

STRATEGIC THINKING FOR LONG-RANGE MARS PLANS

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Planning for a successful Mars Exploration and Development program will be complex and the plans must extend over many decades. Even though we do not want to repeat its plant-the-flag-and-leave goals, the great success of the Apollo program was in large part to its planned organizational structure. Unfortunately, the last 30 years of the post-Apollo manned space program have been seemingly productive, but in the opinion of many, goal-less and directionless years. In spite of the thousands of dedicated and competent professionals working in the field, the government space program has been the victim of a repeated series of bad decisions, some political, some bureaucratic, others financial, which may have caused as much as a quarter century of delay in human space exploration and development. Repeatedly, good designs were abandoned for bad or expensive ones, fundamental research in critical areas such as advanced propulsion was delayed or stopped, and moves to develop radically cheaper launch vehicles postponed. The bad decisions themselves were in many cases made for short-term reasons, and without considering many of their longer-range consequences. The result has now caused many in the space community to question the feasibility and practicality of any manned space exploration program led, managed, funded or sponsored by the federal government. There is no guarantee that any future program will avoid such pitfalls, but it behooves us to attempt to avoid them if we can. Effective, long range and formal planning conducted publicly by both advocate groups and NASA can help reduce the probability of future bad decisions, and make it harder for problems caused by conflict-of interest situations to damage the program.

Because the problems blocking the creation of a Mars program, and most threatening to its success are political and organizational, rather than technical, it is critical for us to deal with the issue of planning, planners, design and control of programs now. One of the most important abilities of humans is our ability to do advance planning. In preparing for Mars Operations, we would be negligent if we did not use that ability to the maximum extent possible before operations start. I also think it is important to get people interested in looking at Mars planning from a variety of viewpoints before a lot of "final or master plans" are created, since more good ideas will then be contributed, and all plans will be better for being subjected to open analysis and debate.

I here present ideas and methods for a long-range planning process for creating a permanent human presence on Mars, partly based on the Delphi Method, and which takes into account both technical and organizational problems. This involves examining often controversial

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and concrete issues where people of good will may differ. My idea consists of a formal plan for planning, which uses inclusive methods to arrive at a consensual Mars Development Scenario. Abbreviated versions of this plan are intended to be used first by the Mars Society and other Space Advocacy groups in an attempt to create a consensus on Mars Programs. Later, it is intended that a more mature version could actually be used by the Sponsors of a real Mars Program to avoid some of the past pitfalls.

The Plan itself would in general follow these steps:

- (1) It first requires posing (and addressing) a list of fundamental questions that need to be asked about the process, including identifying additional fundamental questions. (Some of these questions will be addressed in the process below.)
- (2) Decide what the long term and short-term goals should be.
- (3) Decide how to tell if any goals have been reached and if so, whether the program should be (A) have new goals adopted, or (B) be transitioned to a new program with all new goals, (C) ended,
- (4) Identify the major decision points or alternative scenarios encountered while planning, especially on points where obvious branches to two or more reasonable paths are found, (even though some of the paths may not seem obvious or reasonable to some of the participants).
- (5) In the process, material would be presented from multiple points of view, along with specific facts and arguments from experts on the advantages and disadvantages of each choice at each decision point.
- (6) Identify what assumptions are made by each potential choice (and find out if they are valid).
- (7) Use flowcharts covering the most critical points and pathways leading to Mars development for discussion of the inter-relationships between the decision points that are unique to a specific situation. The resulting flowcharts create a visual representation of the "decision geography". They will have an initially diverging pattern, but one which would eventually converge again.
- (8) The participants must work out the consequences of each decision, and would thus consider the later (downstream) changes in plans and decisions that would be forced by any earlier (upstream) changes.
- (9) In so doing, they must also ask the question: how far upstream in the flow of decisions do we need to go to start planning most effectively?
- (10) We would then attempt to create a rough time and procedural framework where issues relating to Mars Issues in development planning can then be logically and sequentially located in relation to other issues.
- (11) Based on a selection of the best decision points and pathways, the plan requires identification of the major phases of a Mars program, whose correct timing and implementation depend on the right series of decisions.
- (12) Only after this point, by using the Delphi method, would we then try to create a consensus on the best current choices, (including identifying why they are the best ones), as well as

pathways that have generally negative results. (Planners must be ready to re-assess if new technology or pertinent information becomes available.)

- (13) With the framework in place, it again uses the Delphi Method to resolve the major identifiable issues that will confront the planners and managers in most or all phases no matter what direction the program actually takes, (issues partly decoupled from the timeline). Whether these issues can be resolved without extended infighting later depends on how well the pre-program-start agreements on policies and goals have been settled.
- (14) Based on resolution of the best pathways and the major issues, create fundamental policies or guidelines for the program (such as using primarily re-usable Vs single use spacecraft).
- (15) It then requires the participants to negotiate a formal Pre-Program-Start Agreement defining in black and white the Program Goals, General Rules and Policies, Funding Level and Sources, Control and Management of Program, Goal Changing Rules and Termination or Transition Rules. (Much of these items will have already been agreed to in the above process.) Part of the Agreement should cover pathways and policies specifically forbidden by mutual agreement.

Attempts at Long-Range Planning should always explore several different approaches to the problem, and follow some step by step method similar to the one above. For advocacy groups, additional steps are possible: (A) trying to influence the "powers that be" to make the right decisions based on an analysis of the decision tree, and by educating them on the consequences of the decisions, or (B) even attempting to influence who the decision makers are. Some of this activity crosses the boundary into politics. Part of the problem from our point of view is how to persuade the decision-makers to adhere to such a formal system. Part of the answer is that a lot of the groundwork: the build-up of the set of goal statements, decision tree, arguments, supporting facts, pathway framework, etc. can be done in large part by the advocacy groups, if we document our discussions as we go along. Another advantage is that most of the advocates have no directly related personal stake (such as career goals) in the specific outcome of the planning process, and so would be less likely to have conflicts of interest than people representing potential sponsors and financial backers (such as government agencies or companies). Variations of this plan, as used by the Mars Society (and other societies), could lead to an interactive process where people could meet in person and over the net for an extended period to discuss and try to come to a consensus on the best of a series of alternative Mars scenarios for later presentation to other agencies. Part of my idea is to create, outside of government a widely recognized body of planning, information that cannot be easily ignored by the bureaucracy before any Mars program starts. If we can show that it is in almost everyone's best interest, they may actually agree with some of our ideas. This may seem like a lot of formal structure, but considering the past history, and that a Mars Development program involves a major portion of the Human Future, it is worth doing.

Below I have covered in more detail some of the more important steps in the process.

