on a determined course toward colonization. With on-site surface exploitable volatiles, a lunar base could "live off the land" to a greater extent than expected than under a scenario without any lunar frozen water or other volatiles. With a joint surveying and mapping mission of the Moon with American instrumentation and an immediate Soviet launch to lunar polar orbit, globally redundant projects such as the U.S. space station *Freedom* and the Soviet station *Mir* could be replaced with a more culturally and politically diverse lunar base. With marginal modification, modules built for LEO could be placed on the lunar surface and/or attached to Mir. While much has been written on the utilization of lunar volatiles as a source of propellant fuel for a LEO, inner solar system, transportation node, the potential of the discovery of lunar ice will enable human outposts to "live off the land" on the Moon.

The development of strategies focusing on the utilization of existing, nonterrestrial resources on-site is of primary concern. This would not be a departure from the ideology of exploration of the solar system, but would merely be wisely following the Punjabi proverb "Grasp all, lose all." It does not function in a pattern of evolutionary development and growth. Currently, the Western program is not focused in a specific direction. The assessment of these mineralogical maps of the Moon could lead to an evolution of direct launching to the Moon without an expensive station around the Earth. Previously, the U.S. had an existing operational space station, but abandoned it to the elements and its ultimate fiery fate. A lunar base would involve less ultimate short-term and long-term expenditure than would space station development. The primary justification made for the lunar base is the ultimate export of volatiles to LEO.

With the recent offer by the U.S.S.R. to launch a germanium gamma ray spectrometer instrumented platform to the Moon, the direction of the planet for the next 25 years will become clearer. Comparing the Ride Report and The National Commission on Space Report, Hempsell found that each of these pathways of solar system expansion could be developed in the twenty-first century. His conclusion was that immediate investment in an extensive lunar infrastructure would offset its initial costs.

Current human decisions will have an impact on global development over the next thousand years. These decisions include proposals and data that will reinforce our commitment to expansion off the planet. The previous lunar mission and telescope images that have been compiled over a 30-year period should be digitized in a standardized format and integrated into a GIS computer database. The gamma ray spectrometer data would then be only one level of the overlaid cartographic information. This same technique could then be duplicated on other terrestrial and nonterrestrial site locations. Currently, the only portions of the Moon that have been mapped with spectrographic analysis are those around the lunar equator from the Apollo exploration period. One example of lunar surface features that have not been mapped totally is the lunar lava tubes, which could supply excellent first-stage radiation shield structures.

A dedicated, one-instrument, gamma ray spectrometer that is being developed for the lunar prospector probe could be used in an identical format to map surface resources on other inner solar system bodies. The resulting maps would also give us definite information on those resource nodes that should be targeted for development and human settlement. With limited monies, hard decisions must be made whether to fund projects that, while of immense scientific merit, have little utility to the potential expansion of our species off the planet. Any expansion off the Earth will involve lunar resource development in some manner. The discovery of lunar ice at the poles would influence the immediacy of a lunar polar station.

Spectral surface characteristics of the Moon have been an ignored area of scientific inquiry. The sensing systems and launching platforms are available, and a prospector mission would cost about $30 million in a shuttle launch configuration through to a $75 million cost. While it is not a flashy area of study, it will pave the way for permanent habitation of our nearest celestial body. Politicians should be supplied with maps and information, rather than fantasian utopian images, to base decisions of funding and political directions of scientific research.

When the U.S. President Thomas Jefferson sent Lewis and Clark westward, he expected and received detailed reconnaissance maps. These maps were the basis of all later discussions of how the U.S. should expand. Many expensive interplanetary probes have been launched without any discussion as to whether they will impact on the expansion of the human solar system ecumene.

The germanium gamma ray spectrometer is an inexpensive, already extant instrument that, while not necessarily answering many scientific questions, will tell human beings where and how to direct their expansion of the mineral exploitation of the Moon.

N93-17257 1993008068 488059

**UTILIZATION OF GEOGRAPHIC INFORMATION SYSTEM IN LUNAR MAPPING.** A. A. Mardon, Department of Space Studies, University of North Dakota, Grand Forks ND 58202, USA.

