ELECTROMAGNETIC PHENOMENA IN LANDSLIDES

Andrzej PRAŁAT [1)]*, Krzysztof MANIAK [1)] and Ivan POMPURA [2)]

[1)] *Institute of Telecommunication and Acoustics, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland, Tel. +48-713202580, +48-713203118*
[2)] *Slovenské Magnezitové Závody, akciová spoločnoct', 049-16 Jelšava, Slovenská Republika, Tel. +421-584822434*
**Corresponding author's e-mail*: andrzej.pralat@pwr.wroc.pl

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ABSTRACT
The nature of the electromagnetic phenomena, which occur in active landslides, is explained. The mechanism of electromagnetic emission generation in active landslides and EE measuring techniques are described. Special attention is given to pulsed electromagnetic emission (PEE) fields. The authors propose an original system for measuring both continuous and pulsed electromagnetic emission of landslides. For such measurements boreholes must be drilled in the landslide. It is essential that the tubing constituting the borehole's lining be made of a material, which does not attenuate electromagnetic fields. Besides its primary function, i.e. the registration of landslide electromagnetic activity, the system can be used for the examination of the structural inhomogeneity of rock strata subjected to considerable stresses. The results of EE examinations of the Kawiory landslide in south-western Poland and of the post-extraction cave in the SMZ Jelšava Mine in Jelšava in Slovakia are presented.

KEYWORDS: electromagnetic emission, landslide, landslides monitoring, PEE (Pulsed Electromagnetic Emission), slope stability

1. INTRODUCTION

It has been established that landslides when active become a source of electromagnetic radiation, which is due to the considerable mechanical stresses in the landslide's body and the occurrence of a friction force along the slip boundary between the landslide's strata. As a result, energy is released. One of the forms of this energy is electromagnetic radiation, which often has an impulse character. It has been found that landslide electromagnetic emission is within the low frequency range, practically it does not exceed 50 kHz. This is corroborated by the results of investigations carried out on the Stavlichar landslide, reported in (Mastow et al., 1989). Pulsed electromagnetic emission with the maximum intensity at frequencies below 10 kHz was registered there. Also significant was the intensified electromagnetic emission observed in periods of the landslide's heightened activity, mainly after longer rainy periods. Similar conclusions are drawn in (Rudko et al., 1989) where the results of long-term research conducted on the Krasnaja Dubrava landslide are presented. Electromagnetic emission in a frequency range of 1÷50 kHz was registered there. It is significant that the highest emission levels were registered when large blocks of rock situated close to each other and other landslide layer inhomogeneities occurred in the landslide's body. Interesting results of investigations of the complex of landslides in the Uzh Valley are reported in (Kharkhalis, 1995). As already mentioned, the electromagnetic emission of landslides usually has an impulse form. The phenomenon is called PEE (Pulsed Electromagnetic Emission). This subject is discussed in detail in (Bláha, 2002), (Duras and Bláha, 2002) and (Vybiral, 2002). The measurement of PEE fields consists in registering the number of electromagnetic impulses in a unit of time. The most common unit is impulses per second [imp./s], but this is entirely conventional. PEE fields are registered by a probe lowered in a measurement borehole having depth H. The probe reacts to the electric component or the magnetic component of the electromagnetic field, as shown in Fig. 1. An additional receiver may be placed on the surface of the ground in the immediate vicinity of the borehole to register the overground electromagnetic fields affecting the measurements.

Four basic types of PEE traces are usually registered in boreholes, as shown in Fig. 2.

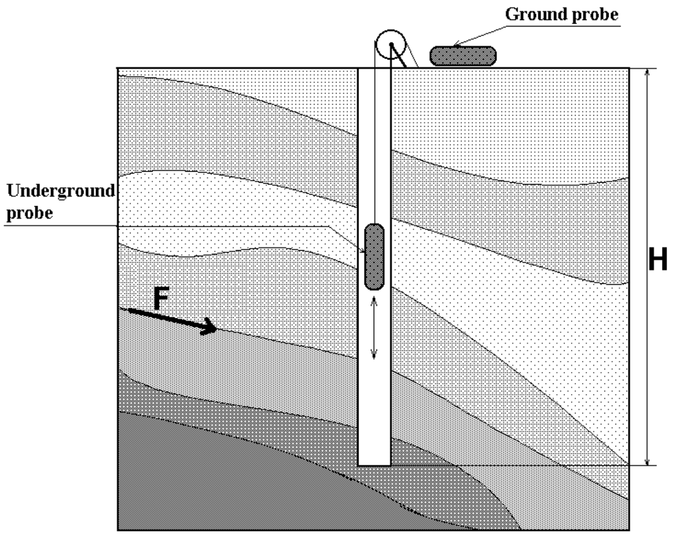

Fig. 1 PEE field measuring technique.

