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A PROPOSED SCHEME FOR LUNAR GEOLOGIC DESCRIPTION

By
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November 1969

Prepared under NASA Contract No. T66353G

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ABSTRACT

The usual aim of describing an object is to convey a mental image of that object to some audience. Many geologic field descriptions fail to do this, because they are mnemonic notes, understandable only to the person who made them. Such field descriptions may be adequate for terrestrial work, but they are unacceptable as lunar geologic descriptions, which must be immediately assimilated by a data center on earth. In order to be readily intelligible, lunar descriptions must be systematic. At the same time, the difficult logistics of lunar exploration demand that a system of description be logical, flexible, and easy to remember.

Description can proceed in two steps: 1) analyzing the object under examination into a hierarchial array of parts, and 2) discussing the properties of each part, as it is considered more fully. Properties of geologic features may be grouped into four classes: optical, mechanical, geometrical, and structural. Depending upon the type of feature and the scope of the description, information from some or all of the classes would be included.

Routine application of the scheme can be learned by practicing description of common objects; application specifically to geologic descriptions can be practiced on field trips and by working with photographs of geologic features, as well as building stone, thin sections, and soil and rock excavations.

General recommendations for lunar traverse procedures and for description of geologic features emphasize the need for a systematic approach.

INTRODUCTION

This report considers the process of description and the problems that arise when descriptions are made under difficult conditions, such as those of lunar exploration. We present both a theoretical approach and practical suggestions that should lead to more comprehensible and complete geologic descriptions.

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* This report is an outgrowth of work funded by the National Aeronautics and Space Administration, Contract T66353G, toward the development of procedures for lunar exploration.

Although we have conferred with several colleagues and consulted many references, we must jointly and equally accept responsibility for what is presented in this paper, which represents our interpretation of what constitutes good practice in verbal geologic description.

Many of the ideas and suggestions are not new, and indeed have been applied by scientists and writers for a long time, but, to our knowledge, have not previously been set forth explicitly for the benefit of the astronaut-geologist.

During the past few years the U.S. Geological Survey has simulated lunar traverses in order to learn how to gather and process geologic information during lunar missions. Test subjects in the field have radioed their observations to a data center for immediate analysis. These simulations have pointed up the need for detailed study of techniques for describing, transmitting, and recording data when radios are used. Accordingly, a field test was held in southeast Nevada in April 1967 after preparation and field trial of several kinds of description guides and recording forms (Lucchitta and others, 1969, 1969a, b). The conditions under which the field man operated were analogous to those proposed for Apollo missions in that: (a) prior study of the field area was restricted to aerial photographs, (b) the field man gave his location primarily by grid coordinates on a photogeologic map, and (c) rather than taking notes himself, he radioed all his observations to the data center.

Many of the practical recommendations presented here are based on this test, but also include findings from other exercises. The main emphasis of this paper is on geologic description and communication, which concern the astronaut more directly than does data recording.

THE PROBLEM OF GEOLOGIC DESCRIPTION

In this paper we are assuming that the aim of describing a geologic object is to convey to the listener or reader a mental image--and so an understanding--of the object being described, by explaining what it is made of and how its component parts are put together.

Nature of Geologic Data

Attempts to communicate geologic information by radio have emphasized that some data are rather easy to convey in words while others are not. In general, the easily conveyed ("verbal") data are those for which there exist well-defined and clearly labeled conceptual models that are universally understood. The term "subrounded," for example, applies to a reasonably well-defined, though generalized, geometric form. Similarly, "granite gneiss" identifies the conceptual model for a type of rock with certain widely accepted attributes. Any model--geologic or otherwise--is an idealization that conveys a certain amount of information.

A model rarely depicts a specific object precisely, but it may convey an adequate understanding of the object if enough terms and modifiers are used. Word models are commonly inadequate and too cumbersome to depict the details of complex geometric relations, especially since these details are unique to each object or locality. Graphic models convey this sort of information much more efficiently. Thus, although "fold" suggests a general geometric model, and "assymmetrical anticline" a more refined model, a specific asymmetrical anticline can be accurately portrayed only by a map, cross section, or photograph. Photography will probably be the best means of depicting lunar geometric data.

The following pages concentrate on the problem of conveying an adequate mental image by means of "verbal" data.