Substantial digital remote sensing, lunar orbital photography, Earth-based remote sensing, and mapping of a variety of surficial lunar phenomena have occurred since the advent of the Space Age. This has led to a bewildering and quite disparate collection of archival sources insofar as this digital data and its cartographic representation can be found within many countries of the world. The importance of this mapping program in support of human expansion onto our nearest planetary neighbor has been recognized since the advent of the Space Age [1]. This is still as true as when it was stated in 1964 that, "The program for landing men on the lunar surface requires that suitable and safe sites be defined and verified before the actual landings" [2].

In 1991 only the U.S.A. has landed humans on the Moon. If during the preceding decade efforts had been dedicated to developing inexpensive labor-intensive tasks such as the detailed mapping of the Moon [3], we would be further ahead today in lunar exploration. A series of small-scale maps of the Moon at 1 km to 1 cm, done with the support of Geographic Information System (GIS), would serve decision makers well in the process of accessing the development of manned occupance of the Moon. Nothing has been published to this date on the use of GIS in a lunar mapping context [4].

Maps and the data that they are derived from are the primary way in which people explore new environments and use previously discovered data to increase the bounties of any exploration. The inherent advantage of GIS is that it would allow immediate online access on the Moon of topographically represented data [5,6], with analysis either on site or from Earth. This would mean that astronauts in the field would be able to get instantaneous cartographic data representations on any of the suited visual monitors that would be part of an astronaut's extravehicular suit.

Any vehicles or shelters that would be used on the Moon would have internal video monitors. The multiple database maps could be instantaneously represented on the screens of those persons using transmitted data in order that decisions on the direction of a route of traverse or assistance in the selection of a site to use could be worked out on the spot in the field. A similar proposal was presented to the National Science Foundation on the mounting of video map monitors on the dashboard of snowmobiles used in the field in Antarctic traverses. These monitors could be viewed while riding along on the snowmobile. Personal experience in the Antarctic shows that other members of the Plateau-based field team were continually referring to our maps for a variety of purposes. An inertial guidance system could be used in conjunction with lunar satellite telemetry to give onboard GIS exact, continuous coordinates on the entire lunar surface. It would be rather difficult to handle a conventional two-dimensional cloth or paper map from inside a spacesuit. Orbital photography could be directly portrayed or portrayed with graphic enhancements in the lunar environment.

Further developments in GIS cartographic representation make it now possible for it to be used in the form of a video monitor, and apropos the GIS this would be well suited to the medium of maps that will be used in space.

A GIS would be operationally actualized in a lunar field environment by becoming a standard part of the astronaut's lunar surface suit. A variety of configurations could be envisaged for use in the field. The first proposed configuration of GIS that the author proposes is that a small 10–15-cm full-color monitor be installed on the side of the interior of the spacesuit helmet. This screen could display the entire range of topographic features and would have the resolution of the current high-resolution television screens. The astronaut would swivel his head to either the right or the left to see this screen. The second proposed configuration is a Heads-Up Display (HUD) on the faceplate of the helmet. This would be similiar to the HUD that is seen in fighter aircraft allowing target acquisition and data displayed in a manner that can be seen through [7]. Thus monochromatic lines or a full-color display could portray multiple datasets in a see-through monitor; in very simple terms the helmet face plate would become the monitor. The graphic information could be switched on and off and different densities of graphic and digital information could be displayed on a HUD system. The third configuration in which GIS could be displayed is in the form of a chest-mounted screen that would swing out and could be viewed when looking directly downward. The fourth configuration is a screen in a portable carrying case that could be held up by one hand to view. The fifth configuration is the faceplate could be replaced by a monitor close to the eyes with no translucent properties [8].