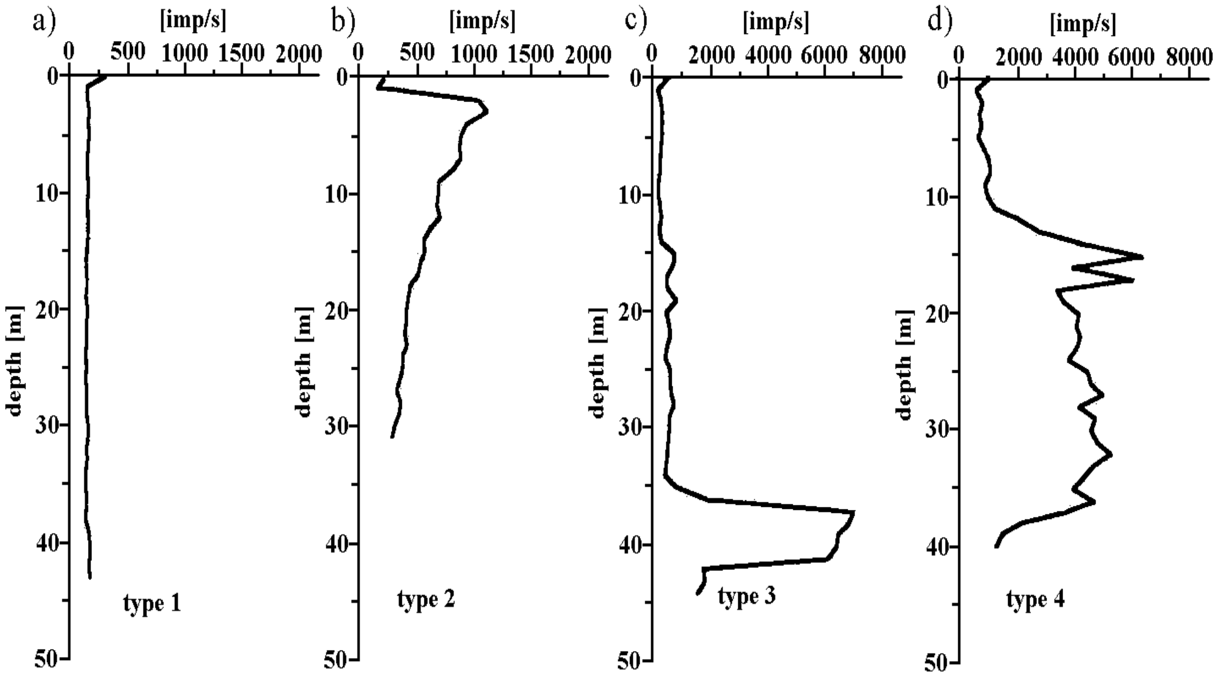

Fig. 2 Basic types of PEE fields registered in measurement boreholes, (Vybiral, 2002).

- type 1, Fig. 2a.
  A practically constant number of impulses over time (150÷300 [imp/s]) is registered along the entire borehole. A trace of this type is characteristic of rock slides. No forces or stresses, which might cause sliding, occur here. Obviously one cannot ascertain what is happening at depths below the borehole. A constant number of impulses over time is often referred to as 'background radiation'. It is worth noting that some stable landslides may emit a certain number of PEE impulses.
- type 2, Fig. 2b.
  For landslides of this type a large number of impulses is registered near the ground's surface. The number decreases with depth. This state is characteristic of landslides in which the surface layers are active. Then the surface layer rock material broken up by erosion is subject to sliding.

