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FUTURE GEOPHYSICAL TECHNIQUES FOR PROBING BENEATH THE REGOLITH - PROSPECTING OBJECTIVES David W. Strangway University of Toronto

After the presentation by H. Davis, when it was pointed out that Canada and Trudeau had cut the U.S. off their oil supplies, I'm not sure that I should really stand up here and talk about things from a Canadian point of view, but nevertheless I'm here and will say something about geophysical methods of exploring the Moon. I'm going to say a little bit about magnetic and electromagnetic methods as they might be applied to understanding the nature of the near surface of lunar materials. It's obvious from many of the previous discussions that the use of lunar materials is going to require us to understand something about how they are distributed. This is where geophysical methods can play a role. It is rather interesting that in the lunar environment I believe that it is possible to do much more, more effectively, in terms of geophysical techniques than it is in terrestrial problems. This is largely because in the terrestrial environment, we have water which causes rocks to be conductive. The dry nature of the lunar surface means that electromagnetically we can penetrate to very significant depths in the surface and we can do a high-resolution mapping of a kind that we are unable to do in the terrestrial environment.

I want to refer to just two methods although there are many others that could be used. I actually should perhaps qualify this discussion by saying that about 3 or 4 years ago, about a year and a half before Apollo 17 went, I remember going through a very similar kind of discussion with Chris Kraft and a number of high-level managers at the center because there was a move at one point to try to automate the rover on Apollo 17 and to leave it behind to traverse several hundred kilometers across the lunar surface and do some of the things that I'm going to talk about now. Naturally, too late, and too expensive and it would have introduced many complexities into the mission at that point.

Figure 1 illustrates the distribution of metallic iron among different materials on the surface. Of course, the soils or the regolith is the material that people are most interested in. And, as you can see, there's something like 0.5 weight percent metallic iron distributed through the lunar regolith materials. If we were going to run magnetometer surveys or traverses across the lunar surface, there would be significant anomalies due to the remnant magnetic fields. This would be a noise problem from the point of view of trying to map the distribution of iron because you would have to worry about eliminating them. In terrestrial exlploration, you always have a magnetic field present -

a very significant magnetic field - and this permits you to map the induced fields with a small component of remanent field. The induced fields can then be interpreted in terms of the magnetite content or the magnetic minerals that are present. On the lunar surface, there is essentially no field and therefore essentially no induced magnetization and therefore you would not be able, with a simple magnetometer system as such, to map the distribution of metallic iron. You would not be able to map the distribution of iron on the lunar surface without doing something a little more clever than just taking a magnetometer around. A magnetometer would find you anomalies, but they would have no particular relationship to the amount of metallic iron present. You would have to use an artificial source. You could lay a large coil out on the surface that could be used to generate a static dc field. This would magnetize the surface. You would then traverse with a system which would map the magnetic field both in the presence and in the absence of this artificial source located at a lunar base or at a base station. From the differences between these two, you could then map the susceptibility distribution, which would then be directly interpretable in terms of the metallic iron distribution in the upper part of the surface.

I have to mention that there would be a complexity to this; perhaps it's a detail. In figure 2 it can be seen that the magnetic properties of the lunar materials are, in fact, very complex. After you turn off a static dc source, the magnetization continues to decay for a considerable length of time. So, by looking at the way in which this magnetization decays as a function of time and by looking at the strength of the mangetic field that would be created due to your artificial source, you would be able to say something about the distribution of the grain size of the iron as well as about the amount of the material. So fundamentally then you would have to use an artificial-source technique which could map the susceptibility variation. This could be interpreted in terms of the metallic iron present. By looking at the time dependence, you could also determine something about the distribution of the grain sizes of this metallic iron.

Now let me turn to the next set of methods. These are the electromagnetic methods. Conventionally the Earth contains very conductive materials. This means that when we put a transient or a pulse of electromagnetic energy out, that the eddy currents generated will simply circulate through the materials. One then attempts to measure these eddy currents as a result of the applied transient. These are very well known techniques. There are airborne systems flying all over the world in the exploration for mineral deposits and they're all dependent on the fact that there are eddy currents being generated. The thing you would map in an electromagnetic experiment on the moon would, in fact, be dielectric constant and as figure 3 is attempting to illustrate, the dielectric constant of the returned lunar soils is almost entirely a function of the density. You could then map the thickness of the regolith in very considerable detail.