(1) ASKING FUNDAMENTAL QUESTIONS:

What questions need to be asked (and addressed) before we start planning a Mars program? A good examination of them by the real decision-makers will increase the probability of correct decisions. They can also serve as a basis for beginning discussions. Some of these pertain to actual negotiations, others to discussions by advocacy groups:

- What other fundamental questions have we missed?
- What formal agreements should be made between major sponsors before the program starts?
- What should the stated goal(s) of the program be?
- How can non-government organizations have a say in designing a Mars program?
- Is it possible for a Mars program to be a for-profit Enterprise?
- Should a government program cooperate with a non-government program and how?
- If the program is government funded, how can we avoid having the government agency in charge from "running away with the ball", by altering the program plan or changing the schedule for its own benefit?
- What groups (besides space groups, government and industry) should be involved in the planning?
- Who (besides space groups, government and industry) should be involved in the actual program?
- What would the government expect to get out of funding a Mars Program?
- What would the other interested parties expect to get out of it?
- Should we start a program with no guarantee that it will be self-sustaining or lead to a permanent base?
- Should we accept or support politically a program that is not open-ended?
- Would an open-ended but single goal program, AKA Apollo, be inevitably self-limiting?
- How should an "open-ended" program be run or evolve so as not to become a dead end?
- Is a re-usable Mars vehicle architecture (after launch) vital to the survival of an open-ended program?
- What is a "financially sustainable" annual cost for a US Mars program, 1, 2, 3, 5 Billion?
- Should the Program be international in scope and participation?
- What is a "financially sustainable" annual cost for an International Mars program, 1, 2, 3, 5, 10 Billion?
- How best can we reduce the annual cost - what is the most critical cost parameter?
- On what basis should we conclude that the "cost" of waiting exceeds the cost of starting?
- What parts of the cost and or program might be funded or managed by private enterprise?
- How soon and in what scope should planning and R&D for the initial landing phase and science/sortie missions, their transport vehicles, hab. units, equipment, and materials processing start?
- How soon should planning for the permanent base phase start, in conjunction with the sortie phase?
- Would any major upgrades in equipment or vehicles occur at the transition to this phase.
- What long-lead time items should be funded first?

- What kind of surface and atmospheric transport should be developed for use on Mars?
- What effort should go to creating technology for use of in-situ materials beyond fuel and volatiles?
- What kinds of items should we be able to make from local resources at each phase.
- What balance should be struck between single use or re-usable science and exploration "sortie" bases and a "main" or "development" base which would be expanded?
- When and on what basis should a main base site be selected or expanded vs. continuing to build and - use sortie bases?
- What factors should be considered in selecting a "permanent" base site?
- What proportion of time and money would be spend on (1) pure science, (2) exploration, (3) operations and maintenance, (4) base expansion, and (5) research and testing of technology for base development?
- Could an economic system exist at a permanent Mars base and on what basis would it operate?
- What minimal conditions would be needed for an "economy, - could it be seeded or jump-started?
- If there was no or only a minimal economy, on what long-term basis would the base be sustained? This should include comparisons to Arctic and Antarctic scientific and industrial bases.
- What would come after the permanent base phase?
- At what point and how would a base transition formally to a colony? (colony requires a new plan)
- Should any consideration be given to possible future terraforming plans (such as avoiding areas like the floor of Hellas which would be flooded) in selecting development base sites?

2. DEFINE THE GENERAL AND SPECIFIC JUSTIFICATIONS, PURPOSE, GOALS AND OBJECTIVES OF THE PROGRAM

I created a list of general goals and objectives for space activities in general about 10 years ago called "WHY SPACE". A number of these are especially relevant to a Mars Program. Which set of general goals the planners agree to, if any, will have a very large impact on the conduct, direction, and sustainability of the program.

General Goals For Mars Development:

1. Pure Science - Information about Mars to compare to the Earth and other planets.
2. Practical Information about Mars to allow mankind to survive and grow on Mars.
3. Expansion of Human Civilization to another planet (growth).
4. Backup copy of Civilization and Mankind in case of natural catastrophe or war on Earth.
5. Tourism and cultural expansion - new experiences for humanity
6. Social diversity and freedom from dominating state authorities (frontier environment)
7. Providing a greater diversity of types of places to live and work.
8. Spreading LIFE to a probably sterile world.
9. The Human drive to Explore.

10. Inspiration and education of today's youth.

Also required is a list of specific and concrete goals, which should support the general goals. Examples (with dates) would be: Placing a small orbiting Mars Base and refuge at Mars by 2015, Conducting a reconnaissance of Phobos for volatile resources by 2018, Identifying and investigating at least 5 potential Base sites by 2018, Finding one or more base sites with accessible water (by drilling or mining) by 2020, Creating a permanent Exploration and Development Base on Mars by 2025, Testing (on Mars) 3 types of prototype equipment for smelting and fabricating metal or composite pressure shells from Mars materials by 2022, etc.

(3) TELLING WHEN GOALS HAVE BEEN REACHED & WHAT TO DO NEXT

This may seem obvious, but what is needed is a formal agreement in advance as to how to tell when or if each goal has been reached. For example the Space Shuttle was declared "operational" after just 4 test flights". Specific numeric limits for acceptance of factors such as size of a completed base, closeness of a resource to a base site, concentration of a resource, etc. should be set. The agreements must be flexible enough for the parties to be able to change the definitions when changed circumstances warrant. The main purpose is a means of keeping a completed step from being continued indefinitely due to bureaucratic inertia, or from starting a new step before we are ready to do so.

4) SOME OBVIOUS ISSUES AND DECISION POINTS.

The decision point is where you have to make a decision on one issue in a series of issues, because that decision affects what the next issue or set of issues is. Phase 4 consists of gathering a wide variety of opinions and choices like these over an extended period, with minimal emphasis on evaluation.

