TARONE

# Was There Life on Mars?

## Politeness Strategies in a Research Article from a Heated Scientific Debate

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**ABSTRACT**

This paper analyzes a scientific research article (RA) in the field of planetary science using the perspective of genre analysis. A subject specialist informant was interviewed to provide insight into writer choice and language use in the genre. This study worked largely within Myers' (1989) framework in which a variety of language phenomena in RAs are explained by application of the Brown and Levinson model of politeness. The purpose of the study was to better understand the ways in which writers use various politeness devices (such as expression of emotion and the hedging of claims), and the choices writers make to employ or not employ such politeness devices. The results of the study show infrequent use of positive politeness strategies, but heavy use of negative politeness strategies, primarily hedging. Hedging was used almost exclusively in the Introduction and Discussion sections of the article, and the amount of hedging seems to be linked not to the relative strength or weakness of the claims, but rather the amount of face-threat those claims presented, the communicative purposes of different sections of the article, and the authors' choice about the degree to which they want to sound firm or even aggressive. Finally, hedging in this case was used not only as a politeness strategy to save face for the readers, but also as a defensive move to shield the authors' position from attack and save their own face in the event of counter-arguments.

# INTRODUCTION

One of the driving forces behind English for Specific Purposes (ESP) research has been a wish to help non-native speaking (NNS) students to better understand, and ultimately better produce, the spoken and written genres of their chosen fields of study. Clearly, for students pursuing advanced degrees, mastery of the academic or scientific research article (RA) is a must. Graduate seminars often revolve around the discussion of current and noteworthy publications, and students writing theses or dissertations must make a thorough review of all research relevant to their topic. Furthermore, publication in academic or scientific journals is the key to a successful career; it impacts hiring choices, promotions and raises, and even tenure decisions. In the academic and scientific worlds there is simply no avoiding the research article.

Given the importance of RAs in academic and scientific communities, it seems imperative that teachers be equipped to help their academically-oriented students both understand them and write them. In order for teachers to do this, ESP researchers need to help uncover the forms and functions of the language of RAs. As this is done, a better explanation can be given to NNS students and other novices to academia for how to understand what they read, as well as how to write as they are expected to.

Since Myers (1989) published his work applying the Brown & Levinson model of politeness to the study of scientific writing, it has been widely accepted that RAs exist in a complex interactional setting in which researchers state claims that may support or contradict the claims of other researchers. According to Myers (1989), this interaction necessitates the use of a variety of politeness strategies which allow researchers to make their claims in a way that shows deference to the scientific community, yet still present their own ideas as clearly as possible.

Although the appropriate language and strategies for making claims must be learned by anyone who tries to enter a new field, it might be expected that novice NNS students would have greater difficulty in this process than novice NS students, who have a better command of the language and might have stronger intuitions about its use in the new discourse commmunity. If teachers are to assist novice writers in learning the language and the strategies for appropriately making claims in academic and scientific discourse, we must first come to understand how expert writers handle this situation, so that we can provide a usable model for students to emulate in their own work. The goal of this study is to bring us one step closer to that usable model by analyzing the writing of one group of expert writers using the perspective of genre analysis.

**Background and Theoretical Framework**

In an attempt to facilitate a better understanding of the forms and functions of politeness strategies in RAs, which were first described by Myers (1989), this paper will analyze a scientific RA using the perspective of genre analysis. Genre analysis was best defined by Swales (1990), who placed at its core the assumption that people who share a certain set of goals will seek each other out in their work to further those goals. Through this process are formed *discourse communities*, that is, "sociorhetorical networks that form in order to work towards sets of common goals," (Swales, 1990, p. 9). Genres then are the language through which discourse communities converse; one distinguishing characteristic of an "established member" of a discourse community is "familiarity with the particular genres that are used in the communicative furtherance" of the community's common goals (Swales, 1990, p. 9). A genre, as Swales' (1990, p. 58) defines it, is "a class of communicative events, the members of which share some set of communicative purposes. These purposes are recognized by the expert members of the parent discourse community, and thereby constitute the rationale for the genre."

Since this description of discourse community and genre is central to genre analysis as a research method, it is clear that I cannot proceed in using this method without first demonstrating that the article in question exemplifies a recognizable genre from an identifiable discourse community.

We begin with a group of scientists trained in different fields and specializations (astronomy, geology, mineralogy, geophysics, meteorology, etc.) and the problem of identifying a discourse community. Swales (1990, p. 24) sets forth "six defining characteristics" for "identifying a group of individuals as a discourse community." If it can be shown that these six characteristics fit the interesting mix of scientists in question, there can be little doubt that they constitute a discourse community. The first, and perhaps most important, of Swales' (1990, p. 24) six characteristics is that "a discourse community has a broadly agreed set of common public goals." In the case of any group of scientists, the primary goal is certainly to advance the state of knowledge in their field. While the group may have other goals, none has anywhere near the force of this primary goal. For planetary scientists in particular, this goal can be more clearly defined as a quest for a better understanding of our planetary system, its history and origins, and the forces and mechanisms at work in it today. Planetary science is, notably, "an interdisciplinary subject" which "defies easy description" (Morrison & Owen, 1996, p. v). Indeed, it might even be said that a further goal of the scientists working in this field is to integrate the knowledge of a number of specialized scientific fields in an attempt to gain a more comprehensive picture of our planetary system than could be achieved by any specialized field alone.

The second defining characteristic of discourse communities is "mechanisms of intercommunication among its members," (Swales, 1990, p. 25). One clear example of this characteristic in the planetary science discourse community is the international Lunar and Planetary Science conference held annually in Houston, Texas since 1969. Papers from conference presentations are published each year following the conference, which is itself an example of the third characteristic, that "a discourse community uses its participatory mechanisms primarily to provide information and feedback," (Swales, 1990, p. 26). Fourth, "a discourse community... possesses one or more genres," (Swales, 1990, p. 26). An example in this field is the scientific research article, a genre shared by countless other scientific communities. Additional genres may include research grant proposals, conference presentations, lectures, etc. Moving forward through our identification process, we see that, "In addition to owning genres, a discourse community has acquired some specific lexis," (Swales, 1990, p. 26). This point is clearly acknowledged in the preface to the introductory textbook, *The Planetary System*, where the authors note, "Any scientific discipline has a lot of specialized jargon. Planetary science, which draws from several disciplines, may be worse than most.... [We included] standard terms... such as albedo, chemical equilibrium, coma, and fractionation," (Morrison & Owen, 1996, p. vii). Finally, "a discourse community has a threshold level of members with a suitable degree of relevant content and discoursal expertise," (Swales, 1990, p. 27). That is, membership changes over time as the community adopts apprentice members and loses established ones. That this field requires an introductory textbook at all seems evidence enough for the apprenticeship of new members. The existence of established members is evident in comments made by my subject specialist informant (see below), that the authors of the article examined here, "have backgrounds as much as thirty years in the field, and they are absolute experts in looking at this sort of stuff, and they've written many, many papers," (see Appendix A, li. 675-6).

With all of Swales' six identification characteristics addressed, it becomes clear that although this group of scientists may come from diverse backgrounds, they nevertheless do make up an identifiable discourse community of planetary scientists. Now, the question of whether the article I analyze here belongs to a recognized genre is somewhat easier to answer than the question of discourse community. Research articles are perhaps the most widely recognized genre within the field of ESP. Swales (1990) devotes a rather extensive chapter to "Research Articles in English"; Hyland (1998) has written an entire book on a single phenomena within research articles; Myers (1989) and numerous other researchers have done work on various facets of research articles. With that said however, is it clear that this discourse community uses the research article genre? It seems clear that they do. The article I chose appeared in the journal *Meteoritics and Planetary Science*, a research publication devoted entirely to this field of science. Additionally, my informant referred several times to "the literature", that is, the set of research articles read by the discourse community, as the correct way to communicate with others in the field. For example, "Now these fellows feel that they have a point, and they want to make their point. And they're doing it properly. They're answering everybody in the literature. They're not getting on television and saying, 'You guys are crazy.'" (Appendix A, li. 333-8).

The source of this quote is, as I have said, a subject specialist informant. The practice of interviewing a subject specialist informant in ESP research was established by Selinker (1979, p. 212), who argues that "we have to learn to seek professional assistance in a principled way in order to understand the technical texts our students are required to read." He bases this claim on the observation that language varies from one discourse community to another, and from genre to genre within a particular community. What we learn about the language of one genre or community may not be transferable to others (Selinker, 1979). Subject specialist informants can help guide ESP researchers because they have already become experts with the genres and language forms specific to the community. The informant has the inside knowledge, the ESP researcher has the methods and background in language research to make use of that knowledge. Thus a collaboration between an informant and an ESP researcher can be a very productive one, in terms of the knowledge gained about language use in scientific, academic or other specialized fields.

It is in this tradition of genre analysis with the use of a subject specialist informant that the present study is conducted. As stated earlier, the purpose of the study is to better understand the says in which writers use the various politeness strategies identified by Myers (1989), and the choices writers make to employ or not employ such strategies in citing one another's work in research articles in the field of planetary science.

Myers (1989) proposed that a wide range of linguistic features in scientific RAs could be explained by application of the Brown & Levinson model of politeness. Brown & Levinson (1987) describe a 'Model Person' who has two conflicting sets of desires, or 'face wants'. The first of these, referred to as 'positive face', is the desire to be accepted and approved of by others. The second is the desire to be independent of and unimpeded by others, referred to as 'negative face' (Brown & Levinson, 1987). Certain actions, such as giving an order, making a request, or prohibiting an action, threaten the face of other people. These actions are known as 'Face Threatening Acts', or FTAs. When committing an FTA, the 'Model Person' must find the correct balance between saving his own face and saving the face of the other that will achieve his desired goal. In this model, 'politeness' involves the use of strategies to mitigate the face-threat of the act. Politeness strategies oriented towards a person's positive face are 'positive politeness' strategies and those oriented towards a person's negative face are 'negative politeness' strategies (Brown & Levinson, 1987).

Myers (1989, p. 3) argued that a number of common features of scientific writing, such as "the use of passives, nominalizations, hedges, acknowledgments" should be interpreted not simply as the result of convention, but as "rational strategies for dealing with the social interactions involved in publishing an article." That is, publishing a RA is more than just making a report of the results of a research study. It is also a social action. The primary purpose of any RA is to make a new claim, an action with is inherently face threatening, "because it is a demand by individuals for communally granted credit" (Myers, 1989, p. 5). If the article is to be published, this face-threat must be appropriately mitigated while still keeping the claim clear enough that the authors can make their point. It is this need to keep the delicate balance between being polite and advancing one's own claims which gives rise to many of the features, such as those listed above, which typify scientific writing.

Of all the features of scientific writing which Myers (1989) discusses in terms of politeness strategies, one in particular has received intense scrutiny. That one feature is *hedging*. As a phenomenon in scientific writing, hedging has been widely discussed, as researchers work towards a definition of both its form and its function. Myers (1989, p. 12) identified hedging as a negative politeness strategy "when it marks a claim, or any other statement, as being provisional, pending acceptance in the literature, acceptance by the community--in other words, acceptance by the readers". Hyland (1998, p. 69) rejects this interpretation as inadequate to explain the use of hedging in scientific writing and concludes that "discourse community norms are likely to play a larger part than credited by the Myers/Brown & Levinson model." According to Hyland (1996,

p. 433), "Hedging is the expression of tentativeness and possibility and it is central to academic writing where the need to present unproven propositions with caution and precision is essential." In this sense, hedging might be seen not only as descriptive of scientific writing but as prescriptively required as the appropriate way to express scientific claims. Keeping both of these perspectives in mind, Crompton (1987, p. 286) attempted to provide a functional definition of hedging, and in so doing advocated "the restriction of *hedge* to designate language avoiding commitment". Similarly, by drawing on both Myers (1989) and Hyland (1996) in her analysis, Okamura (1997, p. 98) concluded that "politeness seems to be working in scientific research articles" and that "the writer's intentions hidden in context seem to account for the different conclusions drawn by Myers and Hyland towards the function of hedges." That is, the explicit function of hedging may be to denote possibility or avoid commitment, but the implicit function, buried in the context, may be to mitigate face-threat.

In spite of all that has been written on the subject, a consensus has yet to be reached on the effectiveness of a politeness model for interpreting scientific writing, in particular as regards the phenomenon of hedging. This lack of consensus may stem in part from the differing research methods of each of the studies. Both Myers (1989) and Hyland (1996) focused on RAs from a single discourse community (molecular genetics), but each arrived at a different analysis. It is worth noting that neither of those studies made use of interviews with a subject specialist informant to verify their analyses. Okamura (1997) perceived this limitation and attempted to overcome it in her own study, with some success. However, that study moved away from working within a single discourse community, and her analysis included RAs from seven different fields. Likewise, Hyland (1998) built upon his earlier study by making use of a corpus-based analysis of "academic English", which broadened the scope of the analysis considerably.

Unlike any of these previous studies, and in contrast to the seeming trend towards a widening of scope, this study focused on a detailed analysis of a single RA from a single discourse community, that of planetary science. Furthermore, this study examined all politeness strategies which could be identified in the article in an attempt to move away from a focus on hedging specifically and towards a renewed focus on politeness strategies in general. A key component of the study was an interview with a subject specialist informant which brought to bear the inside knowledge of an expert member of the discourse community on the analysis of language use and writer choice. This analysis worked within Myers' politeness model, and was guided by four research questions, aimed towards furthering our understanding of the ways in which writers choose to use (and not use) various politeness strategies. These were: 1) Which politeness strategies are used by the authors in this article? 2) Which strategies occur frequently and which infrequently? 3) Does the use of politeness strategies vary by section (e.g. Abstract, Introduction, Discussion, etc.)? 4) What factors can be identified which motivated these writers' choices to employ or not employ politeness devices?

## METHODS

### Subject Specialist Informant

As Selinker (1979) recognized, in any research project that makes use of interviews with a subject specialist informant, "the quality of the specialist informant is uppermost." Since this study set out to analyze language use in a field in which the researcher was at best a novice, it was of paramount importance to work with an informant who would provide clear and reliable answers to questions about language use in the field. With this consideration in mind, I chose to work with one of my former professors, whom I knew quite well, and whom I trusted to provide the kind of relevant insights necessary to carry out this study.

I judged this professor to be a suitable informant for a number of reasons. First of all, he had been working in the field of planetary science since its early days (for over 40 years), and is by any assessment an expert member of the discourse community. He had worked as a researcher at the Johnson Space Center for many years before becoming a university professor, and was professionally acquainted with most of the other scientists working in the field, including two of the authors of the article analyzed in this study. Additionally, I felt that he would make a good language informant because, as a NS of English, he had done his own doctoral degree in Germany, and so had personally gone through the process of learning to work in a specialized field in a second language. Furthermore, he was an instructor at a liberal arts university, where he led an inter-disciplinary program in planetary science as well as working on an inter-disciplinary honors program. These experiences gave him a good deal of experience working with both students and professors unfamiliar with the discourse conventions of his particular community, and so he had a good understanding of the types of problems confronted by novices attempting to write in his field.

**Materials**

The material for this study was a single research article from the scientific journal *Meteoritics and Planetary Science*[1]. The article was chosen because it is one of a number of articles through which a high profile, intensely emotional debate is currently being carried out in the field of planetary science. This debate concerns the possibility of life on ancient Mars. In

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[1]Bradley, J., McSween, H., and Harvey, R. (1998). Epitaxial growth of nanophase magnetite in Martian meteorite Allan Hills 84001: Implications for biogenic mineralization. Meteoritics and Planetary Science, 33, 765-773.

1996, a team of NASA researchers published an article in the journal *Science* in which they claimed that they had discovered fossilized remains of bacteria in a meteorite that came from Mars. This announcement was a watershed moment in the field of planetary science. If it could be proven that life had once existed on Mars (and hence that life on Earth was not unique), that knowledge would change everything for these scientists. Although many scientists within the community believe that there should be life in other parts of the universe (even in the solar system), to date there has been absolutely no hard evidence to shore up this belief. Thus it has remained largely a question of philosophy rather than science. The NASA team's radical interpretation the data in this case constitutes the first movement of the study of extra-terrestrial life out of the realm of science fiction and into the reality of working scientists. The debate has been changed from one of philosophy ("What should we expect to find in the universe?") to one of hard science ("What have we found in the universe?"). If the NASA team's position is eventually accepted as accurate, this topic will remain open for scientific study, and the debate will never again be purely philosophical.

While the evidence presented in the 1996 *Science* article was strong, it was not incontrovertible. Although the authors of that article succeeded in convincing most of their discourse community that their interpretation was the correct one, there were still a number of vocal detractors. Among those detractors are the authors of the article analyzed in the present study. This article was published in 1998, two years after the original *Science* article. It provides a direct counter-claim to the "Martian life" claim, by interpreting the same features not as fossilized bacteria, but as ordinary minerals. It was for this reason that I chose this article: it was written by a group of scientists who dissent from the majority view but argue for a conservative position, and who are making their best attempt to disprove a controversial and ground-breaking piece of work. This article was written in the midst of a heated, emotionally charged debate, where the stakes on both sides were very high. As such, I expected to find in it extremely careful writing, carefully wrought claims, and the judicious use of politeness strategies to deal with the difficult social context.

**Data Collection Procedures**

I began with a careful reading of the article, highlighting those sentences and expressions in which I recognized the use of a politeness strategy. In this process, I worked within Myers' (1989) model of politeness. The positive politeness strategies I looked for included: identification with the criticized position, particularly through use of first person plural pronouns; expression of emotion to exhibit identification with the common goals of the community; assuming common ideas or experiences; and joking. I also looked for the following negative politeness strategies: hedging; personal attribution of claims; and marking the provisionality of researcher-developed terminology. Each of these strategies is identified in Myers (1989).