Approaches to Geologic Description

The conventional field geologist makes observations and records data he considers pertinent in a notebook or on a map. Since these field records are commonly meant for his use alone, they tend to be cryptic but nevertheless adequate, because the geologist commonly need not communicate his results to others until after he has organized and studied the field data, and because he generally has enough time to rectify incorrect or incomplete observations before he presents the results.

Lunar geologic work will be quite different. Because of severe time and mobility restrictions, both exploration and data handling must be as efficient as possible.

Exploration can be efficient only if the astronaut can select data critically. To do this he must know what geologic problems should be solved and what observations must be made to solve them.

Efficiency in data handling presupposes immediate and thorough organization of the field data. The procedures being developed for Apollo lunar exploration call for collaboration between astronauts--the first-hand observers--and an earth-based facility which will record information, check its clarity and completeness, answer questions, and perhaps suggest traverse changes. Data will be communicated as they are gathered. If they are to be studied promptly enough to improve the traverse, they must be understandable as soon as they are received; to be readily understandable, they must be presented systematically.

Checklists or flow charts often result in rigid systematization, and are hard to memorize, slow to apply, and often not comprehensive enough for the variety and complexity of geologic data. What is needed, then, is a scheme of description adequate for lunar exploration and logical, flexible, and easily remembered. Such a scheme would lead not only to more logical and more comprehensible description, but also to more complete and better organized observation, thereby increasing the efficiency of both data gathering and data handling.

In contrast to more ordinary field description, the scheme presented here places great emphasis on how the object being described is broken down into parts, and on how this breakdown is reflected by the organization of the verbal description. Like a good lecture, the oral description should present not only the data themselves, but also the plan according to which they are organized. Titles and paragraphs serve to show the organization of written descriptions, but oral descriptions must rely on clear statements of each change of subject.

The proposed scheme is an outgrowth of natural and common techniques of oral description, and thus is relatively easy to use and remember. Observers commonly analyze an object into parts, then attempt to comprehend the whole object in terms of a model--or mental image--defined by the names, properties, and relations of these parts. With unfamiliar objects this process is slow and deliberate; with familiar objects it may be so rapid as to appear instantaneous, in which case the observer quickly arrives at a mental image or name that represents the object. In either case, the process is commonly too haphazard to convey an adequate comprehension of the object to a listener: the observer tends to make logical jumps that are justified on the basis of his knowledge or previous experience, but which commonly are incomprehensible to anyone else. Furthermore, he tends to shift his attention haphazardly from one part of the object to another, often jumping scale. This is very confusing to the listener. But the basic process is excellent when organized better; by being familiar to both astronaut and data-recording team, it should provide a common ground for adequate description and comprehension.

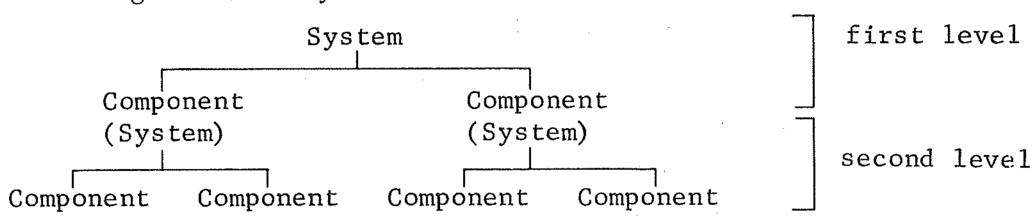
A SCHEME FOR DESCRIPTION

The reasons for selecting an object to describe are beyond the scope of this paper. But once an object has been selected, the first step in a description is to analyze the object into a hierarchy of systems and components, and the second step is to discuss the properties of each system at any level of the hierarchy according to a definite format.

First Step: Analyzing the Object

The first proposed step towards systematic description is to consider each object as a system made up of components. Each component can, in turn, be considered a second-level system made up of other components; the process can be continued to whatever level of analysis is dictated by the aims of the description.* This procedure breaks down ("analyzes" in the strictest sense) each object into a ranked outline--a hierarchy--of parts. Each level of the hierarchy generally includes components of about the same size, type, or complexity.