A. Access to Mars:

1. LAUNCH POINT TO MARS: (a) Earth Surface (b) Earth Orbit Rendezvous (c) Earth Orbit from "facility" (affects costs and design of payloads, time frame for program)
2. LAUNCH VEHICLES USED: (a) existing ELV (b) new ELV (c) new 2STO rocket powered RLV (d) new SSTO rocket powered RLV (e) new airbreathing RLV (same affects)
3. ORBIT TO ORBIT PROPULSION (a) Chemical (b) Nuclear (c) Ion/Plasma/Hall solar or nuclear thrusters (d) other. (affects size of payload or speed of trip)
4. EARTH ORBIT TO MARS ORBIT (TRANSIT) VEHICLES:
 - I type: (a) expendable general purpose - one use (b) general purpose - a few uses (c) maintainable - general purpose.
 - II. optimal size for vehicle and crew if only 1 vehicle is flown per mission.
 - III.(a). optimal crew and vehicle size based on earth launch type and cost and assembly method. (b). optimal crew and vehicle size for multiple vehicles per mission.
 - IV construction and/or earth orbit assembly considerations:
 - (a) single unit - no assembly (large launch vehicle or small vehicle)

- (b) modular vehicle - multiple launches required, smaller launchers, no mass limit
- (c) construction in earth orbit required with supporting infrastructure.
- (d) inflatable (transhab type) or rigid metal construction
- 5. NEED FOR ANY PERMANENT IN-ORBIT FACILITY(S) (a) None (b) Limited Fueling and Earth Return Stage storage bay (c) b plus refuge (d) fully capable orbiting base.
- 6. ATMOSPHERE ENTRY METHOD BY MANNED CRAFT: (direct entry from solar orbit via aerobraking) (b) partial aerobraking and orbital insertion and transfer to re-usable landing ferry (c) rocket powered orbit insertion and transfer to re-usable landing ferry.
- 7. ORBIT TO SURFACE VEHICLES (a) expendable: general purpose - one use, (b) expendable general purpose - a few uses, (c) maintainable - general purpose, (d) maintainable, specialized use, (e) maintainable - modular multi-function.
- 8. FUNCTIONAL TYPES OF ORBIT-TO-SURFACE VEHICLES NEEDED (a) crew transfer with abort to surface self rescue capability (b) crew/hab combo (Mars Direct) (c) pressurized cargo ferry (d) unpressurized "flatbed" cargo ferry for large objects (like habs).
- 9. SURFACE POINT-TO-POINT TRANSPORTATION: Rover? Airplane? Sub-orbital (Hopper or Surface to Orbit vehicle?), Range and payload requirements?

B. Mars Base Planning

- 1. TYPE OF HAB UNIT FOR INITIAL SORTIE BASE MISSIONS (a) inflatable (b) rigid
- 2. SURFACE HAB UNIT INTEGRATION: (a) separate units for delivery by cargo ferry (b) part of single use Transit Vehicle (c) part of single use Lander.
- 3. ENERGY SOURCE FOR SORTIE BASE: (a) solar cells (b) nuclear (reactor) generator (c) nuclear heat source
- 4. "PERMANENT" MANNED BASE SITE SELECTION (a) by unchanneled drive only (b) manned survey: < 5 missions (c) extended manned survey: < 25 missions) (d) none
- 5. "PERMANENT" MANNED BASE SITE QUALIFICATION PARAMETERS: (a) must have provable water or ice supply by drilling or excavating. (b) use water from CO2 and Hydrogen stocks.
- 6. MATERIAL USAGE AT BASE SITES (a) volatiles and fuels only (b) crude fabrication of structural materials (c) fully developed (on earth) fabrication technology for habitation structures, etc.
- 7. DESIRED LATITUDE OF MANNED BASE (a) near-equatorial (b) "temperate" (c) polar or near-polar. (affects energy use, orbital access to surface, thermal hazard to some metals / materials).
- 8. TERRAIN AND ROCK TYPE AT MANNED BASE: (a) southern highland cratered terrain (b) northern lowland lava plain (c) volcanic region (d) outwash region (e) eroded regolith & valley region (f) polar deposit (g) sand dunes.
- 9. DIVISION OF LABOR AND EFFORT AT A SORTIE MARS BASE & A "PERMANENT" BASE: (1) maintenance & operations. (2) construction and base expansion, (3) Mars technology development (4) Mars science, geology and exploration.

5. INCLUDE MULTIPLE/ALTERNATE POINTS OF VIEW IN GATHERING OPINIONS

In gathering opinions on issues and decisions, it has been long shown that two heads are often better than one, and that no one person or few people will come up with as many good ideas as a larger group. While gathering the ideas, only a minimal effort should be made to evaluate or judge them. The evaluation phase is done later under better-controlled conditions.