In figure 4, we show the loss tangent or the losses associated with lunar samples. The ones with open symbols are measurements that may have been contaminated during the lab processes by small amounts of moisture and the set that do not have the squares on them represent good, high-quality, high vacuum measurements made of the loss tangent. We have indicated that the losses seem to be very much controlled by the ilmenite content. So the dielectric constant itself is largely controlled by the fact of whether the material is soil or solid and the loss tangent is controlled in part by the density and in part by the amount of ilmenite that's present in the material. Now if you were to attempt to build a system which you could be put on a roving vehicle which would be a time-domain system, where you'd send up pulses and watch them reflect, you would be able to map the lunar regolith. You would undoubtedly pick a frequency less than about 30 megahertz. It turns out that at higher frequencies there are enough boulders and they are large enough that the Moon is good scatterer. In fact, at radar frequencies, it's a very good scattering object, but at around 30 megacycles and from there on down we know that the Moon is a very smooth object. There are not very many large boulders that would cause scattering. Basically this means, then at 30 megacycles, the Moon is a poor scatterer, and this means that it is highly transparent. It means that you can do very high resolution mapping of stratigraphy in the top kilometer of the lunar surface, giving you a good measure of the thickness and the nature of the regolith as you traversed across the surface. Finally, of course, because of the ilmenite content, if there were massive concentrations of ilmenite, these would be very good reflectors. I remind you that the ilmenite on the lunar surface is completely nonmagnetic, so you would not look for ilmenite with any of the magnetic methods, but high concentrations of this material would cause the surface to behave as good reflectors. So electromagnetic exploration on the Moon could be done quite effectively, it could be done with high resolution and it could be done to considerable depth. It would detect not only the stratigraphy just as one does in ice sounding - but it would also be a way of mapping the ilmenite content distribution.

I believe these techniques could become very effective for great depth penetration, for high-resolution mapping, and for mapping very carefully and in much detail the distribution of metallic iron and the distribution of any metallic conductors or good reflectors. So geophysical mapping on the lunar surface, in fact, could be a very useful method of prospecting or exploring for these kinds of materials. I suppose I should finish off by pointing out that there have been a number of papers mentioning water. Of course, everybody would like to use electromagnetic methods to find water. They are not going to do you very much good, I believe, in the lunar environment. First of all, water molecules can stick themselves onto surfaces. Because of the large surface area associated with lunar samples, you can probably stick up to almost 0.1 percent of water, as a monolayer , which gets very tightly bound onto the surfaces and does not then affect the electrical properties very significantly. That amount of water is kind of a threshold level for detection. If there was any more than that, you would probably detect it. Any less than that and it is so tightly bound that it does not respond and cannot be detected. Water might be present in the form of ice in the polar regions. Again this would be a problem. If you freeze

