NASA Technical Memorandum 108823

An Ethnographic Object-Oriented Analysis of Explorer Presence in a Volcanic Terrain Environment: Claims and Evidence

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(NASA-TM-108823) AN ETHNOGRAPHIC OBJECT-ORIENTED ANALYSIS OF EXPLORER PRESENCE IN A VOLCANIC TERRAIN ENVIRONMENT: CLAIMS AND EVIDENCE (NASA. Ames Research Center) 57 p

N94-33608

Unclas

G3/54 0012114

May 1994

National Aeronautics and
Space Administration

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Table of Contents

PRECEDING PAGE BLANK NOT FILMED
PAGE ii INTENTIONALLY BLANK

List of Figures and Tables

Figures

Tables

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PAGE iv INTENTIONALLY BLANK

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SUMMARY

An ethnographic field study was conducted to investigate the nature of presence in field geology, and to develop specifications for domain-based planetary exploration systems utilizing virtual presence. Two planetary geologists were accompanied on a multi-day geologic field trip that they had arranged for their own scientific purposes, which centered on an investigation of the extraordinary xenolith/nodule deposits in the Kaupulehu lava flow of Hualalai Volcano, on the island of Hawaii. The geologists were observed during the course of their field investigations and interviewed regarding their activities and ideas. Analysis of the interview, using ethnographic and object-oriented methods, resulted in the identification of key domain entities and their attributes, explorer interactions with the environment, and relations among the entities. The results support and extend the author's previously reported continuity theory of presence, indicating that presence in field geology is characterized by a variety of metonymic relations. The multiplicity of these relations accounts for some redundancies and variabilities of presence. The pervasiveness of metonymic relations suggests that object-oriented domain analysis should expand beyond "part of" and "kind of" relations to metonymy and metaphor, particularly in domain analysis for the design of virtual presence systems. The results also provide detailed design specifications for virtual planetary exploration systems, including an integrating structure for disparate data integration which supports the Exploration Metaphor, discussed by the author in earlier work, by means of "terrain posting" and "terrain queries." Finally, the results suggest that unobtrusive participant observation coupled with field interviews is an effective research method for engineering ethnography.

INTRODUCTION

Field geologists are particularly appropriate subjects for the study of presence because the essential purpose of field work in geology is to exploit presence in order to understand a terrain environment. Terrain provides richly complex and varied environments in which to be present, and field geologists are intensely interested in the arrangement and history of the terrain. Further, terrain is a record of its own creation by a complex series of events, that is, it preserves a geologic record that geologists can read. One might ask in what ways does presence aid in the understanding of geologic environments, what is the nature of that understanding from the point of view of a field geologist, and how can this be applied to the design of planetary exploration systems utilizing virtual presence?

In a previous study (ref. 1), I took field geologists to a geologic setting and asked them to demonstrate and discuss geologic field work under two conditions. In one condition they were unencumbered by equipment, and in the second, each geologist wore a head-mounted camera and display, and carried a video recorder. In the latter condition, the headset replaced their views with video views, and the recorder captured their visual experiences and comments. Three conclusions were reached in that study: the first related to the nature of field geology and a theory of presence, the second involved design, and the third applied to methodology. The first conclusion was that continuity relations are characteristic of presence in field geology. These relations were identified as persistence of governed engagement, context-constituent, and state-process. The second conclusion was that studies of geologists in the field could, by means of a combination of ethnographic and object-oriented analyses, provide guidance for the design of virtual planetary exploration systems. The third conclusion was that increased "ecological validity" should be sought in future field studies, that is, geologists ought to be observed during explorations conducted in the field *for their own purposes*, unencumbered by artificial interventions. The reason cited was that if continuity is at the heart of presence in field geology, then the activities observed and studied ought to be naturally related to each other and to the environment by the purposes of the field geologists.

The study described in this paper was designed to build upon the previous study (ref. 1) by acting on its conclusions. First, the field geologists observed in the present study were conducting explorations in the field for their own purposes. Further, the participant observer did not intervene by altering the relationships between the environment and the explorers, as had been done in the previous study. Second, the analysis of these observations is a test of the idea that field studies of the domain of field geologists can lead to useful design specifications for virtual planetary exploration systems by coupling ethnographic methods with object-oriented analysis. Third, the results of this study were analyzed to see if they provide evidence to support the claim that continuity relations are characteristic of the presence of field geologists. (The study was not, however, designed to test the null hypothesis that continuity relations are not characteristic of the presence of field geologists. That would have required intervention and imposition of different conditions or "treatments." For examples, see reference 1. Intervention would have violated the ecological validity of the observations.)

The results of this study could lead to improvements in the design of planetary exploration systems that utilize virtual presence. Thirty years of operational experience with such systems, and the initial design of a virtual planetary exploration system, are described in reference 2. The continuing development of this technology requires additional, specific, domain-based design specifications. Further, given the glut of valuable but diverse spatial data sets describing Earth and the other planetary bodies, there is a great need for intuitive integration of disparate environmental data. This must go far beyond improved standards for spatial data formats, to a virtual re-integration of environments based on all of the data derived from them. This will allow computer-supported investigation of environmental data to be based on an Exploration Metaphor (refs. 2, 3). The results and conclusions presented in this paper are intended to move the technology in that direction.

The author wishes to thank the field geologists with whom he was associated in this study for their generosity, openness, and trust. Access to scientists during the conduct of their research, particularly for an ethnographic study, is a rare privilege, and is greatly appreciated. This research was supported by the NASA Space Human Factors program, RTOP 506-59-65.

The author is solely responsible for any misconceptions that may be apparent in this paper regarding the activities or ideas of the subject field geologists, or of field geologists in general. The opinions expressed in this paper are those of the author, and do not necessarily reflect those of his employer.

The mention of certain products in this paper is for clarity of description. It does not constitute an endorsement by the author, NASA, or the government of the United States.

DOMAIN ANALYSIS

Object-Oriented and Ethnographic Analyses

Domain analysis, that is, analysis of a field of human endeavor, is common to ethnographic and object-oriented analysis, though the purposes differ. In both cases, there is an attempt to identify and understand the symbols of importance in the domain, the attributes of those symbols, the relationships among symbols, and how people in the domain interact with them. In ethnography, traditionally a branch of anthropology, the purpose is to understand a human culture, and to translate that understanding into the terms of another culture. Examples of domains studied include pre-industrial cultures unaffected by modern technological imperatives, or subcultures operating within a larger society. In object-oriented analysis, the purpose is to determine what is necessary to design a computer system, especially the software and the human interface, that meets the needs of a group of people for a particular purpose in a particular domain. Examples include systems for the domains of air traffic control, banking transactions, and computer-based drawing.

Interest has recently been increasing in the use of ethnographic domain analysis to guide computer system design. For example, there has been debate about the emerging application of ethnographic techniques, in contrast to those of experimental psychology, to the design of human-computer interactions (ref. 4). There has also been an interest in applying ethnographic techniques to knowledge acquisition for expert system design (refs. 5, 6). I observed geologists in the field and proposed that ethnographic analysis could be usefully linked with object-oriented analysis to bring field observations to bear on the design of virtual planetary exploration systems (ref. 1).

Object-oriented analysis (OOA) of domains, for the purposes of object-oriented design (OOD) of computer programs, is somewhat better established. In a survey of the field, Monarchi and Puhr note that after two decades of conceptual development, OOA and OOD methods have begun to emerge in the last few years. OOA, they assert, "models the problem domain by identifying and specifying a set of semantic objects that interact and behave according to system requirements" (ref. 7, p. 38). OOD, in contrast, "models the solution domain...and should still be [implementation] language-independent...." Fichman and Kemerer compare object-oriented methods with more conventional ones, and observe, "With object orientation, the mapping from analysis to design does appear to be potentially more isomorphic" (ref. 8, p. 36). This isomorphism is intended to bring the structure of the domain into the structure of the designed computer program. Monarchi and Puhr (ref. 7, p. 46) assert that, in addition to its coherence, a design should be evaluated in terms of its "semantic dimensions," that is, "how closely does the design reflect the mental model which the users, analysts, and developers have of the situation?"

Laurini and Thompson assert that the object-oriented approach to geographic information systems (GIS), and spatial information systems in general, will replace current approaches. They argue that conventional relational databases are too computer-oriented, rather than being oriented toward the phenomena that are modeled. "The object-oriented approach, a relatively new method in computing, is an attempt to improve modeling of the real world. Whereas previous modeling approaches were more record oriented, essentially too close to the computers, this new paradigm is a framework for generating models closer to real-world features. The ideal would seem to be to provide an isomorphy, that is a direct correspondence, between real-world entities and their computer representation" (ref. 9, pp. 621-622).

Ethnographic analysis is an important addition to OOA because it can expand OOA toward increased focus on the domain and the user. In this view, the object-oriented domain model is derived, *independently of system requirements*, from the domain inhabitants. The alternative to this emphasis on the domain apart from the system is the very real potential that the user's domain model will be ignored or given short shrift. For example, Booch writes, "For highly complex systems, domain analysis may involve a formal process, using the resources of multiple domain experts and developers over a period of many months. In practice, such a formal analysis is rarely necessary. Often, all it takes to clear up a design problem is a brief meeting between a domain expert and a developer. It is truly amazing to see what a little bit of domain knowledge can do to assist a developer in making intelligent design decisions" (ref. 10, p. 143). This attitude is one which troubles Forsythe and Buchanan, who write, "At the present time, however, few knowledge engineers have received any training in ethnographic methods and few seem open to trying this approach. On the contrary, under pressure of time and money, most appear to want to spend less rather than more time with their experts" (ref. 6, p. 437).

In order to conduct a domain analysis, information about the domain can be gathered from a variety of sources, but the most important source is the domain expert in his or her working environment. Coad and Yourdan encourage the analyst: "Strive to get an intuitive feel for the challenges and frustrations your client faces; put yourself in his [or her] shoes and stay there a while" (ref. 11, p. 58). They suggest, for example, "Sit with an overloaded air traffic controller for an entire shift." They further suggest obtaining more extensive access to domain experts in order to ask questions and check interpretations.

Forsythe and Buchanan recognize that a longer, more immersive interaction is appropriate. "To an anthropologist it appears obvious that the best approach to knowledge elicitation would be to apply ethnographic methodology. In this case, knowledge engineers would attach themselves to an expert or group of experts as participant observers for a period of weeks or months" (ref. 6, p. 437). Conceding that most knowledge engineers are constrained from expending that much time and effort, they recommend that they should at least learn how to properly interview domain experts. Spradley, an ethnographer, strongly recommends interviews as the basis for ethnographic analysis, but he asserts that these ought to be done after immersion in the field has helped the analyst to appreciate the domain of the people being interviewed (ref. 12). He further suggests that analysis should be informed by repeated and varied immersion in the domain of interest. According to Fetterman, "The interview is the ethnographer's most important data gathering technique. Interviews explain and put into a larger context what the ethnographer sees and experiences" (ref. 13, p. 47).

Ethnographers and object-oriented analysts also agree that additional insights should be sought from a diversity of formal and informal documentation. Thus, appropriate sources of domain information include domain immersion and observation of domain experts, discussions and interviews with domain experts, and review of domain documents.

There is no agreement among analysts regarding the precise steps of domain analysis, but there is broad agreement on general principles. All agree that entities (such as symbols, "native terms," "indigenous concepts," objects, categories, or classes) should first be identified. Subsequent steps include finding the relationships among these entities, and finding the attributes and behaviors of the entities.

Booch lists potential sources of these entities, including people, roles, organizations, tangible things, things remembered, places, events, events remembered, concepts, devices, and systems (ref. 10, p. 141). Other entities can be found as participants in "kind of" and "part of" relations, or as participants in interactions. In identifying entities, it is important to recognize the difference between the name class of an entity (e.g., pit), the name of its category (e.g., geologic feature), and an instance of the entity. An instance is a concrete, specific, unique entity (e.g., a particular pit named "goat skull pit").

The relations among entities, especially "kind of" and "part of" relations, are of particular interest to both ethnographic and computer-oriented analysts. According to Monarchi and Puhr, "Most [computer-oriented] authors would agree that these are two primary ways of organizing objects, or two kinds of generic relationships among objects" (ref. 7, p. 39). They point out, however, that there is little agreement among computer-oriented analysts regarding the use of other relations, and only "kind of" relations are directly supported by most object-oriented programming languages. Spradley considers the relations "kind of" and "part of" to be very important, and also suggests others, including: "is the cause of" or "is the result of," "is a reason for doing," "is a place for doing," "is used for," "is a way to do," and "is a step (stage) in" (ref. 12, p. 111).

Attributes of entities are seen in the features that distinguish one entity from another, which includes the state information associated with the entity. Sometimes, what initially appears to be an object is merely an attribute of a more tangible object, as when "address" is an attribute of "house." If no attributes are found for an entity, Coad and Yourdan suggest questioning its viability (ref. 11).

Entity behaviors include the actions of domain entities, the responsibilities and services of domain entities, and the responsibilities and services of entities in the system to be designed. Operations that change or transmit the values of attributes are among the important services.

In light of this discussion, continuity relations identified in my previous field study (ref. 1) can be seen as candidate relations among domain entities in the field. The continuities of governed engagement are relations that ensure that there are no discontinuities in the existence of entities in the environment, so that, for example, rotations, translations, scalings, and views are relatively predictable. Context-constituent relations relate geologic entities in a hierarchical way, and geologists traverse these relations. State-process relations relate the state of the terrain (the effect) to the geologic processes (the cause) which created it. They also relate representational artifacts (state information) to the dynamic process of observation.

Much of the available domain information is verbal, that is, consisting of words. It is from these words that domain models, consisting of entities, their attributes and behaviors, and relations among them, can be obtained. According to the ethnographer Jacobson, this is entirely reasonable. "People's words constitute the primary evidence for cultural categories or representations. In ethnographies these are sometimes referred to as native terms or indigenous concepts" (ref. 14, p. 12). "It should be noted that the presentation of native terms as evidence for claims about the ways in which people conceptualize their worlds has a long history in ethnography" (ref. 12, p. 13).

Some object-oriented analysts suggest paying particular attention to the nouns and verbs they come across in their search for domain entities. Booch (ref. 10) cites a method developed by Abbott (ref. 15) in which the system developer writes a short text describing the (small) domain problem to be solved, and then extracts the nouns and verbs as an indication of key variables and actions. Coad and Yourdan suggest noting nouns found in domain material but caution against merely underlining nouns in a text and then considering them as entities (ref. 11). Clearly, the single use of a word, especially if it is in a short text written by a developer rather than a domain expert, seems a thin reed upon which to build a domain model.

Fetterman notes that he has "often inferred the significance of a concept from its frequency and context" in text (ref. 13, p. 97). Thus, one way to glean entities from domain material is to note which ones are frequently mentioned. Specifically, frequently used nouns might be expected to indicate important entities, and frequently used verbs might be expected to indicate important actions. The use of these words in the context of the material suggests attributes, behaviors, and relations, as well as additional entities.