Unfortunately, I found Myers (1989) description of hedging to be somewhat difficult to employ in attempting to identify hedges, and so I turned to Crompton (1997) for a more workable definition. He proposes the following "test" for "determining whether or not a proposition is hedged: Can the proposition be restated in such a way that it is not changed but that the author's commitment to it is greater than at present? If 'yes' then the proposition is hedged," (Crompton, 1997, pp. 281-2). Using this test, I was able to more confidently discriminate between hedged and unhedged claims.

After completing this process, I again read through the article looking for sentences in which statements were made baldly, without any recognizable politeness strategy present to mitigate their claim. Specifically, I looked for unhedged performatives and "be" copulas. These places were also marked in the text.

After I had identified the sections of interest to me, either for use of politeness strategies or for an apparent lack of them, I formulated questions to pose to my specialist informant. In some cases this involved drawing my informant's attention to variation in the use of politeness strategies within the article, and asking for his opinion on the cause for that variation. In other cases, I posed alternative ways of writing a sentence or phrasing an idea, and asked for my informant's opinion of the alternative. Finally, many questions arose naturally from the conversation and were not planned in advance, but rather came up in response to information from my informant.

I interviewed my informant at his home, in one afternoon for about 2 hours. The interview was tape recorded and later transcribed.

**Data Analysis Procedures**

In order to better relate the information gathered in the interview to the data from the article itself, I organized both of these in a single document with the sentences from the article in the left-hand column, and excerpts from the transcript in the right-hand column. Organizing the data in this way allowed a clearer picture of the reference of items in the interview transcript.

Excerpts from the transcript were chosen for this paper based on the amount of relevant information they contained, and also with the goal of including at least one excerpt that dealt with each type of politeness strategy identified. Furthermore, one excerpt was chosen because of the information it contained about the lack of politeness strategies in a particular section of the article.

## RESULTS

### Which politeness strategies are used by the authors in this article?

The only positive politeness strategy I identified in this article was that of expressing emotion as a way of "exhibiting responses that assume shared knowledge and desires," (Myers, 1989, p. 8). This occurred twice in the article, in both cases introduced by use of the word "unfortunately" at the beginning of a sentence discussing the limitations of available data. The first occurrence is in the Introduction (par. 1) and reads as follows:

> Unfortunately, most of the magnetite appears to provide no direct information about its growth mechanism(s).

The second occurrence in the first paragraph of the Discussion section (par. 11), and reads as follows:

> Unfortunately, while all of these petrographic observations are consistent with the various populations having formed during thermal excursions, none of them constitute absolute proof of the high-temperature origins of the magnetite in ALH 84001.

I also found use of two different negative politeness strategies in this article: hedging and marking the provisionality of researcher-developed terminology. The first of these, hedging, appeared in a variety of forms, often combined in the same sentence. The types of hedging I identified included use of non-factive reporting verbs (particularly "suggest"), copulas other than "be" (particularly "appear"), modal verbs, and modifiers such as "probably", "likely", and "apparently". Additionally, some claims were hedged by inclusion of phrases such as "suggests but does not prove" (par. 13).

The second negative politeness strategy I identified was the marking of some terminology as provisional or restricted. Although this was not done explicitly, throughout the article five different terms were set off in the text with quotation marks, as in this example "Experiments suggest that the ideal lattice "misfit" between two crystal structures should not be more than ~15%..." (par. 12). This kind of marking clearly indicates that the demarked term is not widely used outside of the researchers' specific domain (experimental mineralogy), and likely indicates that it was developed by the researchers themselves, for their own use, and is not being proposed for more general use in the discourse community.

**Which politeness strategies occur frequently, and which infrequently?**

As noted above, positive politeness strategies were infrequent, occurring only twice in the entire text. In comparison the negative politeness strategies were much more frequent. For example, the marking of terminology as provisional occurred 9 times for 5 different terms., and I counted 36 clear tokens of hedging (that is, cases that passed the "test" proposed by Crompton (1997) noted above). In addition to those 36 hedges, I noted a number of other cases which have been considered instances of hedging under other definitions, but which I did not count (for example, the use of impersonal subjects such as "our findings" or "our observations"). However, whether or not all these hedges can be attributed to politeness strategies is not entirely clear. This difficulty of interpretation is discussed in some detail in the Discussion section below.

**Does the use of politeness strategies vary by section (e.g. Abstract, Introduction, Discussion, etc.)?**

Yes, there was evidence of variation in the use of politeness strategies from section to section of the article. First of all, politeness strategies were most apparent in the Introduction and the Discussion section. Hedging, the strategy with the greatest number of tokens in this text, did not occur at all in the abstract or the "Experimental Procedures" (Method) section, and occurred only once in the "Electron Microscopic Observations" (Results) section. In contrast, there were 5 tokens of hedging in the Introduction and 27 in the Discussion section. While the Discussion section is by far the longest section of the article, and thus even if politeness strategies were equally distributed it should include more than any other section, this number is nevertheless relevant in comparison to the obvious lack of hedging in other sections.

A notable change in the type and amount of hedging can be seen in the Conclusions section. While in the Introduction and Discussion section the use of the non-factive reporting verb "suggest" and the copula "appear" are prevalent and a variety of other forms of hedging occur, in the Conclusions section only one form of hedging occurs: the use of modifiers. "Probably" occurs twice and "likely" once in this section, but aside from those hedges, there are no politeness strategies to be found. Instead, what one finds are unmitigated (or barely mitigated) claims like these:

> Although neither mechanism (epitaxy or spiral growth) is unique to high-temperature vapor-phase growth, evidence of *both* mechanisms in ALH 84001 is entirely consistent with vapor-phase whisker growth phenomena observed in nature and laboratory syntheses and inconsistent with what has been reported for biologically produced magnetites. (par. 24)

In reference to this section, my specialist informant commented:

> That's not polite. That's not polite at all. They just shot 'em.... Yeah, they really just came right down to the very end, and they said, 'Here's all our evidence. We can see this can happen, this can happen, this can happen, this can happen, but it doesn't hold up in relationship to what you have said.' They shot 'em.
> (Appendix A, excerpts from li. 791-3)

Interestingly, variation in type of politeness strategies occurred even in cases where the same claim was made twice in different sections of the article. This is most evident when one compares the two following sentences, the first taken from the abstract and the second from the Introduction:

> *Epitaxy rules out* intracellular precipitation of these magnetites by (Martian) organisms, provides further evidence of the high-temperature (>120° C) inorganic origins of magnetite in ALH 84001, and indicates that the carbonates also have been exposed to elevated temperatures. (last sentence of abstract)
>
> *Our findings appear to rule out* an intracellular origin for these magnetites and instead provide additional new evidence for an origin by vapor-phase condensation at elevated temperatures. (last sentence of Introduction, par. 2)

When asked about this variation, my specialist informant made the following remarks:

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|---|---|
| Researcher: | So, for me, it seems that the abstract is a lot more direct. |
| Informant: | It must be. This the way we write these things. |
| Researcher: | Uh-huh. But why? [laugh] |
| Informant: | And the reason for it is this: *the abstract is to give away the farm.* This is true! You are to write an abstract that may be a hundred or a hundred and fifty words at the most. And *in it you tell exactly what's going on in as concise and pure language as you possibly can*, all the way on through. And the reason for it is this: the abstract is not an addenda. What it is, is an opportunity for the reader to go over and make the decision, do I want to then go and seek out the details. |

(Appendix A, li. 40-49)

**What factors can be identified which motivated these writers' choices to employ or not employ politeness devices?**

One factor I anticipated might influence writers' use of politeness strategies was the relative strength of their claim. It seemed likely to me that writers in a weaker position would need to employ more politeness strategies, because they would need to be even more deferential in bringing their work to the attention of the community than writers with a stronger case. However, my informant explained that this was not necessarily the case.

Informant: ...but their validity system is not what I would say terribly suspect, as much as it's not something that you can sit here and say it's an absolute.... (Appendix A, li. 156-7)

Informant: If they said absolute, they're just opening themselves up for somebody to come down and jump right on down [on them]
Researcher: ...I'm interested in... how much they hedge when [they] have a weak position and how much they hedge when they have a strong position.
Informant: *Frequently they'll hedge even if they have a fairly strong position, unless they've decided that they want to just plain step right up to the brink of the precipice.* (Appendix A, excerpts from li. 179-185)

Secondly, from Myers (1989) I expected that use of politeness strategies should be tied to the amount of face-threat inherent in a claim, rather than the importance of the claim scientifically. While it is difficult to assess the face-threat of a claim, Myers (1989) proposed that face-threat is heavily dependant on the number of researchers whose work would be impacted by the claim. If one looks at the claims in this article from this perspective, they are not highly face threatening, even though they are direct counter claims to the NASA team's "Martian life" position. Based on the interview with my informant, I found that first of all, the number of researchers engaged in this debate is relatively small. Additionally, the counter claims in this article do not negate all of the NASA team's work, but only one out of four different lines of evidence they have developed. Finally, it is the NASA team's position which is really the groundbreaking, widely influential one. The researchers in this team are arguing for retention of the current world-view, thus ultimately arguing for *less* impact on the wider scientific community. When analyzed from this perspective, the paucity of politeness strategies and the directness of the claims in the Conclusions section makes a good deal of sense.

Finally, my informant's comment that "the abstract is to give away the farm.... You are to write an abstract that may be a hundred or a hundred and fifty words at the most. And in it you tell exactly what's going on in as concise and pure language as you possibly can…" (Appendix A, excerpts from li. 43-7) indicates that these writers were guided in their use (and non-use) of politeness strategies by the communicative purposes tied to the different sections of the article. Here we can see that the abstract has a specific purpose, and that purpose dictates the type of language that may be used within it.

## DISCUSSION

### On the Function of Hedging

This paper has worked within Myers (1989) framework, assuming that politeness is a consideration in scientific writing, and that scientists make use of politeness strategies such as hedging and expressing emotion to mitigate the face threat of their claims. In past work, this position has been criticized as inadequate to fully explain the function of hedging in scientific writing. Upon first glance, this criticism is supported by my specialist informant. When questioned about the use of hedging in this article, he focused on the point that the authors cannot claim that their evidence is "absolute", indicating that the purpose of the hedging is to show the actual limitations of their data, not to express a lack of commitment to their claim. However, if one looks more closely at the interview transcript, it becomes apparent that politeness is also a consideration. The recognition by my informant that the Conclusions section, which makes a number of strong claims with very minimal use of hedging, is "not polite at all" implies that hedging does in fact function as a politeness device. It is only if hedging functions to show politeness that its absence can be interpreted as impolite.

However, I would argue that these interpretations of hedging do not, in themselves, explain the full function of hedging in scientific writing. Rather, it seems that hedging serves the additional purpose of protecting one's position from attack. Evidence for this interpretation can be found in several comments made by my specialist informant, such as:

> Informant: If they said absolute, they're just opening themselves up for somebody to come down and jump right on down [on them].
> (Appendix A, li. 179-80).

And:

> Researcher: They couldn't just leave that last sentence off? And just say, "these, all of these petrographic observations are consistent with blah-blah-blah." And stop at "thermal excursions." Period. Couldn't they just say that?
> Informant: No.
> Researcher: Why not?
> Informant: For the simple reason that, ah, if they do, then they're leaving themselves wide open for other explanations....
> (Appendix A, li. 247-53)

These comments reflect the defensive function of hedging: the writers need to protect their interpretation from attack by competing research teams. By directly acknowledging the limitations of their own claim, they leave less room for others to point out those limitations.

In addition to this defensive function, in this article the authors used a combination of positive politeness by expression of emotion and hedging to accomplish a further purpose: saving their own face. In response to this sentence from the Discussion section (par. 11):

> Unfortunately, while all of these petrographic observations are consistent with the various populations having formed during thermal excursions, none of them constitute absolute proof of the high-temperature origins of the magnetite in ALH 84001.

My informant made the following remarks, in which you can see the orientation of this hedging towards the *writers'* positive and negative faces:

Informant: Well, the amelioration of the argument that they're presenting right here is, my guess is, something that, I wouldn't be surprised that this, this sentence came from McSween. Uh, he's not necessarily hedging his bets as much as he's standing there saying, *'hey, we don't wanna appear completely stupid in front of these people'*.

(Appendix A, li. 351-6)

As I understand it, this demonstrates the need for writers to show, through hedging, personal attribution, or other strategies, that they are aware of the limitations of their own interpretation, and that they are familiar with their competitor's position(s). If they do not do this, they fail to demonstrate a thorough and comprehensive view of the situation in which they are working. To ignore their limitations and the arguments against them is to appear ignorant. Thus, politeness strategies serve to save *the writer's* face, as much as that of the others.

However, even when these restrictions on what cannot be said and what must be said are followed, it seems clear that writers are still faced with the decision 'How far do I want to push this?' That this decision is still open to writers can be seen in my informant's comment:

Informant: Frequently they'll hedge even if they have a fairly strong position, unless they've decided that they want to just plain step right up to the brink of the precipice.

(Appendix A, li. 184-5)

It is my opinion that this is just what the authors of this article chose to do in their Conclusions section. While most of the Discussion section is more of an ordinary attempt to account for and understand the results of their research study (with the claims in it appropriately mitigated), the Conclusion is something else entirely. Its purpose is to serve as a very pointed challenge to a group of rival researchers, and in order to accomplish this purpose, the authors throw hedging to the wind and "step right up to the brink of the precipice". These scientists are enmeshed in a heated debate with very high consequences for being wrong, and as such they cannot afford to sound uncertain, even at the expense of sounding impolite.

**On the Need to Mark the Provisionality of Researcher-Developed Terminology**

Myers (1989, p. 16) writes, "It is an FTA to try to appropriate some phenomena by giving it a name oneself....So the introduction of a new term has to be marked with some sign that the writer suggests it only provisionally, subject to its adoption by the community." However, I question whether the explicit marking of new terminology as provisional can accurately be described as a hedge. It seems more likely that writers acknowledge new terms as provisional in an attempt 1) to be truthful and 2) avoid an FTA altogether. Consider the process through which new terminology is developed: a researcher, or team of researchers, working on a project, encounter some new phenomenon for which they have no accurate descriptive term. Yet to document their research, they must call the phenomenon *something*, and so a new term arises out of descriptive necessity. This process is identified clearly by my specialist informant:

> Informant: ...when you start out in a new field, and say it's something that you have observed, and you're starting to try and get a handle on what's going on, the biggest problem that you have, is... what kind of nomenclature do you use?
>
> Researcher: Right, exactly.
>
> Informant: And you have to develop a nomenclature before you can make... well, one of the things you do is you may come out in a paper, and you say, 'This looks like a such-and-such, and so I have... used the term such-and-such.' If other people like this, and they feel this is worthwhile, they go ahead and ascribe it to you when they refer to your paper, and they carry it on.... Cause all you're doing is attempting to define the field in a short term way.
>
> (Appendix A, li. 580-9)

As can be seen in the preceding comments, when researchers then publish their work, if no other published work includes a term which accurately describes the phenomenon they are reporting on, they turn to the terminology they themselves have developed. They have no other terminology at their disposal; they must use their own. Hence the writers acknowledge the provisionality of their terminology as a matter of course: it *is* provisional. No one else has been using it; no one else may even have heard of it.

As I see it, the face-threat that Myers rightly perceives in the process of naming phenomena comes not through the development of new terminology, which is a matter of necessity, but rather in the proposition that one's own terminology should be adopted by others in the field. It is not an FTA to name something *for your own purposes*, but it is an FTA to name something *for the community*. So it seems that what writers do when they mark a new term as provisional is not *hedging per se*, but rather outright *avoidance* of the FTA. They will not claim to act on behalf of the community, but leave it for others to decide if their new term will be adopted.

## CONCLUSIONS AND IMPLICATIONS FOR ESL/EFL TEACHERS

While this study indicates that politeness is a concern in academic writing, and that one function of hedging is to phrase claims in an acceptably polite way, it is important to note that this function of hedging is not necessarily consciously present in the minds of the writers. Although it seems clear that politeness strategies are used intentionally, the writers have other purposes in mind in using them. However, politeness does seem to be an important function of hedging at a point below the writers' level of awareness. These findings are consistent with those of Okamura (1997), and re-emphasize the fact that hedging in scientific writing is a very complex phenomenon, which takes multiple forms and serves multiple purposes.

While the authors of this article are clearly in a different position than that faced by most novice writers, it is nevertheless useful to study the strategies these expert writers used to deal with this high-stakes situation. Their choices to employ and not employ politeness strategies provide insight into how RAs are 'supposed' to be written, as well as what factors influence decisions regarding the use of these strategies. By clarifying the purposes of various politeness strategies, and by identifying factors which influence expert writers' decisions about how and when to use and not use them, we can present more accurate and useful guidelines to novice writers.

For example, in this study we see the importance of marking the provisionality of terminology developed in the course of a research study. We can now demonstrate to students *why* this is to be done, as well as show them methods of how to do it (using phrases like, "I have used the term such-and-such," Appendix A li. 587, and marking with quotation marks). We can also demonstrate to students that the amount and degree of politeness strategies they should use is partially determined by which section of a paper they are writing, as well as by their own decision of 'How far do I want to go with this?' Although it might be argued that the only way to acquire the proper basis for making this decision is through the process of initiation into a discourse community, it can also be argued that if students are equipped with some of this knowledge *before* attempting to enter into a particular discourse community, they will be more likely to succeed in doing so.

References

Bradley, J., McSween, H., and Harvey, R. (1998). Epitaxial growth of nanophase magnetite in Martian meteorite Allan Hills 84001: Implications for biogenic mineralization. Meteoritics and Planetary Science, 33, 765-773.

Crompton, P. (1997). Hedging in academic writing: Some theoretical problems. English for Specific Purposes, 16, 271-287.