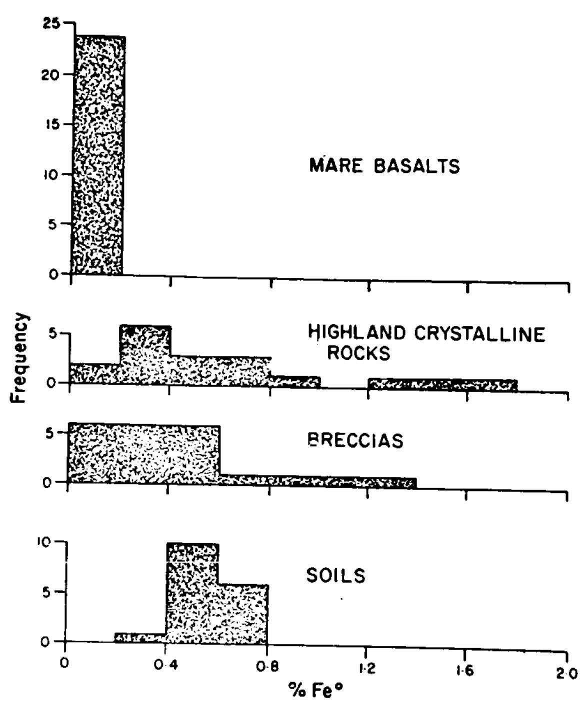
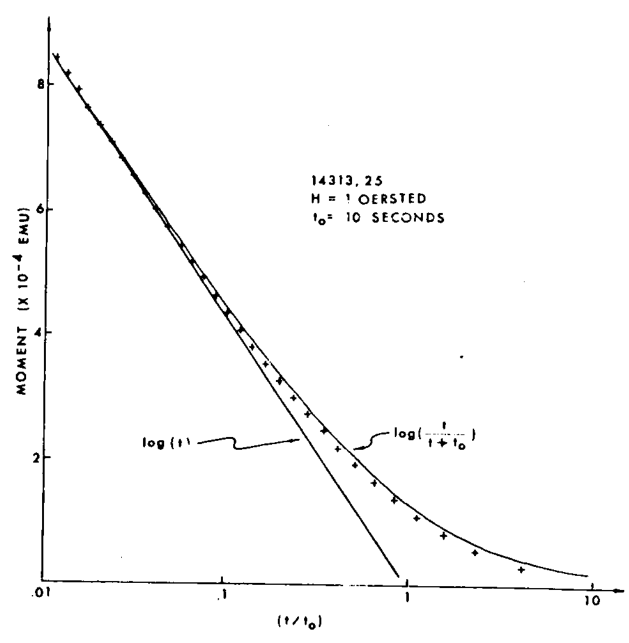


FIGURE 1:

Distribution of metallic iron in various types of lunar materials.

FIGURE 2:

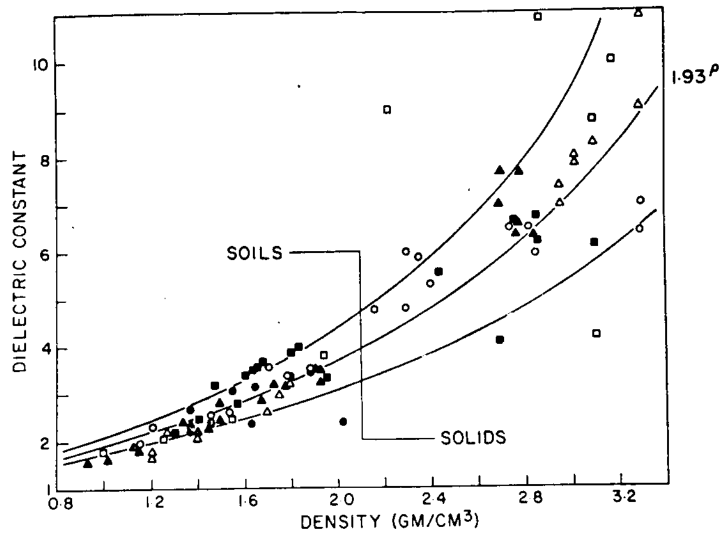
Decay of magnetization in a soil breccia after magnetic field is turned off - x are experimental points and show the so-called magnetic aftereffect which lasts for longer than the time of application of the field.

