

COMPARATIVE STUDY OF MARTIAN AND EARTH'S FROZEN ROCKS BY TDEM METHOD AND INSTRUMENT

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Introduction:

The MARSES is the TDEM sounding instrument developed of searching for water, water-ice or permafrost layers existing in some depth under the visible surface of Mars. There are many evidences that water once was abundant on Mars.

There are stream lined islands formed by flowing water, flow patterns reminiscent of wadis in Earth deserts, and outflow channels thought to have been formed by sudden out-rush of subterranean water. The secondary task is to measure the soil properties of the subsurface of Mars, which include porosity, electrical resistance of the liquid phase, thermal conductivity, temperature dependence. A main task of the MARSES system is to examine changes in subsurface properties of local areas regolith on the martian surface, and to relate them to optical images and other remote sensing data in order to understand the nature of different terrain forms. The dried up regions of Martian frozen rocks is considered to have been developing during more than 3.5 bln years, so the upper layer boundary of permafrost can serve as an indicator reflecting the course of martian paleoclimate evolution [1].

Subsurface Science

Analysis of the ground-based geophysical cryolithozone related to electromagnetic studies, which takes into account characteristics of the preliminary electrodynamics model of martian cryolithozone. This model based on the current geological concepts of the cryolithozone structure, on the estimations of the ice containing material or wet fraction of subsurface horizons at negative temperatures, on physicochemical transitions in the solutions of KCl, NaCl, CaCl₂ with the martian regolith and so on. All of them show the potential possibilities of the Mars electromagnetic sounding in the depth range up to one kilometer both the planetary surface or satellite orbit.

The presence of the low conductivity screens in the cross section structure and bad grounding conditions decrease the efficiency of the traditional (or so called vertical methods of electric

sounding or VES) contact sounding methods. But such a screen is not a barrier for magnetic field and in these conditions an inductive sounding with controlled source is more useful.

The usefulness of different methods of the inductive sounding (frequency modulation or impulsed one) in cryolithozone studies is defined by the following factors:

- cryolithozone is characterized by the relatively low conductivity of permafrost soil of weak contrast of geoelectric section;
- the season variations of phase state of upper and deep layers of martian surface may exit;
- the high and low conductivity screens at the surface and in the depth of permafrost soil may also exit.

These aspects can limit the possibilities of the high frequency sounding (HFS) method for Mars cryolithozone structure studies. The experience in experimental studies of permafrost clay formation in the earth conditions, which are similar to martian permafrost soil, shows that the depth limit of HFS methods is about 50 m.

VIKING and Opportunity Mars Rovers experiments showed that Martian soil contains substantial component of magnetic materials (about 4%) and therefore Martian surface deposits belong to the soil class, completely different from lunar regolith, and whose properties are widely used to estimate the attenuation in the HFS method. Chemical composition of Mars subsurface material is characterized by the following parameters: 40-45% SiO₂, 7-7.5% Al₂O₃, 17-19% Fe₂O₃, 5-7% MgO, 5-6% CaO, 0.4-0.7% TiO₂, 6-7% SO₃, 0.3-0.9% Cl and traces of K.[2]

Chemical analysis based on the conclusion that 60-80% of Martian soil material are the smectic clay mixtures with different soluble salts, such as keyserite (MgSO₄) or sodium chloride (NaCl). iron oxide (Fe₂O₃), calcites (CaCO₃) and quartzites (SiO₂) are supposed to be present also.

Martian soils are substantially different according to their properties in comparison with the pure surface ices and glacier ices on the Earth. The relative magnetic susceptibility of the Earth soils is close to 1, but Martian soils may have much more higher values of magnetic susceptibility.

Estimations show that the attenuation in this environment could be several orders of magnitude higher than in ice.

Therefore even in martian equatorial regions (from -30° to +30° latitude) with several hundred of meters palagonites or montmorillonites layers the HFS method could not give an information about cryolitozone structure up to the depth of 500 m, which is upper border of ice-bearing layer. In the middle latitude region (from 30° to 50°) the depth of upper border of permafrost layer should be equal to 100-150 m and though at high latitudes it might be even at the surface and in this case HFS method allows one to measure the depth of permafrost [3,4].

The difficulties of the estimation of attenuation (which is in its turn the sounding depth) require the comparative studies in the natural earth conditions close to martian ones.

Physical basis of the TDEM Sounding method

In the TEM sounding the transmitter and receiver coils are used. In some cases, the transmitter loop is also used as the receiver coil (coincident loop). When the current is switched on or off in the transmitter coil then field induces subsurface eddy currents which are in their turn induce secondary voltage in the receiver coil. For the homogeneous half-space (in the near zone) the induced voltage in the receiver coil is given by

$$E(t) = I * Q * q * (\rho \pi)^{-3/2} (\mu / t)^{5/2} / 20 \quad (1)$$

where Q, q - the surface of a transmitter and a receiver coil (m²) respectively,

$\rho = 1/\sigma$ - resistivity (1/Ωm),

μ - magnetic susceptibility.