Hyland, K. (1996). Writing without conviction? Hedging in science research articles. Applied Linguistics, 17 (4), 433-54.

Hyland, K. (1998). Hedging in scientific research articles. Philadelphia: John Benjamins Publishing Co.

Morrison, D. and Owen, T. (1996). The Planetary System 2nd ed. Reading, MA: Addison-Wesley.

Myers, G. (1989). The pragmatics of politeness in scientific articles. Applied Linguistics, 10, 1-35.

Okamura, A. (1996). Politeness in scientific research articles revisited: The use of ethnography and corpus. Chapter in: Ryan, A. and Wray, A. (Eds.). (1997). Evolving models of language: Papers from the annual Meeting of the British Association for Applied Linguistics held at the University of Wales, Swansea, September 1996. Philadelphia: British Association for Applied Linguistics in association with Multilingual Matters.

Selinker, L. (1979). On the use of informants in discourse analysis and language for specific purposes. *IRAL* 17, 189-215.

Swales, J. (1990). Genre analysis: English in academic and research settings. New York: Cambridge University Press.

JA: OK. I happen to know a little bit about this article but not a lot. I, I know, what's going on 'cause I know two of the authors quite well.

SW: Do you?

JA: Oh, yeah, McSween and Harvey are two fellows. I've been in the Antarctic with both of them.

SW: Great! That makes it even better because you might have some…

JA: I don't know Bradley, but, [Hatley?] McSween used to be chairman of the Department of Geology at University of Tennessee in Knoxville, and uh, Ralph Harvey now runs the Antarctic Meteorite Program. He took over from Bill Cassidy just a few years ago, and he is ah, teaching at Case Western Reserve in Cleveland.

SW: OK.

JA: So I, I know them quite well. Although I can't necessarily give you the exact derivation of all of this. Some of these, ah terms that they use

SW: Mm-hmm

JA: Both of them, Hap McSween and Ralph Harvey, especially Hap McSween is a very noted mineralogist. And, ah, I'm not that strong in mineralogy. I'll do the best I can as we go along here.

SW: OK.

JA: OK?

SW: Well it's, like I said, it's more questions about uhm, you know your intuitions about the language use, more than about the the, content material so, but you have to know the content material somewhat in order to know why they would make a certain choice, because, me looking at it, I don't know for example if some piece of evidence they're providing is a strong piece of evidence or if it's weak, or… or that's the kind of information I as an outsider don't have.

JA: Right

SW: But you, as an insider in the community would know something about. So that's why we, we work with subject matter experts.

JA: OK

SW: So, my first question is, if you take a look at the end of the abstract

JA: Alright

SW: The authors have a sentence that begins with "Epitaxy rules out intracellular precipitation of these magnetites…" dadadadada… Can you see where that is?

JA: Yeah, I've, I'm right in there

SW: Mm-hmm, yep. And then, in the end of the last paragraph of their introduction section they have very nearly the same sentence. Uhm… and they're writing about the same content material, but they change it a little bit and they say, "These magnetites nucleated and grew…," and there's kind of a, some more information there and then it says, "Our findings appear to rule out an intracellular origin…."

JA: Right.

SW: So, for me, it seems that the abstract is a lot more direct.

JA: It must be. This the way we write these things.

SW: Uh-huh. But why? [laugh]

JA: And the reason for it is this: the abstract is to give away the farm.

SW: [laugh]

JA: This is true. You are to write an abstract that may be a hundred or a hundred and fifty words at the most. And in it you tell exactly what's going on in as concise and pure language as

you possibly can, all the way on through. And the reason for it is this: the abstract is not an addenda. What it is, is an opportunity for the reader to go over and make the decision, do I want to then go and seek out the details.
SW: Mm-hmm.
JA: And so in the abstract, for example, he says, "Epitaxy rules out intracellular precipitation in these magnetites and provides further evidence of the high-temperature inorganic origins..." and this is an extremely important point for them, "and indicates that the carbonates have also been exposed to elevated temperatures."
SW: Mm-hmm.
JA: Now, when you go through then the Introduction and you find you're going along here, you'll notice, "Our findings appear to rule out..." Now what they are saying is it's not absolute, but it's close enough that...
SW: Mm-hmm.
JA: ah, ah, "for these magnetites", and instead, what they're saying is "appear to rule out an intracellular origin, but they provide additional new evidence for an origin by vapor-phra, vapor, vapor-phase condensation."
SW: Mm-hmm.
JA: "at elevated temperatures." What they're saying then, is this: uhm, intracellular precipitation is one way that you can get this, epitaxial is another way.
SW: Mm-hmm.
JA: etc. But what they come along with here, and the, what the, the thing is, the "appear to rule out" is not as important as their saying in Introduction, we're gonna provide new evidence for an origin on a basis of elevated temperatures. And the reason for this, and this is very important to anyone that has been following this field, was McKay *et al.* went ahead and defined what they think is a possibility of fossilized bacteria found in a Martian meteorite. The first argument that came along was that what was the temperature of formation?
SW: Mm-hmm. Yeah, I, I was aware of that.
JA: If the temperature of formation was above a hundred Cel, Celsius there is a good chance that these things are not bacteria but are probably something like magnetite.
SW: Right. Mm-hmm.
JA: Which is an intergrowth.
SW: Mm-hmm.
JA: And so this is what, this is the real key.
SW: So, so, their actual main point is the second part of that
JA: Right
SW: [Paragraph?] so they're sort of, putting it at the end for maybe some kind of
JA: They're not saying that you couldn't have intracellular stuff
SW: Mm-hmm.
JA: But they're saying "appears to rule that out". But what's more important is the fact that they [....] are providing new evidence saying that these were formed under elevated temperatures.
SW: Mm-hmm.
JA: And notice that they didn't give you temperatures in here.
SW: Right.
JA: And that's a good way to handle the Introduction.
SW: Mm-hmm.

JA: They're giving you all the background. In fact what the Introduction does, more than anything else, is also a literature review.
SW: Right, exactly.
JA: And that's a very important thing as far as, ah, ah, a science article is concerned.
SW: Oh, yes.
JA: And that's something that people that don't write for science don't quite understand.
SW: Mm-hmm.
JA: They'll do a literature review in Education courses, and that's their whole paper. To us, it's the basic thing that comes up, it's the Introduction
SW: Mm-hmm.
JA: And that just sets the tone all the way through
SW: Right. 'Cause you have to give some information about other people in the field who have been doing similar work.
JA: Exactly. You have to..
SW: Uhm, so you know what the background is
JA: you have to say, these things are known, and ah, move from....
SW: Mm-hmm. Mm-hmm. Yeah, we actually do the same thing in papers like the one I'm writing here. We'll have, I'll have to go back and cite different people who have proposed different models for how these different things work, and then I go on to try and define my own findings, and maybe
JA: Yes.
SW: Use their model or reform their model, or do whatever, but it's the same, it's the same structure.
JA: Got it.
SW: So that's my first question. Uhm... let's see... and you already answered that one, so... [laugh] ah... so, really what you're saying is the most important here, I kinda had missed this, is the second part of the sentence, which is the part about the new evidence.
JA: Exactly...
SW: So, they put that at the end of the sentence
JA: Yeah, so remember, "our findings <u>appear</u> to rule out"
SW: Right
JA: "an intracellular origin and <u>instead</u>..."
SW: "and <u>instead</u>" and that's where kind of the key point of that sentence is, so
JA: Right, that's the key point
SW: it's at the end, it's typical actually, what we refer to as end weight, the most important thing goes to the end.
JA: Right
SW: Because it's the last thing you read. [laugh]
JA: and they think that vapor-phase condensation at elevated temperatures is better.
SW: Mm-hmm. So they think that's a <u>better</u> solution than this other one and they're sort of saying, well there is this... possible interpretation, but we think it's not... <u>that</u>, it's this other thing. OK.
JA: Their biggest comment all the way through here is, ah, elevated temperatures.
SW: Mm-hmm. OK.
JA: OK?

SW: Alright. Uhm, so the next question is going to be uhm, looking at the discussion section and the first paragraph… of the discussion section.
JA: [Where are we…]
SW: So, it's starting here, and it continues on through… oh, wait, no, here, here. This whole paragraph. So I've got a bunch of stuff highlighted there. And my questions here are about what writers refer to as hedging moves. And hedging is what you do when you try to make a claim less direct, or less absolute. And this paragraph I noticed that they used a lot of different hedging expressions, for example they used a lot of modals like "may be" and "possibly" and "may have formed"… uhm, "a logical explanation" instead of just saying something like, this explains dadadadada.
JA: Yeah….
SW: Now, what, what in your opinion is the purpose of, of this rather extensive hedging? Because, to me it seems like they're building up sort of this logical argumentation. Uhm, for uhm, their point, but they're constantly sort of, hedging it, as they go along.
JA: Well, this is one of these cases where you have information sitting on this side and you have information sitting on this side. And the people that are sitting over here on the left side are arguing against the validity of the information on this side.
SW: Mm-hmm.
JA: But their validity system is not what I would say terribly suspect, as much as it is it's not something that you can sit here and say it's an absolute.
SW: Mm-hmm.
JA: So that's what you can tend to run into.
SW: Mm-hmm.
JA: And what they're doing is hedging their bets.
SW: Mm-hmm.
JA: And you'll notice what they said here, ah, "and the intimate admixing of sulfide and magnetite"
SW: Mm-hmm.
JA: "may be consistent"
SW: Right.
JA: "with this magnetite having formed… in place"
SW: Mm-hmm.
JA: "by thermal oxidation of sulfides."
SW: Right.
JA: You see, they're suggesting that may be going on. "Similarly" then they get a "logical explanation for the vein magnetites is that they precipitated." So they can keep building their case, but it says also, and this is a very common thing, "voids that intersect the surfaces of the carbonates, which suggests
SW: suggests
JA: "they may have formed…" They're, they're not saying they're absolute.
SW: Right.
JA: If they said absolute, they're just opening themselves up for somebody to come down and jump right on down…
SW: Right, that's exactly the point. So uhm, kind of, my question is though, I'm kind of interested in when people hedge like this, how much they hedge when they're, have a weak position and how much they hedge when they have a strong position.

JA: Frequently they'll hedge even if they have a fairly strong position, unless they've decided they want to just plain step right to the brink of the precipice.
SW: Mm-hmm.
JA: That's always the case that comes on up. And one of the things that you find that in science like this, and we're talking about science as opposed to say, medical science.
SW: Mm-hmm.
JA: Medical science comes along and takes, that's one of the arguments that we have with them, they'll take a series of things of things, that may be, uh 15 out of 20 cases provide such and such, or 15 out of 25, and they'll right a paper and they'll come along and they'll just say, this is the most significant result. We would never do that in science. Ever. We would never do that for the simple reason that it's just, it's too speculative at that point.
SW: Right.
JA: You have to have large numbers of things. Notice they said, "which suggests they may have formed…"
SW: Uh-huh. That sounds to me like it's strongly hedged.
JA: That's right, but their final statement is the most important one.
SW: Mm-hmm.
JA: "Unfortunately, while all of these petrographic observations are consistent"
SW: Mm-hmm.
JA: "with the various populations of magnetite" now they're talking, they're not, "having formed during thermal excursions, none of them constitute absolute proof of the high temperature origins of the magnetite in Alan Hills 84001."
SW: Mm-hmm.
JA: That's a major, major point.
SW: Mm-hmm.
JA: What they are saying is… that populations of magnetite that are not related to the types of magnetites systems we're looking at in relationship to the bacteria that we think are found. Ah, they, they're consistent with other populations, but none of them constitute absolute proof.
SW: So… I dunno, it it's to me it's like they put this sentence in. I wasn't sure what exactly what its purpose was, because they've been going along the whole time saying, we don't have absolute proof. Uhm…
JA: Well, I…
SW: Doesn't it seem to sort of weaken the argument by putting in this part about none of them constitute absolute proof?
JA: Yeah, it does weaken the argument, but by the same token, what it does is that, you have to be aware of the fact that what they're trying to do is to say that the magnetite is one particular argument against the bacteria in this particular…
SW: Mm-hmm.
JA: substance. And they're only one out of say, four arguments.
SW: Mm-hmm.
JA: That have been going on here.
SW: Mm-hmm.
JA: And the interesting aspect of it is, is that ah, they, prior to this they talk about a "logical explanation" ah, which is "possibly… shock-generated liquids".
SW: Mm-hmm.

JA: "McKay and Lofgren", and that sort of thing. And so they're going to have to sit there and say, while we think that this is a high temperature condensate and a high temperature formation, the ah, evidence also shows it's consistent with with things going within what they call thermal excursions or high temperature formations, but that does not constitute absolute proof. What they're saying is, that even though they can form like this, we have to have some kind of absolute proof that says this is what went on in this meteorite.
SW: Mm-hmm. In this particular case.
JA: And they can't say that.
SW: So it can happen this way, and if it does happen it often looks like this
JA: Right
SW: But, we can't absolutely prove that it did happen this way. OK.
JA: [see what...] [long pause]
SW: Do you have something else you wanted to comment on? [long pause while both speakers read]
JA: Well, they're talking about a couple of different things in the petrographic system, but they have to hedge their bets right there.
SW: Mm-hmm.
JA: There's no way that they can just plain [tinker?]... Notice, they they're
SW: They couldn't just leave that last sentence off? And just say, "these, all of these petrographic observations are consistent with blah-blah-blah." And stop at "thermal excursions." Period. Couldn't they just say that?
JA: No.
SW: Why not?
JA: For the simple reason that, ah, if they do, then they're leaving themselves wide open for other explanations. Notice what they're doing is, is they're taking a look at uhm, they as petrographic experts are saying, this is what we think is going on, however...
SW: Mm-hmm.
JA: there are still other people that... you'll notice these, at this particular time, when this paper was written, these fellows were about the only people who were really screaming and yelling and saying, hey wait a minute, we think there's a problem here.
SW: Mm-hmm.
JA: And we think the problem is a high-temperature phase.
SW: Mm-hmm.
JA: But, you see, there's no absolute information that sits there right at this particular point and says this is what we have.
SW: Mm-hmm.
JA. This, this whole thing is is rather an interesting situation.
SW: Yeah. Yeah, that's one reason I chose the article. Because I knew it, there were a lot of, there was a lot of controversy regarding this particular topic. So like, that's one reason I chose it, because I think, they do have to be pretty careful with the way they phrase things.
JA: Well, you'll notice that what's going on here is that... they, all the way down through here [paragraphs] eight, nine and ten that you have listed here, they were looking at magnetite whiskers that had been formed under very high temperature situations, such as in fumeroles and uh, for example in the valley of ten thousand smokes and places like that.
SW: Mm-hmm.

JA: Well, that's all well and good, but then when it comes down to the petrographic associations they are looking at magnetite in comparison to other things. Magnetite on sulfides, magnetite on glass-rich veins, magnetite on carbonate surfaces, these all should provide some insight into the thermal history of the minerals. And, they say that the magnetite in 84001 is concentrated in sulfide-rich bands. And, "the intimate admixing of sulfide and magnetite is consistent with having been formed by thermal oxidation of sulfides." What they're saying is the temperature situation is there.
SW: Mm-hmm.
JA: But then they come along and they say, "A similar logical explanation is that they precipitated when the carbonate was invaded and possibly melted by shock-generated liquids."
SW: So, actually they're proposing two, two possible alternatives here.
JA: Well, if you stop and you look at something like this, now where is the heat coming from?
SW: Mm-hmm.
JA: If the heat is coming from such things as a volcano, or so, that's going to be different than a shock-generated induced system.
SW: Right.
JA: And with a shock-induced system, and that's something that people are talking about, and here's the question of, was the shock that occurred when the projectile hit Mars, excavated the material, sufficient enough to produce magnetite whiskers.
SW: Was it hot enough at that point in time, to create this…?
JA: And so when you take a look at this "and melted with shock-generated liquids, McKay and Lofgren." Gary Lofgren is also a theoretical or experimental petrologist, and a very good one. And he had looked at this and ah, his comment was the similar explanation. So here we have two people that are ah, petrologists, McSween on one hand and ah, Harvey has done some experiments, not as much as McSween, but McSween and Lofgren could have an argument. They're both experimental petrologists.
SW: But they have alternative, kind of…
JA: Well, they're both looking at it from slightly different sides.
SW: Right. So one person is saying this is vapor-phase condensation and the other side is saying shock melting, so…?
JA: Well, it's very difficult to tell whether you're getting regular metamorphosis or shock metamorphosis.
SW: Mm-hmm.
JA: And you have to be awfully good at the game to be able to do it. I couldn't tell. But I know that there are things that are part of this.
SW: Mm-hmm.
JA: That you look at, and I think that's what they're talking about.
SW: Mm-hmm. Uhm… Let's see I had one other question about that last sentence that they have. They're beginning it with "unfortunately." And I thought that was kind of interesting because you don't see that a whole lot in scientific writing that people are kind of expressing an emotion about something.
JA: That's what they're doing.
SW: Hmm?
JA: They're expressing an emotion here.
SW: Right, and who is supposed to feel that this is unfortunate? The readers? The writers? Both?

