locally would be valuable. Many industrially important elements are highly incompatible and in a magma will tend to become concentrated in the residual melt, so that useful concentrations may form [7]. However, the enormous literature on lunar rare elements is focused instead on their use as tracers of large-scale geologic processes (e.g., partitioning of REE) and thus is not directly applicable to economic geology.

For example, much lunar Cr is present as Cr^{++}, due to the reduced character of lunar rocks [9], and Cr is enriched in the lunar crust relative to Earth. The mechanism of this enrichment seems somewhat obscure, however. Presumably, Cr^{++} is excluded from compact Fe-Mg silicates in the lunar mantle, as it is a large ion [10]; moreover, Cr^{++} has large Jahn-Teller effects and hence prefers distorted crystal sites. Hence the Cr on the surface probably arrived as Cr^{++} in residual melts originally fractionated out of the mantle. However, surface Cr commonly exists as Cr^{+++}, especially in chromite [11]. Data from reduced chromian slags indicate that at low temperatures CrO is unstable and will disproportionate into Cr metal and Cr_2O_3 [12]. As Cr metal is more electropositive than Fe, this suggests that some of the native Fe on the Moon may result from reduction by Cr^{++} oxidation, and textural relations support this interpretation [13]. In any case, understanding Cr mobility due to its varying redox behavior may allow finding areas enriched in it, and may also have implications for deposits of native Fe.

Moreover, as this example suggests, the slag literature seems to be a largely overlooked source of possible insights about the behavior of silicate melts under extremely reducing conditions. They may provide information on rare elements in particular. Many slags contain not only Cr^{++}, but Ti^{+++} or even Ti^{++} [12]. The ceramic literature may also be useful as many high-performance ceramics are anhydrous. Indeed, industrial experience has already provided extremely useful analogues for some non-terrestrial processes, e.g., Sill's [14] modeling of the role of sulfur in Venus cloud processes, using observations from Lunge's [15] industrial treatise on the obsolete lead-chamber process for commercially producing sulfuric acid, and Lee et al.'s [16] observations of molten sulfur flows in commercial mining operations to infer behavior of natural flows on Io. Such literature also seems an underused source for potential insights into lunar conditions.

Surface Signatures: It is not enough to predict mechanisms by which ores may be formed; they must also be found. Seeking a distinctive signature from orbital sensors is an obvious and relatively cheap approach; e.g., it has been commonly advocated for detecting whether cold-trapped polar volatiles exist. Many if not most ore deposits will be too small, however, to show up with the resolution proposed for probes such as the Lunar Observer. For example, a deposit of pure ilmenite 100 m on a side, which would be more than enough to support an initial lunar installation, would not be seen.

Detection of such small deposits must be more subtle, especially as global increases in resolution are not practical. Instead, the signature of potentially favorable geologic settings for concentration of the desired element must be sought; once such areas have been identified, they can be targeted for further investigation.

It seems underappreciated that this is how mineral exploration is carried out on Earth. For example, an explorationist seeking Au mineralization in Nevada does not begin by mapping the entire state at 1-m resolution. Instead, he ,or she focuses attention on promising areas identified on the basis of their general geologic setting, and maps them in detail. Similarly, small but promising areas on the Moon, initially found by remote sensing, can be later focused on in detail with high-resolution sensing, and in the case of the most favorable areas, actual samples can be collected.

Conclusion: In summary, a viable ore resource contains as high a concentration of the desired element as possible in a form that is as easy to recover as possible, and such deposits moreover are unusual, resulting from rare processes or unusual extremes of common processes. This will be true of lunar resources as much as terrestrial ones. To explore for lunar resources, therefore, the lunar geologic literature must be reevaluated with this perspective, using our knowledge of global lunar processes to establish geologic contexts, and then determining what element-concentration processes might occur locally in such contexts. Terrestrial analogues, such as magmatic ore formation, as well as lunar samples that seem to reflect unusual processes, should help identify such possibilities. Industrial experience with possibly relevant systems such as reducing slags or anhydrous ceramics may also provide insight on possible ore-forming processes. Once possibilities are established, then attention can be focused on promising lunar localities.