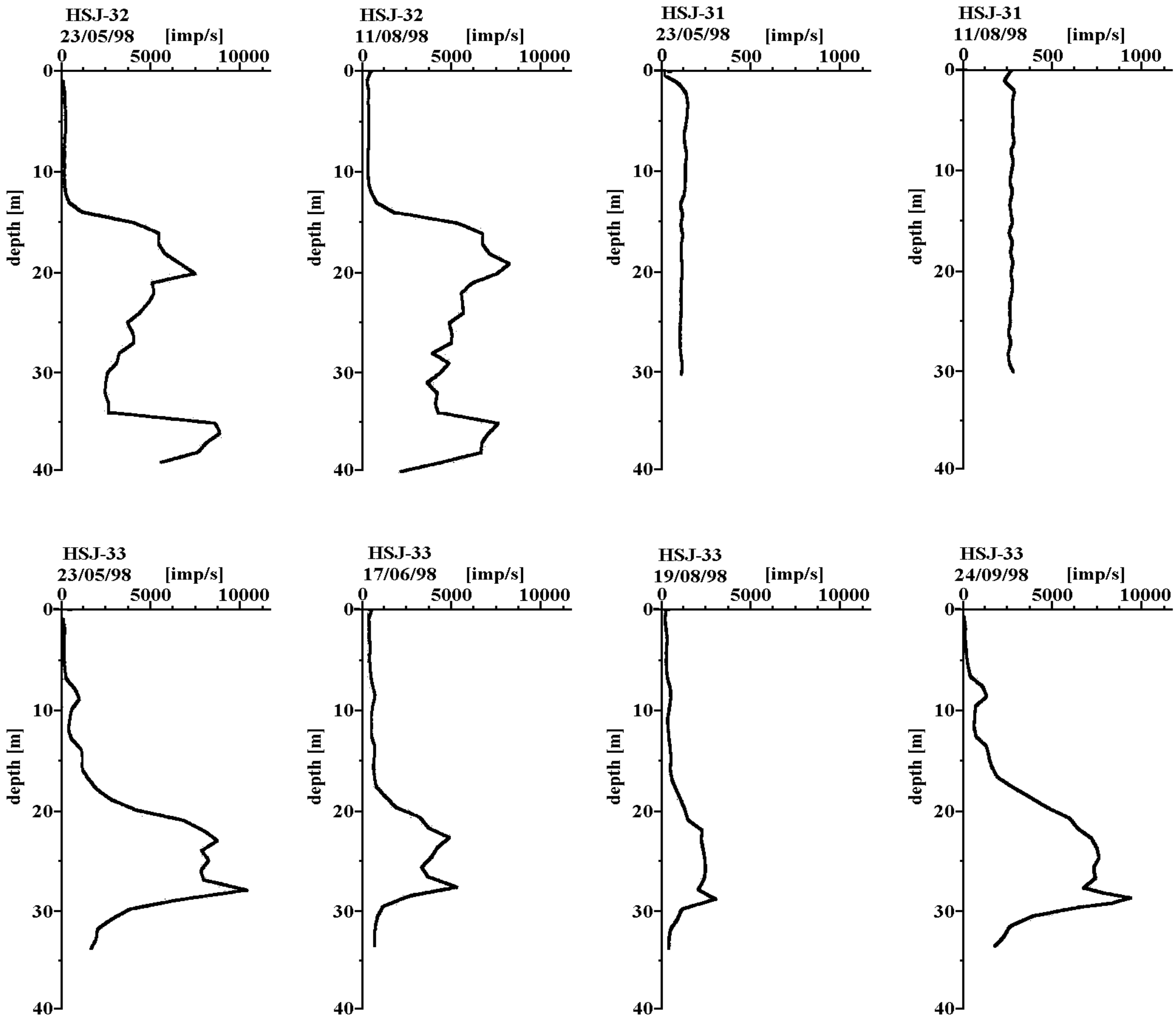

Fig. 3 Changes in number of PEE impulses over time, (Vybiral, 2002).

- type 3, Fig. 2c.
  In this case, at a certain depth the number of registered impulses increases rapidly and then quickly returns to its initial value. One can infer from such a PEE field trace that a large rock block shifting in the landslide or another inhomogeneity occurs at this depth.
- type 4, Fig. 2d.
  The landslide becomes divided into two zones: a stable zone of near-surface layers and a zone of deeper strata undergoing sliding, which is manifested by a high intensity of the PEE impulses.

As stated in (Vybiral, 2002) on the basis of long-term observations, the PEE field for each measurement borehole exhibits a similar shape over time. Only the numerical range of the scale of emitted impulses shifts as shown in Fig. 3.

2. LANDSLIDE ACTIVITY MEASURING SYSTEM

The measuring system is able to register both the pulsed and continuous electromagnetic field magnetic component along the measurement borehole down to depth H. A detailed description of the measuring system, and in particular of the investigative method, is included in patent application (Prałat et al., 2004). Measurements can be performed using two probes, referred to as measuring receivers. One of the probes, called an underground probe, is lowered in the measurement borehole at a prescribed measuring step Δh through the predicted slip plane (see Fig. 1). In the model system the measuring step is 5 cm. The other probe constantly registers the magnetic field near the borehole. From the measurement point of view, the field represents an interfering signal. It has been found that many active landslide areas are characterized by a narrow range of intensified magnetic field emission frequency. Hence the measuring probe should have