Diagrammatically the breakdown is:



As an example, a rock (system) may comprise several types of minerals (components). Each mineral type (system) in this same rock consists of a number of chemical compounds (components). As another example, a certain house (system) has four walls and a roof as components. The front wall (system) is composed of a solid portion and openings (windows and doors). The solid portion (system) has bricks and mortar as its components. The bricks (system) are of two kinds. Figure 1 shows the hierarchic structure of this analysis, assuming that the observer wished to pursue it as far as the two kinds of bricks in the front wall.

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* We have not used terms such as subcomponents and sub-subcomponents because they are cumbersome and because in practice it is best to think about each level of a hierarchy separately.

In presenting the analysis, the observer should identify the components in a system, and (briefly) explain how these components are related to one another (e.g., "Red sandstone conformably overlies gray sandstone.").* The components are usually identified on the basis of some characteristic property that best distinguishes them. Often this will be an obvious property, such as color, weathering characteristics, or position. Further discussion of the properties of each component is deferred until each component, in turn, is treated as a separate system with its own properties. The selection of components depends on the observer and on the purpose of the description, since a given system can commonly be described in terms of various combinations of components. In a sequence of red and gray rock units comprising interbedded sandstones and shales, for example, the components could be defined on the basis of either color or rock type.

How far an analysis is carried depends on two factors: (1) The purpose of the description. There is no point in carefully describing features that have no bearing on the problem posed. (2) The vantage point of the observer in respect to the object being described. From a distance of several hundred yards, for example, an observer could state that there were alluvial deposits along a stream valley and give a pretty good account of the overall color and geomorphic expression of the deposits; but he could do little more than guess at the sand:silt ratio of the deposits.

In summary, an observer should first decide how to break down an object into a hierarchic array of components. He should then state what the description will encompass or how far he will carry his analysis (e.g., "I will describe the outcrop down to individual beds."). Finally, he should present the hierarchic

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* "To exhibit the structure of an object is to mention its parts and the ways in which they are interrelated." (Russell, 1948, p. 250.)