Metonymy and Metaphor

A relatively unfamiliar notion, metonymy, may well be fundamental to an understanding of presence and field geology, and to the design of virtual presence systems because it is a very broad and inclusive class of associations among entities in an environment. Metonymic associations are complementary to those of the more familiar notion of metaphor.

Metaphor is important to user interface design because the familiarity of users with their "native" task environment can be applied to the otherwise unfamiliar computer interface (ref. 16). The desktop metaphor is perhaps the best known interface metaphor. It is intended to utilize one's familiarity with things on a real desktop such as papers, folders, scissors, and clipboards, to help one understand the functions of corresponding icons on a computer screen. Since metaphor is a literary device, it is reasonable to look to literary sources for deeper insight into its potential. In *A Handbook to Literature*, metaphor is defined as "an analogy identifying one object with another and ascribing to the first object one or more of the qualities of the second" (ref. 17, p. 287). Hence, the desktop metaphor ascribes qualities of the real desktop to qualities of the icon-based computer interface.

More importantly for the purposes of this discussion, the metaphor entry in reference 17 refers the reader to a related entry on metonymy where literary critic Roman Jakobson is cited as an authority on the subject. In one of his essays focusing on metonymy in literature Jakobson notes that metaphor is association by similarity and contrast, whereas metonymy is association by contiguity (ref. 18, pp. 306, 307). Accordingly, an interface based on metaphor would be built upon advantageous similarities and contrasts, whereas an interface based on metonymy would be built upon advantageous contiguities. A metaphoric interface might encourage selection of an icon because of its similarity to something else, whereas a metonymic interface might encourage interaction with an entity because of its contiguity with another entity. Thus, for example, the metonymic interface would be well suited to interacting with the constituents of a context because, according to Jakobson, "the constituents of a context are in a state of contiguity (ref. 18, p. 99).

Even the desktop metaphor utilizes metonymy in the relationships among the constituents of the desktop environment. Many of the associations between a paper and a folder, for example, are metonymic since one is found in the same context as the other, one can be adjacent to the other, the folder can contain the paper, and so on. Thus, once the guiding metaphor is established, many entities within the referenced domain will be related and structured according to metonymic associations. Further, during interactions with these entities, the sequence of interaction can lead from entity to entity either through their similarity/contrast, which Jakobson calls "the metaphoric way," or through their contiguity, which he calls "the metonymic way" (ref. 18, p. 110). Thus, a metaphoric view of a single-screen, multiple-page cockpit information display system might be organized around similar kinds of things, so that, for example, all screen pages referring to electrical systems are linked together in proximity. In a metonymic view, the information might be organized around the working environment of the pilot, that is, the entities associated by the various phases of flight.

In its simplest form metonymy associates physically adjacent entities, such as those with a common physical context, but it can also, according to Jakobson, enable one to associate logically adjacent entities, and thus to "proceed from the whole to the part and vice versa, from the cause to the effect and vice versa, from spatial relations to temporal ones and vice versa, etc., etc." (ref. 18, p. 308). Thus, metonymy is likely to be a valuable complement to metaphor in the design of virtual presence systems: Metaphor involves leaps of association among similar or contrasting things that may be widely separated in the environment, whereas *metonymy involves contiguous associations that are congruent with the inherent physical and logical structure of environments*. Entities in a natural environment are sometimes structured according to their similarities, as when aggregations of similar rocks form a deposit, but they are more commonly structured according to associations based on adjacency, including those relating neighbor and neighbor, whole and part, cause and effect, space and time, etc. For this reason, metonymic relations are likely to be particularly important to the study of geology in the field. These relations include the adjacencies of similar rocks in aggregations, the adjacency of dissimilar entities at "contacts," the geologic context of a constituent, the cause of a given feature, or the sequence of events which deposited objects in a particular arrangement.

At a more fundamental level, Jakobson asserts that "the dichotomy" between metonymy and metaphor "appears to be of primal significance and consequence for all verbal behavior and for human behavior in general" (ref. 18, p. 112). He bases his argument not only on literary studies, but also on his observations of various forms of aphasia, in which either metaphor or metonymy predominates. On this basis he concludes that the competition between metaphor and metonymy is "manifest in any symbolic process" (p. 113). If this idea is valid, then it is important to consider the full range of associations, from those based on similarity and contrast to those based on contiguity, in the analysis of verbal behavior, behavior in general, or any other symbolic process, including the presence of field geologists in natural environments.

FIELD SITE

The field site is on the island of Hawaii, the so-called "Big Island" of the Hawaiian Islands. It is on the northern slope of Hualalai Volcano, which is 2,521 m above the Kona Coast on the western, leeward side of the island. The site is part of the 1800-1801 Kaupulehu lava flow. It is situated about 3 km above State Highway 190, near the Hue Hue telephone repeater station towers. The site is located at lat. 19°45'20" N., long., 155°55'50" W., at an elevation of 880–970 m above sea level, with most of the key areas between 910 and 950 m of elevation (ref. 19). The area explored during this study is approximately ellipsoidal, with a north-south major axis of about 800 m and an east-west minor axis of about 250 m. Most of the areas of interest fall within a 210-meter-diameter circle at the center of the ellipse. The region of the site belongs to the Bishop Ranch Estate, and permission to visit the site was obtained from the Estate.

The Kaupulehu flow was the larger of two large lava flows—the other is the Hue Hue flow that composed the eruption of 1800-1801. Together, the flows cover an area of approximately 119 km^2, and have a total volume of 300,000,000 m^3. The Kaupulehu flow originated from the main vent at an elevation between 1,650 and 1,800 m above sea level, and flowed north 16 km to the sea. There have been no more recent flows, but Hualalai did spawn several thousand earthquakes on Hawaii in 1929. Some did damage in Kona and were felt in Honolulu (ref. 20).

The Kaupulehu flow is considered remarkable because it contains a huge abundance of fragments of dunite, a rock consisting mostly of the mineral olivine, and related rocks. At the field site, these inclusions "are almost unbelievably abundant" (ref. 20, p. 131) (fig. 1). The individual fragments range from one to several tens of centimeters across, and have thin coatings of lava. In places at the

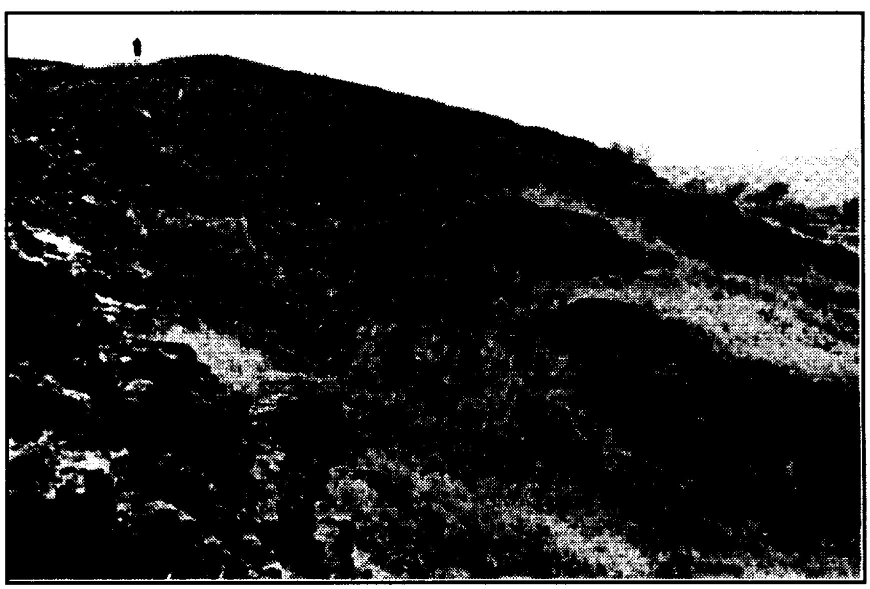

Figure 1. A huge deposit of xenoliths/nodules in the 1800-1801 Kaupulehu lava flow of Hualalai Volcano. The picture was taken from the opposite rim of the huge depression at "north vent," looking north, which is the downhill direction. Four geologists in the scene, two near the upper left, and two near the lower right, provide a sense of scale. For a stereo view of this xenolith/nodule deposit, as seen by the geologist at the upper left, see figure 3.

site, aggregations of the rounded fragments "resemble a huge heap of potatoes; broken open and viewed at close range they look more like big bonbons, with a chocolate shell enclosing bright green or gray centers" (p. 131). Microscopic bubbles of carbon dioxide are contained in the inclusions. Their gas pressure is very high, indicating that the crystals containing them were formed at depths of 10 to 14 km, near the upper part of the mantle or the lower part of the crust.

The geologists chose this site because it is of interest to them as professional planetary explorers and field geologists. They know that it is unique in the abundance of nodules found there, and they know of evidence indicating that the nodules originated in the upper mantle or lower crust. They said that if they could understand the emplacement of xenoliths at this site on Earth, they would have a better chance of finding similar kinds of nodules on the Moon and Mars. Such samples, they said, would yield valuable information about the interiors of those planetary bodies. The geologists had read the proposed explanations of how the nodules came to be emplaced in such great abundance at the repeater station site and they were curious to see if the site supported those explanations or if other explanations were appropriate. This trip had been planned as a reconnaissance, a chance to get a feeling for the site and to plan more detailed investigations to follow. Over the course of the trip, the field geologists revisited this field site several times and also visited several other minor sites on the 1800-1801 flows.

To appreciate abstract analysis of a physical domain, it is useful to have a sense of its reality as experienced when present. Robert Louis Stevenson described the Kona lava fields in travel sketches published contemporaneously in the *New York Sun* during 1891, and later in collections of his works (ref. 21). His description is important here because it illustrates how the terrain is described by a non-scientist of acute sensibility. "We traversed a waste of shattered lava; spires, ravines; well-holes showing the entrance to vast subterranean vaults, in whose profundities our horses' hoofs doubtless echoed. The whole was clothed with stone florituri, fantastically fashioned, like debris from the workshop of some brutal sculptor; dogs' heads, devils, stone trees, and gargoyles broken in the making. From a distance, so intricate was the detail, the side of a hummock wore the appearance of some coarse and dingy sort of coral or a scorched growth of heather. Amid this jumbled wreck, naked itself and the evidence of old disaster, frequent plants found root."

Having first-hand experience in this kind of terrain, one finds that Stevenson's description rings true (fig. 2). It is worthwhile to note the use of vivid metaphors in the writer's search for a way to characterize the features and objects he had seen. These metaphors reach outside the terrain itself to relate the things seen to other, various things—broken sculptures, coral, and heather—that are far away, and even widely separated from each other. This, it will be seen, is fundamentally different from the way field geologists characterize these features and objects.The eruption of Hualalai Volcano in 1800-1801 was a fiery, frightening, and traumatic series of events (ref. 22). After eating Hue-hue, a breadfruit forest owned by the legendary King Kamehameha I, and the king's extensive fish ponds, Pele, the fire goddess, was said to be still angry and hungry. Many hogs were thrown alive into the torrents of molten lava to appease Pele. The rivers of fire destroyed several villages, plantations, and fish ponds, and filled a deep bay 20 miles long. At last, the king, afraid for his life but resolute, offered a lock of his own hair, a part of himself, as a sacrifice to Pele, and she was appeased. At the time of the eruption, John Young, one of Captain Cook's crew and an advisor to the king, was living 30 km to the north at Kawaihae. Though he kept no known written records, in 1823 he told Rev. William Ellis the approximate date of the eruption (ref. 20).

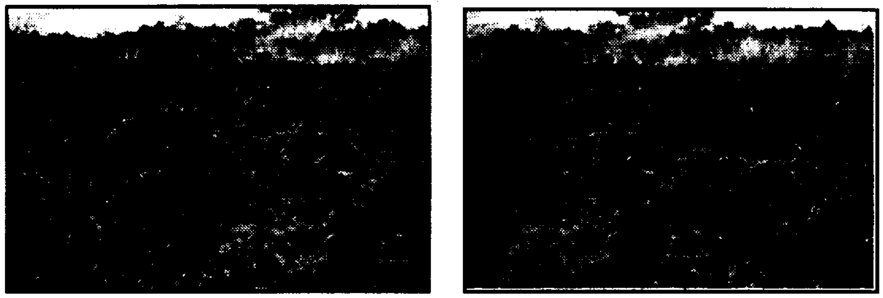

Figure 2. Stereo view of a typical aa (blocky) lava flow. This view shows the kind of terrain metaphorically described by Robert Louis Stevenson. This is part of the aa flow which separates the south vent area from the central vent area. Walking on this kind of terrain is difficult, and is avoided where possible.

Note: The stereoscopic images included here (figs. 2, 4) may be fused by the method of uncrossed fusion, or by using a Taylor-Merchant Corp. Stereopticon 707 viewer, available in most college supply shops. For uncrossed fusion, focus on a distant target, then hold the figure up to your eyes as if it were the display of a virtual reality viewer, but without attempting to focus or change convergence. Allow the blurry images to fuse. Gradually move the figure away to normal reading distance, while maintaining the original convergence. You should see "three" blurry rectangles. The center one is the stereo view. Slowly focus on the center image and wait. Fusion will occur in a few seconds.

The arrival trope is an important and pervasive descriptive device in ethnography, and it has many variants (ref. 23). Its purpose is to establish orienting relationships between the ethnographer, the domain to be studied, and the reader. Here, it would bring the reader beyond the hard facts of the geology of the site, beyond its literary and historical-mythological images, even beyond its fictitious and overwrought image as a purely extravagant vacation land, to a more visceral image of its reality, as directly beheld when one comes to experience presence. In engineering ethnography, this trope is probably a luxury, and will be omitted here. This brief comment will have to suffice to establish an orienting notion of the utter reality of the site, beyond attributed and extraneous associations.

METHOD

Two field geologists conducted, solely for their own purposes, a field trip to explore a site on the 1800-1801 Kaupulehu lava flow of the Hualalai Volcano. I accompanied them as a participant observer, and took note of the activities of the geologists as they explored the volcanic terrain environment. I walked where the geologists walked, looked at what they looked at, touched what they touched, and tried to understand what they tried to understand. I collected various kinds of data, and on the morning after the first full day of exploration, interviewed the geologists. The interview data are analyzed in this paper.

The interview answers were analyzed in a sequence of steps:

1. Word frequencies were determined and an initial set of key domain entities and actions were identified,
2. Frequently used nouns were grouped based on similarity, providing domain categories (additional key entities) and "kind of" relations,

3. Using the categories as a guide, the interview transcript was reviewed to identify attributes of the key domain entities,
4. The interview transcript was again reviewed, with special attention to the key domain entities and actions, to identify explorer behaviors,
5. The interview transcript was further reviewed, with special attention to the key domain entities and actions, to identify additional relations among the domain entities.

Since the interview revealed the importance of the geologists' field notebooks, those were also reviewed, but no word-frequency analysis was performed on the contents. The notebooks were generally used to check the consistency of findings from the interview analysis. In addition, attribute and relation results were slightly supplemented with material from the notebooks, including a few additional attributes involving notes, and a few additional details regarding specific features in the environment.