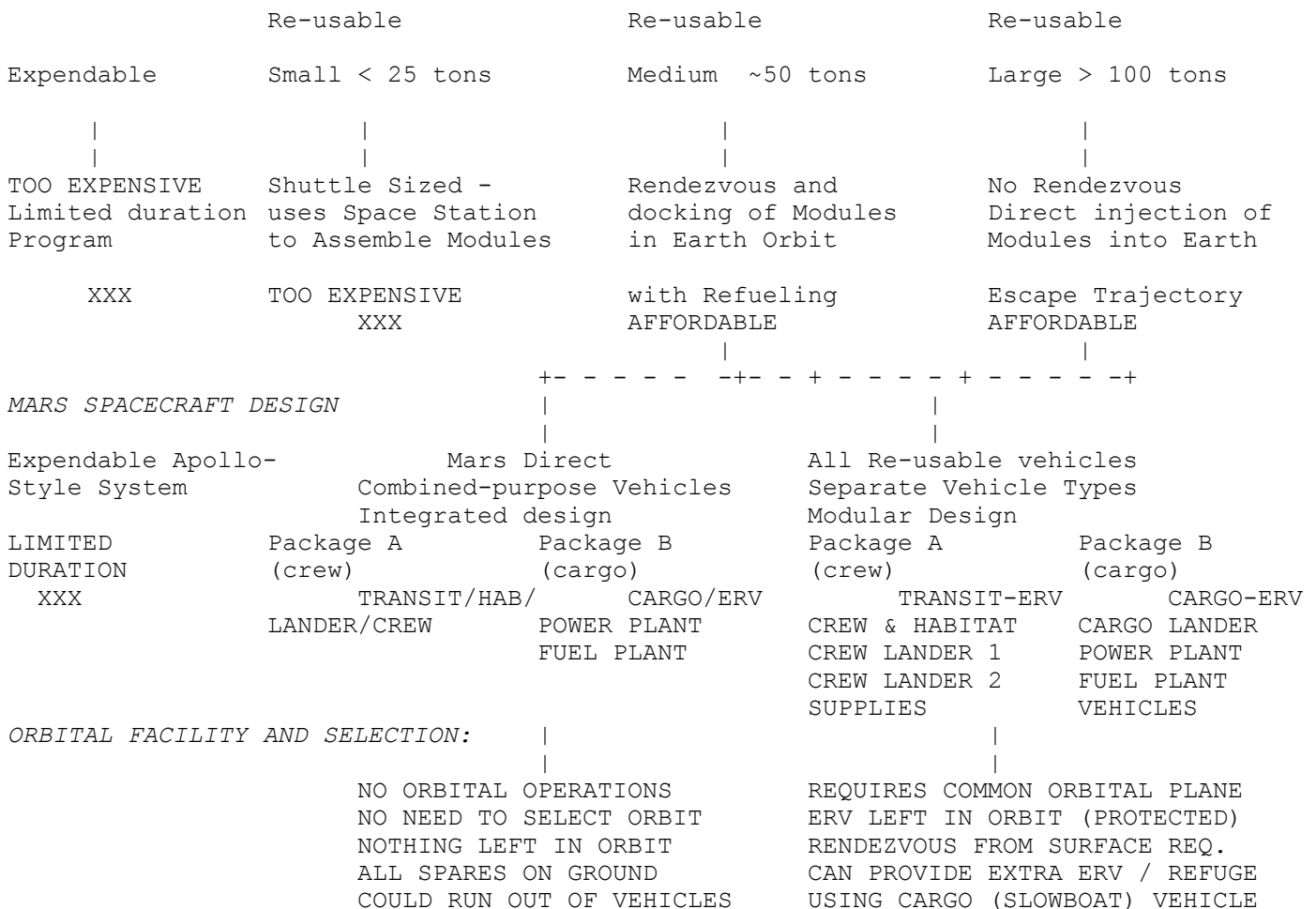
6. CHECKING THE VALIDITY OF ASSUMPTIONS

The two main types of assumptions we are concerned about here are logical and technical. Technology advances so rapidly that what was impossible a few years ago is easy today. Frequent re-assessments of technological assumptions should be an important part of Mars planning. Planners should defer to engineers when discussing what current technology can do, but should be cautious in accepting negative assessments of future technology. Experts are not needed to check logic - just clear thinking!

7. USE OF FLOWCHARTS

Here is an example of a simple flowchart illustrating the issues covered under steps 8 and 9. Much better charts can be created using professional flowchart software.

BOOSTER TYPE:



Examples of interacting issues that should show up in flowcharts:

- Crew size vs. vehicle number and size per expedition.
- Cost-time tradeoffs interact with re-usable or expendable vehicles
- Earth Launcher capacity affects design of the Mars vehicles.
- Purpose of expedition affects type of bases and expeditions
- Policy of creating in-space capability at Mars or not affects type of equipment.
- Mars orbit selection or not affects development base location and vice versa.
- Initial Mars materials usage affects type of equipment taken on sortie expedition.
- Detection of raw materials affects location of development base.

8. CONSEQUENCES: DECISIONS AFFECTING OTHER DECISIONS:

A good example of consequences and how issues are inter-related is the major issue (an issue affecting multiple phases) of re-usable vehicles at Mars. (Issues affecting just a single phase also need to be evaluated in a similar way.) This argument bounces back and forth as it progresses, first favoring one method, then the other. While use of re-usable vehicles for Earth Launch can be partly decoupled from the design of the Mars transit and lander vehicles, the design of the transit vehicle/landers themselves are tightly coupled. With the original Mars Direct design for example, the initially unmanned Earth return vehicles go down to the surface in direct entry, without orbiting at all. The use of aerobraking at this point greatly reduces the need for fuel, but the need to take all of the structure of the earth return vehicle down to the Martian surface and then have to re-launch it back into orbit is a heavy penalty to pay, (and results in a very cramped return vehicle). It also results in a Earth-Mars transit vehicle which can not be used again, since it is left on Mars, although the habitation section used during transit to Mars is also used on Mars [Zubrin].

However, under a re-usable vehicle policy, we would separate the components into Earth-Mars Transit Vehicles, docked Habs, and Mars Landers (or ferries). This allows both the transit vehicles and the ferry vehicles to be re-used. We would then need to get into Mars orbit first before we can use the lander to land. This would mean expending fuel to slow both the transit vehicle and lander into Mars orbit. There are two factors which mitigate this: (1) if the landers could be re-used, many fewer of them would be needed, enabling additional cargo to be brought along and conserving vehicles for future use, and (2) the approaching manned transit and cargo vehicles could be designed to use partial aerobraking to kill most of their extra velocity, before raising the "peri-ares" into the proper orbit. This maneuver takes only a little fuel. It seems clear that a set of initial return to orbit vehicles (or ferries) could be sent to Mars, along with a set of Earth return vehicles (one of which could be the cargo propulsion module), which would be left in orbit. The reduction in mass required to be boosted back into orbit would allow extra fuel to be delivered to orbit instead, allowing a bigger or faster earth return stage and a happier crew.

Use of separate vehicles means that a specific orbital plane must be selected by any of the preceding cargo vehicles whose initial destination is orbit, rather than surface. This means that rendezvous operations would be required at approach to Mars, and after return to orbit. Any hazard caused by failed rendezvous operations could be mitigated by allowing remote control of the unmanned orbiting section so that it could rendezvous with any stranded vehicle. Another backup would be an abort to surface capability, with at least one surface Hab able to support the crew for an extended period. The unmanned orbiting Earth return vehicles (with always a spare present) could be shrouded with a thermal blanket/micrometeorite blanket, keeping them protected while the crew is on the surface. The vehicles left over from each expedition would be left in Mars Orbit, stored inside protective thermal and meteoroid blankets. After just a couple of expeditions, a good number of spares would exist, and more cargo space could be turned over to scientific and development equipment. For early expeditions, the cargo ferry might have an emergency crew compartment and would remain on the surface until the mission was over, serving as a backup means of returning to orbit. All ferries would have an extra-large capacity fuel tank, capable of carrying more than enough extra Mars-derived fuel back to orbit for the return trip to Earth.

This issue also interacts with the policy decision of having in-space capabilities at Mars, not just surface capabilities. For example, the ability to explore and possibly utilize resources on Phobos or Deimos may become a high priority goal, which the Mars Direct system would not provide. On the other hand, a pre-program agreement could allow a variation of the Mars Direct system to be used to build up surface capabilities for a certain period, and then when certain goals had been met, the need for in-space capabilities would be addressed. The issue then is more simply: how to maximize cost-efficiency so that we do not run out of vehicles.

9. HOW FAR BACK ALONG THE DECISION STREAM TO GO

Good examples of linked issues are the Space Access - Time Clock problems, which directly affect the design of the Mars vehicles. NASA upper management wants to keep doing incremental improvements to the shuttle, which (based on airframe lifespan), would allow the shuttles to keep operating for another quarter century. Unfortunately, this will lead to only very "incremental" cost reductions, which means access to space will not get cheap very soon if NASA gets it's way. The impact of annual cost on Mars planning affects not only the cost of a mission, but also the very design of the spacecraft. Using the shuttle to orbit pieces of Mars spacecraft and assembling them in orbit would be very expensive. Using a new expendable booster would also be expensive, and unless one of sufficient capacity already existed, would cost a lot to develop. Using a new re-usable booster (with at least a re-usable first stage) might take a couple more years, but would reduce the cost per mission, while waiting for a re-usable airbreathing vehicle of sufficient size might take 10-15 years, since the first commercial version might be too small. Currently we are in a vicious circle of: no mission, so no booster will get built, and so we can't do the mission.