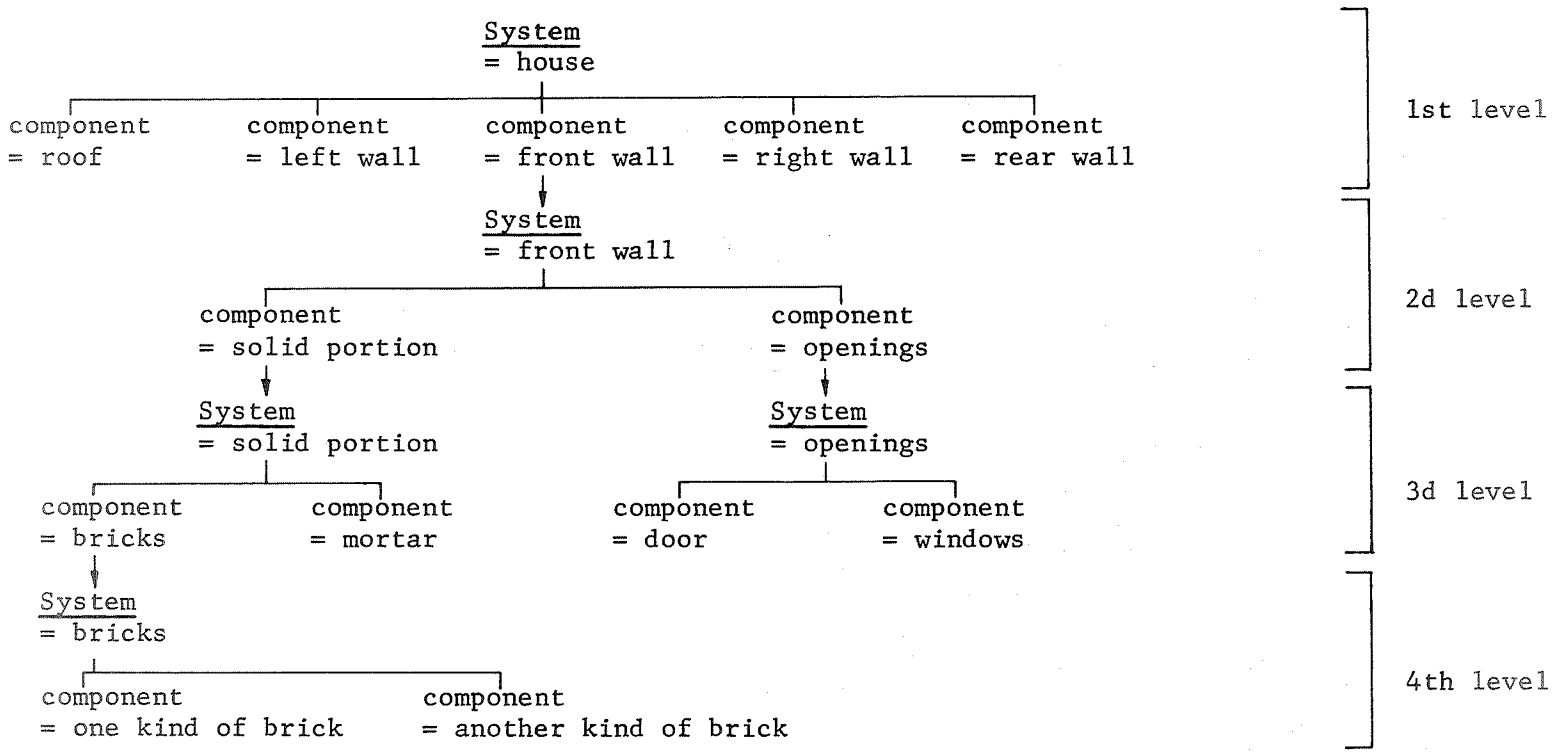

Figure 1.--Partial hierarchic analysis of a house into systems and components.

analysis, identifying components and explaining how they are related to one another.

The hierarchic analysis of the above-mentioned house follows as an example. Note that although the components are identified ("roof"), most of the relations between them are stated only implicitly ("front," "sides") because of the familiarity of the system = "house."

> I wish to point out the unusual brick work in the front wall of house number three-seven-one-one on Stevens Street. The house has a roof and four walls; the back wall of the house is not visible to me. The front wall has openings, namely a door and three windows. The solid portion is made up of bricks and mortar, except for wooden frames around the doorway and windows. There are two kinds of bricks--red and yellow.

This analysis seems artificial with an object like a house because the components are so familiar: they need no identification beyond naming them ("roof"), and their mutual relations are obvious. But this kind of analysis is an important first step toward systematic description of any less familiar object, because it forms a framework for further discussion. Outlining the hierarchic structure of a system before discussing the system in detail enables the listener to understand what components are present and how these components are related, and so to visualize the system more readily. The attention of most observers alternates between large- and small-scale features when they first scan a field of view, but reporting observations in this manner (non-hierarchically) confuses the listener, and results in a haphazard and incomplete treatment of the subject. The method of hierarchic analysis is applicable not only to large or complex systems such as a whole field of view, but also to smaller or simpler objects, such as a single block of rock.

Second Step: Discussing Properties

The second proposed step towards systematic description is to discuss the properties of each system in the hierarchy, using the same general classes of properties at each level of the heirarchy. Most descriptions include information that falls into several general classes of properties, such as shape, size, position, color, texture, and structure. (See Krynine, 1948, p. 132; and Griffiths, 1961, p. 488-489.) Each general class of properties (e.g., size) embraces many specific properties (e.g., thickness). Such general classes apply to description at all scales, even though the specific technical terms for properties in any one class may not: For example, the size of a mineral grain is usually presented differently from the size of an outcrop. Still, the general classes suggest a description format that can be applied at any scale.

As an example, the description on page 9 might be continued as follows (the classes of properties being presented are shown in sequence in the margin):

<u>System: house</u>	The house is located on the north side
position	of the east-west trending street and set in about four-zero feet from the street. The
shape	house is square, about three-zero feet on a
size	side and about three-zero feet high at the
<u>System: front wall</u>	crown of the roof. The front, which is par-
position size shape	allel to the street, is one-five feet high under the side eaves and three-zero feet
<u>System: door</u>	high in the center. The door is in the
position	center of the wall; two of the windows are
<u>System: windows</u>	on either side of the door halfway towards
position	the sides of the house, and the third window is on the second floor, centered over the doorway.
<u>System: solid part of front wall</u>	I believe I mentioned that the front is made up of two colors of brick and

<u>System: red bricks</u> color size shape position	light-gray mortar. The red bricks predominate and are smaller, about eight inches long by four inches wide. They are laid up in the conventional overlapping fashion.
<u>System: yellow bricks</u> color size shape position	Larger yellow bricks about eight inches square are scattered at random in the wall. From here the yellow bricks appear glazed, so they may better be called tiles.