Data Acquired

Various kinds of data were acquired by the participant observer. One very important but intangible form of data is the experience of personal observation. The importance of this experience seems comparable to the importance of presence in the field cited by the geologists. A more concrete form of data includes the scribbled notes entered into a pocket notebook, often made while walking on uneven terrain in order to keep up with the geologists. Additional notes were made during the evenings. The notebook entries were transcribed and augmented with remembered details immediately after the trip. Imaging data include videotapes and 35-mm slides, taken to document important elements of the environment, and the related field activities and comments (in the case of video) of the geologists. A formal interview was conducted and was recorded on videotape. Copies of the field notebooks of the geologists were obtained after the trip. In addition to these materials, supporting information included references and maps describing and representing the site, its environment, and the related geological facts and issues.

Field Interview

On the evening after the first full day in the field, a series of questions was composed and written down by the observer. The next morning, before the second day in the field, an interview was conducted at the hotel. The videotaped interview contains the most concrete, semantically structured, and objective data acquired during the trip.

Although it seems likely that there might have been some benefit to conducting the interview out on the lava field, such as the ability of the respondents to refer to things in the immediate environment (ref. 1), the setting worked against this idea. The wind is rather strong at the site, and the wind noise would have been detrimental to the audio portion of the interview. Having already recorded video in the field on the previous day and having reviewed it the night before the interview, it was obvious that the wind noise was a potential problem.

In a very real sense, this was still a field interview, despite the fact that it was not conducted in the terrain environment. There were significant benefits owing to the recency of the field activities and to the fact that the group would be returning to the field immediately following the interview. The specific questions asked were developed from the experiences of the first day in the field, and the answers were based on the actual events and places of that day's activities, which were still fresh memories. In addition, the geologists were still very much engaged in the geologic issues raised during the interview, for they were going out again that day to further address these issues. Finally, the answers to the questions were more interpretable because of the participant observation and its recency.

The questions generated after the first day of observation seemed to fall into five groups, so they were re-ordered so that related questions were asked together. The five topics were traversals, outcrops, notebooks, subdividing and chunking the environment, and presence. Twelve questions were planned: 4 on traversals, 2 on outcrops, 2 on field notes, 3 on subdividing and chunking the environment, and 1 on presence. As it turned out, most of these questions led to follow-up questions based on the responses of the geologists, for a total of 16 follow-up questions: 6 on traversals, 1 on outcrops, 2 on field notes, 2 on subdividing and chunking, and 5 on presence. The 28 questions asked during the interview (and the answers given) are listed in appendix A.

Analysis of Word Frequencies

The frequency of use was found for each distinct word spoken by the geologists in giving their answers to the interview questions. These "raw" counts required consolidation, subdivision, and adjustment of the frequencies to account for singular and plural forms of nouns, multiple forms of verbs, and various ambiguities of usage, as described below. The results are compact and verified lists of the most frequently used nouns and verbs. Words on these lists can be interpreted as being among the key entities and actions of the domain.

To analyze the number of times words were used in the interview answers of the geologists, several steps were required. First, the videotaped interview was transferred to audio tapes. Then, high school student interns at NASA transcribed the interview using a word processing program. The transcripts and audio tapes were then thoroughly reviewed by the principal investigator and the transcript was corrected. A plain text copy of the transcript was made in which all punctuation was eliminated (except single apostrophes in contractions and hyphens in compound words), and all text was converted to lower case. This text was transferred to a computer running the Unix operating system, for further processing. On Unix, an "awk" script called *wordfreq* (ref. 24), and the *sort* utility, were used to produce two lists of words and frequencies, one ordered alphabetically and the other in descending order of frequency. These provided the first look at the data, and were marked up extensively, which quickly led to the conclusion that a database should be created from the data. Accordingly, the two-column list of words and corresponding frequency counts was then imported into a custom-built database. Use of the database made it easy to do a variety of analytical tasks, including labeling parts of speech, labeling noun and verb categories, selectively viewing lists of words that met certain criteria, sorting on various criteria, and flagging certain words.

Starting with the most frequently used (and thus the most important) nouns and verbs, the interview transcript was reviewed in order to reduce the raw data to a compact and verified list of key entities to guide the rest of the object-oriented analysis.

Rather than count various forms of words as separate entities, their frequencies were summed and applied to the root word. For example, if the noun "pit" was used N times and the noun "pits" was used M times, then a single entry was made for the root noun "pit" with a frequency of N + M. Similarly, the various forms of each verb were reduced to a single entry for the root verb. Thus, if the following forms of the verb "see" were used with the frequencies shown in parentheses: "see(W)," "seeing(X)," "seen(Y)," and "saw(Z)," then these would be reduced to "see(W + X + Y + Z)." Other consolidations into single entities with summed frequencies included words that seemed to be used synonymously during the interview.

Several kinds of ambiguities were eliminated by reviewing usage in the interview transcript. For example, some words could have been used as either nouns or verbs, so the frequencies of use for each case (which sum to the raw input count) had to be counted by hand. Other subdivisions of frequency of use were done to account for multiple meanings of a single noun. Further, if a noun or verb was used in a colloquial sense, such as when phrases like "I think," "I guess," and "in fact" were tossed off without real meaning, the frequency was decremented for each occurrence. Nouns used as adjectives were treated as nouns. This is justified because phrases like "nodule bed" could just as well have been "bed of nodules."

Words that are generic or auxiliary were counted but dropped from further analysis. Generic nouns such as "thing" were dropped because of their lack of specificity. Auxiliary verbs such as "could" and "would" were also dropped.

Ethnographic Object-Oriented Analysis

The first step in the ethnographic object-oriented analysis of the field interview was to analyze the word frequencies in the answers, as described above. This provided ordered lists of the most frequently used nouns and verbs. The noun list was interpreted as an initial set of important domain entities to be further analyzed. The verb list was interpreted as including important domain actions. These actions were used, along with the domain entities, to aid in identifying entity behaviors and relations.

The remaining steps of the ethnographic object-oriented analysis are (1) categorize key entities to aid identification of attributes, (2) identify attributes of key entities, (3) identify explorer behaviors, and (4) identify relations between key entities.

Several complete reviews of the interview transcript, and a great many references back to the transcript, were necessary in order to conduct the analysis. In addition, the geologists' field notebooks provided some supporting information.

The list of most frequently mentioned nouns, a result of the word-frequency analysis, includes the most important entities in the domain (to the extent the interview answers span the domain). Forming categories based on these entities is an important step in the overall object-oriented analysis because it reduces redundancy and improves the efficiency of the search for the attributes of the domain entities. Categories reduce the number of concepts from one long list to a small collection of short ones that cover the same information; this makes it easier to grasp the entire scope of the list (ref. 25). Categories are also important because they represent important additional domain entities. In addition, categorization creates "kind of" relationships between the members and the classes.

Using the category results, the search for attributes is more efficient. Instead of searching for the attributes of each of the top nouns/entities individually, the first step is to find the attributes that are common to each category. Then, the attributes of each distinct subcategory, if any, are found. Once this is done, it is then only necessary to find the attributes that are unique to each of the individual entities.

Attributes were recognized as state information associated with entities, such as characteristics which distinguish one class of entities from another, or one instance of an entity from another. Others were recognized as things remembered or of interest about entities. Additional ways to identify attributes included recognizing that a collection of similar values suggested the existence of a variable, or interpretation of the verb "is" as an assignment operator, where appropriate. Other attributes were suggested by descriptions of entities, including names and definitions, descriptions of relationships to other entities, or pointers or indices to variously associated entities. As analysis of the transcript progressed, new entities were suggested by collections of attributes or behaviors, or both, or distinctions between collections.

It is important to recognize that the assignment of attributes to entities is a matter of viewpoint. All of the "attributes" could be associated with the explorer, rather than with the other entities, because the entire set of attributes is derived from the geologists, not the entities themselves. Instead, attributes are literally "attributed" to the entities. This approach models the domain as seen by the geologist.

The most frequently used verbs called attention to important explorer behaviors. Behaviors of other entities were also considered. Since most of the entities are inert, it was not expected that any behaviors would be identified, except in the case of historical molten lava flows which had shaped the site. These behaviors were treated as relationships among geologic entities, rather than as behaviors.

The assignment of "behaviors" is also a matter of viewpoint. Although observation of human behavior in the field is common to ethnographic and object-oriented domain analysis, OOA has a more system-oriented view. Since one key goal of OOA is to package the attributes of entities together with their services, there is an emphasis on identifying the "responsibilities" of entities that are inanimate, and even sometimes intangible. This is not particularly natural, but is driven by the system-oriented nature of the analysis. The domain-oriented ethnographic analysis is more natural in that behaviors are associated with those entities which act. Later, in the system representation, entities which are passive in the actual, physical domain can acquire responsibilities in the virtual domain. In addition, the explorer, some of whose field behaviors are assigned to other entities as their services, is then both internally represented and externally present by means of the user interface to the system. The transition from the field view of the domain to the system view is, therefore, not a simple mapping, but requires the distribution of many responsibilities from true actors to those acted upon. This pushes the model of the user deep into the internal workings of the system, to levels far deeper than the "user interface."

The interview transcript was also reviewed in order to identify relations between key domain entities. These relations included those between the explorer and the geologic components of the environment, those among geologic components of the environment, and those involving representational artifacts. Relations of interest included those described in the introduction, that is, common OOA relations, suggested ethnographic relations, continuity relations from the previous field study, and metonymic relations. These, of course, overlap to some extent.

RESULTS

The results presented below include (1) answers to the interview questions, (2) word frequencies and the initial set of key domain entities and actions, (3) domain categories and their members, (4) domain entity attributes, (5) explorer behaviors, and (6) relations among the domain entities.

Interview Responses

The questions asked and the answers given during the interview are paraphrased in appendix A. The appendix shows both planned questions and response-based follow-up questions. The wording in the appendix is more concise than the wording used during the interview, especially for the answers, but the vocabulary, spirit, and nuances are well represented. Answers to interview questions varied greatly in length. Sometimes an answer was short because the initial answer led immediately to a follow-up question. In most cases, however, the longer answers were those which drew extended and sometimes animated responses from the geologists, whereas the short answers indicate questions about which they had much less to say.

In answering the interview questions, the geologists identified the domain entities that were of interest, described their attributes, and discussed their interrelationships. They also described their own exploration behaviors, their evolving conceptions of the site and the relevant geologic processes, and their methods of building up that understanding. All of these are presented systematically, and in great detail, in the remainder of this section. The purpose of appendix A is to provide a sense for the form and character of the interview, since the full text of the interview answers is the basis of the subsequent analyses.

Word Frequencies

Table 1 is a list of nouns used most frequently by the field geologists in their answers to the interview questions. Nouns with a frequency of use greater than or equal to 10, of which there are 24 after consolidations and subdivisions, are listed. These are among the most important nouns/entities in the domain, to the extent the domain was spanned by the interview. As described in the Results section, singular and plural forms are treated as a single entity, nouns used synonymously are treated as a single entity, and nouns with multiple senses are separated into different entities. Although nouns used fewer than 10 times are not listed in table 1, several of those are mentioned in the category results section as appropriate.

Verbs with a frequency of use greater than or equal to 10, of which there are 23 after consolidations and subdivisions are listed in table 2. Among these are the most important actions in the domain, to the extent the domain was spanned by the interview. Verbs of different forms are treated as equivalent to the base form.

In giving their answers the geologists used 9,028 words, many repeatedly. Of these, 1,296 were unique words, including singular and plural forms of nouns and various forms of verbs. In the answers, each word was used an average of 6.97 times, but in fact, the frequency distribution of word use varies considerably. Some words were used hundreds of times, and hundreds of words were used once. By running the *awk* script *wordfreq* on the raw word counts produced in the initial output of *wordfreq*, that is, on the second column of the two-column list of words and corresponding counts, a "bin" count is produced. This shows the number of words used a certain number of times. Thus, for example, one word, "the," was used 464 times by the geologists in their answers. The next most frequently used word was "and," used 285 times. At the other end of the frequency scale, there are 649 words tied for being the least frequently used, that is, words used only once. The raw noun with the highest frequency was "things," which was used 35 times. The most frequently used raw noun referring to something specific was "vent," which was used 30 times. The most frequently used raw verb was "was," at 107, and the most frequently used raw verb describing an action was "see," used 63 times. Only 139 raw words were used from 10 to 63 times. (The term "raw" refers to the words and their frequencies prior to the processing, described in the Method section, which consolidated singular and plural nouns, consolidated the various forms of a root verb, grouped synonyms, subdivided multi-use words, and eliminated generic or auxiliary words.)

Several sets of synonymous words were treated as single entities. The words "xenolith" and "nodule" were counted as synonyms because the terms were used synonymously in the answers given during the interview. This is despite the fact that they are not equivalent terms, since a nodule is a kind of xenolith. Review of the transcript indicated that one of the two geologists preferred the term "nodule," and the other preferred the term "xenolith." The words "feel," and "feeling" were also used synonymously.

Some words were used to express more than one meaning, and so they were subdivided into separate entities. The words "picture" and "image" were each used in two different senses, one meaning "photograph" and one meaning "mental image." In addition, the words "photo" and "photograph," whose use is obvious, were also used. To find the true frequencies of use of the two underlying entities, the frequencies of words synonymous with "photograph" were summed for the one entity, and frequencies of words synonymous with "mental image" were summed for the other entity. The component nouns and their counts for these two entities are shown in table 1. The word "flow" was used as a noun meaning either rock or molten lava, and as a (low frequency) verb. The verb "going" was often used in the phrase "what's going on," which has nothing to do with locomotion. These uses were decremented from the frequency of the root verb "go."

All nouns with frequency greater than or equal to 10, and the most frequently used forms of the verbs "see," "look," "go," "think," "know," "come," and "walk," were closely checked to decrement frequencies for colloquial uses, of which, for several of these, there were a significant number.

Some words were dropped because they are generic or auxiliary words. Generic nouns that were dropped include the following (frequencies given in parentheses): "thing" (62), "something" (20), and "stuff" (14). The verbs "do," "want," "try," "can," "could," and "would" were also counted but omitted from the frequency list, since they merely serve as auxiliaries in verb phrases. The verbs "have" and "be" are also usually auxiliary verbs, but they are included in the list because of their possible but unanalyzed usage to express possession or being.

Table 1. Most Frequently Used Nouns

Noun/Entity	Frequency	Noun/Entity	Frequency
Xenolith (28), nodule (20)	48	Occurrence	14
		Bed	13
Vent	44	Picture (11), image (2); (mental)	13
Channel	29		
Site	29	Direction	12
Picture (16), image (6), photo (4)	26	Side	12
		Surface	12
Area	24	Deposit	11
Lava	24	Idea	11
Note	22	Place	11
Flow (rock)	20	Fact	10
Pit	20	Flow (molten)	10
Feel (8), feeling(8)	16	Tube	10
Map	14		

Table 2. Most Frequently Used Verbs

Verb	Frequency	Verb	Frequency
Is	271	Start	17
Have	114	Walk	17
See	83	Seem	16
Be	72	Find	15
Look	67	Record	15
Get	43	Write	13
Go	40	Use	12
Think	25	Work	11
Know	22	Say	10
Come	20	Trace	10
Make	20	Understand	10
Take	20		

Domain Categories

That part of the domain that is spanned by the interview appears to consist of three categories: environment, explorer, and representation. The "feature" category is by far the largest of the environment categories, and it appears to have several subcategories, including functional, formal, and event features. Other robust geologic categories include geologic objects and geologic localities. Still other geologic categories include materials, parts, and spatial parameters. (In the attributes results section, which follows this one, these last three categories are found to represent attributes, rather than entities with attributes.) Nongeologic categories include the explorer and representation categories. Entities in the explorer category contain entities in the mental object category and use entities in the tool category.