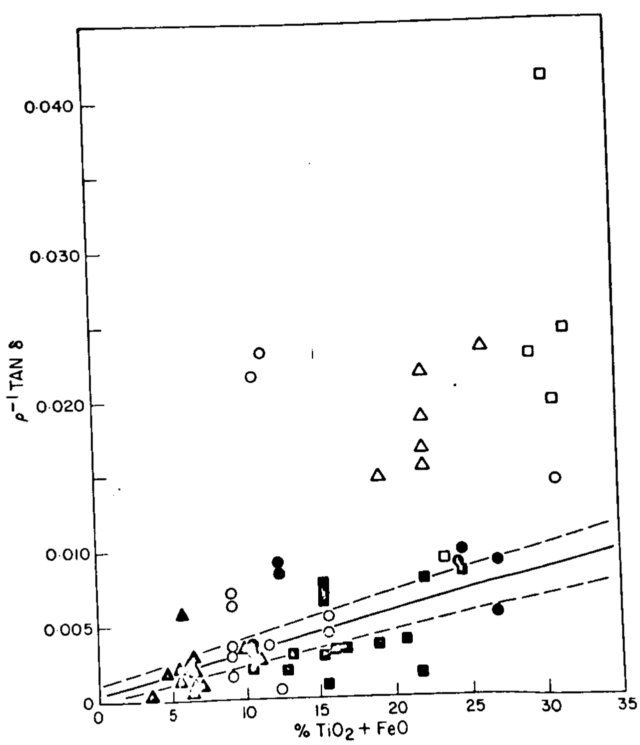


the water, it also becomes a very poor conductor and the molecules are not able to respond to the electromagnètic fields. Therefore, whether there is less than 0.1 percent or whether there is a lot of it present in the form of very hard forzen ice, you would not really be able to detect the water. Either of those two cases would be transparent essentially to the electrical methods.

FIGURE 3: →

Dielectric constant of lunar samples as a function of density - open symbols for Apollo 11,12, 14 where moisture not carefully controlled.





← FIGURE 4:

Density normalized loss tangent versus chemical analysis of titanium and iron (approximately ilmenite content). Open symbols are for early measurements where moisture was not well controlled.

DISCUSSION (Strangway Paper)

SPEAKER 1: You mentioned this prospecting was considered on Apollo 17. Do you have any idea of what the mass would be of a device - not the traversing device, but just the prospecting device that you'd need. Is this a very big thing or a small thing?

STRANGWAY: No, these devices I'm sure can be packaged into 5-, 10-, 15-pound type of units. If you're going to put it on an automated vehicle that would obviously be much the controlling factor. There were experiments of this general nature that were carried. You wouldn't carry those same experiments in the same form. You know, you would take the knowledge that you now have and do the thing rather differently, but I'm sure the basic packaging and electronics and all the rest of it could easily be put into 15- or 20-pound packages quite readily.

SPEAKER 2: Dave, I know the purpose of our geophysical surveys is to find concentrations of economic value so we can pay the geophysicist for his Jeep and his axe and his beer and the other things he needs to go do these good things. And I understood that the regolith is, by comparison to the Earth's crust, an undifferentiated source. Could you give any quantification at all of the relative merits of doing these geophysical surveys in the context of this session this afternoon of an economic type of thing?

STRANGWAY: I can't really give you an answer to that. These would be largely tools that would map the geometry of this material. If you picked your frequencies right, you probably also could set it up so that you could get a distribution of the particle sizes. And if it was important in the manufacturing process that you don't pick up areas and sample areas with lots of big boulders and things in them, you might first pick an area in which there is a fairly thick amount of fairly fine grained material and then that would become your base of operations. So I would think of these as sort of presurveys, if you like, for looking for these particular kinds of conditions. If ilmenite was important to you and you were wanting to extract that, you would obviously again want to pick the area where there was the greatest amount of that material present. It's not an easy question for me to answer in terms of tradeoffs, but if you found variations from place to place of factors of 2 or 3 in some of these things, I would assume that that would make a fair amount of difference in the manufacturing or the extraction/mining process itself.

SPEAKER 2: Is that order of differentiation you're looking for, factors of 2 or 3 rather than thousands as we have on the Earth's crust?

DISCUSSION (Strangway Paper)

STRANGWAY: I think probably that's right. I think the soil tends to have a sort of a homogeneity to it. That's right.

SPEAKER 3: Just a bit in response to that last question. We've looked a little bit at this problem. If you look at the analog of Meteor Crater in Arizona, although most of the impacting projectile is destroyed or disrupted during the impacting, a small fraction is injected as lenses in the wall rock. In other words, in Meteor Crater you have lenses of mixed nickel-iron with the bedrock. These type of things might be locatable in the walls of the small impact crater.

STRANGWAY: If we open that door, you know, we can get ourselves into long discussions as to the amount of material that is present in the soils of meteorite contamination in general. And certainly there is some, but I think many people now agree that percentagewise, in terms of the metallic iron that's being found in these areas, very little of it is probably of extralunar origin. Some of it, certainly, and I think there's no question that some of it is, but the bulk of what we're talking about in here is very fine grained and it's processed or it's developed in situ as a result of these impacting processes. So I guess in principle, while I would have to say it sounds reasonable, there is really very little evidence that there's very much of this kind fo stuff to be found.