In this case the sounding depth (the skin-layer thickness) can be estimated as

$$\delta \sim 2 / (t * \rho)^{1/2} = Z. \quad (2)$$

On the Earth the minimum receiving signal may be ~ 10 μV, on the Mars where industrial noises are absent it can be order of magnitude less, which gives possibility to study more deep layers.

The sounding in the near zone implies the limitation on the dimension of the coil, defined by:

$$L(\text{coil}) \sim \delta. \quad (3)$$

The main parameters of Transient Electromagnetic Device for Mars Electromagnetic Sounding

First of all, we have to establish the necessary relations between of sounding time t (□s), the level of signal in the receiver coil E (□V) and the

depth of sounding Z (m), which is estimated on the base of the skin-layer thickness.

These relations are [5]:

$$E(t) = 1.6 * 10^4 * (I * Q * q) * (\rho^2 t^5)^{-0.5}, \quad (4)$$

$$t = 50 * (I * Q * q / E)^{0.4} * \rho^{-0.6}, \quad (5)$$

$$Z = 7 * (\rho * I * Q * q / E)^{0.2}. \quad (6)$$

The formula (6) allows to define the depth of sounding on the base the mean resistivity of subsurface geological structure and the level of the signal in the receiver coil $E(t)$, and formula (5) allows to estimate the perpetrate time of sounding. It has been shown that the value of ρ decreases up to 100 Ω · m in the frozen salinity solution in the depth 400 m [5].

This value has been chosen as the mean resistivity of a sectional geological structure which gives the value of $E_{min} = 10 \mu V$. Let transmitter and receiver coil have 10 - turns with $R = 10 \text{ m}$ and $I = 10 \text{ A}$. Then from (5) and (6) it is easily to obtain $t_{max} = 1907 \mu s$, and $Z_{max} = 440 \text{ m}$. If we take as $t_{max} = 2000 \mu s$ and the value of ρ from relations (4)-(6) with index 10^{-2} and 10^{-3} (300 and 170 Ω·m, respectively), it will give level of signal $E = 1.7$ and $4 \mu V$, and depth $Z_{max} = 775$ and 583 m , respectively. Therefore the minimum level of signal in the receiver coil is defined as $1 \mu V$.

Transmitter generates in a wire loop a sequence of rectangular current pulses with intensity 1-10 (and more) amperes. Magnetic field is generated by these currents which flow in any conducting layers under surface.

These eddy currents establish a secondary magnetic field, which is registered by a receiver loop. Since the eddy currents do not occur instantly after transmitted current is switched off, but decay gradually, their presence are detected by the transient voltage which is induced in the receiver coil.

Thus, recording of these "transients" is, in fact, means detecting conducting layers under the surface. The better conductivity of layers, the more voltage is released and the longer this transient. A recorder can measure the decay process at the various delay times. The important advantage of TDEM technology in comparison with the continuous e/m wave systems is that the measurement is taken when the transmitter is switched off.

The depth of sounding depends on the size of the loop L , current intensity I , sensitivity of the receiver, maximum delay time and subsurface soil resistivity ρ .

Comparative investigation of martian and Earth's frozen rocks

The goals of the MARSES Experiment based on the TDEM instrument is comparative

investigation of martian and Earth cryolithozone (possible investigation of subsurface relics of martian life) and the interpretation of geophysical data of subsurface soil structure [6], including :

- the theoretical development of comparative models of subsurface frozen structure for typical rocks which formed martian cryolithozone in the mixture of polygonites and montmorillonites;
- the development of the software package for detailed analysis of subsurface martian structure - porosity, electrical resistance of liquid phase, thermal conductivity, temperature dependence, which are in agreement with the interpretation of data obtained in the field testing and laboratory supporting measurements;
- the estimation of maximum depth of sounding and resolution of the MARSES instrument in the conditions of rocks close to martian subsurface soil;
- possibility to study subsurface frozen water component using TDEM instruments and induced polarization (IP) device in several areas which are close to martian conditions: Antarctic, Iceland, Hawaii (volcanic area);
- improvements of hardware and software on the base of the field studies in order to use in the earth conditions, including environmental and geophysical application, and future space experiments on the martian surface.

Choosing right methods and instruments for Mars' cryolithozone structure research is the present day task for future missions on Mars.

Data analysis of Mars' near-surface element composition (Mossbauer spectrums from Mars Exploration Rovers) shows magnetic materials presence on the surface.

In some extent it confirm the "theory of meteorite Mars' upper crust evaporating". At the same time crust structure will develop under any frequency or time-domain sounding methods in additional induced polarization effects.

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