The most frequently mentioned domain entities appear to fall into three major categories: environment, explorer, and representation. By far the largest category is "environment," which is not surprising considering that the environment was the center of the geologist's interests. Within the "environment" category, there are several component categories.

The category with the most entries among the top nouns is "feature." This category of geologic entities includes "vent," "channel," "flow(rock)" (that is, flow in the sense of the rock which resulted from the solidification of the flow), "pit," and "tube." The feature "vent" might be subcategorized as a functional feature—in contrast to features subcategorized by their form—because its function is very clear and is the basis of its name, whereas its form is somewhat ambiguous and open to interpretation. Distinguishing the term "vent" as a functional feature is important because several formal features at the Hue Hue telephone repeater station site had been labeled as vents by previous field geologists, and there is some question whether they truly functioned as vents. The answer to this question bore directly on the issue of nodule emplacement by the flow. In describing the formal features thought to be vents as "vents," the geologists said that they used the term tentatively, as if "in quotes." Other features or kinds of features from the low-frequency nouns include "crater," "unit" (as in flow unit, a component of a flow), "aa," "pahoehoe," "textures" (aa and pahoehoe are examples of flow textures), "dike," "patterns" (flow patterns were of particular interest), "spatter," and "(topographic) bench."

A very important kind of feature, "aggregation of xenoliths/nodules," was derived from the interview, but only indirectly from the noun frequencies, by noting the many uses of the terms "xenolith" and "nodule" as qualifiers of features like "occurrence," "bed," "deposit," "pocket," "exposure," or "layer." Further, there were many uses of "xenoliths" or "nodules" as a single word to denote an aggregation. An individual nodule or xenolith was clearly not as important as an aggregation of them. One term for an aggregation of xenoliths/nodules has special interest because it is a metaphorical term inviting comparison with a more familiar form outside the environment. The term, "amphitheater, " is a reference to the north vent pit with its "talus slope" of nodules (figs. 1, 3).

For one subcategory of features, the names of its members convey a sense of the events associated with them. This subcategory might be called "feature/event" and has three members from among the most frequently used nouns: occurrence, deposit, and flow(molten). The names "occurrence" and "deposit" capture a sense of the event that created the feature. The name "flow," used in the sense of molten lava, connotes a sense of the feature as an event in progress. The geologists sometimes spoke of the flow (generally meaning a component of the total flow) in an active sense such as coming down and covering things, in reference to its role as a component event, during the events of the eruption. This is clearly distinguishable from the use of the term "flow" to refer to the rock solidified from the flow.

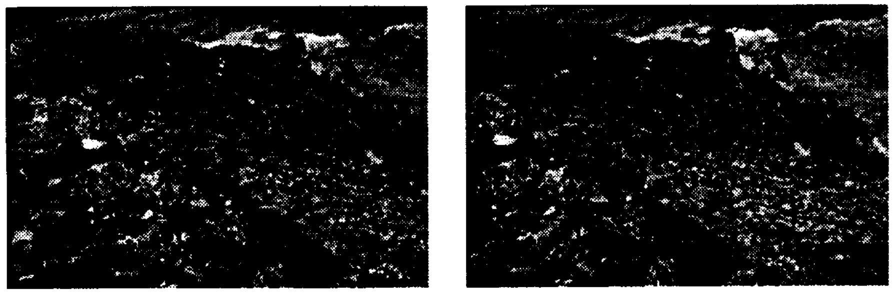

Figure 3. Stereo view of the huge xenolith/nodule deposit from the rim of "north vent." This figure illustrates the appearance of xenoliths/nodules in the most significant occurrence, as seen from the point of view of the geologist at the upper left of figure 1, looking east.

The category with the most frequently used nouns, "xenolith/nodule," is called the "geologic object" category. (Recall that the frequencies of "xenolith" and "nodule" are added together because they were used essentially interchangeably.) The only other geologic object of significance mentioned during the interview was "clast," although it was not used frequently. Infrequently named geologic objects include "rock," "boulder," and "chunk." In this study, membership in the geologic object category is rather sparse, but its inclusion as a category seems appropriate, even if only to capture the notion of things in the terrain that are separate entities, in contrast to "features." Also, in other similar domains, such as lunar field geology, this category would include "sample" and other important terms.

Another category of geologic entities is "geologic locality," whose members, from among the most frequently used nouns, are site, area, and place. The frequency of use of these terms, especially of "site" and "area," indicates the importance of this category, which is clearly distinguishable from "feature" and "geologic object." Additional, less frequently used locality terms include "station," "locality," and "location." The term "station," although infrequently mentioned explicitly, is central to the important tasks of gathering observations and thoughts in the notebook, in writing, in sketches, and in linking those entries to specific localities in the terrain by marking the station numbers on the map. This further supports the importance of this category.

The remainder of the most frequently mentioned geologic entities seem to fall into several categories which might be called "material," "part," and "spatial parameters." From the small number of members from among the most frequently used nouns, and their relatively lower frequencies of use during the interview, it can be determined that these are not among the top categories of interest to the geologists. Still, the number of low-frequency members in each category indicates that they are important to a comprehensive model of the domain.

The only material mentioned among the top nouns is "lava," which was often used to qualify the even more frequently used term "flow." Low-frequency members of this category include "mineral," "olivine," "clay," "feldspar," "pyroxene," "magma," and "basalt." The non-equivalence of member levels indicates that there is substructure in this category. Note, for example, that olivine is a "kind of" mineral, and that feldspar and pyroxene are groups of rock-forming minerals each with a common general chemical formula (ref. 26).

In reference to the parts of geologic features or localities, the terms "side" and "surface" were used fairly frequently. Other less frequently used terms in this category include "end," "top," "wall," "head," and "bottom."

The category "spatial parameters" contains spatial entities of interest that do not fit into the "locality" category. This category has only one member, "direction," among the most frequently mentioned domain entities. During the interview, the term "direction" was used somewhat frequently, especially with respect to the very frequently used term "flow." One reason for creating a category to contain this single term is that it seemed likely that there would be other similar kinds of terms. Other less frequently used spatial parameters refer to direction in terms of the compass (e.g., north, east, south, west) or relative to the slope of the site (e.g. up-slope, down-slope). Still other members include "distribution," "concentration" (of features or objects), "depth," "extent," "geometry," "measurement," "thickness," and "geobarometry."

By far the most frequently mentioned domain entities were the geologists themselves. This is indicated by the very high frequencies of use of the pronouns "I," "we," "me," "us," "you," "they," "them," and occasional proper nouns to refer to each other and to other explorers. Since all of these terms refer to the same kind of entity, all of the frequencies of use would be summed, resulting in the highest frequency of all.

The most frequently mentioned domain entities "contained by" the explorer can be categorized as "mental objects." These domain entities are: "feel/feeling" (used interchangeably), "idea," "picture/image (mental)" (that is, picture used to refer to a mental picture), and "fact."

The explorer's tools were not mentioned with frequency greater than or equal to 10 during the interview. Those mentioned include tools for making representations, such as camera (used seven times) and notebook (four).

Three domain entities that were among those most frequently mentioned during the interview can be categorized as neither explorer nor environment. These are "picture/image/photo" (that is, picture used in the sense of "photograph"), "note," and "map." These fall into the category of representations. Another entity in this category that was mentioned, though with frequency of only 8, is "sketch," which is very important to the representation of observations in the field notebook.

Attribute Analysis

Results of the attribute analysis are presented in detail in appendix B, and the hierarchy of attribute inheritance among classes of domain entities is presented in table 3. The outline shown in table 3 represents the structure of the "kind of" relationships among the dominant classes in the domain. Attributes of higher levels are inherited by those of lower ones. Attribute variables and example values for these classes are listed in appendix B.

Table 3. Hierarchy of Attribute Inheritance

- Entities in the environment
    - Generic geologic entities
        - Specific geologic entities
            - Features
                - Aggregations of xenoliths/nodules
                - Flows
                - Vents
                - Layers
                - Pits
                - Outcrops
            - Geologic objects
            - Geologic localities
    - Explorers
    - Traversals
- Representations
    - Views
    - Notes
    - Maps
- Explanatory models

The categorization (or classification) of the domain entities, a result of the preceding analysis, has been modified slightly by restructuring the categories according to the attributes. For example, two new classes, generic geologic entity and specific geologic entity have been added. Specific geologic entities share all of the attributes found for generic geologic entities, but generic ones lack many of the attributes of specific ones. Thus, for example, "pits" in general share certain attributes, but specific instances of "pits" share additional attributes. Also, the suggested subdivision of the domain into explorer, environment, and representation remains, but the subdivision is not quite so tidy with respect to the attributes. Explorers, though quite distinct from geologic entities, are nonetheless entities in the environment, as are traversals (another new entity resulting from the attribute analysis). Finally, no attributes were found for the categories "material," "part," and "spatial parameter," indicating that they are probably not viable entities (ref. 11). Instead, they appear to be attributes of geologic entities. The attribute "material" has different values according to which entity inherits the attribute. For example, most discussions of materials during the interview were in reference to geologic objects, so that is where those attribute values are placed. Different values of the attribute "material" associated with "flow" are placed with that entity. Most values of the attribute "part" mentioned during the interview are associated with features, and a few are associated with geologic objects.

Many category members identified in the previous section are not shown in table 3 or appendix B because the interview analysis revealed no *unique* attributes associated with them. They do, however, share the attributes common to members of their categories. Thus, having attributes, they are viable domain entities.

There are a number of additional points to be made about the attribute results. First, as explained in the Method section, the attributes are truly "attributed" as opposed to inherent, such as when the explorer attributes an instance-explanatory model to an occurrence of nodules, or several instance-explanatory models to a site. Second, there are undoubtedly many other attributes besides the ones listed in appendix B, but only those derived from the interview and from the field notebooks of the geologists are listed; the interview answers supplied nearly all of the attributes. Of the attributes presented, only examples of values, not a comprehensive list, are provided. Third, attributes are listed in appendix B as if they were data structures not only because it is natural, but also because this eases the transition to object-oriented design. Fourth, as will be seen later on in this section (Relation results), some of the attributes suggest relations among the entities. Fifth, for the record, much of the material suggesting the attributes of explanatory models, and their relations with geologic entities, was derived from the full text of the lengthy answer to question 7, "How did your understanding of the emplacement processes evolve during the traverse?"

Explorer Behavior

The field geologists described many of their field behaviors during the interview, sometimes in directly answering a question, but more often in illustrating or elaborating an answer.

The geologists used a map to gain initial familiarity with the site and the nodule distributions, and as a framework for observations. Occasionally, they operated on the traversal plan. To get a feel for the place and its geology, they walked around and looked. The feeling that they got for the environment, as a result of the walking and looking, was organized in three parts: a model of the site as it is, a model of the events and processes that shaped it, and an explanation of how the events and processes produced the current state of the site. The geologists performed many operations on these internal models in gaining familiarity with the locality, and incrementally built up their feel for the place and its geology. Their interactions with the terrain itself nearly all involved going and walking, and looking and seeing. They traced continuities of the flow and of the nodule beds deposited by the flow. Once something interesting or relevant was found, the things they "saw" were typically geologic facts, relations, and processes. In using their notebooks at stations, they recorded features, relations, and processes as evidence for explanatory models.

The goal of a geologic field reconnaissance is to gain familiarity with the site. The Jackson and Clague map (ref. 19) of nodule deposits gave the geologists their initial familiarization with the general arrangement of the significant nodule deposits at the Hue Hue telephone repeater station site, where the nodules/xenoliths are uniquely abundant. The numerous deposits are marked on the map as irregular black shapes on a white sheet that also includes many thin lines representing flow features. This very schematic map cannot, of course, provide familiarity with the natural appearance of the site. Thus, it could not serve as a definitive guide for finding the deposits, but could only suggest the best places to look.

The map also served as a framework for observations. The geologists looked at the map to locate significant features, to locate themselves relative to mapped features, to locate features and localities visited or not visited, and to see how observations fit into a broader pattern. In addition, the geologists recorded their station locations on the map with a circled station number, thereby relating their station observations and notebook entries to the map. They also used the map to identify and locate possibly significant but ambiguous or questionable features requiring them to "go and look at that and see what [the mappers] are trying to convey there."

The geologists occasionally operated on the traversal plan. Once the general traversal plan was created, it was common to modify it in the face of observations, and then to return to the original plan. An interview question about the traversal plan in general brought out some elaboration about the operation of choosing the first point of a traverse. The criteria cited for selecting a point at which to start a traverse included the following: that the point be easily accessible, that it be near a prominent landmark, that it be a particularly interesting site, and that it be located where the greatest number of nodules occurred.

The field behaviors which most explicitly served the goal of familiarization are variations on "wander about somewhat systematically," "go and look around," and "walk around and get a feel for x," where x has a range of values. Review of the full text of the interview answers shows that values of x include one or more of the following: the site, what is there, where it is, what it looks like, how it is laid out, its local context, and "what's going on." Clearly, these items define a comprehensive range of information, although the phrase "what's going on" requires some explanation. When the geologists tried to explain what they thought was going on, or the kind of thing that might be going on, their comments included attempts to visualize and describe in detail the antecedent geologic events and processes, and explanations of how the current state of the terrain resulted from these events and processes.

The geologists said that "a feeling" (used synonymously with "feel") for the place and its geology, which they defined as "a mental picture, a conceptual model," can only be gained by directly exploring the site, by being present, by "walking around and getting a feel for x." Thus, the feelings they have for each of the values of x (the site, what is there, where it is, what it looks like, how it is laid out, its local context, and "what's going on") are components of the mental picture, the conceptual model of the place and its geology.

According to the geologists, they tried to "see," "understand," develop an "evolving mental model of," and "get a mental picture of" "what's going on." These behaviors also apply to the other components of the feeling for the place and its geology. This can be seen in the fact that when asked about what was not in his field notes or photographs, one geologist said he had constructed a mental model of the site and its contents, and that he could "walk around" in it, reviewing observations and testing ideas. That is, he can see, understand, develop an evolving mental model of, and get a mental picture of the site, its constituents and their locations, observable attributes, arrangements, and contexts.

In summary, the geologists worked to get a feel for the place and its geology in the form of what they called "a mental picture, a conceptual model." This picture/model has three component models: a "walk around" model of the site in its current state, a dynamic visualization model of the antecedent geologic events and processes, and explanatory models of how the current state of the terrain resulted from these events and processes. The picture/model was built up from observations that enabled the field geologists to get a feel for the site, for its constituents and their locations, observable attributes, arrangements, and contexts, and "what's going on."