JA: Well, like I said, they're hedging their bets. "Unfortunately, while all of them are consistent, none of them constitute absolute proof."
SW: Mm-hmm. So, it's them that feels that, the writers that feel that way? They wish that they could have an absolute argument, but they don't?
JA: Well, no, I'll tell you what, I think where this is coming from is Hap McSween. The second author. Uhm, I think that Ralph Harvey is somebody... see I know the people.
SW: Mm-hmm.
JA: And I know that Ralph is going to come out here and he's gonna take his shot.
SW: [laugh]
JA: He's gonna come right after you, claws bared. And Hap McSween has been in the game a lot longer than that, and also knows that he's writing in a negative vein against a very fir, a first class group.
SW: Mm-hmm.
JA: The people that came—th-they're, these people are producing a negative comment in relationship to something that came out from probably one of the finest research groups coming around. Now these fellows feel that they have a point,
SW: Mm-hmm.
JA: And they want to make their point. And they're doing it properly. They're answering everybody in the literature. They're not getting on the television and saying, you guys are crazy.
SW: [laugh] right.
JA: As you can imagine, somebody has found fossilized bacteria on a meteorite that came from Mars. And that's big, big news.
SW: [big, big, news]
JA: Ah, very big news. They awakened the President of the United States the afternoon, the, the the afternoon or the evening that this announcement came out,
SW: Mm-hmm.
JA: and told him that they think they'd found life on Mars. Well, this was just as the paper was coming out in Nature—in Science.
SW: Yeah, actually I have the article around here somewhere.
JA: By McKay and Gibson....[*]
SW: Yeah, I think I've got it with me. I read it because I knew this was a, a reaction to that, so I had to [have it for background].
JA: And that's what you're running into here. Well, the amelioration of the argument that they're presenting right here is, my guess is, something that, I wouldn't be surprised that this, this sentence came from McSween.
SW: Mm-hmm.
JA: Uh, he's not necessarily hedging his bets as much as he's standing there saying, hey don't wanna appear completely stupid in front of these people.
SW: [laugh]
JA: I don't think we've got the kind of information that allows us to stand here and say, absolutely this is what it is.
SW: No, right, right.
JA: Because it's not! There are other arguments.
SW: Mm-hmm, right.
JA: In other words, what you're reading here is very, very good science.
SW: Yep.

JA: And that's what happens in that kind of situation. They're sitting around saying, hey these guys are no dummies.
SW: Mm-hmm.
JA: They did this work, and they've done a nice job on it, and we have an alternative argument, and this is our discussion, and this is what we present.
SW: Mm-hmm.
JA: Because the next thing that's gonna happen is somebody else is gonna come along in here and say, can we replicate what they've been doing?
SW: Right.
JA: If they <u>cannot</u> replicate, then they're gonna say, well you guys are full of…
SW: Right, exactly. And because they're coming out with this counter argument against this extremely prestigious piece of work, they have to be horribly thorough.
JA: That's right.
SW: That's, that's one reason I chose this article. Because I figured it would have to be written extremely carefully.
JA: Yeah.
SW: In this situation, so it's one reason I chose to look at it.
JA: Oh, it is very carefully written. This is,
SW: Mm-hmm.
JA: This is indicative of Hap McSween.
SW: Mm-hmm.
JA: and Ralph Harvey.
SW: Uhm… let's see. I was gonna… the other thing about the "unfortunately" is, we… when you're talking about politeness techniques in writing, or in, in language in general that you kind of talk about two different kinds of politeness moves. One is, what they refer to as negative, where you're, you're kind of giving the other person their space. And, that's what you get with all these "possiblys" and "may haves" and all of that. That's kind of like saying, ok, we know we're kind of separate from you, and we're gonna give you your space.
JA: Right.
SW: There's also this sense of what they call positive politeness, where you want to say, hey look we're part of the group too. And they often mention expressions of emotion as being kind of, this, this positive move. To say, hey look we're part of the team too. And we're not trying to, you know, debunk you. <u>But</u> [laugh], we have this other thing to say. Do you think that could possibly be what they're doing here?
JA: Very well put. Very well put, Susan. That's exactly what we're running into. All of these people know each other. Everybody knows everybody else. <u>But</u>, they are also the quintessential scientists.
SW: Mm-hmm.
JA: They are not going to stand here and say, just because you say ah, it's sixty percent correct we're not gonna, not look at the additional forty percent.
SW: Mm-hmm.
JA: And that's what they're talking about. Alright.
SW: Mm-hmm.
JA: This, what's happening here is that by the time that this paper came out, and then there are people that are saying, are beginning to ask questions about it, the <u>entire community</u> is on trial. And that's, and this is the way science is done.

SW: Mm-hmm.

JA: You hit it right on, there. There's a certain amount of emotion and all that's involved in this. People will, the arguments are still going on.

SW: Mm-hmm.

JA: They're not done.

SW: Mm-hmm. Yeah, to this day. Sure, it keeps going.

JA: It's way too big. And that's exactly what's happening. And you can see…

SW: They don't wanna offend people. But at the same time they want to do good science.

JA: Right. They all wanna do good science. And that's why you see "may suggest" "unfortunately" and we can't say this, we can't say that.

SW: Mm-hmm.

JA: You're right. OK.

SW: OK… [pause, mumbling to self while reading] Some of it is kind of repetitive, because it's the same kind of points coming up over and over again. Uhm… the end of paragraph thirteen. Can you find paragraph thirteen?

JA: Yeah, where it says, "yes, but".

SW: Yes! It says, "yes, but"! I've written in there. Uhm, they have, what I, looks to me like a, what we call a yes-but argument. Which is where you initially set up saying, well we agree with you on this particular point, or this well, you might be right on this other point, but… and then you follow with your disagreement point. And uhm, that's often mentioned as a way to kind of politely disagree with someone.

JA: Yeah.

SW: Would you agree with that that's what they're doing here.

JA: That's exactly what they're doing. In other words they're saying "the magnetite provides only limited insight..."

SW: Mm-hmm.

JA: In other words, we're talking about what is the formation temperature of the carbonates. And, this becomes a major, major point. But the magnetite is only a portion of what has gone on. And you'll find in subsequent papers by McKay and Gibson, and all them shown that that is true. But now, this group is saying "carbonate formation may have preceded magnetite formation at significantly lower temperatures." Now again, what they're saying is that possibly could have happened, "although"

SW: Yes, that's the big "but".

JA: even though it had, "the carbonates likely would have been subsequently exposed to elevated temperatures." So now they're coming out with an open statement that says… I think somewhere along the line, they the other people have said that these probably preceded and so of course the temperatures were considerably lower. Bacteria isn't going to survive, and that's what real question is.

SW: Mm-hmm.

JA: And so if it could possibly have come in here, that doesn't necessarily mean that the higher temperatures couldn't have invaded the system.

SW: Mm-hmm.

JA: So they're making quite a strong argument here, but "they would have subsequently…" So in other words they're saying that their formation, which is epitaxy, "provides a plausible solution for two previously unexplained features."

SW: Mm-hmm. They come up with this, they, they say it's a "plausible solution". They don't just come out and say, look this can explain…
JA: No.
SW: these other features.
JA: No. They're saying, we're saying, here's another way, where we're saying this could have occurred at higher temperatures. In other words, what sorts of things have gone on.
SW: Mm-hmm. So they're not trying to say, we have the answer, we just have an alternative answer.
JA: Yeah. It's not so much even an alternative answer, as it… what they're really doing is they're coming along and saying, 'look this is what we find, this is an alternative explanation, but have you considered this?'
SW: Mm-hmm. 'Have you thought about this point?'
JA: Yeah, this paper was then ah, very carefully gone over and was answered again in the literature a little bit later on.
SW: Mm-hmm. Like the next year or something.
JA: These guys are coming along and saying, 'Hey wait a minute. Wait a minute. Now we know that certain things happen. Have you considered this, and have you considered that?'
SW: Mm-hmm.
JA: This is kind of a real, a you might say, what I would call… a first line paper that says, 'Look, there's some real problems here. And one of them is this whole question of temperature.'
SW: Uh-huh. OK. Mhmm. One more thing about writing choices. If you, let's see if I can find, I didn't mark down where I got this from. Ah, I hate it when I do that. Uhm… I'm looking for this sentence here, which either is the one in seventeen or thirteen. [pause] Where's page that this is from. I hate it when I forget to mark down where I get stuff from. [pause] Well, anyway, there's this sentence here, see if you can find it. It says, "Most epitaxial magnetite whiskers in ALH 84001 appear to be free from internal defects, for example Figure 3, which suggests but does not prove growth at elevate temperatures." Now later on, in paragraph seventeen, they use almost exactly the same structure, but they only, they leave out the part with "does not prove". They just say, "suggests" in paragraph seventeen, that's what they say. So it's the same, almost exactly the same sentence. But, at a later point they leave out…
JA: "most of the whiskers and other morphologies"?
SW: This is the sentence where they leave out the part that says, "does not prove" but you can look at on my copy. So my question is, why, why here do they use this part about "does not prove" and here do they not use that. I mean…
JA: Well, this, this… [quote*]
SW: What additional information does that give us?
JA: this comes in from the Introduction.
SW: Uhm, no, it's not.
JA: Is it in the Introduction or is it…
SW: It's not. It's in this Discussion section, 'cause that's what I have it headed under here. It's supposed to be paragraphs two through four of the Discussion section, so that would be twelve… yeah, this paragraph. It's gotta be in here somewhere. [pause] Paragraph twelve, paragraph thirteen through seventeen, yeah, here. Right here. And then later on in seventeen, they use this same structure but they put in this additional kind of hedging phrase. And, to me, I don't know, it seems like they're almost weakening their argument too much. But, that's just kind of my

feeling on reading it. Is that, they're almost hedging too much in my, kind of my intuition, but… being an outsider to the argument, I don't know…

JA: Well, they're talking about two different things here. Yeah, thirteen he say, "Most epitaxial magnetite whiskers appear to be free of internal defects" and they're talking about most whiskers. Now he says, now "The coexistence of whiskers and other morphologies, for example platelets," that's something else that comes on in, "that apparently grew by different mechanisms strongly suggests that it is the growth conditions…"

SW: Right, actually that's a different sentence than the one I'm looking at.

JA: "rather than the specific mechanisms of whisker growth…"

SW: That's a different sentence than the one I'm looking at. It's this one. The yellow highlight.

JA: Oh.

SW: I'm sorry. So it's this one and this one that I was comparing.

JA: OK.

SW: So they're using basically the same sentence structure, I mean it's like they took the same sentence and they copied over different, different content, but the same sentence structure. So does the part with the "does not prove" I mean, does that really significantly change how you see that argument? I mean, if you read the sentence and it says, 'which suggests growth at elevated temperatures' I mean, how much stronger is that than, 'which suggests but does not prove growth at elevated temperatures'? If you were given two separate sentences like that. How much…

JA: Well, they're saying…

SW: How much does it really hedge it?

JA: They're saying, "Epitaxial magnetite whiskers appear to be free of internal defects" in other words, nothing else is within there.

SW: As far as we can see, anyway.

JA: "Which suggests, but does not prove growth at elevated temperatures." And then they come along here, and they say, "Dome of the whiskers appear to be free of dislocations."

SW: Mm-hmm.

JA: That's a change within the system. Because there are some of the fumerole magnetite whiskers, well the fumerole magnetite whiskers are those that grew under uh, earth type conditions.

SW: Right, right.

JA: And they're suggesting other mechanisms for crystal growth, they're talking about how crystals are grown, and this becomes a very difficult problem. And I think they're again hedging their bets.

SW: Mm-hmm.

JA: "Simultaneous growth is commonly observed in vapor-phase syntheses and in nature." And they've got a number of things on this, "and the coexistence… appears to suggest the growth conditions rather than the specific mechanism that determine whether they develop in vapors and fluids." In other words, the conditions… so, they're actually saying a couple of different things.

SW: Yeah, they've got a couple of different things, and to me it seems like they've got… the one in seventeen seems to be a little bit stronger. They feel a little more stronger about position there, than the one in paragraph thirteen.

JA: Well, the one in paragraph thirteen…ah is part of

SW: [papers shuffling, laughs] It's kind of a mess.

JA: Is part of this discussion of epitaxy.

SW: Mm-hmm.

JA: Then when you get over here, you're talking about growth from a vapor-phase. And so it's growth in two different ways. And they have to, ah take a look at it from the standpoint of, could it grow in epitaxy, could it grown in a vapor-phases growth.

SW: Mm-hmm.

JA: So, and then the "whisker" which came out, "is restricted in this paper to single crystals with unusual elongated morphologies…." [pause]

SW: What do you think about the term "whisker"? [laughs] To me, it sounds, it seems like kind of a silly word to use.

JA: Well, it's…Well, what it is, is a, nothing other than an attempt to assign some sort of a, of a word that suggests what it looks like. I don't know who coined that term.

SW: It sounds, to me it sounds almost, kind of humorous, as a term. Which is kind of interesting.

JA: Yeah, I think it's, it's not a large part of this whole thing, but I don't know where the whiskers came from.

SW: No, I don't either, they don't say.

JA: But it's something that's, it's a small part of what they're looking at., but it becomes a…

SW: It's important enough that they define it.

JA: And somebody can go along with this, and probably notices that maybe the guy who was first looking at growth of magnetite in volcanoes, see this, "whisker condensed, '93" "Symonds in '93" ah, oh! Zies in '29 probably was the guy who coined the term, 'cause he looked at intergrowth whiskers in the Valley of 10,000 Smokes. My guess is…

SW: Yeah, I think… yeah. It's kind of interesting, well, one of the papers that I read previous to taking on this research project, they talk about one of the ways of not offending people is when you're doing something a little bit risky, like coining a new term for something, you try to lighten the mood by making it rather humorous. [laugh]

JA: On occasion this is true, but the other hand, something you have to also remember is that, when you start looking at something in science, and I was involved in some of this way back in the 1960's, over forty years ago, and I was first looking at certain kinds of phenomenon in relationship to both the aurora and magnetic fields and that sort of stuff, we were coining terms all along.

SW: Mm-hmm.

JA: But one of the reasons we that were doing this was that, when you first start out in a new field, and say it's something that you have observed, and you're starting to try and get a handle on what's going on, the biggest problem that you have, is how, what kind of nomenclature do you use?

SW: Right, exactly.

JA: And you have to develop a nomenclature before you can make, well, one of the things you do is you may come out in a paper, and you say, 'This looks like a such-and-such, and so I have coined the term, or I have used the term such-and-such.' If other people like this

SW: Mm-hmm

JA: and they feel this is worthwhile, they go ahead and they ascribe it to you when they refer to your paper, and they carry it on.

SW: Mm-hmm.

JA: And that's the way a lot of this stuff comes out.

SW: Right.

JA: Cause all you're doing is attempting to define the field in a short term way.

SW: Right, but then if it's a useful term it gets… carried, carried on.

JA: It's one of the, kind of fun things to get into something brand new in science. Because you're the first person on the field, so to speak, so you're saying, 'This is what's happening. This is what I see.' And if other people will pick it up, gee-whiz, then all of the sudden you get cited.

SW: Mm-hmm.

JA: Because you're the first one to describe it.

SW: Right.

JA: And that's probably what happened. I wouldn't be surprised if that guy in '29 is the one [who said it].

SW: Who called them that, coined that term. Yeah, interesting. Alright, uhm, let's see. The next part that I kind of had some questions about was paragraphs 21-24. At the end. I think it's the Discussion section?

JA: Here it is.

SW: or Conclusions or something like that? They have this section they call, "Implications for Martian Biology". What do you think of the section heading? Do you think that's… appropriate? Or is it kind of in-your-face? To me, when I first read it, I thought, 'that's really in-your-face'. [laugh] [pause]

JA: Well, one of the things that's happened here, and here comes Ralph Harvey.

SW: [laugh]

JA: And Ralph was very adamant from the very beginning.

SW: Mm-hmm.

JA: Because he said he knows magnetite and that sort of stuff. And he's jumping into this, in all of this, and he says… they feel that they have to say something in relationship to this.

SW: Mm-hmm. 'Cause that's really the whole point of doing the research on this, wasn't it?

JA: You'll notice in the acknowledgements just who they talked to. They had reviews by John Kerridge, Kathy Thomas-Keptra, Alan Trieman, and Paul Vogel for reviews.

SW: And those people are all… on which side of the debate?

JA: Wang, Keller, and Boctor for discussions, Symonds and Boctor for fumerole magnetites, and Barclay for vapor-condensed… yeah, this is… very, very well done. And uh…

SW: So do you think that they needed to include that section, or?

JA: Oh, yeah.

SW: Why?

JA: Well, she said that the magnetite whiskers may have been biologically produced. They are saying, 'We think that there's a certain amount of evidence that says that they're not. Because of the high-temperature phase.' And they say even if the sizes and morphologies are characteristic of magnetotactic bacteria, it is unlikely that they are unique.

SW: Mm-hmm.

JA: "Highly distinctive chains of single-domain known as magnetosomes may be unique to biological processes, but <u>they have never been documented in Alan Hills 84001.</u> [pause]

SW: See, I got to this point in the paper when I was reading it and I thought all of a sudden they got a lot more… to the point.

JA: Yeah.

SW: Uhm, up until this point they've been pretty reserved with their… kind of their counter-claiming, they're just sort of sticking to their, their research, and this is what it shows, and then they get to this point and they're like, 'Look! This is what it means.' And to me it seems like they got a lot more direct at that point. But I don't know if I can quantify exactly where…

JA: What they're saying is that they think, that regardless of how strong these people are in their comments, there's an alternative explanation.

SW: Mm-hmm.

JA: And they have to address this "Implications for Martian Biology." There's no other way that they can do this. They have to put in this particular section, because Thomas-Keptra and Gibson are coming along here and saying, 'Wait a minute. This is something. We think that this was formed under a biological… case."

SW: Mm-hmm.

JA: And so, I would think the paper would be weakened badly if they didn't address this.

SW: If they didn't address the question directly.

JA: Right. I think they have to. There's no question about it. And, I wouldn't be surprised that even… for example, John Kerridge and Alan Tremain, I suspect, are very significant and insisted that this be in here. You know, if you're carry this whole thing through, you've gotta answer this question, and this implication.

SW: Alright.

JA: You can come along and talk about things theoretically, but where does this apply to what it is you're trying to say? And what you're really trying to say is that these are not of biologic origin.

SW: That's the whole point, basically… of the entire, of doing the project at all.