The cost issue is basic to persuading the nation that a financially sustainable Mars program is feasible. A limited program of 2 launches a year such as Mars Direct could be accomplished with an expendable booster, but some suggest that waiting until a re-usable booster is available would greatly expand the number of men and the amount of material that could be sent to Mars for the same cost, thus greatly expanding the scientific and utilitarian aspects of a Mars base.

There are at least four reasons for waiting for a cheaper booster: (1) The higher cost of using existing or proposed expendable launchers could result in a limited duration, non-sustainable Apollo style Mars program with non-re-usable hardware. Just like Apollo, use of expendable Mars spacecraft would require a constant production of vehicles paid for by the government. If the government was paying for them, at some point it might decide to stop, (just like Apollo), forcing an end to the program. (2) Once the effort to design and build a vehicle has already been expended, we tend to remain "stuck" with it long after it is obsolete. (3) If we wait, we can design Mars vehicles to be built in a semi-assembly-line mode, similar to how the Russians build Soyuz modules, and thus with cheaper launch costs and cheaper vehicles, we will (4) be able to launch several of each kind per expedition, not just one. This will allow greater safety and allow operations to continue if a single vehicle is damaged or fails. We have the time now, before any program is started, to think out in general the best vehicle designs, for not just the first few landings, but for at least a decade of missions. Some fear, however, that any delay in starting the program, while waiting for re-usable heavy boosters, or that a drawn-out program like the aerospace plane, could delay or stop the impetus for the program. This kind of decision will obviously be heavily involved with politics.

One solution would be for the program to be initiated at the same time that the booster work was started, so that the long lead time work would be done and spacecraft would be ready when the booster was ready. This of course, requires a level of coordination, but not cost, similar to that of the Apollo program. Any funding peak would have to be minimized. A reasonable compromise would be to schedule the expedition phase to start as soon as at least a two-stage fully re-usable commercial vehicle was available, and get assurances that any cheaper follow-on vehicle would be able to handle all of the cargoes currently planned or in use.

What is most likely to happen, however, given the current situation, is the "time clock syndrome". This is the hurried-up design and development of a program's hardware, driven by a manager's need to "show results" and "lock in" a design, once a program is approved and started, before support for the program wavers. The decision stream for deciding on the type of vehicles to use could thus begin the minute there is a viable political move toward a Mars program. The forces controlling the program feel they must get it underway right away, and thus quick and dirty designs (such as single use manned spacecraft) are used instead of designs which would be better for a long range program. (A similar syndrome in Hollywood becomes obvious when a producer has the sets built before the script is written.) Government managers are not immune to these pressures, even though there is no profit motive pressing on them. In fact, it is obvious that

there is already in existence inside parts of NASA (among the "empire builders") some pressure to create an "instant program" by grabbing existing designs and start building Mars spacecraft.

This situation is one of the best reasons for backing up and creating a long range plan which specifies the goals and lifespan of a program, and then designs spacecraft and equipment (using the best current technology), to best fit the demands of that program. If such a plan existed before a program was approved, it should have a strong effect on the new program's policies.

10. CREATE TIMELINE AND SELECTED PATHWAY FRAMEWORK

Once the decision points and major issues are settled, use the existing flowchart framework to eliminate or place on a lesser priority the less desirable paths, and then link the remaining ones together in a timeline, with a start date of 0. The subsequent program events are measured from this start date, which would mark whenever the program was approved. Existing management techniques inherited from Apollo are sufficient to schedule the development and production of the needed equipment.

11. IDENTIFY MAJOR PHASES OF THE PROGRAM

A Mars program can be divided into three main phases: a low cost planning - and research phase, a high cost development and construction period before manned operations, and the medium cost operations phase after manned flights begin. (A more detailed list of major phases would emerge from the process.) The planning phase is intended to provide sufficient funds to create preliminary paper designs and to develop and test long lead-time hardware, without tight scheduling and funding pressures. By the time the development phase begins, many promising technologies, designs and methods may be omitted from the plan, simply because there is not enough time left to do so. This is why a lot of the planning and long lead-time development must be done before a goal date is set for the first expedition.

If development takes place during a period of eight years, its annual cost can be distributed so that it does not greatly exceed that during the operations phase. Finally, during the operations phase, the goal is to keep annual operating costs as low as possible, to minimize political problems, and to maximize the amount of funds available to actually operate the base and do exploration and science. In other words, if you don't have to spend a billion dollars a year on new launch or transit vehicles, that billion may be available for bigger crews, more exploration equipment, etc. If a continuing supply of new vehicles is not needed during the entire operations phase, it will be much easier to maintain operations for a long time.

The operations phase can also be divided into to sub-phases: (a) the period of initial landings at science oriented sortie bases when information is being gathered both to understand

Mars as a planet and to decide on the desirability, feasibility and usefulness of sites for phase (b) a "permanent" "development base". Such a base should be located in an area easily accessible from whatever standard Mars orbit is used, not at too high a latitude, near the widest possible variety of terrains and geological features, and at or near site(s) of demonstrated resources such as water (see appendix). Several options exist for transitioning to this phase: (1) selecting a "main" base before the first landing, (2) selecting it after a certain number of landings, (3) selecting it after certain facts have been established, or (4) not selecting a single main base at all. Guidelines must be established and agreed on for this transition decision before program start, because of three undesirable pathways: (A) arbitrary program termination (a la Apollo), (B) indefinitely getting "stuck" in a sortie base stage because of a lack of political will by the managers to make the commitment to switch resources to establishing and building a development base, or (C) selecting the wrong site for the development base.

12. FINDING THE BEST PATHWAYS

It has also been shown that the ideas are discussed much more fairly, and the group comes to a consensus faster, than when the proponents are known during the discussion. .