Although properties can be discussed while the hierarchy is being outlined, we do not recommend doing so. Many geologic features are rather large, so that while the various parts of the feature can best be outlined from a distance, detailed data on the properties (e.g., composition, size) of many of the parts can only be obtained upon closer examination of the feature. Hence, separating the analysis from the discussion of properties coincides with a logistic problem commonly encountered in fieldwork. More importantly, defining the hierarchic structure before any other description enables a recorder to sketch an outline of the description, and so to know what systems the observer will be discussing at length. The recorder can thus check for completeness of the subsequent description. Separating the analysis from the discussion of properties is additionally helpful because the observer concentrates on one aspect of observation and description at a time.

Classes of Properties for Geologic Description

The properties mentioned in a disucssion of a geologic system will usually fall into four general classes (table 1). These classes are easy to remember and hence useful, but others may wish to group properties into different classes. Which of the four classes are used in any description depends on the type of object described and on the aim and scope of the description. A description of a stratigraphic section, for example, would probably include information in all of the classes; a description of

Table 1.--Types of information usually needed in a discussion of a system

Type 1. Identification of object (This may often be a repetition of the identification made when feature was mentioned as a component of a larger system.)

examples of identification:
general composition (e.g., "granitic")
type of object or name (e.g., "boulder;" "upper half of the ash bed")

Type 2. Properties

Class A. Optical properties

examples of specific properties: color, luster, albedo, surface texture

Class B. Mechanical properties

examples of specific properties:
strength, coherence, geomorphic exposure, resistance, hardness

Class C. Geometrical properties

1) size-shape
examples of specific properties:
extent, dimension, idiomorphism, sphericity, thickness, angularity, tabularity

2) orientation
examples of specific properties:
attitude, direction, position, trend, location

Class D. Structural properties

1) internal structures (part of the makeup of object)
examples of specific properties:
fabric, cleavage, folds, fractures, texture, layering, joints, vesicle layers

2) external structures (throughgoing; incidental to the nature of the object)
examples of specific properties:
folds, joints, faults, fractures

Type 3. Final identification of object (final opinion; summation)

examples of final identification: type of object, specific composition, specific name

Type 4. Contact relations (to other features or objects)

examples of specific relations:
conformable, sedimentary, embedded, intrusive, parallel, slumped against

fractures in a boulder, on the other hand, would very likely include nothing on optical properties.

Terms shown under each class in table 1 exemplify specific properties that might be discussed depending on the feature being examined and the scale of observation. The classes are intended to be comprehensive; almost all specific properties will fall into one of these classes. The terms an observer uses to define specific properties will depend on his training and experience, but if he systematically considers each of these classes while discussing a system, his discussion should be adequate.

"Identification of object" appears twice in table 1 because an observer might wish to label an object twice in the course of the description: at first provisionally, later more specifically. For example, he might initially identify a rock as "a medium- to light-gray volcanic rock." Then, after describing its other properties, he may be able to make a more refined identification: "I think it is probably rhyolite." Conversely, he might make a sufficiently precise identification right off, such as, "a dark-gray basalt fragment," so that he would not have to make another "identification."

The "Contact relations" of an object to other objects should be discussed as a part of the general setting, and the "Contact relations" of one system to another should be discussed during the initial hierarchic analysis. However, this topic is purposely listed in table 1 as a reminder to amplify this type of information when necessary.

The geologic description below exemplifies both the hierarchic analysis and the subsequent discussion by classes of properties.

> I will briefly describe an outcrop consisting of two rock types: an overlying dark-gray lava flow, and an underlying series of red beds. The red beds can be further broken down on the basis of the lithology and geomorphic resistance into sandstone and

siltstone interbeds. The sandstones are slightly more resistant than the siltstones.

The outcrop itself is well exposed in a cliff face about one-two feet high and about five-zero feet wide. The face trends about north five-zero degrees east. It is transected by a normal fault dipping seven-zero degrees to the northeast. The northeast side has been downdropped about one foot.