Further indication of the use and structure of these alleged internal models can be seen in the operations on them that were mentioned by the geologists among their responses to the interview questions. These operations are exploration behaviors directed not at the environment itself, but at the internal models of the environment. According to the geologists, to have a model is "to have a guiding paradigm," to be able to "put observed facts into a larger context." The geologists stated that during the traverses they frequently double-checked observations and refined or corrected their mental models as a result.

Operations on the internal models of the explored environment, as described during the interview, can be subdivided according to the three model components described above. The operations on walkabout mental models are to "construct a model of [the site] in my mind," to "imagine you are there again," to "walk around in your mental model, just trying to remember to see what might support your idea," and to "use it to test ideas."

Operations on event and process models are to "envision," "reconstruct," "try to picture," and "try to imagine," "how it was," "what happened," "the series of events," "what the eruption might be like," "how the lava flowed, where it went," "based on what you see." One visualization was even cited as an observation: "We see these aa flows come down and cover up some of these materials."

Operations on explanatory models are to "see," and "get a mental picture of," "what is going on" (which was shown in the previous section to involve both events and explanations) and to see that a concept associated with a feature "seems to explain a lot." Further, during the interview, the geologists offered several competing explanatory models (indicating the operations of model creation and maintenance, and the capacity to maintain several models), cited observations as evidence (indicating the operation of recognizing observations as evidence for or against an explanation), compared and contrasted the competing explanatory models (demonstrating an important operation on such models), and referred to other attributes of explanatory models. See the end of appendix B for an example of an explanatory model showing its attributes, as derived from the interview.

The purpose of the field trip was to investigate the nodule deposits of the 1800-1801 Kaupulehu lava flow of Hualalai Volcano, particularly those at the Hue Hue telephone repeater station site. Thus, many of the exploration behaviors gleaned from the interview answers are specifically directed toward the flow, its features, and the nodule deposits.

Interactions of the geologists with the terrain nearly all involved going and walking, and looking and seeing. As the geologists "wandered about somewhat systematically" their primary locomotion behavior was to "go" or "walk," and the purpose of that was to "look at" and "see" "what was there," "where it was," "what it looked like," "how it was laid out," its "local context," and "what's going on." It is not surprising, then, that many behaviors from the interview were of the form "see <feature or geologic object>," "stop and look at <feature or geologic object> more closely," and "spend time looking at <feature or geologic object>." In the act of seeing, the geologists also named the kind of thing seen, thus categorizing it in a name class (and, it seems safe to assume, assigning it a host of attribute variables and values).

This act of seeing and naming was the basis for another very frequently cited set of behaviors, which are of the form "see <something interesting>" or "look at <something interesting>." The "something" in these templates refers to a geologic feature or object. There were many such phrases used to denote the level of interest, including, but not limited to: "something interesting," "something that you haven't really seen before," "something that looks a little different," and "something intriguing."

The geologists were specifically interested in finding and seeing nodule deposits, and related flow features, in order to get a feel for nodule emplacement at the site. They described associated behaviors in such terms as "check out" "significant nodule deposits" and "walk around and look for any" nodules/xenoliths, or deposits or occurrences of nodules/xenoliths. The Jackson and Clague map (ref. 19) served as a general guide, but the geologists relied on observations of the terrain to find nodule deposits. Thus, the map provided the knowledge and expectations to guide, but not eliminate, search behaviors during the traverses. To characterize this, the geologists described behaviors such as "go <to a locality or into a large feature> knowing that the nodules are there" or "walk along certain paths expecting [to find] other xenolith deposits."

The paths they traced were continuities in the flow textures and the nodule beds deposited by the flow. Tracing these continuities was described as "actively tracing [flow texture] patterns that you see," and "you see a nodule outcrop and you walk it." Large flow features included the huge channel and the pits, which appeared to be connected by virtue of having been formed by the same component of the flow, and the geologists proceeded to "trace the chain" of pits, and "trace the alignment of the pits," to "see what the connection was."

Somewhat smaller flow features included shallow collapsed channels on the surface. The geologists said that by being present "you trace these things, and you see beds and see flow stream lines and stuff and you mentally connect them together and you do that all at once and you can move and reinforce that connection by looking at it repeatedly." In the field they could "trace several channels down hoping to find [nodules], searching for them," and could notice that "it looked as if there were either channels or tube systems going in a particular direction [and] hoping to find [nodules] exposed on the surface there." They also described a "more passive tracing where you walk along, you see flow textures and you kind of walk parallel to those, knowing that somehow you're going along the flow direction."

Observation of flow features during the search for the nodules, and observation of nodule deposits once they were found, primarily involved visual information, as indicated by the almost exclusive use of the verbs "see" and "look" by the geologists in describing these behaviors. The information sought about the deposits included "how they occurred, what they occurred in" as well as "where they occurred and what kind of little, local geologic settings they had." Of particular interest were the relationships between the nodule deposits and the contextual flow features.

Once something interesting or relevant was found, the things they "saw" were typically geologic facts, relations, and processes. Such exploration behaviors include seeing if a proposition is true, noticing that something "looks like" (indicates that) a proposition is true, and seeing geologic relations between geologic entities, such as those between layers in a bed or along surface flow contacts. Additional visual behaviors that involved "seeing" geologic processes included seeing the state of a geologic entity that suggests the influence of a geologic process; seeing a "record" or "surface expression" of a process; and "thinking" that one "sees" a geologic process itself, such as the process of lava draining out of a nodule bed, or the process of the flow dropping nodules.

Finally, a few of the reconnaissance observations involved measuring things, such as the thickness of a layer in an outcrop, or the size of an embedded nodule.

In using their notebooks at stations, the geologists recorded features, relations, and processes as evidence for models. The behaviors that define a station are "sit down and make notes," and "record observations in a notebook." The geologists held note writing to be central to field geology. "Note writing is a way of thinking. Field work is really thinking. When you write notes, you're forced to organize your thoughts." Once they have served this organizing purpose, the notes serve "to jog my memory later on."

Notebook operations were well described in the interview. The specific behaviors involved in organizing their thoughts and recording observations begin with "record on the map where you are" and "note the significance of the stop, why you're there," such as the presence of a relevant feature. The next step is to write "a two or three sentence summary of what I think this site is telling us. What's the story here?" (In fig. 4, the geologists attempt to understand the story at station 4.) At almost every station the next step is to make a sketch, if not several, which are generally plan view, with an occasional cross section, and a rare perspective sketch. These sketches, always annotated, serve to record observations, according to the geologists. The notes and sketches record "local geologic relations," and "the geology as seen from that viewpoint only."

Sometimes a note will describe how the current station relates to a previous one, or will integrate observations across several stations into a tentative conclusion. It is very common, the geologists said, for them to go back to localities and features previously visited in order to "sit down and get a mental picture of what's going on" and make notes describing it.

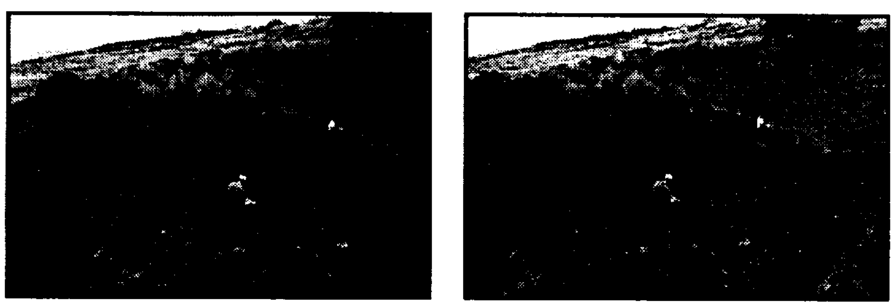

Figure 4. Stereo view of part of the "central vent" showing the geologists taking notes at station 4. This view, looking east, shows the explorers working to understand the geologic story told by the terrain in this part of the central vent.

The geologists were not asked explicitly about interactions with each other, and few interactions were explicitly mentioned in illustrations or elaborations of interview answers. In many of the responses, the geologists said that "we" did this or that, reflecting their having explored the terrain together. Those joint operations that were mentioned explicitly included taking a fellow explorer to an interesting site, looking at a map and discussing sites to be visited, planning the next phase of the traverse, and seeking the other's opinion.

Domain Entity Relations

Review of the transcripts revealed relationships between key entities that were among the candidate relations of domain analysis, as described in the Introduction. Nearly all of the relationships involved geologic entities. These relationships involved similarity and environmental contiguity among the geologic entities, and other contiguity relations including interactivity with the explorer (a nongeologic entity in the environment), and association with representations and explanatory models. Some of these can be deduced from the preceding results sections on categories, attributes, and explorer behaviors, but this section offers a different point of view, one presenting a unified view of the relationships.

As seen in the foregoing results section on attributes, all entities in the environment were found to share the attribute of location, which indicates that the most fundamental relationships among those entities involve location.

Relations involving the explorer are especially seen in explorer interactions with the environment. These interactions are well explained as explorer behaviors in the previous section, but it is important to recognize that these actions also involve certain explorer-environment relations. For example, consider the following behavior as a relation: explorer "walks around (in)" environment. To "walk" is one of the most important explorer-environment interactions/relations, as indicated by the verb frequencies (table 2). To "walk" involves very different constraints on changes of explorer position and orientation relative to the environment than, say, to "fly." Similarly, the relation "look/see," the most important explorer-environment relation, as derived from the verb frequencies (table 2), establishes a different relationship between the explorer and features or localities in the environment than "listen/hear," "touch/feel," "lift/heft," etc. Thus, to walk around and look/see is more than the description of a behavior, it is a description of a set of relationships between the explorer and the environment.

There are concrete spatial and temporal relationships established between the explorer and the environment by seemingly simple behaviors. Underlying the more obvious relationships inherent in "walking around and looking/seeing," for example, (or even flying around and looking/seeing) are relations that ensure that there are no spatial/temporal discontinuities in the existence, position, orientation, or scale of entities in the environment, so that, for example, rotations and translations of the geologist relative to features, geologic objects, or geologic localities result in geometrically predictable views of a stable environment.

The relationships between the explorer and the environment over time are constrained by some of the relatedness among geologic entities. In walking and looking/seeing, the geologists moved from feature to feature and locality to locality. They did not explore similar features or localities as a group, one category after the other, but instead sequentially explored features related by proximity, or features/localities that were found in the context of other features/localities, or features that were aligned with nearby features, or features/localities that seemed to be related by a common geologic process such as a lava flow from a vent. The explorers traced flows to find features that were related to each flow, or followed nodule beds to see if they continued from vent to pit to channel, which would establish the existence of important geologic relations. The relative locations of features or localities, and their geologic relations, which are all environmental contiguities, were far more important to the interactions between the explorer and the environment during exploration than the relative similarities among features or locations.

Relations associated with the explorer include "part of" relations among mental objects, and their associations with geologic entities. The most important of the mental objects, according to the noun frequencies (table 1), are "feel/feeling," "mental picture," "idea," and "fact." The entities "idea" and "fact" are associated with one after the other of every significant geologic entity, and become parts of the encompassing "feel/feeling" and "mental picture." As shown in a preceding subsection (Explorer Behavior), the mental objects "feel/feeling" and "mental picture" encompass each, and ultimately all, of the important geologic entities and their relationships. These entities are themselves parts of more comprehensive mental models of the site, which are also described in the previous section, including walkabout models, dynamic simulation models, and explanatory models.

Relations involving representations seem to link them to most of the important entities, both intangible and tangible, of the domain. Maps, which relate to the terrain with selective fidelity and scope, were used by the geologists to find the site, and to find the significant nodule deposits and related features within the site. At certain important localities/features, the geologists established stations, noted their locations on the site map, observed and thought, and took field notes, including sketches and text. The act of recording established relationships between each station and the on-going, in situ geologic insights ("ideas" and "feelings"), the features and objects of particular interest at that locality, the traverse, the map, the notes and sketches, and specific pages in the field notebook. Thus, stations relate the flow of observations (the process of exploration) to the key specific geologic entities, and to their representations (that is, state descriptions).

Photographs were also taken at some stations, as well as at intermediate points on the traverse. In most cases, the features or localities were familiar enough to the geologists, or perhaps were rendered in such detail, that they expressed confidence that when reviewing each photograph, they would remember the relationships between these representations and their insights at the time, the features of particular interest, the point along the traverse, the location on the map, and the direction of view. These relationships would not necessarily be available, of course, to someone else viewing the photographs.

Pictures of geologic entities are of two kinds: mental and photographic. Text and sketches are two kinds of notes made in field notebooks. The kinds of sketches include plan view, cross section, and perspective.

In general, relations involving geologic entities are relations of similarity or contiguity. Categorization, naming, and similarities of aggregated geologic entities account for the similarity relations. Attributes common to geologic instances suggest additional relationships involving geologic contexts, explanatory models of processes, geologic interest, traversals and stations, and representations such as field notes.

Similar features were grouped in name classes, such as "pits" or "vents." Thus, a variety of instances of roughly circular depressions that are several meters or more deep and several meters or more across would be called "pits." A collection of collapse pits, a pit associated with a spatter cone, and a very large pit with a huge deposit of nodules, each of which appeared to have been a source of molten lava, were at least tentatively called "vents." In naming a feature, the geologists effectively established "kind of" relations, that is, they determined that some observed terrain configuration was "a kind of" pit, or "a kind of" vent, etc. Establishing each "kind of" relationship assigned a group of attribute variables for which values could be sought, including, for example, "instance of explanatory model" (appendix B).

Other "kind of" relations were also found. The objects "nodule" and "clast" are "kinds of" xenolith. "Kind of" relations were identified between "aggregation of nodules," one of the most important features, and specific "occurrences," "deposits," "lag deposits," "banked deposits," "layers," "beds," "pockets," and the "talus slope." Kinds of vent include rootless and rooted. "Kind of" relations also exist between "layer" and the kinds of layer: "nodule bed," "flow," "froth zone," "vesiculated zone," and "transition zone." Kinds of flow texture include aa and pahoehoe. Other important "kind of" entities include relating a found rock to a particular kind of rock, or relating materials in a geologic object to a kind of mineral.

The geologists related many geologic entities by context and "part of" relations. It is important to note that the component parts of geologic entities are generally much less discrete that those that are usually of interest to object-oriented analysts. Further, "parts of" things were interesting to the geologists because of their geologic relations to other parts, that is, how each was within the context of the other. Thus, in the domain of geology, "part of" relations are context-constituent relations. Prepositional phrases revealed context relations similar to the forms "X is next to Y" and "X is in the Y," etc., where X and Y are localities, geologic features, or geologic objects. Descriptive noun phrases of the form "the X of (the) Y of (the) Z" revealed nested contexts, as in "the xenolith deposits of the 1801 flow of Hualalai Volcano." Sometimes, the verbal context provided the geologic context, as when a feature or locality was specified and later comments were made in reference to that feature or locality. In subdividing the field site, the geologists recognized several areas that are related to the site by "part of" relations, including "north vent area," "central vent area," "south vent area," and the interstices of surficial basalt. Individual nodules/xenoliths were related to the feature "aggregation of nodules/xenoliths" by "part of" relations. The large channel was related to "north vent" by considering it to be part of "north vent complex." Each of three collapsed and connected pits was considered to be part of the central vent. In addition, the geologists considered a layer to be "part of" an outcrop, and a tube as part of "the plumbing system" of a volcano.