The task before the group now is how to evaluate the ideas in a fair fashion. Part of this is judging how well each method addresses the program goals. It has been repeatedly shown that ideas are usually judged by whom they come from, rather than on their merits. To evaluate and choose among the differing pathways that have been established, many believe The Delphi Method is one of the best techniques, where ideas are submitted without the group knowing who the submitter is until after a discussion of the idea. It is means of dealing with a complex problem or reaching a group consensus by sidestepping the effects of personality clashes and dominance. It does not require a physical meeting, and the participants do not even have to know who the others are. Therefor submitted ideas are judged more by their merit than by who proposed them. Reasons for using Delphi include: diverse background and personalities of the group, where time and travel is limited, and where disagreements, dominance problems, value differences and other human biases already exist. [Turoff]. The possible objectives of Delphi are (1) to determine or develop a range of possible alternatives, (2) to explore or expose underlying assumptions or information leading to differing judgments, (3) to seek out information which may generate a consensus within a group, (4) to correlate informed judgments on a topic spanning a wide range of disciplines, (5) to educate the group on the diverse and interrelated aspects of the topic. [Turoff]

This method uses a coordinator or coordinator team to manage the interaction between the participant panelists and experts. The coordinator first presents the panel with information (in this case all the information gathered during the previous steps: (1-11), then asks for opinions and/or forecasts on a set of defined topics. The coordinator then receives the responses, edits, clarifies, and summarizes the information. The coordinator tries to identify and order the reasons and assumptions behind the judgments, then gives the set of anonymous feedback to the panelists

with a second round of questions. These rounds continue until a consensus is reached or the experts opinions cease to change [Classnotes]. Experience has been that the experts often converge on better solutions faster than when in a face to face meeting! Note that existing Internet software is ideal for this type of interaction!

A major article on the Web contains many suggestions for improvements to the original process, which may be critical to effective use of the Delphi process). Of critical importance is how the panelists are selected. Lang suggests panelists should be selected from 3 groups, stakeholders, experts, and facilitators [Lang]. In the case of a panel run by an advocates group, we would get to pick the panelists and coordinators, not a government agency! It is probable that a series of panels would be held, to pick the best pathways from each phase of the program.

13. SETTLE MAJOR ISSUES AFFECTING THE PROGRAM (EXAMPLES)

These issues, common to many phases or sub-phases of a program, cannot be settled until the best pathways have been identified. Use a similar consensus-building method.

One major issue (now rearing it's ugly head in the space station) is how much crew time and effort should and can be expended on science and exploration, and how much needs to be expended for operations and maintenance. A "science-only" expedition will not need any development. This issue will be a major factor in the decision on when to switch emphasis from sortie missions to a development base, because it will (at least temporarily) change the ratio of science time to operations time. A Martian astronaut's time will be extremely valuable during at least the first decade of operations. Therefore decisions will need to be made on how his or her time is best used. This reflects back to the basic purpose and goals of the mission and program, and will cause bitter disputes between science and development oriented people unless the purpose and goals are agreed to early on.

Another of the most critical issues, and one to which little attention has been paid, is that of using in-situ Mars resources (other than the atmospheric gases). Bob Zubrin, his associates and several others have pioneered the Mars Resources field when absolutely no attention was being paid to it, and they have made it an integral part of manned Mars missions. By now, several functioning units have been built and demonstrated, which can create propellants and other useful volatiles from the atmosphere. This is the type of technology that should be available during the initial phase of sortie base operations. Now, we must move beyond the pioneer stage (of atmospheric resources only) and look at the industrial stage! This topic will become critically important once it is time to select a development base site.

The first factor in Mars resources is that Mars is not extremely depleted in atmospheric volatiles, as is the moon. It will be much easier to get the water and gases needed in the processing of other solid resources than on the moon. The low gravity, near vacuum and low nighttime temperatures will still be challenging. It is reasonable to ask: what types of structural

materials and equipment can be made from Mars resources, especially if we develop and prepare equipment to do this before the missions start. Work should start on miniaturization of concentrating / smelting / fabricating technology with specific end products in mind. Each early mission would then carry one or more prototypes of the equipment to test it under real Martian conditions. Any problems could then be worked out in time to assist in the construction of one or more permanent bases.

The second factor is that there will be a wider range of raw materials available on or under Mars than on the Moon. Martian soil may be source of a significant variety of mineral salts and volatiles (no rain for 3 billion years). Simple magnets might be able to recover large quantities of meteoric iron in some areas. Water under the permafrost or ice regolith layer may be rich in brine, with different metallic salts in solution. Some Martian sand might be mostly quartz, a good source of pure silicon dioxide. Volcanoes erupting long ago through the "wet" layer may have created limited bodies of ore. On Mars, rock and its components would play a much larger part in the lives of the crew than it does for most city people on Earth, where we are surrounded indoors by large amounts of formerly living material (wood, leather, wool, etc.), and ever increasing amounts of synthetic materials like plastics and alloys. City people might even define that unfamiliar substance called "rock" as a "non-living and non-synthetic solid"!

The third factor is deciding which items are worth creating at Mars during each phase, compared to the cost of bringing the item all the way from Earth. Low value and high weight and bulky items would be good candidates, such as some form of concrete, glass, structural metals and plastics, insulation, etc. The value of an item will decrease as time goes on, with the highest value being during the first mission. However, crew time will also be valued most highly during the first mission. Therefore, a balance of crew time use (Mars cost-effectiveness vs. Earth cost-effectiveness) will have to be struck. Crew and staff time will initially be split between exploration, science, operations, maintenance, and Mars technology development, and later construction). One way of reaching a compromise would be for simple types of fabrication of larger objects to be done on Mars, with smaller items requiring much more elaborate tasks to build coming from Earth. For example, simple pressure shells for hab units could be fabricated on Mars, while the complicated air locks that would bolt on to the ends of the shells could come from Earth. Other relatively simple materials that might be fabricated would include energy collection film, parts for vehicles, tools, drilling pipe, structural materials for plant growth structures and habitation structures.

The fourth factor is the cost of developing the processing equipment back on Earth and how much it will cost to bring it to Mars. Remember that even a partly automated process could multiply the capabilities of a single crewmember manyfold. Even current industrial techniques may be able to create relatively miniaturized equipment that requires little attention. Robots may eventually be able to take over some of the tasks of crewmembers, and they would not need food and oxygen! However, also remember that the managers and sponsors may not be inclined to spend money to design and create expensive equipment for a base that might never be built. Again, this points out the importance of pre-agreement on goals and policy. Some types of

equipment might not rely on automation, but depend specifically on human operation; doing things that robotic equipment would be unable to do reliably enough due to mechanical failure rates.

A good example of this would be a deep drilling rig on wheels, which would enable a Development Base crew to drill for and extract water and brine from below the permafrost layer. A major advantage of the rig would be that it would also provide invaluable scientific access to the crust of Mars, and enable the crew to attempt to find any life that might exist a mile or more deep. The joint development and scientific community's sponsorship of the rig would raise the chances of its approval. However, the depth of any "global water table" in the regolith and rock might vary greatly depending on the actual elevation of each site, so only certain sites (such as the floors of Hellas and Vallis Marinaris might have water less than a mile or two deep. At most sites the water could be sealed many miles deep under the cryosphere, beyond reach of any reasonable drilling rig, until the means exists on Mars to build large one. The newest information indicates that there may be much more water ice at many sites in the upper crust of Mars (at least north and south of 45 degrees latitude) than was previously thought, and that large parts of the very flat Northern Lowland Plains and the floor of Hellas were originally covered with deep water before Mars froze [Clifford].