The utilization of screens for display purposes would be very easy, for vehicles would probably have monitors for other assigned purposes, namely the secondary purpose of displaying any required maps. Out of all the variety of ways to display cartographic information, the one that is most likely to be developed and utilized is the HUD on the spacesuit helmet faceplate. All internal video monitors could be used in a similar manner to that used by pilots, for example a HUD, either in the form of a direct voice command or through focusing one's eye on a certain area of the screen and blinking. This technology is rumored to have been developed to a high degree in the USAF Apache helicopter and F-18 [7]. This would allow the astronaut to move smoothly on the display screen from different databases and from different scale-map displays. The monitor display could go from a 1-cm- to 1-km-scale topographic display to a 1-cm to 1-m topographic display with a blink of the eye and/or a vocal command. Other suit status information could be displayed or overlayed onto this information.

Historically, maps were created before an expedition began, based on all accessible information about an area that was relevant. A lunar utilization of the available GIS would allow the modern and future lunar explorer the opportunity to have immediately updated maps that use several Earth nations' archival resources. Thus, ironically, this could be its most impressive contribution manifested by its inherent speed and agility to address new problems.

The author proposes that the new cartographic techniques that have been developed within the GIS could be applied to the methods of archival storage, retrieval, and representation of the bewildering array of lunar surficial phenomena data sources [9]. GIS cartographic technology allows the multiple overlaying of disparate digital and cartographic data in order to correlate and substantiate new patterns. Then contemporary and historical lunar data compiled by a variety of nations could be referenced for retrieval. These sources would in some cases be damaged with the passage of time [10]. GIS could be used to archive and allow new and novel utilization of any old unused data.

An examination of the references in NASA *Technical Abstracts* from 1958 to 1989 suggests that there is first of all a correlation with exploration activity and the publication of maps. After the funding cuts of the 1970s, on average the ratio of entries under lunar mapping and lunar photography has been less than it was before and during the active exploration stage of the Moon by the U.S. This also means that it does support an active mission of exploration of the Moon. One problem with this form of analysis is that it relies heavily upon the abstracting heading system. Many articles that directly relate to the topic of mapping are not covered in the abstract headings. The author proposes that over a 30-year period abstract publication rates can indicate interest in the space program and specifically lunar mapping. Future increases in the appearance of mapping heading abstracts might indicate an increased serious interest in lunar exploration by the U.S.A. At the current time the mapping headings do not correspond to the numbers that appeared in the 1960s before the manned lunar landings.

A future area of research that could be developed upon the integration and data entry of all the lunar maps and orbital and surface photography is the comparison of photographs to measure the small meteorite impact rate on the Moon. This would involve the superimposition of future images over preserved past images. This would be another means, that we currently do not have, to measure temporal differences in small-body meteor impact rates. Evidence of mass slope slippages along crater walls that might also occur could be seen in compared images. These observations could be seen when comparing 1960s and 1970s images with future lunar images. Using archived historical aerial photography to compare changes over time in the cultural and physical landscape has been quite common on Earth, and on the Moon archived images in an internationally standardized computer medium might provide us with valuable insights into planetary processes.

A robust lunar-planetary-scale mapping program is a primary prerequisite to a well-informed decision-making process in the site selection of permanent lunar facilities [1]. The utilization of GIS in support of this goal would be timely and has precedents in site selection procedures on Earth [11]. Historically, mapping has been the major tool in exploration over the past half millenium. This newest powerful tool for the modern cartographer could be cost-effectively used to accelerate and correctly discern optimal lunar sites for utilization.

We went to our Moon over 20 years ago with technology that makes our current general technological level seem extremely advanced. Our movement to our nearest planetary neighbor is not a matter of needing superior technology but is one of organizing what we currently know in a superior manner. Using technology that has already been proven and is inexpensive to support, our drive out from Earth has greater potential for success than in developing unproven technology. A universal cartographic database founded on the principles at the center of GIS would become the same helpful tool for exploration that the ancient maps of Herodotos, Ptolemy, and Strabo were to Columbus in his discovery of the "New World" in 1492.

"Discovery is documentation" [12] and, simply, the most useful form of documentation for exploration is the map. This still applies to our future exploration of the Moon as it is applied to historic exploration on Earth. This use of historic maps in exploration has been shown in Henry the Navigator's use of Necho's African map. This map, as described in Herodotos' History, was made in the sixth century B.C. The map described the legendary circumnavigation of Africa sponsored by the Egyptian Necho. This was then used in the fifteenth century A.D. by Henry the Navigator to justify the Portuguese southward exploration in their attempt to follow Necho's described legendary circumnavigation of Africa 2100 years previously.