Context-constituent relations, when assembled, take the form of a hierarchical network. Appendix C shows many of the relations assembled for key geologic instances of the site. One form of deviation from a tree structure is due to overlapping references to the same feature in a different context. Another deviation (not shown in appendix C) is that some entities are so important that, in addition to their local relations, they are directly related to even higher levels in the near-tree. Examples include the case in which the huge occurrence of nodules in the talus slope is considered to be one of the defining constituents of the entire site or the entire flow, or the case in which the outcrop at station 12 is held to be a key entity in understanding "what's going on" at the site.

Relations involving geologic processes were used by the geologists to relate geologic domain entities. For example, flows are related to vents because flows reach the surface by means of vents. The area influenced by a vent is a locality related to a feature by the geologic process of eruption from the vent. The entities "vent" and "nodule" are related by the process in which nodules are strewn out from vents, and nodules are deposited near vents. "Flow (molten)" and "nodule" are related because lava flows transport nodules, lava flows drop or deposit nodules, and lava flows can drain out of aggregations of nodules. In the process, lava coats nodules. The process of cooling accounts for the relationship between flow (molten) and flow (rock). The process of cooling from the outside of a flow to the inside accounts for the formation of lava tubes. Rootless vents are fed by lava tubes from rooted vents that are uphill. If lava tubes drain and collapse, channels or pits can be formed along its length. Nodules carried or deposited by the flow can be found exposed in pits and channels.

Geologic entities were also associated with explanatory models. This can most easily be seen in the attributes, where each generic geologic entity has an attribute called "generic explanatory model," and where each specific geologic entity has an attribute called "instance explanatory model." Model-entity relations are cause-effect relations, in that the model explains the processes that account for formation of a geologic feature or object at a particular locality. Thus, this relation is also a state-process relation, where the model describes the geologic process, and the entity is the related current state of the terrain.

IMPLICATIONS OF STUDY RESULTS

The implications of the results fall into three categories: the theoretical, design, and method.

Theoretical

There is evidence from the results to support the claim that presence in field geology is characterized by a variety of continuity relations. This notion was asserted in my previous study (ref. 1), and is further supported by this one. The first of the continuity relations is the persistence of governed engagement, some components of which are determined by physics and physicality, and others of which are self-imposed. A second kind of continuity relation includes those among contexts and constituents, which involve physical adjacencies. A third kind of continuity relation associates entities that are logically adjacent. A subset of these are state-process relations, linking cause and effect, process and product, or experience and representational artifact. All of these continuity relations are metonymic relations. Recognition, reinforcement, and exploitation of these relations during exploration aids in the understanding of geologic environments. Further, these relations help to account for the nature of that understanding from the point of view of the field geologists.

There is evidence from the results to support the claim that the persistence of governed engagement among entities in the environment is an essential characteristic of presence in field geology. Without the persistence of governed engagement, that is, without continuity of continuous existence, and the associated continuities of spatial and temporal transformations such as translations and rotations (ref. 1), interaction with and among the ever-changing entities in the environment would be so unstable and varying that it would be impossibly difficult to accumulate an understanding of them. The persistence of governed engagement provided the environmental stability which enabled the geologists to traverse and observe the terrain, identifying key entities, their attributes and behaviors, and relationships among the entities, and then from these developing detailed models consisting of descriptions of the current configuration of the terrain and earlier geologic events and geological explanations.

Constrained to persist in the environment and constrained from discontinuous translations, the explorers were not free to move directly from any feature or location to any other, but were constrained to transition along the metonymic relations of physical adjacency. Thus, the persistence of governed engagement imposed the requirement of continuous traversals. The need to disengage from locomotion for in-depth observations and thought, and for note-taking, modified continuous traversals to include stations.

Persistent engagement between the geologists and the environment was also governed by self-imposed constraints. For example, the geologists looked for physical continuities of features and willingly allowed them to constrain their traversals and observations. They sought continuous features such as flow textures, pits aligned with a channel, and nodule beds, and "traced" them by "walking" them, comparing the continuous flow of observations with the continuities of the feature. Thus, they recognized and reinforced the continuities of the terrain by exploiting the continuities of their presence. Another example of self-imposed governed engagement was the constraint to transitions among physically or logically adjacent domain entities. For example, the explorers transitioned from each important physical feature to its context, to parts of the feature, to its earlier forms, to its cause, to explanatory models, and to representations. All of these entities are associated by metonymic relations, that is, they are physically or logically adjacent in the domain of field geology. Thus, the explorers allowed their engagement with the terrain to be persistently governed by metonymic relations that are dictated by the discipline of field geology.

Winograd and Flores (ref. 27) utilize a concept in human-computer interaction design that is similar to the persistence of governed engagement. They adapt the term "throwness," a translation of Heidegger's (1927/1962) term "Geworfenheit" (ref. 28) to represent the notion that one can never fully withdraw from the action of everyday experience. They assert that one is "thrown" into action, unable to really disengage (since withdrawing still has consequences), particularly in the multitude of high-pressure interpersonal exchanges inherent in the business domain. Their emphasis on engagement with action and interpersonal exchanges differs from this paper's emphasis on the persistence of governed engagement. The later kind of engagement addresses spatial, temporal, and logical engagement with an environment, and it places a greater emphasis on the nature of the enforcement of that engagement. Still, the underlying notion of persistent engagement is similar.

Importantly, Heidegger's use of the term Geworfenheit is more general than its use by Winograd and Flores. Heidegger uses throwness to refer to disclosure of the fact that one is limited, and determined to some extent, by conditions and circumstances beyond one's control. It is, in his view, a component of "Befindlichkeit," or "the state in which one is to be found" (ref. 29). Such shades of meaning make Heidegger's comprehensive exegesis a rich resource for further exploring the notion of persistent engagement in presence and virtual presence. For the moment, it is sufficient to note that the concept of throwness clearly supports the claim that the persistence of governed engagement is an essential characteristic of presence.

There is evidence from the results to support the claim that context-constituent relations among geologic entities in the environment, and traversal of these relations, are essential characteristics of presence in field geology. This evidence includes many context-constituent relations, such as those among the hierarchy of entities in appendix C. Such relations are, as indicated above, imposed by the coherence of terrain, that is, contexts and constituents are held in governed engagement. This imposes structure on the entities which comprise the environment. When all of the geologic entities and the context-constituent relations among them are assembled, the result is a schematic but comprehensive structural model of the environment of interest. It is vital to recognize, however, that this structure is a function of the domain of interest, and that the same environment would yield different context-constituent hierarchies for different domains, such as different scientific disciplines.

Results of the analysis of explorer behaviors and the analysis of relations among geologic entities show that traversal and observation proceed from one geologic entity to the next, from one part of the terrain to another, where one adjacent entity is context for the other or where each is context for the other, where each contains constituent parts, and where each is contained within larger contexts. This traces a network of relations among geologic entities having a variety of levels of contextual scope. Thus, a hierarchy of context-constituent relations is defined in which entities have more inclusive scope at high levels and more specificity at lower levels. This hierarchy represents the relations among the geologic entities that comprise the context-constituent structure of the geologic environment. Because geologists traverse from entity to entity within the environment, they traverse the context-constituent hierarchy structure.

In traversing the context-constituent hierarchy, the geologists cannot violate governed engagement, so the structure must enable traversal from every observed entity in the terrain to every other observed entity, by a continuous path. Thus, each of the context-constituent relations must involve metonymic relations of physical adjacency. (If constituents do not touch or overlap, contexts provide the connections among their constituents.) Just as the geologists could walk from the north vent area to the central vent area to the south vent area, or from one pit within the central vent area to another, or from the aa-pahoehoe contact in the south vent area to a nodule-filled pit in the central vent area, traversal of the context-constituent hierarchy represents transitions, constrained by metonymic relations of physical adjacency, among contexts and constituents. This has important implications for design.

There is evidence from the results to support the claim that state-process relations are essential characteristics of presence in field geology. This evidence includes, for example, the fact that geologic entities are directly associated with (1) explanatory models (thus linking cause, as explained in the model, and effect, which is the resulting geologic entity), (2) dynamic simulations of the processes which contributed to its creation (thus linking geologic process and geologic state), and (3) representations such as sketches and photographs (thus associating the flow of experience and the process of exploration with more permanent representational artifacts). The evidence seems to indicate that state-process relations are a subset of logical adjacencies, which are all metonymic relations. Unlike physical adjacencies, which associate one tangible environmental entity with another, logical adjacencies associate a geologic entity with nongeologic entities that are significantly related, at least within the domain of interest. Examples of such important, logically adjacent, nongeologic entities include sketches, field notes, field notebooks, photographs, maps, facts, ideas, mental pictures, feelings for "what's going on," walkabout models, dynamic simulation models, explanatory models, and scientific literature.

In a previous study, state-process relations were said to be hierarchical (ref. 1). The current study indicates that this is due to association of the state-process relations with the context-constituent hierarchy (CCH). Thus, these relations do not form a separate hierarchy, but link logically adjacent "annotations" to the CCH.

All of the continuity relations described above are metonymic relations. Thus, the central theoretical claim, supported by the evidence of the results, may now be rephrased and thus improved: *Presence in field geology is characterized by persistent governed engagement of the explorer with geologic, representational, and explanatory entities such that transitions among them tend to occur by means of physical or logical adjacencies, that is, by means of metonymic relations.* In general, as presented in the Introduction, metonymic relations are contiguity relations which are congruent with the inherent physical and logical structure of real environments, so their central role in presence is reasonable. Thus, whereas the nature of entities encountered during presence varies from domain to domain, it seems likely that most of the important relations of domains, especially environment-oriented domains, are metonymic, and that this characteristic is common to presence in all domains.

The pervasiveness of metonymic relations suggests that they would provide a more appropriate basis for object-oriented domain analysis than the commonly used "part of" relation. For symmetry, metaphor should replace the "kind of" relation in OOA. Metonymy and metaphor are more inclusive relations than "part of" and "kind of" relations. Further, "part of" and "kind of" relations are insufficient to characterize presence in the domain of field geology. Even considering "part of" relations as inclusive of "context-constituent" and other physical adjacency relations, other metonymic relations are missing, including state-process relations, and their superset, logical adjacency. In fact, all relations imposed by the persistence of governed engagement are metonymic, and "part of" relations are but a small subset of these. "Kind of" relations also seem limited. They are descriptive of relations among somewhat obviously similar entities but do not include relations among metaphorically similar entities ("dogs' heads" are not "kinds of" aa lava, "potatoes" are not "kinds of" inclusions in the Kaupulehu lava flow, and "amphitheater" is not a "kind of" entity at the north vent), nor do "kind of" relations include relations among contrasting entities.

Metonymy includes "part of" relations as well as the other adjacency relations essential to presence, and metaphor includes both broad similarity relations and contrast relations. Thus, *to be more comprehensive, it would be useful to consider metonymy and metaphor as the two poles of object-oriented analysis.*

Presence, characterized by a variety of metonymic relations, exhibits redundancy and variability. To add or delete any one of the metonymic relations does not establish or eliminate presence, but only increases or decreases it. Redundancy enables the degree of presence to be varied according to which metonymic relations are enforced or supported. Further, these relations appear to contribute to presence unequally. One would expect the continuities associated with the persistence of governed engagement, for example, to contribute more to presence than those of logical adjacency. Still, when trade-offs must be made in support of presence, it is useful to recognize that some metonymic relations may be sacrificed while still retaining some of the continuity benefits of presence. Even some of the most fundamental relations of governed engagement, such as those between head movements and views, can be omitted while retaining some useful continuities of presence. (See page 36, last paragraph.)

Recognition, reinforcement, and exploitation of metonymic relations during exploration aids in the understanding of geologic environments. Further, these relations help to account for the nature of that understanding from the point of view of the field geologists. This occurs in something like the following way. A sparse, generic, somewhat annotated, context-constituent hierarchy must certainly exist before the first trip to a site, and literature reviews and other research would have already instantiated, with details of the specific field site of interest, some of the entity nodes, attributes, behaviors, relations, models, and other annotations of the CCH.

Field exploration then provides information that further elaborates and instantiates the annotated CCH. Recognition of entities in the field subdivides the environment, and recognition of relations among them reintegrates them into a structural model of the environment, the CCH. Previous experience and on-site observations associate attribute variables and values with these entities. Further, since the geologists are present in the field, the persistence of governed engagement enforces metonymic relations, the essence of CCH connectedness, with the entities of the environment. As they traverse the environment, their understanding of these metonymic relations accumulates, contributing to the structure of the CCH. Ideas, feelings, remembered views and observations, notes, sketches, photographs, and other logically adjacent entities are associated with geologic entities, which are also nodes in the CCH, as the exploration progresses.

Gradually, the CCH becomes sufficiently descriptive that it can serve as the basis of more integrated models, which are also key domain entities. The most straightforward of these is the walkabout model. The dynamic simulation model, developed in parallel, is more challenging. It is built up by associating remembered descriptions, film clips, and observations of the behaviors of molten lava flows with various entities in the CCH. This eventually results in a view of events at the site that is sufficiently comprehensive for the purposes of the field study. Explanatory models, associated with various constituent entities and their contexts, are developed in parallel with the walkabout model and the dynamic simulation model, and are ultimately unified into an explanatory model for the site to account for how the current state of the terrain, represented in the walkabout model, must have been produced by the geologic processes that are pictured in the dynamic simulation model. These models (the walkabout, simulation, and explanatory models, which are based on the annotated context-constituent hierarchy) comprise a geologic understanding of the terrain environment, derived from both previous professional experience and presence at the field site. This understanding would be available to the geologist during subsequent field explorations.

Design

The results provide evidence to support the claim that ethnographic object-oriented analysis (EOOA) of geologists in the field can provide information useful to designers of virtual planetary exploration systems. Rather than confining that design information to "human factors guidelines," (e.g., statements such as "The interface should be consistent") the EOOA provides detailed design specifications. These specifications are isomorphic with the way geologists think about their domain when present in the field. The specifications include identification of important entities of the domain and their attributes and behaviors, and relations among those entities. Key classes of entities are listed in tables 1 and 3. Two additional domain entities were identified from the explorer behavior analysis: the walkabout model and the dynamic simulation model. "Kind of" relations in table 3 indicate the inheritance hierarchy among key classes of entities. Attributes of many of the key domain entities, presented in appendix B, indicate variables and their values to be encapsulated within the system objects representing the domain entities.

Beyond these entity specifications, metonymic relations between geologic entities, and those between geologic entities and logically adjacent ones (e.g., representations and explanatory models), suggest the specification of a framework for the integration of disparate environmental data. Further, the existence and utility of the walkabout and dynamic simulation models suggests that digital elevation data and other terrain data should also be subdivided and encapsulated (by means of pointers and ranges) with nodes in this framework for use in creating virtual environments.