A basis for agreement to spend more money during the development phase of a program hinges tightly on the program goals. A "science only" program will have no need for expansion and development. Even though most people supporting development also strongly support science, many (but not all) scientists will not reciprocate, as they (being specialists, just like most people), are interested only in their specialty: science, not in colonization or development. Thus if the long range goals established early on include eventual colonization, getting funding for materials processing will be much easier.

14. CREATE FUNDAMENTAL POLICIES AND GUIDELINES

Here are examples that could resolve the major issues. These depend on the prior establishment of goals and best paths and resolution of the major issues.

- A. All launch, solar transit and ferry vehicles used for this program will be re-usable and repairable, with the exception of special early habitation payload ferries and emergency crew modules.
- B. Part of the Mars development effort will be the creation of an in-space capability out to the orbit of Deimos, including science missions and rescue operations.
- C. We will assure the program's financial sustainability within established funding limits.
- D. A major portion of research and development funding prior to manned launches will go to developing prototypes of miniaturized extraction, smelting and fabrication equipment for use in converting Mars resources into usable structural materials such as metals and glass.

15. NEGOTIATE POINTS OF THE FORMAL PRE-PROGRAM-START AGREEMENT.

A. Include the Goals, Rules, Exclusions, Phases, Pathway and Major Issue Choices, and Schedule already adopted by the previous planning sessions. Add to this some of the following:

B. Agree on whom Controls the Program?

As an example of a control-of-program problem currently affecting prospects for any Mars program, we need look no further than the related Space Access and Timeclock Dilemmas covered earlier.

There are several ways that we might try to assure that any plan (such as the one under step 9) created to sidestep those dilemmas was followed. (1) Educating the public, media and decision makers on the consequences of not following the plan in certain ways would allow public pressure to be brought to bear on errant managers. (2) With such education, it might be possible to get a firm political agreement with the managing agency and supporting party to agree to a set of firm policies under which the program would operate. (3) Part of such an agreement would mutually identify a set of bad policies or paths that would not be followed. (4) Another method would be to create an oversight commission, which would not be responsible for running the program, but would have the power to make sure that basic policy was followed. The executive branch would delegate part of its authority to the commissioners. The primary difficulty with commissions is trying to find commissioners who do not have glaring conflicts of interest. Anyone employed or on the board of a company doing significant work for the agency involved would automatically have such a conflict of interest, which could divert the plan. Thus it would be very important, at the beginning, to try to agree on a fair and open process to select commissioners.

C. Agree on A Financially Sustainable Program

Another problem is achieving a balance between a sustainable program (which can support missions for at least a decade after they commence) without requiring additional annual expenditures, and a faster program that creates political enemies simple because of it's size. If the annual cost is too high, there will be continual calls to end the program and divert the financial juices to some other purpose. Again, here is where we must get a public and political agreement whereby the parties should agree on (a) what the goal(s) of the program should be, that (b) the annual cost is reasonable and sustainable, that a long term program is desired, that (c) increases in funding will not be requested except to cover inflation, (d) what the fundamental policies governing the program should be (e) how to determine when or if the goals are met, and (f) what or when its endpoint or transition point to a new program with new goals should be,

with new funding levels established. Many programs originate with backroom deals, and as such, are hard to control due to the unspoken prior agreements. This is why all agreements should be on public record.

Getting the annual cost down is another decision area that is tied to others. In the current climate a cost of 2 to 3 billion may be sustainable. The space station program is marginally sustainable at 2 billion, but has had poor cost management and poorly defined goals, so it has had marginal support politically. It has always needed a little more than the set allocation to continue. Once (a) the station is built, and (b) a re-usable manned vehicle is available to transport crews and supplies to and from earth orbit, the annual cost will be dramatically less – enough to even allow gradual expansion of the station. This logic also applies to a Mars program.

Another critical issue is the diversion of funds - both from and to the program. The program should be provided with at least a 10% buffer for contingencies, but should be designed to be able to shrink in size slightly if major operational problems develop. In return for a pledge of good financial management and not asking for more money (unless additional goals are approved within the scope of the program), the program should also be isolated from diversions to other programs (other than a declared national emergency).

D. Agree on Levels of Financial Support, Sponsorship of and Participation in the Program

It would be beneficial to have additional sponsors and sources of funding for a Mars program. International sponsorship would make it more difficult for our government to back out of the program once it was started. (Diplomatic repercussions may be one reason why the Clinton Administration has not ended the Cassini program in spite of its vociferous anti-nuclear opponents.) Non-profit and Scientific Organizations could also have a hand in sponsorship of such an expedition and could, for example, build and sponsor robotic rovers that might also work in conjunction with such an expedition, especially if the launch costs of Mars-bound cargo can be reduced. Small advanced smart rovers that could be unpacked and set up from cargo by the crew and released on the surface could multiply the "eyes and ears" of the limited base staff, and could also retrieve rocks at remote sites and return them to the base for analysis. However, the participation of all these groups would make planning and pre-program start agreements all the more important.

Private enterprise should be allowed to play a large role in the expedition. The two main types of participation are mission support and mission result products and services. Mission support includes Earth based launch services and construction and support of Mars Transit vehicles and crews. It may also be possible for private companies to deliver unmanned cargoes to Mars orbit for an agreed on price. It is still likely that the Transit vehicles themselves would be owned and operated by a government agency for at least the Sortie Base Phase. Examples of mission result products and services include future interactive video and remote viewing systems and software would allow earthbound viewers to experience the Mars expedition almost as if

they were there. A major aspect then would be not only immediate media coverage of the expedition, but also gathering the video and topographic data to be used with the video equipment later. Another source of income would be bringing back Mars rocks for sale to the public. The collection and return to Earth of such rocks could be coordinated with the expedition's geologists, so that they would get first pick of any rocks of especial scientific value. Current NASA policies strongly disapprove of such involvement in private enterprise, so this is a significant obstacle to private enterprise in addition to their discouragement of private launches and vehicles. There are probably many other ways of making money on Mars Sortie Missions.

