ON PERFORMANCES OF GROUND PENETRATING RADARS FOR MARS SUBSURFACE EXPLORATION.

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Introduction: Among the future missions for Mars exploration, two will operate ground penetrating radars. The first one is the Netlander mission (CNES) that proposes four landers, each carrying a 2 MHz fixed GPR [1]. The second one is the Mars Express mission (ESA) that will fly an orbital sounding radar [2]. Both instruments aim at exploring the first layers of the martian subsurface for water and ice detection down to a depth of ~3 km. This radar penetration depth was estimated for the Netlander instrument using an electromagnetic numerical simulation [1]; these computations were first made with a simple model of the martian megaregolith under the form of successive layers of sediments, fresh basalt, ice and water. An attempt was also made to take into account the effect of iron oxides in the upper 30 meters of the soil but the possible effect of salts and clays that could be also present in the martian soil has not yet been looked at. We present here the results of recent experiments in the Republic of Djibouti, a region that looks very similar to Mars, which show that these elements could dramatically decrease the radar penetration because of strong conduction and relaxation losses.

Ferromagnetic and salt materials in Mars subsurface. Recent results show that the martian subsurface is likely to contain ferromagnetic materials [3,4,5] such as maghemite for instance. Other iron bearing minerals such as hematite were also detected in the martian soil [6,7]. The presence of hematite could be explained by hydrothermal alteration of iron rich basalts [8]. Such hydrothermal activity could also generate evaporites [9,10,11] which are very conductive in presence of water. In particular, cementing sulfur salts [12] and gypsum dunes [13] are suspected on Mars. All present models of the martian soil predict that the subsurface materials are perfectly dry down to ~2 km and the effect of salts should then be much reduced (compared to the Djibouti case where the measured high conductivity seems to indicate a certain level of humidity). Nevertheless, the upper layers of the martian soil could be highly conductive and magnetic, leading to significant conduction and relaxation losses, and hence reducing the radar depth of investigation [14].

A test site in Djibouti. GPR fieldwork experiments were conducted in February 1999 at frequencies of 100 and 500 MHz in a terrestrial site that may provide a good terrestrial analogue to Mars: the Republic of Djibouti in East Africa (see Fig. 1) [15]. It is located in the Afar depression, a triple junction between Somalia, Arabia and the rest of Africa that presents a unique emerged rift with active basaltic volcanism. This region is arid, with very rare vegetation. Basaltic rocks found in Djibouti have similar mineral content than martian basalts analyzed by Viking and Mars Pathfinder instruments, as shown in Table I. Basalts found in Djibouti originate from layering flood lavas (the Afar Stratoid Series [16]) that look like the stratigraphy of the upper crust of Mars as revealed by high resolution MOC imagery [17]. The sediments produced by alteration and weathering of these basalts have strong magnetic properties and contain a high concentration of iron bearing materials. Calcareous lacustrine deposits can also be observed in several places. Moreover, the Djibouti region shows strong hydrothermal activity [18] that produces large quantities of evaporites and gypsum. Finally, as for Mars, the whole region is covered with fine basaltic dust.

A first analysis of GPR data collected during the February 1999 investigations indicate a penetration depth of less than 5 meters at 100 MHz. Figure 2 presents signal attenuation in various materials: basaltic sand, rhyolites, calcareous lacustrine deposits (diatomite), clay and fresh basalt.

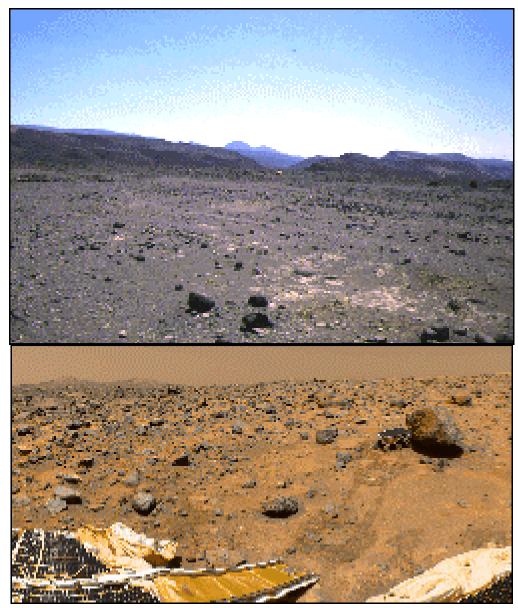

Figure 1: A typical djiboutian landscape (top), compared to a Mars Pahtfinder scene (bottom).