JA: That's right. That's right.

SW: This is the point. Uhm, do you you think that they can get away with putting it this directly… because of who they are? I mean, because they have sort of, a reputation for being more… sort of experts in this field?

JA: Well, they're all…

SW: Do you think if they were a little bit less well known, they could get away with putting it quite this directly?

JA: I think what you're doing here, is owing the [hunch?]

SW: Say it's a bunch of unknown grad students at, you know, California.

JA: They'd probably never have gotten this far.

SW: They'd never've gotten this far?

JA: Not at all. For the simple reason that a group of unknown grad students first and foremost wouldn't have the background these people have.

SW: Right.

JA: These people have backgrounds as much as thirty years in the field… and they are absolute experts in looking at this sort of stuff, and they've written many, many papers.

SW: Mm-hmm.

JA: And the reviewers in this case are people that are both for and against them. And a group of graduate students would… well, a group of graduate students would never get into this journal without having a major professor sitting there and telling them the attitudes and this is what's going on. And his name would be on the paper.

SW: So it's just too hard to get into this journal? For one thing?

JA: No, it's just that everybody in this field knows everybody.

SW: It's too much of a clique?

JA: It is a real clique. But it's a clique that doesn't agree.

SW: Mm-hmm.
JA: Now these are, these are first class people. First class. There's no doubt about it.
SW: Yeah, they would have to be to publish this much of a, a, basically a direct attack on somebody else's position.
JA: Right, that's exactly what's going on here. And they're saying that this is, basically they said right down here in the Conclusions "inconsistent with what has been reported for biologically produced magnetites."
SW: Mm-hmm.
JA: Before they can say that, they'd better make their case. And they are making their case very strongly.
SW: So you feel that they did a good job of, of leading up to this point? They've got it supported well enough, they can say that?
JA: Well in the very end, listen, "In any event, the complex thermal history… within the fracture zones makes the interpretation of evidence for possible biologic activity even more problematic." They are sticking to it. See, what happened was, when Gibson, McKay, and Kathy Thomas-Keptra first came out and said this, it hit the boards, right off.
SW: Mm-hmm.
JA: One of the reviewers is a fellow named Kerridge. Now, John Kerridge is a professor of physics and whatever out there in California. And one of the first things that happened is somebody got a hold of him on the national press and—Newsweek, and places like that—and John Kerridge, without really looking at the evidence, came right along and said, 'Oh my God this can't happen.' And he was plastered all over the globe, in videos and everywhere else. And John Kerridge was becoming a little bit of an asshole.
SW: [laugh]
JA: I'm a little surprised that John shot so quickly from the hip.
SW: Mm-hmm.
JA: But because he did, he somewhere along the line had to come back and show that something was going on. Now he's a reviewer in this particular case, but it turns out that the negative comments started to come from Ralph Harvey. Well Ralph Harvey's position got strongly ameliorated or at least tempered by Hap McSween. So in other words, what I'm giving you here within in all of this is an awful lot of personalities that are involved.
SW: Mm-hmm.
JA: I mean, John Kerridge will get up and say things at meetings and Gibson will just go through the roof, and say, 'Kerridge, you don't know what you're talking about.' And this sort of thing.
SW: Mm-hmm.
JA: Well, Ralph Harvey did the same thing and Ralph got a little… testy himself at some of the meetings. And he was, and he and John Kerridge and a couple people were kinda known as the <u>detractors</u>. Well, luckily enough, Hap McSween is a little less… rambunctious than they are.
SW: Mm-hmm.
JA: And I think he's the one who gotten into this right now.
SW: Mm-hmm. So he's put together a little bit more of a reasonable…argument.
JA: I think that Hap is a far more reasonable individual than ah, Ralph Harvey. See?
SW: Yeah, actually I've read some of Harvey's articles when I was looking through stuff for, for a good example to work with. I read some of Harvey's too.

JA: They, they published a three page paper in Nature. And they came out very quickly. Well that resulted in things coming out from Kathy Thomas[-Keptra] and some of these other people. ... The problem is, Kerridge hasn't wrote anything.
SW: Yeah, see that's interesting to me too, because I looked at <u>a lot</u> of articles when I was trying to choose one to, one or two to use as examples. And I didn't see anything by that name. I don't recognize that name.
JA: John is very well known in this community.
SW: [laugh]
JA: Yes. And he has written, has edited a number of books, as editor and that sort of thing. Why the press jumped on John or got him involved very early, I don't know.
SW: Maybe they knew he would be a vocal... detractor. People have reputations that way sometimes! [laugh]
JA: Well... I really don't know where John's coming from, and I don't think anybody else does either. I kinda think maybe it was a case of... a certain amount of professional jealousy.
SW: Mmm.
JA: That these guys got all of this, and John has always been kind of... John has not been the greatest lover of JSC science. [pause] There's also an argument that tends to go on there that, oh, the people at the Johnson Space Center are way ahead of the rest of us, and this is unfair because they get a first look at all the samples, before the rest of us do. And in a way that's not true, because, when we started setting up the program, and we set it up in such a way—and I was heavily involved in the very beginning aspect of this—that we were not going to let the people from the Johnson Space Center come in and get ahead of anybody else.
SW: monopolize specimens.
JA: No, and I mean they were our colleagues. They were two doors down the hall from me, and I still wouldn't let them in the labs. And part of the reason was that I was working with a lot of these other people. And a lot of these other people didn't realize that we were setting up these roadblocks for even our own people. They couldn't just get in there and start doing these things. Well, this kind of level of jealousy has always been there....

JA: Well, you're absolutely right... and that's why the Conclusion, when you come down to the Conclusion, what you're really doing is you're saying, 'This is what I think my data says.'
SW: Mm-hmm.
JA: And even then, you can still hedge your bet.
SW: Mm-hmm.
JA: You know, one thing that they said, you've got it underlined here, "inconsistent with what has been reported."
SW: I, actually I underlined that phrase several times because he used it over, and over, and over again. Whoever this author is likes that phrase.... And I thought it was interesting because he uses it numerous times.
JA: That particular phrase right there, is taking a big shot at the other people.
SW: How big?
JA: Very big.
SW: So it sounds like it's extremely polite phrase...
JA: They're not saying it's inconsistent with the evidence, as much as they're saying it's inconsistent with what has been reported.
SW: So it's inconsistent with other people's findings.

JA: Listen to the whole sentence, “Although neither mechanism…but it is inconsistent with what has been reported.”
SW: By whom?
JA: By all these other people who have said, they’re saying… Kathy Thomas-Keptra, McKay, Gibson, and everybody else has said that ‘We feel that these are biologically produced magnetites. They are not produced in other manners.’ And what they’re saying here, is that our comments are such that neither mechanism is unique necessarily, but it is inconsistent with what has been reported.’ In other words, what they’re saying is, ‘Folks, this is an argument, and you had better address this.’
SW: So that’s actually, it sounds like it’s a pretty politely made argument.
JA: That’s not polite. That’s not polite at all. They just shot ‘em.
SW: It’s not at all. Really, did they?
JA: “…problematic.” [quote of last sentence of paper]
SW: So, they just shot a hole in their interpretation.
JA: Yeah, they really just came right down to the very end, and they said here’s all our evidence, we see this can happen, this can happen, this can happen, this can happen, but it doesn’t hold up in relationship to what you have said is [*happening?]. They shot ‘em.
SW: Yeah, they did. It’s a really interesting paper.
JA: Yes, it is a very interesting paper.

# Data Analysis

**Excerpts from Bradley, *et al.* Article**
(underlining is mine)

**Excerpt #1: Variation by section**

Epitaxy rules out intracellular precipitation of these magnetites by (Martian) organisms, provides further evidence of the high-temperature (>120° C) inorganic origins of magnetite in ALH 84001, and indicates that the carbonates have also been exposed to elevated temperatures. [last sentence of abstract]

Our findings appear to rule out an intracellular origin for these magnetites and instead provide new evidence for an origin by vapor-phase condensation at elevated temperatures. [last sentence of Introduction section]

**Excerpt #2: Hedging in the Discussion section**

Most of the magnetite in ALH 84001 is concentrated in the sulfide-rich bands around the outer rims of carbonates, and the intimate admixing of sulfide and magnetite may be consistent with this magnetite having formed *in situ* by thermal oxidation of sulfides.

Similarly, a logical explanation for the vein magnetites is that they precipitated when the carbonate was invaded and possibly melted by shock-generated liquids.

The epitaxial magnetites on Fe-rich carbonates are often found within or immediately adjacent to voids that intersect the surfaces of the carbonates, which suggests that they may have formed during thermal decomposition…

**Excerpts from interview with subject specialist informant**

**Excerpt #1: Variation by section**

Researcher: So, for me, it seems that the abstract is a lot more direct.

Informant: It must be. This is the way we write these things.

Researcher: uh-huh. But why?

Informant: And the reason for it is this: the abstract is to give away the farm. This is true! You are to write an abstract that may be a hundred or a hundred at fifty words at most. And in it you tell exactly what's going on in as concise and pure language as you possibly can…

**Excerpt #2: Hedging in the Discussion section**

Informant: …but their validity system is not what I would say terribly suspect, as much as it's not something that you can sit here and say it's an absolute.... If they said absolute, they're just opening themselves up for somebody to come down and jump right on down [on them]

Researcher: …I'm interested in…how much they hedge when [they] have a weak position and how much they hedge when they have a strong position.

Informant: Frequently they'll hedge even if they have a fairly strong position, unless they've decided that they want to just plain step right up to the brink of the precipice.

**Excerpt #3: Additional hedging of the same argument**

Unfortunately, while all of these petrographic observations are consistent with the various populations of magnetite having formed during thermal excursions, none of them constitute absolute proof of the high-temperature origins of the magnetite in ALH 84001.

**Excerpt #3: Additional hedging of the same argument**

Researcher: They couldn't just leave that last sentence off? And just say, "All of these petrographic observations are consistent with" blah-blah-blah, and stop at "thermal excursions"? Period. Couldn't they just say that?

Informant: No.

Researcher: Why not?

Informant: For the simple reason that, if they do, then they're leaving themselves wide open for other explanations.

[discussion of use of "however" as a positive politeness strategy in excerpt #3]

Informant: Well, the amelioration of the argument that they're presenting right here is, my guess is, something that I wouldn't be surprised that this sentence came from McSween. He's not necessarily hedging his bets as much as he's standing there saying, 'Hey, we don't want to appear completely stupid in front of these people.'

**Excerpt #4: Lack of hedging or other politeness device in Conclusion**

Although neither mechanism (epitaxy or spiral growth) is unique to high-temperature vapor-phase growth, evidence of *both* mechanisms in ALH 84001 is entirely consistent with vapor-phase whisker growth phenomena observed in nature and laboratory syntheses and inconsistent with what has been reported for biologically produced magnetites…. In any event, the complex thermal history of the magnetite, sulfides, and carbonates within the fracture zones of ALH 84001 makes the interpretation for possible biologic activity even more problematic.

**Excerpt #4: Lack of hedging or other politeness device in Conclusion**

Informant: That's not polite. That's not polite at all. They just shot 'em…. Yeah, they really just came right down to the very end, and they said, 'Here's all our evidence. We can see this can happen, this can happen, this can happen, this can happen, but it doesn't hold up in relationship to what you have said.' They shot 'em.

**Excerpt #5: Definition of terminology**

The term "whisker" is restricted in this paper to single crystals with unusual elongated morphologies resulting either from (1) anisotropy in the crystal growth medium, or (2) anisotropy introduced into the structure during crystal growth.

**Excerpt #5: Definition of terminology**

Informant: …when you start out in a new field, and say it's something that you have observed, and you're starting to try and get a handle on what's going on, the biggest problem that you have, is… what kind of nomenclature do you use?

Researcher: Right, exactly.

Informant: And you have to develop a nomenclature before you can make… well, one of the things you do is you may come out in a paper, and you say, 'This looks like a such-and-such, and so I have… used the term such-and-such.' If other people like this, and they feel this is worthwhile, they go ahead and ascribe it to you when they refer to your paper, and they carry it on…. Cause all you're doing is attempting to define the field in a short term way.

CONSENT FORM

You are invited to take part in a research study on the English language. You were selected as a possible participant because you are an expert user of the language for your field of study. I ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by Susan Wetenkamp, who is a graduate student at the University of Minnesota taking a course on the use of the English language for academic, scientific, and technical purposes.

**Background Information**

The purpose of this study is to learn more about the ways in which people use the English language, particularly in scientific and technical fields.

**Procedures**

If you agree to be in this study, I will ask you to answer some questions about the way language is used in two or three academic journal articles. I will also ask you for your insights about your own language use and why authors make certain choices in their writing. This interview will be audio taped.

**Risks and Benefits of Being in the Study**

This study has no risks to you.

**Confidentiality**

The records of this study will be kept private. In any sort of report I might write or publish, I will not include any information that will make it possible to identify you, except with your written consent to do so. Research records will be kept in a locked file; only researchers will have access to the records.

**Voluntary Nature of the Study**

You do not have to be in this study. If you decide to participate, you are free to withdraw at any time.

**Contacts and Questions**

The researcher conducting this study is Susan Wetenkamp. You may ask any questions you have now. If you have questions later, you may contact her at wete0003@tc.umn.edu; Phone: (612) 624-0576. The researcher's advisor is Elaine Tarone, 214 Nolte Center; (612) 624-2023.

If you have any questions or concerns regarding the study and would like to talk to someone other than the researcher, contact the Research Subjects' Advocate line, D528 Mayo, 420 Delaware Street S.E., Minneapolis, MN 55455; Phone (612) 625-1650.

You will be given a copy of this form to keep for your records.

**Statement of Consent**

I have read the above information. I have asked questions and received answers. I consent to participate in the study.

Signature John D. Arnett Date 11/25/01

Signature of Investigator Susan Wetenkamp Date 11/25/01

Appendix B
Bradley, *et al* Research Article



*Meteoritics & Planetary Science* 33, 765–773 (1998)


# Epitaxial growth of nanophase magnetite in Martian meteorite Allan Hills 84001: Implications for biogenic mineralization

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*(Part of a series of papers on Allan Hills 84001 and early Mars)*

**Abstract**–Crystallographic relationships between magnetite, sulfides, and carbonate rosettes in fracture zones of the Allan Hills (ALH) 84001 Martian meteorite have been studied using analytical electron microscopy. We have focused on those magnetite grains whose growth mechanisms can be rigorously established from their crystallographic properties. Individual magnetite nanocrystals on the surfaces of carbonates are epitaxially intergrown with one another in "stacks" of single-domain crystals. Other magnetite nanocrystals are epitaxially intergrown with the surfaces of the carbonate substrates. The observed magnetite/carbonate (hkl) Miller indices orientation relationships are $(\bar{1},\bar{1},3)_m \parallel (1,\bar{1},0)_c$ and $(1,\bar{1},1)_m \parallel (0,0,\bar{3})_c$ with lattice mismatches of ~13% and ~11%, respectively. Epitaxy is a common mode of vapor-phase growth of refractory oxides like magnetite, as is the spiral growth about axial screw dislocations previously observed in other magnetite nanocrystals in ALH 84001. Epitaxy rules out intracellular precipitation of these magnetites by (Martian) organisms, provides further evidence of the high-temperature (>120 °C) inorganic origins of magnetite in ALH 84001, and indicates that the carbonates also have been exposed to elevated temperatures.

## INTRODUCTION

The ALH 84001 Martian meteorite has attracted considerable attention because of the suggestion that it contains fossilized evidence for extraterrestrial microorganisms (McKay *et al.*, 1996). Among the evidence cited, there are possible biogenic minerals, including defect-free, single-domain magnetite ($Fe_3O_4$) and sulfides (suggested to be greigite ($Fe_3S_4$) and 4C-pyrrhotite ($Fe_{1-x}S$)) associated with carbonates in the fracture zones of this meteorite. The magnetite sizes and morphologies were described as being similar to those formed by terrestrial magnetotactic bacteria, and the sulfides were suggested to have been formed by sulfate-respiring organisms. Magnetite is potentially a key indicator of the geochemical and thermal history of the carbonate-rich fracture zones of the meteorite. This is because it is found in several distinct petrographic settings, including sulfide-rich and magnetite-rich bands (both on the outer rims of carbonates), glass-rich veins within the carbonates, and as individual nanocrystals decorating the surfaces of carbonates. Unfortunately, most of the magnetite appears to provide no direct information about its growth mechanism(s). In a study of the magnetite in the magnetite-rich bands and on carbonates, Bradley *et al.* (1996) described a population of single-domain magnetite whiskers and platelets, both with and without defects in ALH 84001. One particular type of defect, an axial screw dislocation, observed in some of the whiskers provides highly specific information about growth mechanisms; spirally grown whiskers of many elements and compounds have been synthesized by vapor-phase growth (Nabarro and Jackson, 1958; Nadgornyi, 1962; Levitt, 1970), and they are found in nature as condensates from high-temperature vapors and supercritical fluids (Bradley *et al.*, 1983; Veblen and Post, 1983). A second type of defect, twinning, observed in other single-domain magnetites in ALH 84001 could have formed by either inorganic or biogenic growth mechanisms (Mann *et al.*, 1988). Thomas-Keptra *et al.* (1997) criticized the conclusion of Bradley *et al.* (1996) that twinning is inconsistent with a biogenic origin because twinning has been observed in biogenic magnetites, although it is uncommon and may be species-specific (Majhi *et al.*, 1997; Akai, pers. comm., 1997). However, axial screw dislocations have not been reported in biologically precipitated magnetites.

