation of Mars explorers. McMurdo's Summer population is now between a thousand and fifteen hundred people. Something comparable at IRoM might have around a thousand robots and humans on Mars, with another few thousand scientists, engineers and robot monitors back here on Earth actively involved with the station's science, manufacturing, agriculture and other goings-on. Would something that big seriously alter IRoM? Most of it would remain pristine. Only a few square kilometers of IRoM would be enough to build and power such a McMurdo-comparable station on and under this plain. In comparison, IRoM has an area of around 100,000 km^2. In the 21st century, a science station at IRoM would be a small Earth outpost in a much larger Mars region.

4 COMMENTS ON DETAILS OMITTED FROM THIS PLAN OUTLINE & THE FirGStoL

To carry out the Ironberry Plan, many questions, necessary steps and things, each involving their own details, have not been discussed in this plan outline. For example, how do robots and rovers set up and start the first electricity generation system? How many rovers will be needed to do this? Are these rovers designed to be optimized for infrastructure construction? While the author has preferred answers to these particular questions (see below), there are so many questions like these that a paper limited to around 6,000 words cannot possibly discuss them all. Implementing the Ironberry Plan would take years and require thousands of people's efforts and a vast array of technology. Many things had to be omitted to make this paper readable. Further, there are no definite quantitative answers for some practically important questions right now simply because they are contingent on information and facts that still need to be settled (but soon could be).

An example of such missing, important information is the exact size of the payload that will be landed by the First Giant Spacecraft to Land on Mars (FirGStoL). If the FirGStoL is some variant of a SpaceX Starship, this FirGStoL is unlikely to have a 100-tonne payload, even though SpaceX discusses Starship specifications where the target payload is around 100 tonnes; such Starship specifications are only likely to be achieved when the spacecraft is landed at a well-engineered landing facility. It is worth considering reducing the amount of easily movable payload in the FirGStoL far below 100 tonnes while then adding in the balance of the mass as extra reinforcing to the structure of this spacecraft to make it more resilient to a rough landing. Undoubtedly, considerable planning, experimentation, testing, discussion, lobbying and political point-making will be done before the size and contents of the payload of the FirGStoL are decided upon and brought together.

Fortunately, the Ironberry Plan can be implemented using a FirGStoL with an easily movable payload far below 100 tonnes, perhaps as little as 10 tonnes. Among the full complement of equipment that the Ironberry-Plan FirGStoL would land, this author is most familiar with the equipment for carrying out iron- and steel-making. This iron- and steel-making equipment can be designed to work over a broad range of sizes and masses. It is possible to shrink a complete iron- and steel-making system to under 1.5 tonnes, although such extreme system shrinkage is unlikely optimal (an analysis of this point is not yet done). Further, holistic Ironberry Plan optimization will likely result in using several (redundant) complete iron- and steel-making systems, each of which is more than minimally sized.

Adding complexity to how to design the FirGStoL's payload - but also considerable benefits to the overall plan – is the possibility of incorporating parts of the Ironberry Plan's first payload as parts of the transporting FirGStoL itself. For example, the spacecraft's fuel and oxygen tanks are made of sheet steel. This steel can be re-purposed to make heliostats for a 250 kW concentrating solar electricity generating unit similar to one shown in ref [10] at Newbridge, Australia. At the same time, some of the spacecraft's linear structural members could be used to build supports under the heliostats, the tower supporting the solar plant's receiver as well as the pipes carrying pressurized CO_2 cooling fluid to and from the solar receiver. Further, most of the robots in the FirGStoL could be disassembled while in transport, wherein some major robot parts (such as rover chassis) could become bolted-in members of the spacecraft's structural frame. Similarly, strong pipes used in the iron- and steel-making equipment could be doubled up as bolted-in structural members in the FirGStoL's frame.