Element	XRF Viking [1]	APXS Pathfinder[2]	Djibouti basalt	Djibouti basalt βs_{II}[3]
SiO_2	44.5	55.5	45.09	55.78
FeO	17.4	13.1	17.74	10.0
Al_2O_3	7,15	9.1	12.98	13.47
MgO	6	5.9	5.73	4.16

CaO	5.7	6.1	9.58	7.53
TiO_2	0.58	0.8	3.72	2.46
K_2O	< 0.5	0.8	0.31	1.91
MnO	-	0.4	0.26	0.17
Na_2O	-	1.7	2.79	2.89

Table I. Average percent chemical composition of martian and djiboutian rocks (basalts), [1]after Clark *et al.* 1982, [2]after Rieder *et al.* 1997, [3]after F. Gasse *et al.* 1987.

Penetration depth ranges from 1 to 3 metres, with a better penetration for calcareous materials. Electrical conduction losses in iron minerals, salts and clays (very low resistivity values around 10 Ω.m were measured in sediment areas during previous fieldwork experiments [19,20]) combined with magnetic relaxation losses seem to be responsible for such poor penetration performances.

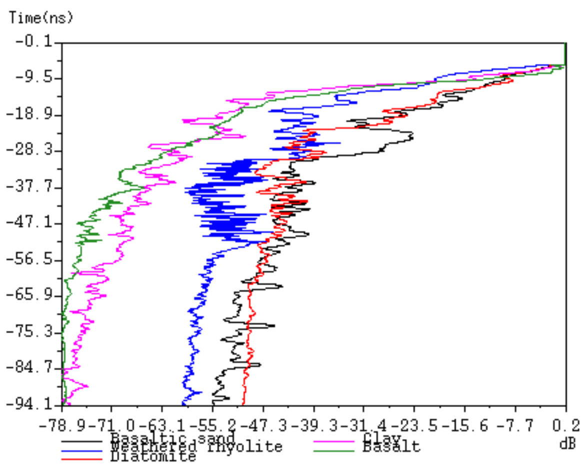

Figure 2: Radar signal attenuation for various materials at 100 MHz.

Consequences for martian radars. Attenuation effects should be carefully studied when considering Mars surface, excepted possibly for polar caps covered with ice. One could in particular think of the Djibouti region as a test site for GPR prototypes that will be launched to Mars. Experimental work and theoretical models have to be developed in order to better understand the role of ferromagnetic minerals, evaporites and clays with respect to radar performances. As operating frequencies foreseen for Netlander and Mars Express radars are much lower (around 2 MHz) than the one used so far in Djibouti, one should also take into account the diffusion effects. This work will be of crucial importance for interpreting future Netlander and Mars Express data (do we detect water, ice, salt sediments, or a transition between a ferromagnetic and a non ferromagnetic layer ?) and to define optimal radar characteristics (frequency, polarimetric capabilities for instance). However, even if actual radar penetration performances for Mars could be much lower than the initial estimation of 3 km, the penetration depth could be an interesting indicator to select sites for exobiological tests and sample return: ferromagnetic regions corresponding to weak penetration are likely to be bad sites for finding any past features of biological activity since the lava flows could have erased evidences, while regions with a good penetration coefficient, such as ones containing carbonates, should better preserve traces of past or actual biological activity. One could in particular use Mars Express radar global mapping capability in order to detect possible carbonate deposits, a high valued target of future Mars exploration.

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References: [1] Berthelier J.-J. et al. (1999) *Planetary and Space Science*, submitted. [2] Picardi G. et al. (1999) *Mars Exploration Program and Sample Return Mission Conf.*, Paris. [3] Hviid S.F. et al. (1997) *Science*, 278, 1768-1770. [4] Banin A. et al. (1992) *In Kieffer et al.*, 594-625. [5] Rieder R. et al. (1997) *Science*, 278, 1771-1774. [6] Lane M.D et al. (1999) *30th LPSC*, Houston. [7] Bell J.F. and Morris R.V. (1999) *30th LPSC*, Houston. [8] Christensen P.R. et al. (1999) *30th LPSC*, Houston. [9] Banin A. (1999) *Mars Exploration Program and Sample Return Mission Conf.*, Paris. [10] Cooper C.D. and Mustard J.F. (1999) *30th LPSC*, Houston. [11] Catling D.C. (1999) *Mars Exploration Program and Sample Return Mission Conf.*, Paris. [12] Bell J.F. (1999) *5th Int. Conf. On Mars*, Pasadena. [13] Thomas P.C. et al. (1999) *Nature*, 397, 592-594. [14] Olhoeft G.R. (1998) *7th Int. Conference on GPR*, Lawrence. [15] Paillou P. et al. (1999) *IGARSS'99*, Hamburg. [16] Barberi F. and Santacroce R. (1980) *Bull. Soc. Géol. France*, 7(6), 891-899. [17] McEwen A. et al. (1999) *Nature*, 397, 584-586. [18] Pouchan P. (1974) *In Carte Géologique d'Easal*, CEGD Bordeaux - Djibouti. [19] Pham Van Ngoc et al. (1980) *Bull. Soc. Géol. France*, 7(6), 863-871. [20] Coopératation technique Djibouti - RFA (1982) Projet 78.2233.1, vol. III.