Explorer behaviors, and relations involving the explorer (each described in the corresponding results subsections), suggest operations of the system, including interactions with the operator. In the system design, many explorer behaviors observed in the field would be distributed to collaborating system objects representing the domain entities involved in the explorer behaviors. This would support an important goal of object-oriented system design, the encapsulation of object services within each object. The dynamic physical relationships between nodules and lava flows, which are involved in explorer modeling behaviors, indicate additional entity collaborations, requiring communications by means of entity-to-entity messages, and additional object services. These would be particularly useful for creating dynamic simulations.

The results of the ethnographic object-oriented analysis, and the preceding discussion of theory, strongly suggest that the CCH, annotated with logically adjacent entities, can be implemented in a virtual presence system to provide a useful domain-based data structure. This structure is isomorphic with the "mental model" of the explorers. The (unannotated) CCH is a framework which can explicitly represent the geologic entities, and the metonymic relations between them, as encountered during presence in a terrain environment. Thus, is can provide the framework for a data structure to internally represent the domain-based structure of the natural environment. Further, the CCH in a virtual presence system can be annotated with logically adjacent nongeologic entities, including sketches, field notes, field notebooks, photographs, maps, facts, ideas, mental pictures, feelings for "what's going on," walkabout models, dynamic simulation models, explanatory models, and scientific literature. *The annotated context-constituent hierarchy integrates disparate exploration data into a unified, domain-based data structure which is based on the natural structure of the environment, as well as on the particular way field geologists think about it.*

This organization can provide a variety of benefits. First, rather than being arbitrarily or geometrically subdivided, environmental data files can be organized in a manner comparable to their use. This would allow, for example, domain-based complexity management of terrain data. Further, a wide variety of associated but dissimilar terrain-related information can be structured naturally around the structure of the terrain, readily accessible by means of logical adjacency relations. This would support the notion of a sort of "terrain query mode" in which a feature, object, or locality in the virtual terrain could be directly queried regarding metonymically associated sketches, notes, photographs, maps, facts, models, scientific publications, and other similar kinds of information, as described previously. Conversely, database systems containing any one of these kinds of items could provide pointers back to the entity in the terrain from which it came, and thus to the other logically adjacent data. This organization supports the Exploration Metaphor (refs. 2, 3), which asserts that human-computer interaction with environmental data is analogous to planetary exploration (as opposed to, say, desktop paperwork).

The annotated CCH provides a structure on which to build a domain-based complexity management system for virtual environments. Since the explorer is to be constrained to presence-like metonymic relations, the location of the explorer within the CCH indicates the features, objects, locations, or annotations which must be presented to the explorer, and the necessary levels of detail. It also indicates which physically adjacent entities can be explored next. Further, unlike the geometric approach to terrain data complexity management (ref. 30), an entity-based approach would never blindly cut domain features, objects, or locations with boundaries between very different levels of detail, but would instead recognize the wholeness of these important entities. Further, the level of detail distribution required for larger or neighboring contexts could be computed once, as long as explorer movement remained within the current context (given contexts with fuzzy or overlapping boundaries), thus saving a significant amount of time over geometry-based complexity-management computations. Only those entities that are within the current context would be subject to on-the-fly complexity distribution calculations, and the context itself might well have a lower level of detail than key constituents within it.

Just as it is in the field, the annotated context constituent hierarchy (ACCH) in a virtual presence system should be an evolving framework for disparate data integration. Since a system utilizing this structure would be shared among numerous explorers, this raises the issue of having multiple ACCHs. Each explorer could develop several of their own for various localities, held in private, but a shared ACCH for a given locality could be used to share information among the group. Eventually, a well-developed ACCH based on the best consensus of expert explorers could be published, and made available to an even wider group. This could be downloaded and personalized for further individual or group use by later researchers.

To support this, it should be possible to post information to a given ACCH, and to post whole ACCHs as well. In this context, posting means sending information to add, modify, or delete entities, attributes of entities, relations between entities, or annotations of entities, or to associate an entire ACCH with a locality. The concept is analogous to posting to an Internet news group, with the important additional notion that the target of the action is a feature, object, locality, representation, or other entity in the environment. In a further analogy to Internet groups, a site or feature of interest might also have associated with it "frequently asked questions (FAQs)," and ongoing discussions among researchers. This mechanism allows the explorers themselves to build up over time the information associated with the environment, and to effectively coordinate and share exploration information in a timely manner, rather than having some database group do that as a stand-alone project.

Terrain posting supports terrain queries. These queries can be directed to a list, a map, a photograph, a geologic feature in a virtual environment, or any other representation of the environment. One could, for example, query a region, feature, locality, object, or other entity in the environment to learn of its scientific interest to a variety of sciences, organizations, or researchers, to review its explanatory models from the point of view of different disciplines, to find associated references, or to locate its multidisciplinary and multi-media data sets.

In a future world of highly accurate global positioning systems, and personal wireless access to vast information networks, actual, physical, geologic entities themselves could be queried in the field in a manner similar to that used in a virtual environment.

The application of metonymic constraints to any spatial interface, even one without "goggles and gloves" or other gesture-based interaction, can bring some of the useful continuities of presence to interaction with the environment. To achieve this, transition from one physical entity to another along relations of physical adjacency should always be an available option and, in fact, could be a requirement while in the "persistent governed engagement" mode. Transition from one physical entity to another must not require transition by means of entities that are only logically adjacent, such as latitude and longitude, or more distantly related, such as files and file names. Further, entities that are logically adjacent to geologic entities should be accessible by means of those geologic entities.

For example, no matter how Mars data are stored on the Planetary Data System CD-ROMs (many of the data files in one set contain 5° X 5° patches of terrain, representing a geometric array of patches), it should be possible for the explorer to begin at some feature on Mars and follow a path in any direction, viewing the terrain continuously, free to explore the entire surface. Although it should be possible to access latitude and longitude for any feature or location, since these metrical entities are logically adjacent to physical entities, it should not be necessary to consider latitude and longitude when roving over the surface. The explorer should certainly not be required to think about or specify environment data files or file names during exploration of the planetary surface. Further, as the explorer moves from entity to entity along relations of physical adjacency, they should not be confined to a fixed level of detail, transitioning only among constituents of a given context, or contexts of equivalent scope (e.g., from crater to crater, or rock to rock, or region to region). Instead, it should be possible to move freely among contexts and constituents, not only laterally among comparable contexts or constituents, but also upward in the hierarchy to entities of larger scope, and downward in the hierarchy to entities of greater specificity. While this entails moving among data files of vastly different resolutions, but it should not interfere with the presence-like transition among contexts and constituents.

Methodological

It is evident that the results support the claim that if the subjects of an ethnographic field study are observed during activities conducted in the field for their own purposes, unencumbered by interventions, their engagement with the environment will be more natural, and hence more useful for observing the nature of their presence in the field, in comparison with my previous field study, conducted at the Amboy lava field (ref. 1). Still, it is also evident that the findings of the previous study, despite the artificiality of its method, were essentially validated and elaborated by this study. The additional benefit gained by the ecological validity of this study seems to have been the opportunity to observe the vastly greater coherence, specificity, and comprehensiveness of the geological investigation of the Hualalai field site. This provided a wealth of structured domain information, whose analysis provided more concrete insights into the nature of presence in field geology, as well as detailed design specifications, which confirms the utility of the method applied in this study.

CONCLUSION

By spending some time in the real world, particularly in natural environments working as a participant observer with those for whom presence is a professional necessity, one can learn a great deal about presence. These lessons can be usefully applied to the design of virtual presence systems. Ethnographic object-oriented analysis can provide systematic methods for characterizing presence and its uses, and can bring this characterization to bear on design by means of detailed specifications.

Refinement and wider application of these observational and analytic techniques could make them increasingly useful for domain-based design of virtual presence systems.

The metonymy of presence in field geology, the web of physical and logical adjacencies, is imposed by the given coherence of natural environments and by what Heidegger termed throwness, and it is further shaped by the dictates of the domain. Field geologists exploit presence by using it to hold them to the inherent structure of the environment, and its domain-based logical associations, in order to extend and instantiate the elements of a corresponding structure which represents their understanding of terrain environments. This conceptual structure can be exported to virtual presence systems, which could have a significant and beneficial effect on fundamental aspects of their design.

APPENDIX A

Interview Questions and Answers

This appendix is a concise paraphrase of the field interview. Questions noted with an asterisk and the category headings were prepared before the interview; the other questions were suggested by the responses of the geologists. All the questions are designated according to the length of responses they elicited: long (485-874 words), (7 responses); medium (160-484), (14 responses); and short (65-159), (7 responses).

Traversal

1.* What was your traversal plan? (Short response)

We didn't really have a traversal plan, other than to walk around and get a feel for the site. We started at a site where the nodules are exposed.

2. What are these nodules? (Medium response)

Nodules are xenoliths which are chunks of the lower crust or upper mantle. They are brought to the surface in a lava flow. The purpose of the field trip was to examine nodule deposits in the Kaupulehu lava flow. After looking at the biggest occurrence of nodules, it was logical to go up-slope from there.

3. Why is it logical to go up-slope? (Medium response)

Some pits seemed to line up, so why not trace *itfurther* [sic] up? Anyway, we wanted to check out the rest of the significant deposits that had been mapped, and they were south of where we started, that is, up-slope.

4. What factors motivated your traversal path as you went along? (Short response)

In some cases we traced possible channels hoping to find nodules exposed on the surface. The idea was, "What direction was the flow?" "How far were they transported?"

5. When looking in this direction, were you going by the map, the site, a combination? (Medium response)

An advantage of the site is that you see a lot of flow textures. We traced these by walking. Where there weren't flow textures, we just looked for anything at all intriguing.

6. Would you define "intriguing" for me? (Short response)

Something that looks interesting, although it may or may not be relevant to our problem.

7.* How did your understanding of the emplacement processes evolve during the traverse? (Long response)

We knew about several proposed models before we came, but we are not comfortable with them after what we have seen, and are now considering alternative explanations.

8.* What made you decide to go into the big channel? (Medium response)

The channel is known to have nodule deposits; it is near the largest occurrence of nodules, which is at north vent; and we wanted to inspect evidence of a connection to the collapse pits and central vent area.

9. What was the evidence for a potential connection? (Medium response)

The pits and the channel appear to be lined up; there is evidence of a tube system; and there is continuity in the nodule bed that we traced from the central vent area to the goat skull pit.

10. In judging the connection, what was the interplay between the map and your traversal? (Medium response)

Use of the map provides a bird's eye view, fitting things you see into a broader pattern.

Outcrops

11.* How did you decide that a given outcrop was sufficiently interesting for study? (Medium response)

It was presence of nodules, clarity of exposures, and an occurrence we didn't understand or hadn't seen elsewhere.

12. What was it about the outcrop near the head of the channel that attracted your attention? There was another nearby that appeared similar, yet you seemed to ignore it. (Short response)

We noticed it, but it was less accessible. Also, we thought we saw zonation, the process of the lava draining out, and we got intrigued by the froth zone between the flow and the nodule beds. We're not done with these outcrops. We were just getting a feel for what they look like.

13.* What was your interest in the small rocks you found in the nearby outcrop? (Medium response)

It caught the eye, and seemed to be feldspathic which is very rare in this kind of flow. I am interested in the chemistry of the xenoliths, not just their placement.

Notes

14.* What did you learn as a result of your site visit that you did not put into your field books or photograph? (Long response)

I developed an evolving mental model of what's going on, one I can walk around in, and a picture in my mind of what's underground and how it connects to the surface vents.

15. You mentioned walking around in your mental model. Would you describe that for me? (Long response)

It's imagining you are there again, walking around, testing ideas, trying to remember to see what might support an idea. If you go back, double check an observation, and find an error in your mental model, you correct it. I also try to imagine or picture the event, the eruption, in detail.

16.* What is in your field notes and why is it there? (Long response)

I record observations, make sketches, and describe what I think the site is telling us, that is, "What's the story here?" I record local geologic relations. They are little notes to myself to jog my memory later on.

17. What motivated your activity following the making of notes? (Long response)

We returned to our general plan, which was to revisit all the sites we had looked at in a cursory manner that morning. We modified that plan a little bit by integrating new observations.

Subdividing and chunking the environment

18.* What are the key landmarks at this site? (Medium response)

The key areas, in a geologic sense, are the occurrence of thousands of nodules, the pits, the "vents," and sub-areas within those, as well as the bedded nodules in the channel. The repeater-station towers aided navigation.

19. Some of these are generic categories, so, okay, what are the categories of things to be seen at the site? (Short response)

Pits filled with xenoliths, those with asymmetrical distributions of xenoliths, bedded xenoliths, and possibly the big tube system that may exist at depth.

20. You mentioned big features that have a hierarchy of landmarks. Would you give me an example? (Short response)

The central vent is a collection of separate collapse pits. Two of them don't have any xenoliths, and the whole floor is filled by a lava flow, partly covering some of the xenolith beds.

21.* What features would you name, and what would their names be? (Medium response)

We use Jackson's terminology: south, central, and north "vents." We didn't name the channel but would call it "north vent channel." Of the collapse pits, we only named the one with the goat skull because it is a bridging element, and needed a name when talking about the alignment.

22.* How would you subdivide the site into interlocking zones? (Medium response)

The north vent area and the north vent channel would be one. The others would be the central vent area and the south vent area. Plus there is a zone of bedded deposits associated with central vent that are right at north vent. The rest of the site is just late surficial basalt.

Presence

23.* What did you learn in the field yesterday that you could not learn without going there? (Medium response)

Just about everything. I now have a feeling for the site, that is, a mental picture, a conceptual model. It would be hard to communicate that to others.

24. How would you communicate to others your understanding of the site? (Long response)

You can't get it from the published literature. Photographs would help, but you don't get a feeling for the landscape, for the correct sense of scale, for the grand scale, the grandeur.

25. Is the feeling for the landscape useful or valuable? Is it worth capturing? (Medium response)

Yes, it is valuable for appreciating what you're looking at. Not it's significance but a feel for what you're looking at. Taking a picture yesterday, I noticed it cut off the flow stream lines at the edge of the frame. When you're there, you see various features and you can mentally connect them together all at once. You can move and reinforce the connection by looking at it repeatedly.

26. Could video capture the missing information by tracing along the pattern? (Short response)

You can do that with a still photo by making a panorama. People used to do that all the time. Panning a TV camera and recording the imagery is useful, but lacks the image qualities of direct viewing.

27. Is there something missing after that? (Long response)

Images of reality key mental pictures. If you have never been to a site, pictures do not bridge the gap because there is no corresponding mental image of the site. Also, I've thought about making field notes with video as I walk along, but it wouldn't capture the essence of my conclusions the way field notes do.

28. What would you lose if you could not stop and write notes in the field? (Medium response)

Note writing is a way of thinking. It forces you to organize your thoughts. The Apollo astronauts didn't take notes on the moon, they just recorded it on TV. Transcripts were made and I have used them. It is a really cumbersome record to use. My notes capture the essence of the work we did.

APPENDIX B

Attributes of Prominent Domain Entities

(See table 3 for an outline showing only the hierarchy of attribute inheritance among classes of domain entities.)