To make this transformer type FirGStoL work, the easily movable and unpackable part of its payload needs to include just one functioning rover robot with excellent tool and material handling capabilities as well as start-up batteries and a small, unfurled solar power unit (perhaps ~3 kW) that can power this first-mover, as well as the next three or five other robots the first mover assembles. A team of assembled tool-manipulating robots can then go on to make a Newbridge-like solar power plant as described above.

Note that a FirGStoL payload dedicated to implementing the Ironberry Plan will be one of the most robust and least expensive payloads imaginable for surviving a rough first landing. Iron- and steel-making equipment and tool-manipulating robots will be considerably tougher and less costly (per unit mass) than most scientific instruments.

The details missing from this paper should provide opportunities for other engineers.

REFERENCES

1. P. R. Christensen and S. W. Ruff. "Formation of the Hematite-bearing Unit in Meridiani Planum: Evidence for Deposition in Standing Water. *J. Geophys. Res.: Planets*, E08003, 2004. https://doi.org/10.1029/2003JE002233.
2. R. E. Arvidson *et al.* "Nature and Origin of the Hematite-bearing Plains of Terra Meridiani Based on Analyses of Orbital and Mars Exploration Rover Data Sets", *J. Geophys. Res.: Planets*, **111**, E12S08, 2006. https://doi.org/10.1029/2006JE002728.
3. P. R. Christensen *et al.* "Detection of Crystalline Hematite Mineralization on Mars by the Thermal Emission Spectrometer: Evidence for Near-surface Water. *J. Geophys. Res.: Planets,* **105**, pp.9623–9642, 2000. https://doi.org/10.1029/1999JE001093
4. https://themis.asu.edu/files/meridiani_hematite_med_2.jpg [last accessed 3 March 2024]
5. https://planetarynames.wr.usgs.gov/Feature/Meridiani%20Planum [last accessed 3 March 2024]
6. B. M. Hynek and G. Di Achille. *USGS SIM 3356: Geologic map of Meridiani Planum, Mars*. USGS Publications Warehouse, 2017. https://doi.org/10.3133/sim3356
7. Anonymous. *Report of the 90-Day Study on Human Exploration of the Moon and Mars*. NASA report, 1989. https://history.nasa.gov/90_day_study.pdf
8. D. Baker and R. Zubrin. "Mars Direct: Combining Near-Term Technologies to Achieve a Two-Launch Manned Mars Mission", *JBIS*, **43**, pp. 519–525, 1990.
9. Anonymous. "Curiosity's Seven Minutes of Terror". NASA video. https://www.jpl.nasa.gov/videos/curiositys-seven-minutes-of-terror [last accessed 3 March 2024]
10. https://raygen.com/newbridge/ [last accessed 3 March 2024]
11. https://www.energy.gov/lpo/ivanpah [last accessed 3 March 2024]
12. https://oxeonenergy.com/moxie [last accessed 3 March 2024]
13. https://www.topsoe.com/processes/carbon-monoxide [last accessed 3 March 2024]
14. https://www.twelve.co/technology [last accessed 3 March 2024]
15. https://www.spacex.com/vehicles/falcon-9/ [last accessed 3 March 2024]
16. https://www.spacex.com/vehicles/starship/ [last accessed 3 March 2024]
17. D. L. Shirley and D. J. McCleese. Mars Exploration Program Strategy: 1995-2020. *AIAA 96-0333, 34th Aerospace Sciences Meeting and Exhibit, Reno, Nv, 1996.* (archived at https://web.archive.org/web/20130511200249/http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/23620/1/96-0064.pdf).
18. W. J. Broad. "Even in Death, Carl Sagan's Influence Is Still Cosmic", *New York Times*, 1998. (archived at https://archive.nytimes.com/www.nytimes.com/library/national/science/120198sci-sagan.html)

19. https://en.wikipedia.org/wiki/Daniel_Goldin [last accessed 3 March 2024]

20. E. Smith and H. J. Morowitz, *The Origin and Nature of Life on Earth: The Emergence of the Fourth Geosphere*, Cambridge University Press, Cambridge, 2016.