References: [1] e.g., Lewis J. S. and Lewis R. A. (1987) *Space Resources: Breaking the Bonds of Earth*, Columbia Univ. [2] Waldron R. D. and Criswell D. R. (1982) In *Space Industrialization, Vol. II* (B. O'Leary, ed.), 1-53, CRC, Boca Raton. [3] Gillett S. L. (1991) *Space Power*; Kuck and Gillett, *Space Power*, submitted. [4] e.g., Warren P. H. et al. (1983) *Proc. LPSC 13th*, in *JGR, 87*, A615-A630; Warren P. H. et al. (1983) *Proc. LPSC 14th*, in *JGR, 88*, B151-B164; Warren P. H. et al. (1986) *Proc..LPSC 16th*, in *JGR, 90*, D319-D330; Vaniman D. et al. (1991) In *Lunar Sourcebook* (G. H. Heiken et al., eds.), 5-26, Cambridge Univ. [5] Pieters C. M. (1986) *Rev. Geophys., 24*, 557-578. [6] Guilbert J. M. and Park C. F. (1986) *The Geology of Ore Deposits*, Freeman. [7] Haskin L. A. et al. (1992) In *Resources of Near-Earth Space*, Univ. of Arizona, in press. [8] Arnold J. R. (1979) *JGR, 84*, 5659. [9] e.g., Basaltic Volcanism Study Project (1981) *Basaltic Volcanism on the Terrestrial Planets*, Pergamon, New York, 1286 pp. [10] e.g., Schreiber H. D. and Haskin L. A.(1976) *Proc. LSC 7th*, 1221-1259; Basaltic Volcanism Study Project (1981) *Basaltic Volcanism on the Terrestrial Planets*, 331, Pergamon, New York; [11] e.g., Haskin L. A. and Warren P. H. (1991) In *Lunar Sourcebook* (G. H. Heiken et al., eds.), 357-474, Cambridge Univ. [12] Rosenqvist T. (1983) *Principles of Extractive Metallurgy*, 2nd edition, 301-302, McGraw-Hill. [13] e.g., Reid A. M. et al. (1970) *EPSL, 2*, 1-5; Brett R. et al. (1971) *Proc. LSC 2nd*, 301-317. [14] Sill G. T. (1983) *Icarus, 53*, 10-17. [15] Lunge G. (1903) *Sulphuric Acid and Alkali, Vol. I*, 3rd edition, Van Nostrand, New York. [16] Lee S. W. et al. (1987) *LPSC XVIII*, 545-546.

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THE TARGET: H_2O ON THE MOON. J. Green[1], J. Negus-de Wys[2], and A. Zuppero[2], [1]California State University, CA, USA, [2]EG&G Idaho, Inc., ID, USA.

The importance of H_2O on the lunar surface has long been identified as a high priority for the existence of a human colony for mining activities and, more recently, for space fuel. Using the Earth as an analogue, volcanic activity would suggest the generation of water during lunar history. Evidence of volcanism is found not only in present lunar morphology, but in over 400 locations of lunar transient events catalogued by Middlehurst and Kuiper in the 1960s. These events consisted of sightings since early history of vapor emissions and bright spots or flares. Later infrared scanning by Saari and Shorthill showed "hot spots," many of which coincided with transient event sites. Many of the locations of Middlehurst and Kuiper were the sites of repeat events, leading to the conclusion that these were possibly volcanic in nature.

If water were formed on the lunar surface in the past through volcanic activity, remnants of frozen H_2O could be expected to survive in the polar regions and in crater rims, protected by meters of fine (15-μm) lunar regolith from the high-vacuum, high-escape velocity, and the long, hot lunar day.

More lunar volcanic resources may possibly be present on the highlands than heretofore believed, a belief based in part on remote sensing of the lunar limb and farside by the Galileo spacecraft in 1990. The probe discovered probable volcanic "cryptomare" provinces on the highlands. Highland volcanism enhances the probability of endogenic water resources on the floors of shadowed polar craters in addition to possible cometary ice input. Modification of Strategic Defense Initiative weaponry for use as orbiting cislunar remote sensors could be useful in detecting ice or ice clathrate within polar craters especially in the vicinity of lunar transient sites. Focused neutron beams from a linear accelerator in polar orbit could be directed onto the floors of eternally shadowed crater floors to detect possible water ice by the 2.22-meV gamma backscatter of hydrogen. Prior to renewed manned exploration of the Moon, many modified SDI systems could be used in active remote sensing exploration for both volcanic and impact-derived volatiles in lunar shadow.