McKay *et al.* (1996) focused on more equant defect-free magnetites in ALH 84001 as possible biogenic minerals. They did not describe magnetite whiskers; however, Thomas-Keptra *et al.* (1997) argued that the whisker morphology did not rule out a biogenic origin for those grains as well, because (defect-free) magnetite whiskers have been described in a modern magnetotactic bacteria (Vali and Kirschvink, 1990). In that scenario, defect-free whiskers (at least those without screw dislocations) could have formed inside cells, which were released upon death and decomposition of the host organisms. In this paper, we report the results of a transmission electron microscope (TEM) study of defect-free magnetite whiskers (and other magnetite morphologies) in ALH 84001, focusing again on crystallographic properties that reflect the mechanisms of crystal growth. These magnetites nucleated and grew epitaxially both on other magnetites and on Fe-rich carbonate crystals within rosettes. Our findings appear to rule out an intracellular origin for these magnetites and instead provide additional new evidence for an origin by vapor-phase condensation at elevated temperatures.

## EXPERIMENTAL PROCEDURES

We studied specimens of ALH 84001 prepared using (room temperature) ultramicrotomy and (cryogenic) ion milling. Magnetite nanocrystals (whiskers and other morphologies) were found in specimens that were prepared using both methods; although they are more difficult to locate in ultramicrotomed specimens, in part because of specimen damage ("chatter") caused by the diamond knife. Specific details of both preparation techniques are described elsewhere (Bradley, 1988; Bradley and Brownlee, 1986; Bradley *et al.*, 1996). We also examined vapor-phase magnetites from two active fumeroles (Merapi Volcano, Indonesia and Valley of Ten Thousand Smokes, Alaska) plus single-domain magnetites produced in the laboratory by vapor-phase condensation (Ford, 1998).

The vapor-condensed magnetites were dispersed in ethanol, ultrasonicated, and transferred to continuous C-film TEM grids using a micropipette. All of the specimens were examined using a 200 keV JEOL 2010 TEM equipped with a solid-state energy-dispersive x-ray spectrometer and a 400 keV atomic resolution JEOL 4000EX TEM. Brightfield and darkfield imaging, lattice-fringe imaging, selected area electron diffraction (SAED), and energy-dispersive x-ray spectroscopy (EDS) were used to study the magnetites. Methods of instrument calibration and x-ray detector standardization are described elsewhere (Bradley *et al.*, 1996).

## ELECTRON MICROSCOPIC OBSERVATIONS

Figure 1 shows a brightfield micrograph of an ultramicrotomed thin section of the outer region of a carbonate rosette within a fracture zone of ALH 84001. As indicated in a previous study (McKay *et al.*, 1996), most of the magnetite in ALH 84001 is concentrated in the sulfide and magnetite-rich bands around the outer edges of the carbonates. A sulfide-rich band (Fig. 1) was analyzed using EDS and SAED. Analyses by EDS revealed that most grains contain O, S and Fe (with O and S abundances negatively correlated), and SAED patterns suggest that they are admixtures of sulfide(s) and magnetite.

Figure 2 shows a brightfield image of a feldspathic glass-containing vein in carbonate. Some carbonate rosettes within the fracture zones are extensively penetrated by networks of such veins. Darkfield imaging (inset, Fig. 2), SAED patterns, and EDS analyses in conjunction with lattice-fringe imaging establish that the veins contain a population of mostly 10–30 nm diameter single-domain magnetites. Parallel oriented crystals outside of the veins (white arrows) are elongated magnetite whiskers and other more equant magnetite morphologies on the surfaces of the carbonates.

Figure 3 shows a brightfield image of nine magnetite whiskers that are part of a "school" of at least twenty whiskers covering an area ~$0.5 \times 1\ \mu$m on the surface of a (single) Fe-rich carbonate crystal within a rosette. Two whiskers (arrowed) are in physical contact, and tilting experiments and darkfield (lattice-fringe) images suggest that they are epitaxially intergrown. Figure 4 illustrates another example of epitaxy; the brightfield lattice-fringe image shows a crystallographically intergrown magnetite whisker (labelled 1) and a magnetite platelet (labelled 2). Bold arrows delineate the zone of attachment where the whisker and platelet share a common *a* axis (see also Fig. 4b). Strong image contrast and Moire fringes along the zone of attachment between the whisker and platelet reflect lattice strain. A series of through-focus lattice-fringe images, together with SAED data (Fig. 4b), suggest that the whisker and platelet are part of an epitaxial "stack" of at least four crystals. In Fig. 4b, coincidence of the ($\bar{2}$,2,0) and (002) lattice planes common to both

FIG. 1. Brightfield electron micrograph of an ultramicrotomed thin section of the outer rim region of a carbonate rosette showing a sulfide/magnetite-rich band (100–500 nm thick) along the edge of the carbonate and an outermost magnetite-rich rim (1–5 $\mu$m thick).

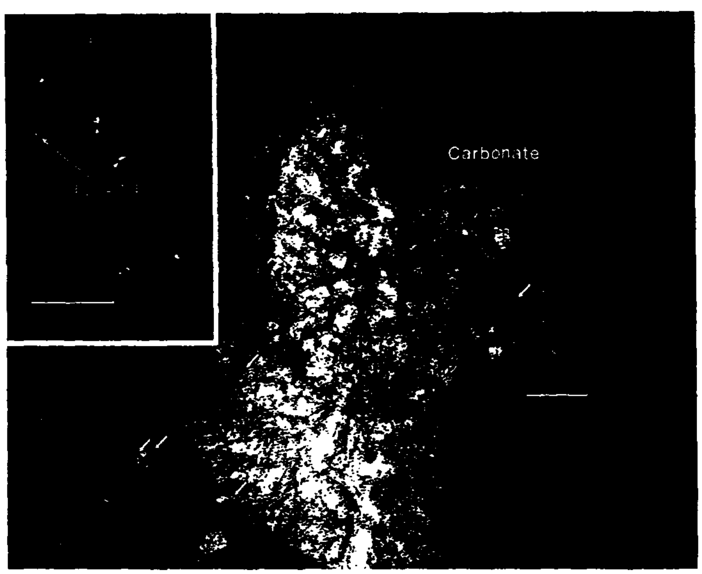


FIG. 2. Brightfield electron micrograph of an ion-milled specimen of a glass-rich vein within a carbonate rosette. Elongated grains (white arrows) outside of the vein are parallel-oriented magnetite whiskers epitaxially grown onto the surface of the single-crystal carbonate. Inset (upper left) is a darkfield image of a region of the vein. The bright grains are single-domain magnetite crystals dispersed throughout the vein.


FIG. 3. Brightfield electron micrograph of nine magnetite whiskers, part of a "school" of more than twenty whiskers, on the surface of a carbonate crystal (ion-milled specimen). Two (epitaxially intergrown) whiskers are arrowed.

reciprocal lattice nets indicates that the whisker (1) and platelet (2) are topotaxially intergrown (*i.e.*, crystallographically intergrown with identical orientations). The pattern also contains diffraction spots from other magnetite crystals within the stack as well as intense spots (labelled "C") from a carbonate crystal. Stacked crystals are commonly observed among vapor-phase condensates (Henriquez and Martin, 1978; Symonds, 1993).

We also examined the crystallographic relationship between magnetite nanocrystals and the carbonate substrates upon which they are deposited. Whiskers without axial defects often exhibit pronounced lattice-strain contrast along one edge where they are in direct contact with other magnetite crystals (*e.g.*, Fig. 4a) or the carbonate substrate. Selected area electron diffraction patterns from these whiskers establish that they grew *via* epitaxy (see also Fig. 2). Figure 5a shows an SAED pattern from a magnetite whisker on an Fe-rich carbonate (ankerite) substrate. The almost rigorous orientation relationship between the [211] zone axis pattern from the whisker and the [110] pattern from the carbonate indicates that the whisker is epitaxially grown on the carbonate. The ($\bar{1}$, $\bar{1}$,3) lattice planes of the magnetite whisker are parallel to the (1, $\bar{1}$,0) planes of the carbonate. Figure 5b shows an SAED pattern from a single-domain magnetite platelet. (A brightfield image of the same platelet is shown in Fig. 4a of Bradley *et al.*, 1996.) The orientation relationship between the [110] zone axis SAED pattern from the platelet and the [110] pattern from the carbonate indicates epitaxial growth of magnetite on the carbonate. The (1, $\bar{1}$,1) lattice planes of the magnetite platelet are parallel to the (0,0, $\bar{3}$) lattice planes of the carbonate (Fig. 5b).

Figure 6 is a darkfield image of a magnetite whisker from a fumerole at the Merapi Volcano, Indonesia. This whisker condensed from the vapor phase onto the inner wall at the high-temperature end (~800 °C) of a quartz tube inserted into the fumerole (Symonds, 1993). We also examined similar fumerole whiskers from the Valley of Ten Thousand Smokes, Alaska (Zeis, 1929). The fumerole samples contain whiskers with and without axial dislocations as well as epitaxially intergrown whiskers and other crystals.

Figure 7 shows single-domain magnetites produced in the laboratory by physical vapor synthesis, a process in which metals are heated above their melting temperatures and the vapors are then exposed to O (Ford, 1998). We observed a variety of magnetite morphologies and crystal defect stuctures among the nanocrystals in this sample, including twinned crystals, defect-free crystals, equant, and teardrop-shaped crystals (Fig. 7). The properties of the single-domain magnetites in this vapor-deposited sample appear indistinguishable from those of some biogenic magnetites (Mann *et al.*, 1984; Iida and Akai, 1996).

## DISCUSSION

### Magnetite Petrography

In principle, the petrographic associations of the magnetite, that is, magnetite on sulfides (Fig. 1), magnetite in glass-rich veins (Fig. 2), and magnetite on carbonate surfaces (Figs. 2 and 3) should provide insight into the thermal history of the minerals within the fracture zones of ALH 84001. Most of the magnetite in ALH 84001 is concentrated in the sulfide-rich bands around the outer rims of carbonates (Fig. 1), and the intimate admixing of sulfide and magnetite may be consistent with this magnetite having formed *in situ* by thermal oxidation of sulfides. (Admixtures of sulfide and magnetite are seen in interplanetary dust particles that were severely pulse-heated during atmospheric entry (Keller *et al.*, 1996). Similarly, a logical explanation for the vein magnetites (Fig. 2) is that they precipitated when the carbonate was invaded and possibly melted by shock-generated liquids (Scott *et al.*, 1997; McKay and Lofgren, 1997). The epitaxial magnetites on Fe-rich carbonates (Figs. 2 and 3) are often found within or immediately adjacent to voids that intersect the surfaces of the carbonates (Figs. 2 and 3), which suggests that they may have formed during thermal decomposition of the Fe-rich carbonates (see below). Unfortunately, while all of these petrographic observations are consistent with the various populations of magnetite having formed during thermal excursions, none of them constitute absolute proof of the high-temperature origins of the magnetite in ALH 84001.

### Magnetite Epitaxy

Another approach to determining the temperature(s) of formation of the magnetites is to examine the *mechanisms* of magnetite formation. Figures 3 through 5 provide compelling evidence of epitaxial growth of whiskers and other single-domain magnetites on the surfaces of carbonates in ALH 84001. Epitaxy, first observed over a century ago by mineralogists who noted that two different minerals can sometimes grow together with a well-defined orientation relationship (Pashley, 1975), is now widely observed and

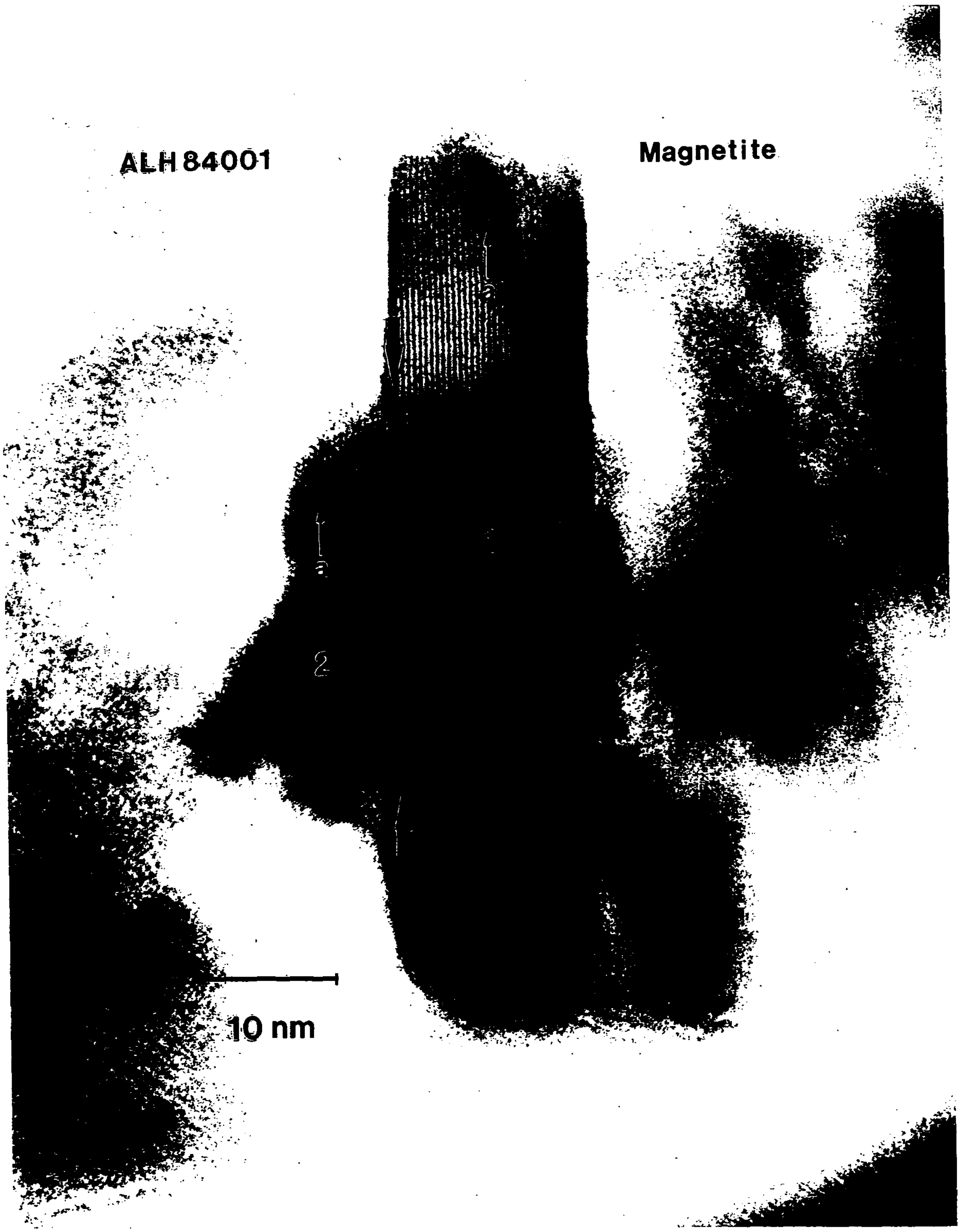


FIG. 4. (a) Lattice-fringe image of a magnetite whisker (1) and a platelet (2) near the magnetite-rich rim region of a carbonate globule (ultramicrotomed specimen). Both crystals are part of an epitaxial stack of at least four crystals. Bold arrows delineate the zone of attachment between the whisker and platelet, and small arrows indicate the *a* axes of each crystal.

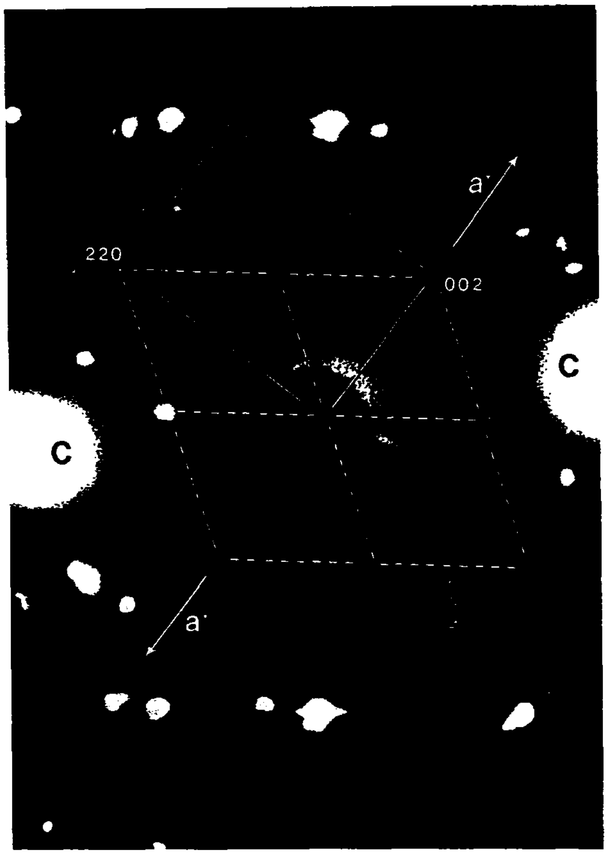


FIG. 4. *Continued.* (b) The SAED pattern from a magnetite stack. The whisker (1) and platelet (2) share a common $a^*$ axis. Solid and dashed nets (corresponding to lattice cross-fringes observed in images) indicate [1, $\bar{1}$ ,0] whisker and equivalent [110] platelet zone axis reciprocal lattice nets, respectively. Coincidence of ( $\bar{2}$ ,2,0) and (002) lattice planes indicate that the whisker and platelet are topotaxially intergrown with identical orientations. Intense reflections (labelled "C") are from a carbonate substrate crystal.

exploited in materials science (Schlom *et al.*, 1997). Epitaxy can occur if there is parallelism of two lattice planes with similar periodicities. Experiments suggest that the ideal lattice "misfit" between two crystal structures should not be more than ~15%, although larger mismatches are observed (Royer, 1928; Pashley, 1956). In Fig. 5a the "misfit" between the magnetite (1, $\bar{1}$ ,0) planes and the ankerite ( $\bar{1}$ , $\bar{1}$ ,3) planes is ~13%. In Fig. 3b, the misfit between the magnetite (1, $\bar{1}$ ,1) planes and the carbonate (0,0, $\bar{3}$ ) planes is ~11%.