E. Agree on how the money will be spent at each phase of the program.

This type of agreement is crucial to prevent conflict over allocations of resource both before and after manned operations begin. Spending on developing materials processing vs. science and transport, and allocating crew hours to running mineral extraction equipment instead of collecting rocks for science are good examples

APPENDIX

SAMPLE PLANNING INFORMATION

These examples show the types of information and information organization used in planning.

A. SORTIE/SCIENCE BASE SITE EXAMPLES:

1. Cydonia Mensae: "edge terrain" ancient highland materials eroded and exposed without aeolian mantle, northern plains materials. Site is geologically diverse and important, despite the presence of the "Face".
2. Floor of Vallis Marineris - wall layers and landslide deposits, layered sediments within canyon system.
3. Elysium Volcanic Region - young water outflow channels, diverse young volcanic units, high heat flow, shallow water table (Thin cryosphere) - bio. search.
4. Edge of South Polar Layered terrains at high latitude - Seasonal and permanent polar cap geology and meteorology, water and volatile analysis, climate history of cap, layered deposits, aeolian mantles, adjacent southern highland terrain. (SUMMER SITE ONLY!).
5. Argyre or Hellas Planitia (at edge of floor): Excavated deep crustal materials in basin rim, channel deposits, lake deposits? on basin floor, aeolian deposits, climate history, fossil microbiology?
6. Memnonia highlands edge, channels, aeolian-eroded deposits (SUMMER SITE ONLY!).

B. MAIN "DEVELOPMENT" BASE QUALIFICATION PARAMETERS

Current information indicates a near-equatorial site or no more than 30 degrees latitude is desirable.

Climate (low latitude) - no polar climate.

Orbital Access - near equatorial for easy landing.

Solar energy Access - near-equatorial for maximum solar energy.

Low altitude - for maximum atmosphere pressure and radiation shielding .

Volatiles Access: Water, low altitude to drill easily to the hydrosphere "sea level"

(The top of water table in regolith/crust may be below the lowest exposed surface on the planet).

Possible access to dissolved metal salts, etc. (in brine and evaporite deposits)

Local and regional geological diversity- for access to a greater variety of raw materials.

(Determination of presence, type, and scarcity of specialized mineral resources depends on global geochemical and mineralogical mapping. Extent of geological and mineralogical diversity is essentially unknown yet. The extent of crustal recycling on ancient Mars resulting in localized ore formation, geochemically "unusual" igneous intrusions/eruptions, etc. are essentially unknown, but will be partially understood after

Mars Surveyor Orbiter (Thermal IR composition mapping), Mars Climate Orbiter (Visible/Near-IR mineralogical mapping), and Mars 2001 orbiter (Gamma-ray spectrometer global elemental abundance map)

C. MAIN "DEVELOPMENT" BASE SITE EXAMPLES

1. Chryse Planitia margin at outflow channels: "safe landing area" , low latitude and altitude, lava plain edge, edge of highlands, channel deposits.
2. Coprates Chasma floor (between wall and layered deposits): deep crustal materials, lakebed?, aeolian and landslide deposits, easy access to canyon wall cross-section, low latitude and altitude.
3. Northwest edge of Hellas Planitia floor: lowest point on Mars? - easiest access to water table, excavated deep crustal materials in basin rim, channel deposits, lake deposits? on basin floor, aeolian deposits, climate history, fossil microbiology, greatest atmospheric radiation protection & pressure.
4. NW edge of Elysium Volcanic Region , (adjacent to Utopia Basin channels): young water outflow channels, diverse young volcanic units, high heat flow?, shallow water table (Thin cryosphere) in basin.
5. South edge of Isidis Planitia floor, (Next to Syrtis Major volcanic area & Circum-Hellas Highlands)

D. PARAMETERS FOR MATERIALS (SOLIDS) PROCESSING (other than volatiles)

The purpose of this list is to better identify the types of materials better created from Mars materials. The first parameter is favorable to their use, the second is not

1. Low/High task complexity in processing: high = electronics.
2. Low / High-energy use: high = aluminum.
3. Low/High volatile use in processing and separating.
4. Easy / Difficult to obtain and process ore into product (ore rarity, concentration and chemical form)
5. High /Low weight or bulk (difficult and/or expensive to bring from Earth): high = structural metals.

E. MAIN TYPES OF GEOLOGICAL RESOURCES ON MARS Distribution Type:

(a) Globally Homogeneous, (b) Latitudinally zoned, (c) Regionally Variable (d) Rare to Non-existent.

1. VOLCANIC ROCK: ultra-mafic rocks (iron-magnesium silicates, basalt,

andesite, rare volcanics including granite) (a,c)

- POSSIBLE PRODUCTS AND SOURCES (for volcanic rocks only)

(l - low, i - intermediate, - high, t -task, e - energy, v - volatiles, p - process, w - weight)

silicon oxide:	basalt glass, andesite -	lt, le, hv,
silicon	quartz or andesite or feldspar	it, he,
phosphorus	apatite (in andesite, etc.)	?
aluminum	anorthosite or calcium feldspar	it, he,
iron	basalt	iv,
magnesium	basalt	ht,
titanium	high-titanium basalt if present	ht,

2. ATMOSPHERE:(a) Carbon Dioxide, Carbon Monoxide, Oxygen, Carbon, Nitrogen, Argon

3. SURFACE VOLATILES: (b, c) Water Ice, Carbon Dioxide Ice, unknown trace volatiles?

4. DUNE SANDS - UN-WEATHERED MINERAL GRAINS: BASALT MINERALS (a,c)

5. GLOBAL DUST BLANKET (a) iron?

6. LARGE SURFACE EVAPORITE DEPOSITS (c) mineral salts

7. SOIL/REGOLITH (mixture: CRUSHED ROCK , SALTS, ADSORBED VOLATILES) (a,b,c). Magnesium, Iron, Water Ice, Sodium, Potassium, Sulfates, Chlorides, trace salts

8. RARE SURFACE EVAPORITES (c,d) Boron, Iodine, Bromine, etc.

9. METEORIC NICKEL-IRON (random distribution) (a,c) : Nickel, Iron, Steel

10. WATER / BRINE AQUIFER (a.,b,c) Access depends on elevation above "global water table" Sodium, Chlorine, Potassium, Iodine, Magnesium, trace salts

11. VOLCANIC EVAPORITES (c,d) Sulfur

12. SEDIMENTARY BEDROCK (c,d) Calcium ?

13. RARE HYDROTHERMAL ORE BODIES IF ANY (d) Titanium, anorthosite, other metal, etc.

14. RARE OR HARD TO GET (low concentration) MATERIALS ON MARS (d)
(minerals that take extensive hydrothermal activity under specialized conditions to concentrate)
Copper, Gold, :Lead, Tin, Phosphorus, Boron, etc.

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