21. R. M. Olsen. "Liberation of Mineral-Bound Water of the Meridiani Planum Driven by Process Heat from Carbonylation Steel-Making and Concentrated Photovoltaic Electricity Generation", *ASCE Earth and Space 2022, Denver, Colorado, 2022* . https://doi.org/10.1061/9780784484470.032

22. F. Eisenhauer, J. D. Monnier and O. Pfuhl, "Advances in Optical/Infrared Interferometry", *Ann. Rev. Astronomy Astrophysics*, **61**, pp.237-285, 2023. https://doi.org/10.1146/annurev-astro-121622-045019

23. B. C. Clark et al. (2005), "Chemistry and Mineralogy of Outcrops at Meridiani Planum", *Earth and Planetary Sci. Let.,* **240**, pp.73-94, 2005. https://doi.org/10.1016/j.epsl.2005.01.040 .

24. S.W. Squyres, S.W., *et al.* "Exploration of Victoria Crater by the Rover Opportunity", *Science*, **324** (5930), pp.1058-1061, 2009. https://doi/org/10.1126/science.1170355.

25. A. McEwen *et al.* "Mars Reconnaissance Orbiter's High Resolution Science Experiment (HiRISE)", *J. Geophys. Res: Planets,* **112**, (E5), 2007. https://doi.org/10.1029/2005JE002605.

26. S. W. Squyres *et al.* "In Situ Evidence for an Ancient Aqueous Environment at Meridiani Planum, Mars", *Science*, **306** (5702), pp.1709-1714, 2004. https://doi.org/10.1126/science.1104559.

27. M. P. Golombek et al. "Erosion Rates at the Mars Exploration Rover Landing Sites and Long-term Climate Change on Mars", *J. Geophys. Res.: Planets,* **111**, E12., 2006. https://doi.org/10.1029/2006JE002754 .

28. M. P. Golombek et al. "Small Crater Modification on Meridiani Planum and Implications for Erosion Rates and Climate Change on Mars", *J. Geophys. Res.: Planets*, **111**, E12, 2014. https://doi.org/10.1002/2014JE004658 .

29. R. M. Olsen. "Iron Oxide Harvesting on Mars", A*IAA ASCEND 2021, Las Vegas, Nv & Virtual, 2021*. https://doi.org/10.2514/6.2021-4037.

30. W. M. Calvin et al. "Hematite Spherules at Meridiani: Results from MI, Mini-TES and Pancam", *J. Geophys. Res.: Planets*, **113**, E12S37, 2008. https://doi.org/10.1029/2007JE003048.

31. R. V. Morris et al. "Mössbauer Mineralogy of Rock, Soil and dust at Meridiani Planum, Mars: Opportunity's Journey Across Sulfate-rich Outcrop, Basaltic Sand and Dust and Hematite Lag Deposits", *J. Geophys. Res: Planets*, **111**, E12S15, 2006. https://doi.org/10.1029/2006JE002791.

32. R. M. Olsen. "Searching Mass-Balance Analysis to Find the Composition of Martian Blueberries", *Minerals*, **12**(6), 777, 2022. https://doi.org/10.3390/min12060777

33. L. Mond, C. Langer and F. Quincke. "Action of Carbon Monoxide on Nickel. J. Chem. Soc.", **57**, pp.749-753, 1890. https://doi.org/10.1039/CT8905700749

34. R. E. Arvidson *et al.* "Localization and Physical Property Experiments Conducted by Opportunity at Meridiani Planum", *Science*, **306**, pp.1730-1733, 2004. https://doi.org/10.1126/science.1104211

35. L. Wan, R. Wendner and G. Cusatis. "A Novel Material for In-situ Construction on Mars: Experiments and Numerical Simulations. *Construction and Building Mat.*, **120**, pp.222-231, 2016. https://doi.org/10.1016/j.conbuildmat.2016.05.046

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