The lava flow is a uniform dark-gray color except for moderate brownish-gray staining along fractures. It is geomorphically resistant, and caps the the cliff face. The flow is generally about four feet thick, but only three feet thick on the southwest side. It extends across the entire outcrop. The flow is flat-lying. It has a crude subhorizontal flow banding that is especially prominent near the base. There are layers of vesicles near the top of the flow that are also subhorizontal. The flow is irregularly fractured into blocks a few feet on a side, typically three to four feet. It lies on what is apparently a weathered soil zone developed on the red beds, which I'll describe next.

As a whole, the red beds are a uniform moderate red-brown color. They are moderately resistant geomorphically, less resistant than the lava flow and they extend the full width of the outcrop. About eight feet of section is exposed. The bedding is uniform, very nearly horizontal, dipping perhaps a few degrees to the north. The beds are cleanly jointed by two sets of joints. The first set, the better developed set, trends parallel to the cliff face. Consequently, I can't determine the joint spacing. The second set trends northwest. The joints are spaced at about one foot intervals.

As for the two types of interbeds within the red beds, the sandstone interbeds are not distinguished by color, but only by grain size and by their moderate geomorphic resistance. They form ledges that contrast with the reentrants formed by the siltstones. The sandstone beds are typically about one foot thick, although the thickness of one more massive bed ranges from about six inches to one and one half feet. This thickest bed has graded bedding ranging in grain size from coarse sand at the bottom to medium sand at the top.

The siltstone layers range from about three to about ten inches thick; the average is about five inches. The fine grain size of the siltstone interbeds precludes additional description. That's all for this outcrop.

PRACTICE IN DESCRIPTION

The scheme of description presented here is intended as a formalization of everyday descriptive techniques. Practice is needed to develop proficiency in applying it. This practice should be divided into two parts: the first, to become familiar with hierarchic analysis (how to analyze an object into systems and components); the second, to learn how to use general classes of properties as a format in discussing each system.

The easiest way to become familiar with the scheme is to apply it to common objects. Most people do this every day to some extent: explaining to a person over the telephone how to reach an office and get some object from a particular desk drawer certainly employs the principles of the scheme. The purpose of practice with common objects is to develop this method of thinking so that it will be automatic, even under the stress of lunar exploration.

Although the general types of information usually needed to complete a geologic description can readily be remembered by the words "identification, optical, mechanical, geometrical, structural, and contact," a little practice is needed to learn to use this listing as a format in description, and especially to remember what specific properties should be considered under each class. Practice in application is best done in the field, but field trips can be hard to come by. Much practice in description can, nevertheless, be gained by working with photographs of geologic features, rock specimens, building stones, thin sections, soil and rock excavations, and the like.

A few trials of the scheme with everday objects should make two points clear: 1) The use of specific names or terms provides a shortcut to description and implies that the observer has seen certain diagnostic criteria that he need not belabor.* Words like "drafting table," "desk," "blackboard," "basalt," and "ejecta" are such terms. Conversely, the word "weak" is not as informative as "friable" or "brittle." If the observer is satisfied that enough criteria are present to justify the use of a specific or technical term, then he should use it. 2) Posing a problem for solution gives a purpose and direction to the description. A person can spend hours describing a room without knowing when to stop. If, however, he is trying to ascertain the function of the room, he will focus on certain aspects.

RECOMMENDATIONS

General Procedures for Lunar Traverses

Before beginning a lunar traverse, the astronauts should summarize feasible objectives, which they will probably have selected by comparing the view through the LM windows with the photogeologic maps and geologic check lists from the data package.

On a traverse, the following procedures are advisable:

1. Tie all information to traverse stations except for interpretation, generalization, and synthesis not restricted to a

* "...not only can objects be directly and unambiguously referred to by names, but they can be unambiguously, even though indirectly, referred to by a description in terms of their properties and relations to other objects." (Fritz, 1952, p. 48.)

specific location.

2. Tell when a station is reached and give location, or state how this station can be located.
3. Give reasons for stopping before beginning detailed description, e.g.:
   a) Station was selected from the LM before the traverse--a photogeologic problem area.
   b) Station represents a deviation from the planned traverse--a good spot for work that could not be picked ahead of time.