Other important parameters for epitaxial growth are substrate surface properties (freshly cleaved, fractured, or etched surfaces are normally required), as well as substrate temperature (Pashley, 1975; Eom *et al.*, 1997). Crystals epitaxially grown at lower temperatures tend to have high densities of internal defects, whereas those formed at elevated temperatures tend to be defect-free. Most epitaxial magnetite whiskers in ALH 84001 appear to be free of internal defects (*e.g.*, Fig. 3), which suggests but does not prove growth at elevated temperatures. Epitaxial growth of magnetite on carbonate was observed when chalybite ($FeCO_3$) single crystals were sealed under vacuum in tubes and heated under their own $CO_2$ pressure to 550 °C (Bernal *et al.*, 1959), and Brearley (1998) has proposed that the magnetite on carbonates in ALH 84001 formed during the thermal decomposition of the Fe-rich carbonates. In both scenarios, condi-

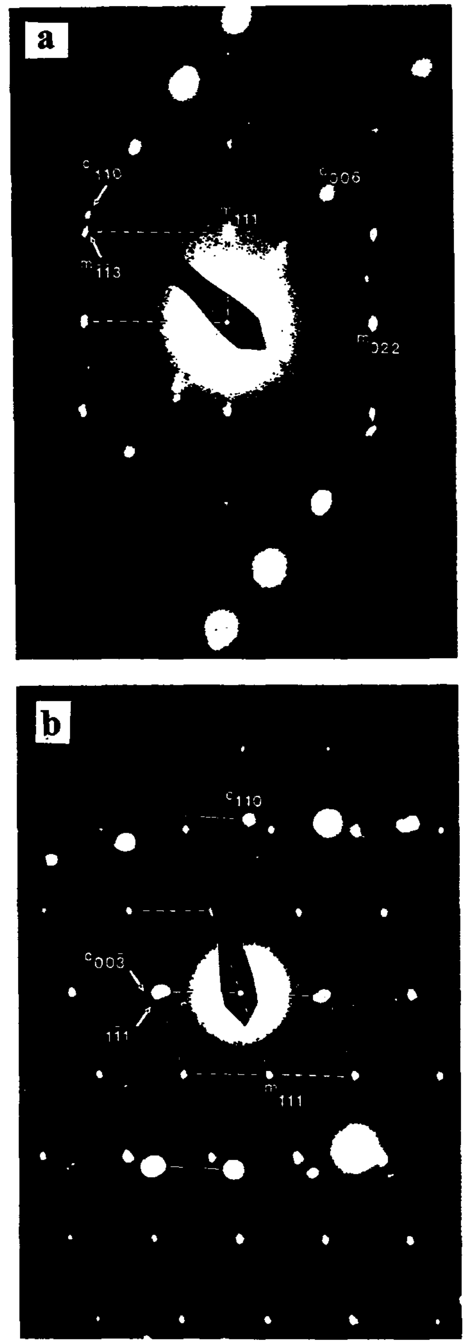


FIG. 5. The SAED patterns from single-domain magnetite crystals epitaxially intergrown onto carbonate crystals. Dashed and solid lines show magnetite and carbonate reciprocal lattice nets, respectively. Lower case labels "m" and "c" (preceeding (hkl) Miller indices) indicate carbonate and magnetite reflections, respectively. (a) Magnetite whisker [211] zone axis pattern and carbonate [110] zone axis pattern. Magnetite ( $\bar{1}$ , $\bar{1}$ ,3) lattice planes are aligned approximately parallel to carbonate (1, $\bar{1}$ ,0) planes. (b) Magnetite platelet [110] zone axis pattern and carbonate [110] zone axis pattern. Magnetite (1, $\bar{1}$ ,1) planes are aligned approximately parallel to carbonate (0,0, $\bar{3}$ ) planes.

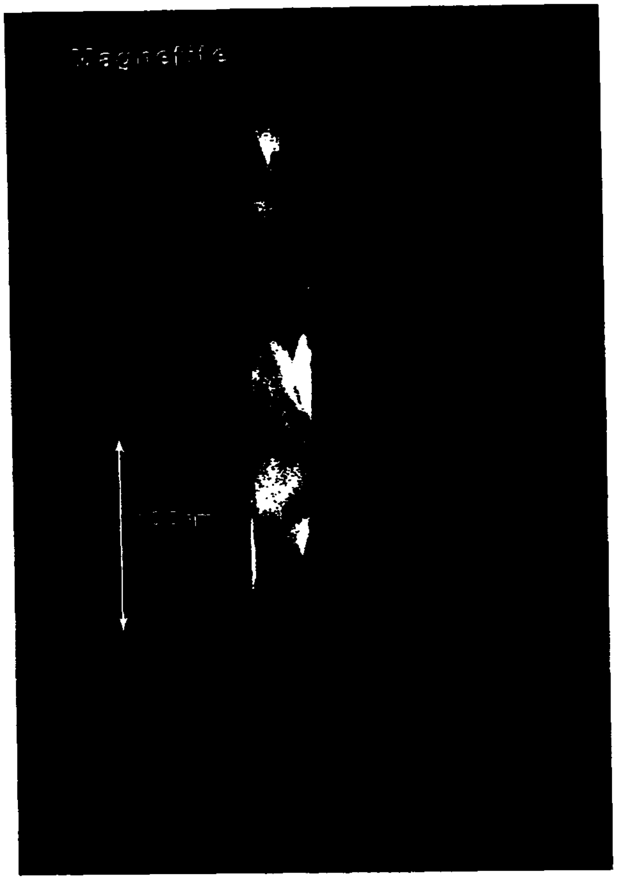

FIG. 6. Darkfield electron micrograph of a magnetite whisker from a fumerole at the Merapi Volcano, Indonesia. This whisker condensed from the vapor phase at ~800 °C (Symonds, 1993). Whiskers with and without axial dislocations as well as epitaxially intergrown whiskers are found in the Merapi fumerole sample and a fumerole (#148) sample from the Valley of Ten Thousand Smokes, Alaska (Zies, 1929), in accordance with vapor-phase whisker growth phenomena described in the literature (see text).

tions are ideal for vapor-phase growth of magnetite. Magnetite films have been grown epitaxially on other oxide substrates in the temperature range 800–1100 °C (Pullium, 1967). The magnetite/carbonate epitaxy in ALH 84001 provides only limited insight regarding the formation temperature of the carbonates. Since they provided fresh surfaces for the nucleation and growth of magnetite, their formation was either concurrent with or before magnetite formation. Carbonate formation may have preceded magnetite formation at significantly lower temperatures, although the carbonates likely would have been subsequently exposed to elevated temperatures during magnetite growth.

Epitaxy provides a plausible solution for two previously unexplained features of the magnetites in ALH 84001. First, while some whiskers contain axial screw dislocations indicating that they grew by spiral growth (Bradley *et al.*, 1996), others appear to be free of interior dislocations suggesting other mechanisms of formation (*e.g.*, Figs. 3 and 4a). Second, magnetite whiskers in ALH 84001 are often found in groups or "schools" with similar orientations (i.e., they are aligned with their longest axes pointing in a common direction; Figs. 2 and 3). Specimen tilting experiments, darkfield imaging, and SAED indicate that whiskers within "schools" have similar crystallographic orientations and that their parallel orientations result from epitaxial nucleation and growth on carbonate (with a particular affinity for carbonate <110> surfaces; Fig. 5). Similarly oriented "schools" of vapor-deposited whiskers (of multiple compositions) have been observed elsewhere (Henriquez and Martin, 1978; Symonds, 1993; Givargizov, 1978).

**Magnetite Whisker Morphologies and Vapor-Phase Growth**

The term "whisker" is restricted in this paper to single crystals with unusual elongated morphologies resulting either from (1) anisotropy in the crystal growth medium, or (2) anisotropy introduced into the structure during crystal growth (Veblen and Post, 1983). (Minerals that are naturally elongated and those formed by pseudomorphic replacement of elongated crystals are not considered whiskers.) Epitaxial growth can be viewed as an example of the first type of whisker growth, in which crystal growth is controlled by the structure of the (external) substrate. Another example is the vapor-liquid-solid (VLS) mechanism of whisker growth where atoms precipitate from a liquid droplet on the end of a growing whisker (Wagner and Ellis, 1965; Givargizov, 1978). Spiral growth about axial screw dislocations is an example of the second type of anisotropic crystal growth. Screw-dislocated whiskers of a variety of metals (Mn, Fe, Co, Ni, Cu, Zn) and refractory metal oxides ($Al_2O_3$, $Fe_2O_3$, CuO) have been synthesized by vapor-phase condensation (Nadgornyi, 1962; Levitt, 1970), and they are found in nature as condensates from high-temperature vapors and supercritical fluids (Veblen and Post, 1983; Bradley *et al.*, 1983; Symonds, 1993). Whiskers that are axially twinned are also an example of the second type of anisotropic crystal growth.

The mechanism of spiral growth *via* screw dislocations was first proposed by Frank (1949) who recognized that crystal growth from the vapor phase can occur at levels of supersaturation well below those expected for classical two-dimensional nucleation. According to the mechanism, an emergent screw dislocation on a crystal face provides a permanent, self-propagating growth step that allows one-dimensional (rather than two-dimensional) crystal growth to occur. One-dimensional nucleation significantly reduces the degree of supersaturation required for crystal growth. Observations of spiral ledges on the growth surfaces of crystals of many compounds and minerals confirm the Frank (1949) mechanism of spiral growth (*e.g.*, Velikoberets, 1968).

Some of the magnetite whiskers in ALH 84001 appear to be free of axial screw dislocations, as are some of the fumerole magnetite whiskers we examined, which suggests other mechanisms of crystal growth. Simultaneous growth of whiskers by multiple mechanisms in the same environment is commonly observed in vapor-phase syntheses and in nature, producing whiskers with and without screw dislocations; twinned whiskers; whiskers with square, rectangular, hexagonal, or round cross-sections; and saw-toothed blades and ultrathin ribbons (Givargizov, 1978; Veblen and Post, 1983; Symonds, 1993; Bradley *et al.*, 1996). The coexistence of whiskers and other morphologies (*e.g.*, platelets) that apparently grew by different mechanisms strongly suggests that it is the growth conditions (*e.g.*, vapor composition, degree of supersaturation, temperature, pressure) rather than the specific mechanisms of whisker growth that determine whether whiskers or equant crystals grow from vapors and fluids. When conditions are appropriate, whiskers can form by a variety of mechanisms (Drum, 1965).

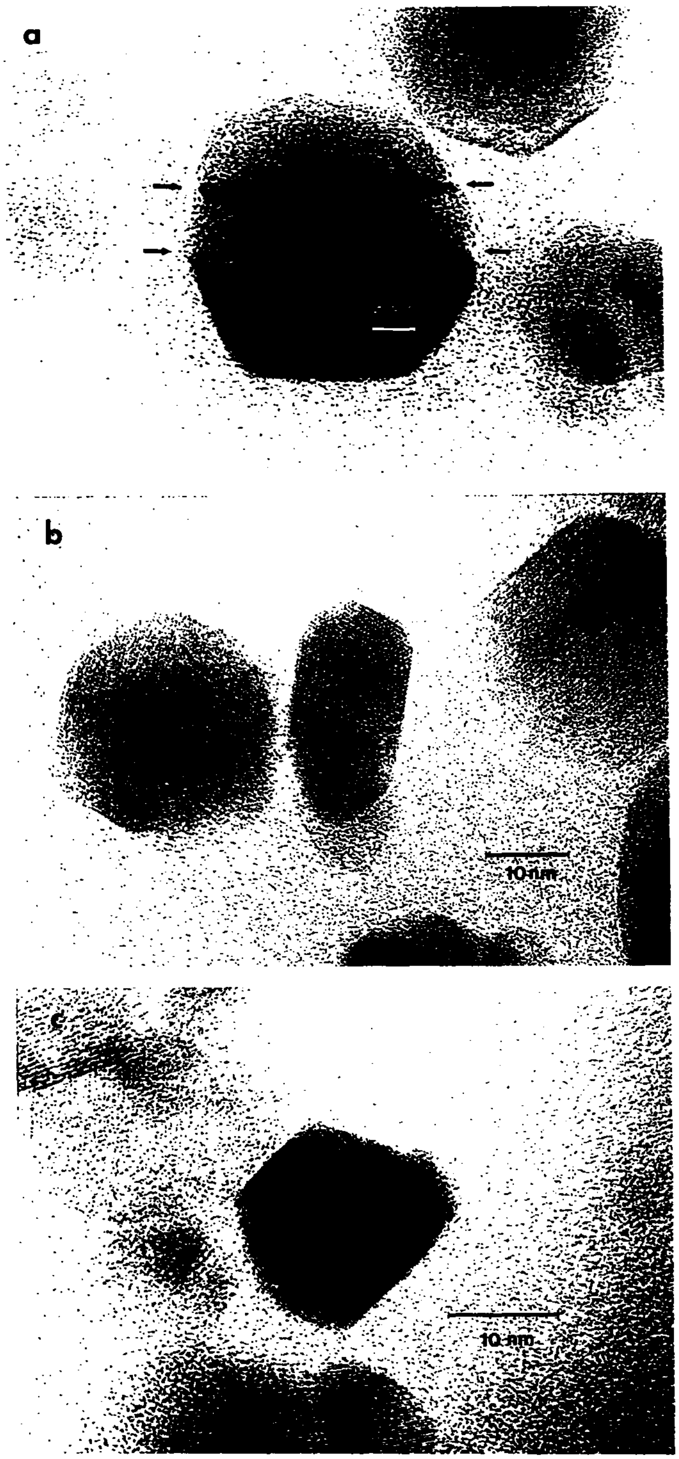


FIG. 7. High-resolution lattice-fringe images of nanophase magnetite produced in the laboratory by the physical vapor synthesis method (Ford, 1998). (a) Doubly twinned magnetite (twin planes are arrowed). (b) and (c) Single-domain magnetites exhibiting pseudoteardrop and parallelpiped morphologies similar to those of some biogenic single-domain magnetites (see Iida and Akai, 1996; Thomas-Keptra *et al.*, 1998).

The overwhelming majority of the magnetite nanocrystals in the fracture zones of ALH 84001 are not whiskers (*i.e.*, their morphologies are more equant), but often the same can be said of crystals in vapor-phase condensate deposits (McKay *et al.*, 1972; Symonds, 1993). For example, we observe that <1% of the vapor-condensed magnetite crystals from two fumerole deposits are whiskers (*e.g.*, Fig. 6), while the rest are relatively equant crystals that provide no specific information about their mechanism(s) of growth. Thus, the presence of magnetite whiskers at any abundance within the fracture zones of ALH 84001 should be viewed as a "fingerprint" of vapor-phase growth.

The specific mechanisms we have identified (spiral growth and epitaxy) provide insight about the thermal regime of magnetite growth in ALH 84001. Although there is vast literature on whisker growth phenomena in general, limited data exist on the formation of magnetite whiskers in particular. Vapor-deposited magnetite whiskers (some with axial features) recovered from the Merapi fumerole, Indonesia condensed at 600–800 °C (Symonds, 1993). Magnetite (and hematite) whiskers from fumeroles in the Valley of Ten Thousand Smokes, Alaska condensed at temperatures up to ~650 °C or higher (Zies, 1929). (We are presently performing a detailed characterization of magnetites from both fumeroles using TEM.) Magnetite with screw dislocations also has been observed in metasomatic deposits, although the temperature was not specified (Velikoberets, 1968).

The growth of crystals by spiral growth is not restricted to high-temperature vapor-phase growth. Spiral growth of massive (as opposed to whisker) magnetite has been observed on the surfaces of steel etched with hydroxide solutions at 300 °C (Asai, 1967). Screw-dislocated whiskers of salts (*e.g.*, NaCl, LiF, $CdI_2$) have been precipitated from aqueous solutions (Amelinckx, 1958). Crystal growth by epitaxy is also observed in aqueous systems. Epitaxial growth of goethite on kaolinite in weathered laterites has been reported (Boudeulle and Muller, 1988), and otavite ($CdCO_3$) was observed to grow epitaxially on calcite from an aqueous solution (Chiarello and Sturchio, 1994). Oriented growth, sometimes called epitaxy, is commonly observed during (aqueous) biomineralization (*e.g.*, Pedone and Folk, 1996). Organic surfaces can function as structural templates that stimulate precipitation and guide the deposition of inorganic ions from saturated aqueous solutions. The basic constructional processes in biomineralization are supramolecular preorganization, interfacial molecular recognition (templating), and cellular processing (Mann, 1993). Mann *et al.* (1993) emphasize that epitaxy does not provide an adequate explanation for oriented growth of inorganic solids in biological systems. (The precipitated solids are often amorphous or poorly crystalline, thus ruling out epitaxy as the orienting mechanism; Fortin *et al.*, 1997.) In any case, aqueous precipitation of the magnetite in ALH 84001 (by biologic or nonbiologic processes) is unlikely because (1) ALH 84001 is a conspicuously dry meteorite (Harvey and McSween, 1996;

Trieman, 1998), (2) we are unaware of any reports of screw-dislocated magnetite whiskers precipitated from aqueous solutions, (3) screw-dislocated iron oxide whiskers have been synthesized from high-temperature vapors in the laboratory (Tallman and Gulbransen, 1967), (4) vapor-deposited iron oxide whiskers (*e.g.*, magnetite) are observed in nature (Symonds, 1993, Bradley *et al.*, 1996); and (5) magnetite has been grown epitaxially on Fe-rich carbonates by thermal decomposition of the carbonates (Bernal *et al.*, 1959).