KEY:

variable: value;
variable (subvar_1, subvar_2, ...)
variable (subvar_option_1/subvar_option_2 / ...)
variable (value_1 , value_2,...)
variable (value_option_1 / value_option_2 /...)
variable (<description of value> /...)
variable [list index] ...

NOTE (1): *The appropriateness of values for these variables depends on the subtype of the geologic entity, that is, whether the instance is a pit, vent, locality, etc. These examples are provided to illustrate the meaning of the variables. They do not represent names or contexts available to all geologic entities.*

Attributes of entities in the environment (1)

location [n] (location description, map location)

location description (<relative to nodules, geologic features, parts of geologic features, cultural features, localities, or map>)

examples: (where the nodules are exposed / in the goat skull pit / next to the beginning of the big channel / near the radio installation / to the first site / at the northern end of the map area)

map location (<indicated location on map relative to represented entities>)

Attributes of generic geologic entities (1) *(inherits Attrib. of entities in the environment; uses explanatory models)*

definition (formal definition, informal definition)

formal from Glossary of Geology, (ref. 26)

informal (chunks of the lower crust or upper mantle /...)

descriptive generic entity name (nodule / pit / skylight / channel / vent / dike / ...)

generic contexts [n] (volcano / plumbing system / flow / tube / ...)

generic explanatory model (explanatory model*) [e.g. relation of pits and tubes]

material [n] (lava / olivine / clay / feldspar / pyroxene / magma / basalt / ...)

part [n] (side / surface / end / top / wall / head / bottom / ...)

* *(see Attrib. of explanatory models)*

Attributes of specific geologic entities (1) *(inherits Attrib. of generic geologic entities; uses explanatory models)*

descriptive instance name (the little pits / goat skull pit / south vent area / central vent / north vent complex / the huge channel / banked nodule deposits / ...)

instance contexts [n] (Hualalai Volcano / 1800-1801 Kaupulehu lava flow / Hue Hue telephone repeater station site / central vent area / central vent / interior of central vent / ...)

assessment of interest (interest value, nature of interest)

interest value (ordinary(none) / understood(none) / different(moderate) / not seen before(moderate) / out of the ordinary(moderate) / interesting(moderate) / intriguing(above moderate) / unique(above moderate) / relevant to the problem you're solving at the time (high) / significant(very high) / key(very high) /...)

nature of interest (facts and/or observations)
facts (has not been seen anywhere else at the site / nodules are known to be present / unique site where nodules are present in great abundance / process is unknown / ...)
observations (saw zonation there / saw four layered nodule beds / saw process of lava draining out of nodule bed / saw process of flow dropping nodules / separates flow layer from nodule layer / ...)
spatial parameters [n] (direction / distribution / concentration / depth / extent / geometry / measurement / thickness / geobarometry / ...)
direction (north / east / south / west / up-slope / down-slope / ...)
impressions/ideas [i] (there appeared to be vents with nodules concentrated in nearby deposits / it appeared that nodules reached the surface at these vents and flowed downhill / it looked as if there were either channels or tube systems that were going along in a particular direction / ...)
associated station number (not applicable / <integer>)
associated sketch of observations (<location in a particular notebook>)
associated field observations in text form (<location in a particular notebook>)
instance explanatory model (explanatory model*)
* *(see Attrib. of explanatory models)*

Attributes of features *(inherits Attrib. of specific geologic entities)*
none from interview

Attributes of aggregations of xenoliths/nodules *(inherits Attrib. of features)*
present at locality (location description*, nodules exposed?, quantity of nodules, forms of nodule occurrence, nodule relation to flow matrix, density of nodule distribution in flow(rock))
nodules exposed? (true / false)
quantity of nodules (tens of thousands / great abundance / large quantity / biggest occurrence / ...)
forms of nodule aggregation [n] (occurrence / deposit / lag deposit / banked deposit / exposure / layer / bed / pocket / major pocket / talus slope / adhering to foundered plate / filling a pit / ...)
nodule relation to flow matrix [m] (suspended / lag deposit /...)
density of nodule distribution in flow(rock) (not applicable / sparse / ...)
* *(see Attrib. of specific geologic entities)*

Attributes of flows *(inherits Attrib. of features)*
state (molten / rock / ...)
material (lava / basalt / ...)
part (surface / ...)
compass direction (generally north / ...)
date of occurrence (1800-1801 / ...)
name (Kaupulehu / none / ...)
associated volcano (Hualalai / ...)
component of what flow (none / Kaupulehu / flow from central vent / ...)
flow texture (aa and pahoehoe / aa / pahoehoe /...)
type if pahoehoe (shelly / ...)
consistency of flow(rock) (massive / frothy / ...)
thickness (thick / thin / ...)
form of emplacement (layer / festoon / toe /...)
nodule bearing? (true / false)

Attributes of vents *(inherits Attrib. of features)*
kind of vent (rootless / rooted / feeder / ...)

Attributes of layers *(inherits Attrib. of features)*
kind of layer (nodule bed / flow / froth zone / vesiculated zone / transition zone / ...)

Attributes of pits *(inherits Attrib. of features)*
characteristics [n] (deep central portion / contains nodules / aligned with other pits / aligned with channel / related to central vent / related to north vent complex / ...)

Attributes of outcrops *(inherits Attrib. of features)*
constituent parts [n] (bed / layer / zone /...)
clarity of exposure (well exposed / covered up / ...)

Attributes of geologic objects *(inherits Attrib. of specific geologic entities)*
geologic object type (nodule / xenolith / clast /...)
size (size class, size description, measurements, ...)
  size class (10cm / 30-40cm / ...)
  size description (football sized / largest / ...)
  measurements (length, width, depth, ...)
material (rock type / minerals / ...)
    rock type (dunite / granite / feldspathic / ...)
    minerals (colors of sample, mineral composition, ...)
      colors of sample [m](green / green with dark green or black / pink and black /...)
      mineral composition [n](mineral constituent, proportion, typical color(s), ...)
        mineral constituent (olivine / pyroxene / plagioclase / feldspar /...)
        proportion (all / most / one third / 60% / ...)
        typical color(s) (green / ...)
part (surface / ...)

Attributes of geologic localities *(inherits Attrib. of specific geologic entities)*
mapped area (map of locality, <approximate boundaries mapped to site itself>)
  map of locality [p] (Jackson and Clague, 1982 / ...)
visitors [q] (<visitor name>, <date>, <duration of visit>)
advantages [t] (little foliage so flow textures are visible / ...)
kinds of entities present [r] (descriptive generic entity name*)
instances of entities present [s] (descriptive instance name**)
  (Each name in list serves as pointer to an instance, which contains its attributes.)
nodule occurrences at locality (nodules present?, <if so: list of indices to specific instances of occurrences; else: null>)
  nodules present? (true / false / don't know)
* *(see Attrib. of generic geologic entities)*
** *(see Attrib. of specific geologic entities)*

Attributes of materials, parts, and non-locality spatial entities
none from interview ; variables and values distributed as attributes to the other entities

Attributes of explorers *(inherits Attrib. of entities in the environment; uses entities in the environment, generic geologic entities, specific geologic entities, features, occurrences of*

xenoliths/nodules, flows, vents, layers, pits, outcrops, geologic objects, geologic localities, representations, views, maps, explorers, traversals, explanatory models, ...)
project (project purpose, pre-trip literature review, traversals [i], publication, ...)
project purpose (examine the xenolith/nodule deposits of the 1800-1801 Kaupulehu flow of Hualalai Volcano / ...)
pre-trip literature review (<"before I came here, I dug up all the literature I could find on this site and the flow, and I read them.">)
traversals [i]*
publication (<"an extreme distillation of a whole bunch of field observations, filtered by the perceptions of the author and the problem he's trying to address">)
current view (view**)
current station (not at station / <station number>)
* *(see Attrib. of traversals)*
** *(see Attrib. of views)*

Attributes of traversals *(inherits Attrib. of entities in the environment; uses specific geologic entities)*
planned traversal activities [n] *(see Explorer behavior results, in text)*
sequence of stations established and revisited [m] (<station number>, ...)
description of traversal path and highlights (<narrative>)
geologic instances of interest [q] (descriptive instance name*, visited?, when visited, duration [u,v], exploration reasons [r], significant events [s], recorded in notebook / ...)
visited? (true/false)
when visited, duration [u,v] (yesterday, all morning / last November, two hours / <null> / ...)
exploration reasons [r] (to see bedded nodules previously seen and mapped by others / to trace nodule beds / to trace flow textures / to see the connection between the pits and the channel / to see any occurrences of nodules / to look for nodules / to investigate the chemistry of the xenoliths / to investigate the variation of minerals crystallized in the magma chamber throughout the active phase of the volcano / ...)
significant events [s] (saw bedded nodules / saw a rock wall instead of evidence of a connection / saw process of flow dropping nodules / <null> / ...)
recorded in notebook (true / false)
* *(see Attrib. of specific geologic entities; Each instance name serves as a pointer to an instance, which contains its attributes.)*

Attributes of representations *(uses specific geologic entities)*
geologic instances represented [n] (descriptive instance name*)
(Each name in list serves as pointer to a instance, which contains its attributes.)
scientific source (Jackson and Clague, 1982 / ...)
* *(see Attrib. of generic geologic entities)*

Attributes of views *(inherits Attrib. of representations)*
view type (direct / remembered / sketch / photograph / video / ...)
field of view (panoramic / narrow / wide / ...)
motion type (static / dynamic / ...)
explorer-environment view relationship type (plane or plan / cross-section / perspective /...)
location of point of view (location* / associated station number** / ...)
date of artifact creation (<date>)

* *(see Attrib. of entities in the environment)*
** *(see Attrib. of specific geologic entities)*

Attributes of notes *(inherits Attrib. of representations)*
observations in text form (<text>)
observations in sketch form (<sketch>)
notebook ID (<notebook ID>)
notebook pages (<page start>, <page end>)

Attributes of maps *(inherits Attrib. of representations)*
description of area included (vent area mapped by Jackson / ...)
description of explorer location on map (we started at one end of the map area / ...)

Attributes of explanatory models *(example of values for one particular model)*
model name: topographic bench model
component of: 1800-1801 Kaupulehu eruption model
model description: topographic bench slows flow from vent(s) uphill and nodules fall out;
perceived quality of this model: may be incorrect;
feelings about the model [n]: uncomfortable;
alternative to models[n]: rooted/feeder vent model, rootless vent model;
model evidence
evidence for [1]: unspecified evidence from the literature;
evidence against [1]: does not explain occurrence of concentrated nodule deposits in pits;
evidence against [2]: does not explain occurrence of asymmetric deposits, especially those on the east sides of the pits, and on the east side of the whole locality;
references [n]: TBD;
sub-model name [n]: subsurface geometry model;

APPENDIX C

Relations among Key Geologic Instances

This appendix shows the key geologic instances at the Hue Hue telephone repeater station site. The stations visited on the first day are shown. The chart is based on the interview and the geologists' field notebooks.

- South vent area
  - Semi-circular spatter cone/vent (station 1; cross section, plan view)
    - Welded spatter
    - Bedded xenolith deposits
    - Deep hole
    - Skylight
  - Leveed lava channel
  - 100–150 m downslope from south vent (station 2; plan view, cross section)
    - Contact between pahoehoe and aa flow

- Central vent area
  - Central vent (station 4; plan view)
    - Small, isolated collapse pit (station 3; plan view)
      - Massive beds of xenolith nodules
      - Circular collapse fractures
      - Foundered blocks
    - Collapse pit
      - Filled with nodules
      - Plates
        - Adhering nodules
      - Pahoehoe flow to northwest
        - Embedded xenoliths near pit
        - No embedded xenoliths farther away
    - Two collapse pits
      - Whole floor filled with younger no-nodule flow unit
      - Interior (station 5; two plan views, one cross section)
        - Slabs of smooth pahoehoe lava (no nodules)
        - Older, wider, nodule-bearing unit
    - Eastern edge (station 6; plan view)
      - No-nodule pahoehoe flow
      - Aa overlapping nodule-bearing and non-nodule pahoehoe flows
      - Pit
        - Deep hole
        - Window on nodule bed
    - Extreme eastern edge (station 7; plan view)
      - Flow from central vent
      - Nodule deposits
      - Collapse pits
        - Deep-hole skylights

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- North vent area/complex
    - Goat skull collapse pit (station 8; two plan views)
        - Very large, rounded nodules
        - Massive beds of 10 cm class nodules
        - Pyroxene
        - Flow drain-back
    - Elongate pit north of goat skull crater (station 9; plan view)
    - North vent channel
        - Inside north vent channel (station 10)
        - Floor of channel upstream from station 10 (station 11)
        - Up near head of north vent channel ; (station 12; cross section)
            - "Key outcrop"
                - Lava flow with suspended nodules
                - Frothy zone, gradational into less frothy material
                - Nodule lag deposit
                - Frothy zone
                - Nodules suspended in underlying flow
            - Similar, but less accessible outcrop
    - North vent pit
        - West wall of north vent pit (station 13; cross section)
        - Outcrop
            - Rubbly pahoehoe lava
            - Massive pahoehoe
            - Nodule bed
            - Suspended xenoliths, gradational in density
            - Second nodule bed
        - Rim of north vent, western side (station 14; perspective)
        - Amphitheater
            - Talus slope
- Late surficial basalt which covers up the record

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
May 1994

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
An Ethnographic Object-Oriented Analysis of Explorer Presence in a Volcanic Terrain Environment: Claims and Evidence

5. FUNDING NUMBERS
506-59-65

6. AUTHOR(S)
Michael W. McGreevy

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ames Research Center
Moffett Field, CA 94035-1000

8. PERFORMING ORGANIZATION REPORT NUMBER
A-94083

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-108823

11. SUPPLEMENTARY NOTES
Point of Contact: Michael W. McGreevy, Ames Research Center, MS 262-2, Moffett Field, CA 94035-1000; (415) 604-5784

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified — Unlimited
Subject Category 54

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

An ethnographic field study was conducted to investigate the nature of presence in field geology, and to develop specifications for domain-based planetary exploration systems utilizing virtual presence. Two planetary geologists were accompanied on a multi-day geologic field trip that they had arranged for their own scientific purposes, which centered on an investigation of the extraordinary xenolith/nodule deposits in the Kaupulehu lava flow of Hualalai Volcano, on the island of Hawaii. The geologists were observed during the course of their field investigations and interviewed regarding their activities and ideas. Analysis of the interview resulted in the identification of key domain entities and their attributes, relations among the entities, and explorer interactions with the environment. The results support and extend the author's previously reported continuity theory of presence, indicating that presence in field geology is characterized by persistent engagement with objects associated by metonymic relations. The results also provide design specifications for virtual planetary exploration systems, including an integrating structure for disparate data integration. Finally, the results suggest that unobtrusive participant observation coupled with field interviews is an effective research methodology for engineering ethnography.

14. SUBJECT TERMS
Human factors engineering, Extravehicular activity, Planetary geology, Virtual reality and presence, Object-oriented analysis

15. NUMBER OF PAGES
60

16. PRICE CODE
A04

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		