Our maps of the Moon, whether they be represented on paper or computer screen, will be the human race's most valuable and inexpensive tool in the exploration and conquest of the Moon.

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N93-17258 1993008069

**MÖSSBAUER SPECTROSCOPY FOR LUNAR RESOURCE ASSESSMENT: MEASUREMENT OF MINERALOGY AND SOIL MATURITY.** R. V. Morris[1], D. G. Agresti[2], E. L. Wills[2], T. D. Shelfer[2], M. M. Pimperl[2], M.-H. Shen[2], and M. A. Gibson[3], [1]Mail Code SN4, NASA Johnson Space Center, Houston TX 77058, USA, [2]Physics Department, University of Alabama, Birmingham AL 35294, USA, [3]Carbotek, Inc., 16223 Park Row, Suite 100, Houston TX, USA.

**Introduction:** First-order assessment of lunar soil as a resource includes measurement of its mineralogy and maturity. Soils in which the mineral ilmenite is present in high concentrations are desirable feedstock for the production of oxygen at a lunar base.

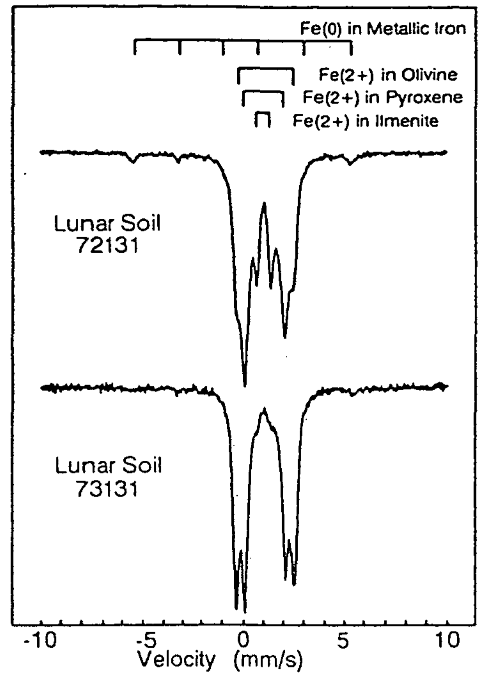


Fig. 1.

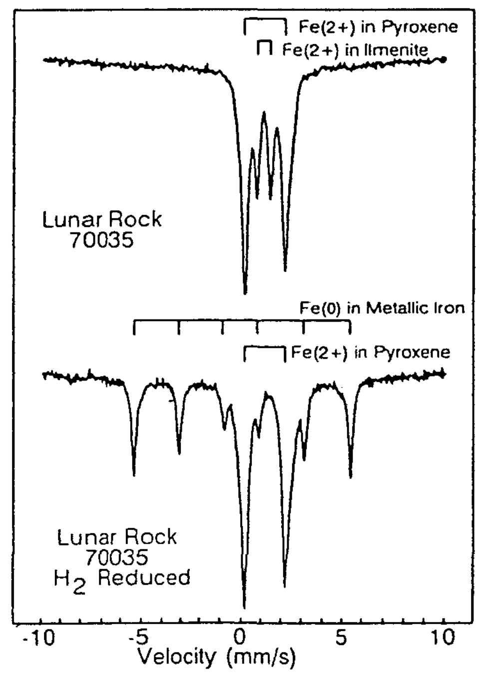


Fig. 2.

The maturity of lunar soils is a measure of their relative residence time in the upper 1 mm of the lunar surface. Increasing maturity implies increasing load of solar wind species (e.g., N, H, and $^3He$), decreasing mean grain size, and increasing glass content. All these physicochemical properties that vary in a regular way with maturity are important parameters for assessing lunar soil as a resource. For example, $^3He$ can be extracted and potentially used for nuclear fusion. A commonly used index for lunar soil maturity is $I_s$/FeO,