   The reasons should also state what geologic data from the station bear on objectives of the traverse.
4. State what should be visible in photographs taken at the station. This speeds descriptions, annotates the photographs, and provides a helpful summary of observations. Only a cursory discussion of sizes, shapes, contact relationships, and distances need be made if a feature is well photographed. But be sure to mention relations that the photograph can't show: e.g., "This is a typical block in the dark ejecta."
5. State reasons for taking any particular sample or set of samples--what should the samples show?
6. Summaries may be helpful from time to time to help place data in context, establish their order of importance, and check for errors.
7. Briefly state ideas and hypotheses that might help document the thought processes that accompanied the observations. This may prove valuable later, especially during debriefing.
8. State plans and reasons for the next stop. This prepares the data center and helps bring to mind again the overall objectives of the traverse.

Description of Geologic Features

It is suggested that geologic features be described in the following way:

1. Briefly explain how detailed the description will be. This helps a recorder prepare for what is coming.
2. Specify the systems and components you will use to describe the object. This outlines the discussion to follow and establishes the geologic context in terms of which more detailed information can be understood.
3. Discuss systems in the order in which they were presented in the analysis.

The following are more general suggestions:

1. Whenever possible, describe objects by comparison with familiar objects or with objects that were described previously.
2. Mention distinctive, characteristic, and important features of any object even though they may seem "obvious."
3. Use specific names or terms whenever possible, because they are more efficient and informative than general terms.
4. Transmit short segments of description (a few sentences at a time). This makes recording easier and reduces loss of information due to poor communication.

The illustrative description of lunar geology given below exemplifies many of these principles. Note that photography largely eliminates the need to discuss "Geometrical properties."

> Station. Coordinates: Hotel 3, 10.4. Check?
>
> This is the planned stop at the fresh-looking blocky crater just northeast of these coordinates. I'll briefly describe, photograph, and sample a typical block here, and describe and photograph exposures in the crater wall as planned. Check? The ejecta from the crater can be divided into two types: sand-sized, incoherent materials, and blocks. The blocks cover about four-zero percent of the surface. I'll say no more about the sand-sized ejecta. I've

sampled them as sample four-seven. Check? I'll describe next the typical rock fragment I just mentioned. It's roughly cubical, about three feet on a side. I've just taken a stereo pair with the rock fragment in the right foreground and a close-up photo with the fragment in the center foreground. These photos should show that the fragment is partly embedded in fine-grained material in a shallow, elongate crater. This is almost certainly a secondary crater, and the block lies in the end of the secondary crater that's farthest from the parent crater. Check?

The rocks looks like a fragment of a flow lava. It is very dark gray, although the top surface is a somewhat lighter gray and is somewhat pitted and porous, suggesting alteration. Check? This is a very coherent rock. It's moderately hard to chip with the chisel. The close-up photo should show the tabular shape of the rock, as well as its relatively sharp corners. Check? The photo will also show some light-colored streaks, which suggest flow banding. I have sampled the top--the possibly altered--surface of this block as sample four-eight, and the sides as sample four-nine. Questions?

I will now describe the crater itself...

SUMMARY AND CONCLUSIONS

The system for verbal description presented in this paper proposes two steps in describing an object:

1) Identify ("label") the parts of the object using their most distinctive properties, and tell how the parts are related to one another ("fine ash lying on dense lava"). Commonly it will be necessary to break the parts down into subparts, that is, to consider the overall object as a hierarchy of systems and components.

2) Discuss each part in turn, first identifying it and then presenting its properties, using four general classes of properties as a guide: optical, mechanical, geometric, and structural; amplify contact relations here if necessary ("The fine ash is light gray...it is totally incoherent... grains are finer than I can resolve...uniform--no observable stratification. The dense lava...").

Many geologic descriptions, as made in the field, are mnemonic notes, understandable only to the observer when he compiles his data. Descriptions of this kind will not be suitable for lunar geologic work because they would not be immediately intelligible, nor would they encourage systematic and efficient gathering of data. The use of the descriptive scheme presented here should help provide systematic and unambiguous verbal descriptions of lunar features, both for immediate assimilation and use by a data center and for post-mission study.

Though analyzing an object into a hierarchic array of components is a natural tendency of the human mind, most routine situations do not require an extensive or systematic application of the method. Most people thus need practice to learn routine application of this way of looking at things. This practice can be obtained through description of common objects.

Similarly, the proposed general classes of properties should serve as adequate reminders of the most important kinds of information needed in geologic description, but learning to apply them routinely to geologic descriptions requires practice.

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