**Sulfides Within the Fracture Zones**

The sulfides within the fracture zones of ALH 84001 are difficult to identify rigorously (Fig. 1), in part because most of them appear to have undergone partial decomposition. McKay *et al.* (1996) reported greigite ($Fe_3S_4$) and 4C-pyrrhotite ($Fe_{1-x}S$) within the fracture zones, but we did not identify either of these sulfides. Moreover, they identified a measured 5.7Å lattice spacing as the {111} reflection of pyrrhotite in the monoclinic 4C system, used this spacing to distinguish the 4C polymorph from other pyrrhotite polymorphs, and identified the {111} plane as the basal plane in pyrrhotites. The (111) lattice spacing in 4C pyrrhotite is 4.7Å (not 5.7 Å, which could be any one of several other lattice spacings); the ~5.7 Å spacing is perhaps the least-diagnostic lattice spacing because it is common to most iron sulfides, and the basal plane in (monoclinic and hexagonal) pyrrhotites is {001} (not {111}) (Skinner *et al.*, 1964; Mukherjee, 1969; Tokonami *et al.*, 1972; Morimoto *et al.*, 1975). (The basal plane is {001} in all crystallographic systems except cubic; Gary *et al.*, 1977.) We found numerous grains exhibiting S/Fe atom ratios that are consistent with greigite (Fe/S = 0.75) and pyrrhotite (0.9 < Fe/S > 1.0). The SAED patterns from a few sulfide grains exhibit what appear to be weak superlattice reflections. These reflections may be indicative of (one or more of the many polymorphs of) pyrrhotite, or they may simply result from unit cell-scale intergrowth of sulfides and magnetite, perhaps resulting from the partial oxidation of sulfides. It is possible for 4C-pyrrhotite and other iron sulfides to be identified in a more extensive TEM examination of the carbonate rims. Commenting on the potential biogenic significance of the sulfides so far documented in ALH 84001, Pósfai *et al.* (1998) conclude that one of them (griegite) is "not an unambiguous indicator of past biogenic activity" and the other two (pyrite and pyrrhotite) "appears to be irrelevant to the question of possible former biogenic activity on Mars."

**Implications for Martian Biology**

Thomas-Keptra *et al.* (1997), noting that elongated magnetite nanocrystals have been observed within modern magnetotactic bacteria, suggested that magnetite whiskers in ALH 84001 may have been biologically produced. However, even if the sizes and morphologies of some magnetite grains in ALH 84001 are characteristic of magnetotactic bacteria, it is unlikely that these properties are unique to biogenic magnetites (*e.g.*, Fig. 7). Highly distinctive chains of single-domain magnetites known as magnetosomes may be unique to biogenic processes (*e.g.*, Iida and Akai, 1996), but they have never been documented in ALH 84001. Furthermore, the release of magnetite crystals from dead cells and their subsequent deposition on carbonate are clearly inconsistent with epitaxy, and the likely requirement of fresh surfaces for epitaxial growth argues against the presence of organic materials, such as biofilms or cell walls (McKay *et al.*, 1997), between the carbonate substrate and the growing magnetites in ALH 84001.

Some of the proposed nanofossils in ALH 84001 are probably magnetite whiskers (Bradley *et al.*, 1996). Apart from their similar sizes, aspect ratios, and shapes, both are found on the surfaces of carbonates within fracture zones. Published SEM images of aligned nanofossils (*e.g.*, Kerr, 1997a) are likely either magnetite whiskers with parallel orientations resulting from epitaxial growth on the carbonates or emergent pyroxene or carbonate lamellae with "worm like" segmented surfaces enhanced by conductive heavy-metal coatings (Bradley *et al.*, 1997; Kerr, 1997b). In describing nanofossils, Gibson *et al.* (1997) noted that several forms contained dark, internal boundaries and suggested that they "appear to be dividing." Our observations of epitaxially intergrown magnetite crystals (*e.g.*, Figs. 3 and 4) provide a plausible alternative interpretation.

## CONCLUSIONS

This study confirms that a major fraction of the "massive" magnetite in ALH 84001 is concentrated in sulfide-rich bands on the rims of the carbonates. Although the mechanism(s) of formation of this magnetite have yet to be fully elucidated, *in situ* formation during thermal oxidation of the sulfides is a strong possibility. Single-domain magnetites in veins probably precipitated when hot liquids invaded the carbonates. Other single-domain magnetites on the surfaces of carbonates grew epitaxially, probably from a high-temperature vapor (or fluid), which is consistent with an earlier study suggesting that other single-domain magnetites in the fracture zones of ALH 84001 grew by the spiral growth mechanism under similar conditions (Bradley *et al.*, 1996). Although neither mechanism (epitaxy or spiral growth) is unique to high-temperature vapor-phase growth, evidence of *both* mechanisms in ALH 84001 is entirely consistent with vapor-phase whisker growth phenomena observed in nature and laboratory syntheses and inconsistent with what has been reported for biologically produced magnetites. As indicated in our earlier study (Bradley *et al.*, 1996), the screw-dislocated magnetite whiskers likely formed at temperatures >500 °C, which is also consistent with (epitaxial) growth of magnetite on carbonate (Bernal *et al.*, 1959; Brearley, 1998), although whisker growth experiments should be performed to confirm the thermal regime of growth of magnetite in ALH 84001. In any event, the complex thermal history of the magnetite, sulfides, and carbonates within the fracture zones of ALH 84001 makes the interpretation of evidence for possible biologic activity even more problematic.

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## REFERENCES

AMELINCKX S. (1958) Dislocations in alkali halide whiskers. In *Growth and Perfection of Crystals* (eds. R. H. Doremus, B. W. Roberts and D. Turnbull), pp. 139–153. J. Wiley and Sons, New York, New York, USA.

ASAI O. (1967) Corrosion of steel in water at elevated temperatures and pressure. IV. Corrosion products of mild steel in high temperature aqueous metal hydroxide solution. *Denki Kagaku* 35(9), 638–642.

BERNAL J. D., DASGUPTA D. R. AND MACKAY A. L. (1959) The oxides and hydroxides of iron and their structural inter-relationships. *Clay Min. Bull.* 4, 15–30.

BOUDEULLE M. AND MULLER J-P. (1988) Structural characteristics of hematite and goethite and their relationships with kaolinite in a laterite from Cameroon. A TEM study. *Bull. Mineral.* 111, 149–166.

BRADLEY J. P. (1988) Analysis of chondritic interplanetary dust thin sections. *Geochim. Cosmochim. Acta* **52**, 889–900.

BRADLEY J. P. AND BROWNLEE D. E. (1986) Cometary particles: Thin sectioning and electron beam analysis. *Science* **231**, 1542–1544.

BRADLEY J. P., BROWNLEE D. E. AND VEBLEN D. R.(1983) Pyroxene whiskers and platelets in interplanetary dust: Evidence of vapor-phase growth. *Nature* **301**, 473–477.

BRADLEY J. P., HARVEY R. AND MCSWEEN H. Y., JR. (1996) Magnetite whiskers and platelets in the ALH 84001 Martian meteorite: Evidence of vapor-phase growth. *Geochim. Cosmochim. Acta* **60**, 5145–5155.

BRADLEY J. P., HARVEY R. AND MCSWEEN H. Y., JR. (1997) No "nanofossils" in martian meteorite. *Nature* **390**, 454–456.

BREARLEY A. J. (1988) Magnetite in ALH 84001: Product of the decomposition of ferroan carbonate. *Lunar Planet. Sci.* **29**, 1451–1452.

CHIARELLO R. P. AND STURCHIO N. C. (1994) Epitaxial growth of otavite on calcite observed *in situ* by synchrotron X-ray scattering. *Geochim. Cosmochim. Acta* **58**, 5633–5638.

DRUM C. M. (1965) Axial imperfections in filamentary crystals of aluminum nitride. I. *J. Appl. Phys.* **36**, 816–823.

FORD Q. (1998) Manufacturing nanocrystalline materials by physical vapor synthesis. *Ceramic Industry* (Jan. 1998), 31–34.

FORTIN D., FERRIS F. G. AND BEVERIDGE T. J. (1997) Surface-mediated mineral development by bacteria. In *Reviews in Mineralogy, vol. 35. Geomicrobiology: Interactions Between Microbes and Minerals.* (eds. J. F. Banfield and K. H. Neaslon), pp. 161–180. Mineral Soc. Am., Washington, D.C., USA.

FRANK F. C. (1949) The infuence of dislocations on crystal growth. *Disc. Faraday Soc.* **5**, 48–54.

GARY M., MCAFEE R., JR. AND WOLF C. L., EDS. (1977) *Glossary of Geology*. Am. Geol. Inst., Washington D.C., USA. 805 pp.

GIBSON E. K., JR., MCKAY D. S., THOMAS-KEPTRA K., ROMANEK C. S., CLEMETT S., ZARE R. N. AND VALI H. (1997) Possible relict biogenic activity in Martian meteorite ALH 84001 (abstract). *Lunar Planet. Sci.* **28**, 413–414.

GIVARGIZOV E. I. (1978) Growth of whiskers by the vapor-liquid-solid mechanism. *Curr. Top. Mat. Sci.* **1**, 79–145.

HARVEY R. P. AND MCSWEEN H. Y., JR. (1996) A possible high-temperature origin for the carbonates in the martian meteorite ALH 84001. *Nature* **382**, 49–51.

HENRIQUEZ F. AND MARTIN R. F. (1978) Crystal growth textures in magnetite flows and feeder dykes, El Laco, Chile. *Can. Min.* **16**, 581–589.

IIDA A. AND AKAI J. (1996) TEM study on magnetotactic bacteria and contained magnetite grains as biogenic minerals, mainly from Hokuriku-Niigata, Japan. *Sci. Rep. Niigata Univ., Ser E (Geology)* **11**, 43–66.

KELLER L. P., THOMAS K. L. AND MCKAY D. S. (1996) Mineralogical changes in IDPs resulting from atmospheric entry heating. In *Physics, Chemistry, and Dynamics of Interplanetary Dust* (eds. B. Gustafson and M. S. Hanner), pp. 295–298. ASP Conference Series, Vol. 104, San Francisco, California, USA.

KERR R. A. (1997a) Martian "microbes" cover their tracks. *Science* **276**, 30–31.

KERR R. A. (1997b) Putative martian microbes called microscopy artifacts. *Science* **278**, 1706–1707.

LEVITT A. P., ED. (1970) *Whisker Technology*. Wiley-Interscience, New York, New York, USA. 273 pp.

MAJHI P., DEVOUARD B, POSFAI M., HUA X., BAZYLINSKI D. A., FRANKEL R. B. AND BUSECK P. R. (1997) Structural features of magnetite from magnetotactic bacteria (abstract). *Meteorit. Planet. Sci.* **32** (Suppl.), A83–A84.

MANN S. (1993) Molecular tectonics in biomineralization and biomimetic materials chemistry. *Nature* **365**, 499–505.

MANN S., FRANKEL R. B. AND BLAKEMORE R. P. (1984) Structure, morphology, and crystal growth of bacterial magnetite. *Nature* **310**, 405–407.

MANN S., SPARKS N. H. C., WALKER M. M. AND KIRSCHVINK J. L. (1988) Ultrastructure, morphology, and organization of biogenic magnetite from Sockeye salmon, *Oncorhynchus nerka*: Implications for magnetoreception.. *J. Exp. Biol.* **140**, 35–49.

MANN S., ARCHIBALD D. D., DIDYMUS J. M., DOUGLAS T., HEYWOOD B. R., MELDRUM F. C. AND REEVES N. J. (1993) Crystallization at inorganic-organic interfaces: Biominerals and biomimetic synthesis. *Science* **261**, 1286–1292.

MCKAY D. S., CLANTON U. S. AND MORRISON D. A. (1972) Vapor-phase crystallization in Apollo 14 breccia. *Proc. Lunar Sci. Conf.* **3rd**; Suppl. 3, *Geochim. Cosmochim. Acta* **1**, 739–752.

MCKAY D. S., GIBSON E. K., THOMAS-KEPTRA K. L., VALI H., ROMANEK C. S., CLEMETT S. J., CHILLIER X. D. F., MAECHLING C. R. AND ZARE R. N. (1996) Search for past life on Mars: Possible relic biogenic activity in martian meteorite ALH 84001. *Science* **273**, 924–930.

MCKAY D. S., GIBSON E. K., THOMAS-KEPTRA K. L., ROMANEK C. S. AND ALLEN C. C. (1997) Possible biofilms in ALH 84001 (abstract). *Lunar Planet. Sci.* **28**, 919–920.

MCKAY G. A. AND LOFGREN G. E. (1997) Carbonates in ALH 84001: Evidence for kinetically controlled growth (abstract). *Lunar Planet. Sci.* **28**, 921–922.

MORIMOTO N., GYOBU A., MUKAIYAMA H. AND IZAWA E. (1975) Crystallography and stability of pyrrhotites. *Econ. Geol.* **70**, 824–833.

MUKHERJEE B. (1969) Crystallography of pyrrhotite. *Acta. Cryst.* **B25**, 673–676.

NABARRO F. R. N. AND JACKSON P. J. (1958) Growth of crystal whiskers, a review. In *Growth and Perfection of Crystals* (eds. R. H. Doremus, B. W. Roberts and D. Turnbull) pp. 11–101. J. Wiley and Sons, New York, New York, USA.

NADGORNYI E. M. (1962) The properties of whiskers. *Sov. Phys. Usp.* **5**, 462–477.

PASHLEY D. W. (1956) The study of epitaxy in thin surface films. *Advan. Phys.* **5**, 174–179.

PASHLEY D. W. (1975) A Historical Review of Epitaxy. *In Epitaxial Growth* (ed. J. W. Mathews), pp. 2–27. Academic Press, Orlando, Florida, USA.

PEDONE V. A. AND FOLK R. L. (1996) Formation of aragonite cement by nanobacteria in the Great Salt Lake, Utah. *Geology* **24**, 763–765.

PÓSFAI M., BUSECK P. R., BAZYLINSKI D. A. AND FRANFEL R. B. (1988) Reaction sequence of iron sulfide minerals in bacteria and their use as biomarkers. *Science* **280**, 880–883.

PULLIUM G. R. (1967) Chemical vapor deposition of single-crystal magnetic oxide films. *J. Appl. Phys.* **38**, 1120–1126.

ROYER L. (1928) Recherches expérimentals sur L'epitaxie ou orientation mutuelle des cristaux d'espéces différences. *Bull. Soc. Fr. Mineral. Crist.* **51**, 7–46.

SCHLOM D. G., EOM C-B., HAWLEY D., FOSTER M. E. AND SPECK J. S., EDS. (1997) *Epitaxial Oxide Thin Films III.* Mat. Res. Soc. Symp., Proc.Vol. 474. 419 pp.

SCOTT E. R. D., YAMAGUCHI A. AND KROT A. N. (1997) Petrologic evidence for shock melting of carbonates in the martian meteorite ALH 84001. *Nature* **387**, 377–379.

SKINNER B. J., ERD R. C. AND FRANK S. G. (1964) Greigite, the thiospinel of iron; a new mineral. *Am. Mineral.* **49**, 543–555.

SYMONDS R. (1993) Scanning electron microscope observations of sublimates from the Merapi Volcano, Indonesia. *Geochem. J.* **26**, 337–350.

TALLMAN R. L. AND GULBRANSEN E. A. (1967) Dislocation and grain-boundary diffusion in the growth of alpha ferric oxide whiskers and twinned platelets peculiar to gaseous oxidation. *J. Electrochem. Soc.* **14**, 1227–1230.

THOMAS-KEPTRA K. L., ROMANEK C., WENTWORTH S. J., MCKAY D. S., FISLER D., GOLDEN D. C. AND GIBSON E. K. (1997) TEM analysis of fine-grained minerals in the carbonate globules of Martian meteorite ALH 84001 (abstract). *Lunar Planet. Sci.* **28**, 1433–1434.

THOMAS-KEPTRA K. L., BAZYLINSKI D. A., GOLDEN D. C., WENTWORTH S. J., GIBSON E. K., JR. AND MCKAY D. S. (1998) Magnetite from ALH 84001 carbonate globules: Evidence of biogenic signatures (abstract). *Lunar Planet. Sci.* **29**, 1494–1495.

TOKONAMI M., NISHIGUCHI K. AND MORIMOTO N. (1972) Crystal structure of a monoclinic pyrrhotite ($Fe_7S_8$). *Am. Mineral.* **57**, 1066–1080.

TRIEMAN A. H. (1998) The history of ALH 84001 revised: Multiple shock events. *Meteorit. Planet. Sci.* **33**, 753–764.

VALI H. AND KIRSCHVINK J. L.(1990) Observations of magnetosome organization, surface structure, and iron biomineralization of undescribed magnetic bacteria: Evolutionary speculations. In *Biominerals* (eds. R. B. Frankel and R. P. Blakemore), pp. 97–115. Plenum Press, New York, New York, USA.

VEBLEN D. R. AND POST J. E. (1983) A TEM study of fibrous cuprite (chalcotrichite): Microstructures and growth mechanisms. *Am. Mineral.* **68**, 790–803.

VELIKOBERETS T. A. (1968) Mechanism of face formation in magnetite crystals accompanying metasomatism and recrystallization. *Dokl. Akad. Nauk SSSR* **182(1)**, 179–182.

WAGNER R. S. AND ELLIS W. C. (1965) The vapor-liquid-solid mecahanism of crystal growth and its application to silicon. *Trans. Metal. Soc AIME* **233**, 1053–1064.

ZIES E. G. (1929) The Valley of Ten Thousand Smokes. *Nat. Geogr. Soc. Contr. Tech. Pap.* **1**, 1–74.