The exploration system seeks to find a surprisingly small amount of water ice. The H_2O would be used for massive cargo propulsion, life support, and material processing. Direct use of the water as propellant in nuclear thermal steam rockets provides nearly the optimum ratio of payload mass per tanker ship mass for lunar ascent and escape missions. The simplicity is of very high practical value to lunar operations. Converting the water into cryofuels provides the most resource-efficient propulsion. To supply 10,000 tons of propellant or rocket fuel to lunar escape would require finding a block of permafrost less than 35 m across. This 10 ktons of fuel is about as much as has been launched during the entire history of space. It would provide the fuel to take 50 payloads of 100 tons each from the lunar surface to an Earth orbit, or to take 25 payloads of 100 tons each to the Moon from low Earth orbit. To deliver 10,000 tons of lunar mass to each of 100 solar power stations of multigigawatt capacity would require finding a mere 160-cubic-meter block of ice.

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LUNAR MAGNETIC FIELDS: IMPLICATIONS FOR RESOURCE UTILIZATION. L. L. Hood, Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721, USA.

It is well known that solar-wind-implanted hydrogen and helium-3 in lunar soils are potentially usable resources for future manned activities. Hydrogen applications include manufacture of propulsion fuel and combination with oxygen (extracted from minerals such as ilmenite) to produce water. More speculatively, helium-3 may ultimately be returned to Earth as a fuel for future terrestrial fusion reactors. For economical mining of these implanted gases, it is desirable that relative concentrations exceed that of typical soils (e.g., [1]). It has previously been noted that the monthly variation of solar wind flux on the surface due to lunar immersion in the geomagnetic tail may have measurable consequences for resource utilization [2]. In this paper, it is pointed out that, for a constant external flux, locally strong lunar crustal magnetic fields will exert the dominant influence on solar wind volatile implantation rates. In particular, the strongest lunar crustal magnetic fields will both deflect and focus incident ions in local regions leading to local enhancements of the incident ion flux. Thus, the most economical sites for extraction of solar-wind-implanted volatiles may be within or adjacent to strong crustal magnetic fields. In addition, solar wind ion deflection by crustal magnetic fields must be considered in evaluating the issue of whether remnant cometary ice or water-bearing minerals have survived in permanently shadowed regions near the lunar poles [3]. This is because sputter erosion of water ice by solar wind ions has been suggested to be an important ice loss mechanism within permanently shadowed regions [4]. Thus, permanently shadowed regions that are also shielded from the solar wind by locally strong crustal fields could be the most promising locations for the survival of cometary ice.

Although the largest directly measured surface magnetic field was 327 nT at the Apollo 16 site [5], it is likely that much larger surface fields exist elsewhere in regions of strong magnetic anomalies detected from orbit. Modeling of the latter suggests surface fields as large as several thousand nT (several hundredths of a gauss) in restricted regions. Direct surface measurements of incident solar wind ions were obtained at the Apollo 12 and 15 landing sites where surface field amplitudes were only ~38 and ~3 nT respectively. Nevertheless, at the Apollo 12 site, incident ions were observed to be decelerated by as much as 70 km/s and to be deflected in direction by ≤10° [6]. We have previously calculated the deflection of solar wind ions by simulated lunar crustal magnetic fields for the purpose of investigating the origin of swirl-like albedo markings that are associated with many of the strongest lunar magnetic anomalies [7]. It was found that significant deflections do occur and that local plasma voids are produced at the lunar surface.

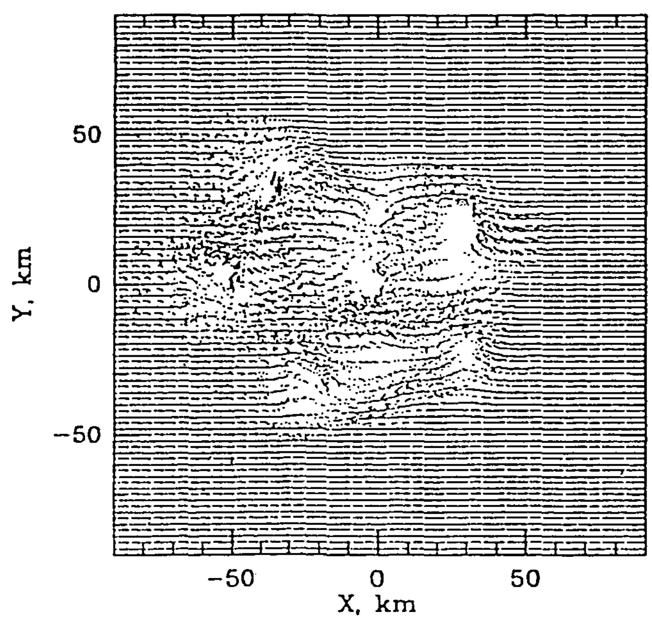

Fig. 1.