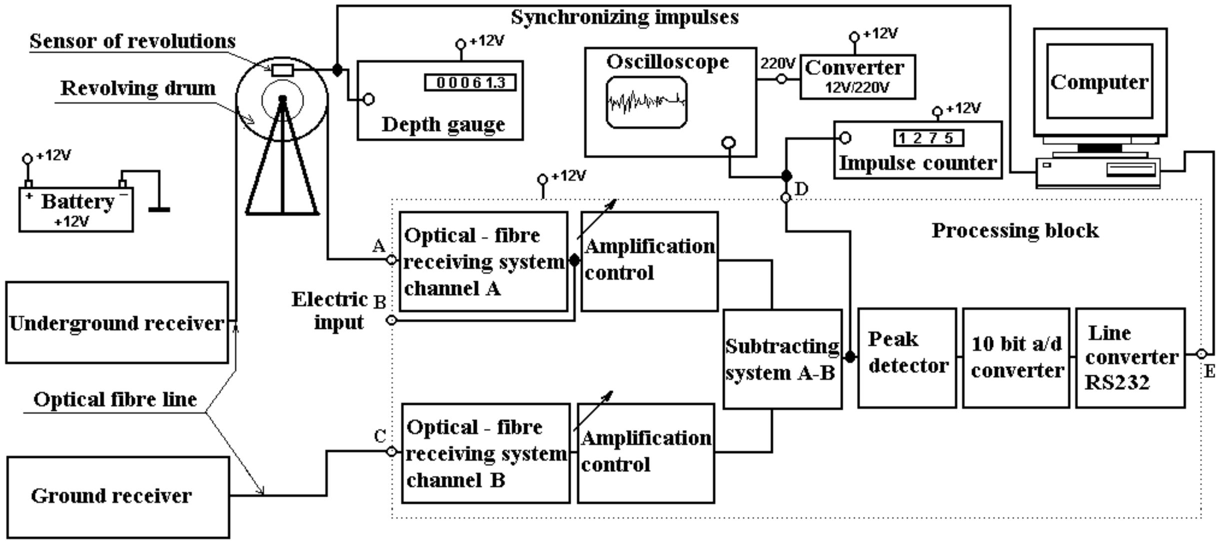

Fig. 4 Block diagram of system for measuring magnetic activity of landslides.

the properties of a band magnetic field receiver with mid-band frequency *fo* corresponding to a frequency for which the landslide magnetic activity is most intense. For the model system *fo* = 14.5 kHz was adopted. The receiver's sensitivity is $4 \cdot 10^{-6}$ A/m. The measuring probe's electronic circuit is characterized by a certain resistance to electromagnetic interference (particularly at a power frequency of 50 Hz). One should also note that interference of this type (e.g. a 50 Hz trace and its higher harmonics) can be easily eliminated since it is quite easily observable. A real interference source for a system of this type are electromagnetic signals having an impulse character and a widely spread frequency spectrum (as it is the case in combustion engines and electric motors). It is also known that electromagnetic radiation is strongly damped by layers of earth and so the influence of external electromagnetic radiation is most significant when the near-surface layers of a landslide are investigated. A block diagram of the measuring system is shown in Fig. 4. The signal from the measuring probes is transmitted by fibre-optic cables whereby the system's sensitivity to electromagnetic interference is greatly reduced. Sockets A and C are the inputs for the optical receivers for respectively the underground probe and the surface probe. The optical signal is converted into an analogue electrical signal and amplified to 1÷10 V/V. Also an electrical input (socket B) is provided for the signal from the underground probe. A subtractor with a unit amplification constitutes another block. The resultant differential signal is fed into a peak detector module. The differential signal can be watched on an oscilloscope (output D). An impulse counter which directly indicates the activity of the landslide at depth *h* is connected to output D. The constant voltage corresponding to the trace's instantaneous peak value is converted by an A/D converter which at its output provides digital information in the RS232 standard. The obtained constant voltage value informs us about the intensity of the landslide processes. The measuring signal (output E) is fed into a PC and recorded on its hard disk. In field conditions the measuring system is supplied with a voltage of 12 V from a car battery. The measuring receivers have their own symmetrical battery power supply of ±9 V.

3. FIELD MEASUREMENTS

Preliminary field measurements by means of the landslide activity measuring system were carried out on the Kawiory landslide in Szybark near Gorlice (south-eastern Poland) in August 2004 in a two week period. During that period the landslide exhibited minimal activity, which was confirmed by measurements concurrently performed by means of an inclinometer. The cause of the low activity of the landslide was a prolonged dry period, which occurred before the measurements. The landslide is composed of solely a mass of clay flowing in its entire volume without any distinct slip planes. The probe was introduced into the measurement boreholes drilled for the inclinometric measurements. The boreholes were lined with an insulated PVC tube. PVC does not damp electromagnetic fields and most importantly, it does not significantly change the shape of the traces of electromagnetic field electric and magnetic components. Plastic is also a good electric insulator and its presence in the landslide body should not affect the distribution of the self-potentials in the landslide. Because of the galvanic contact between tubing and earth (a good electric conductor) and the presence of water inside the tubes (already at a depth of a few meters) it is rather unlikely that a variable distribution of electric charges will arise along the

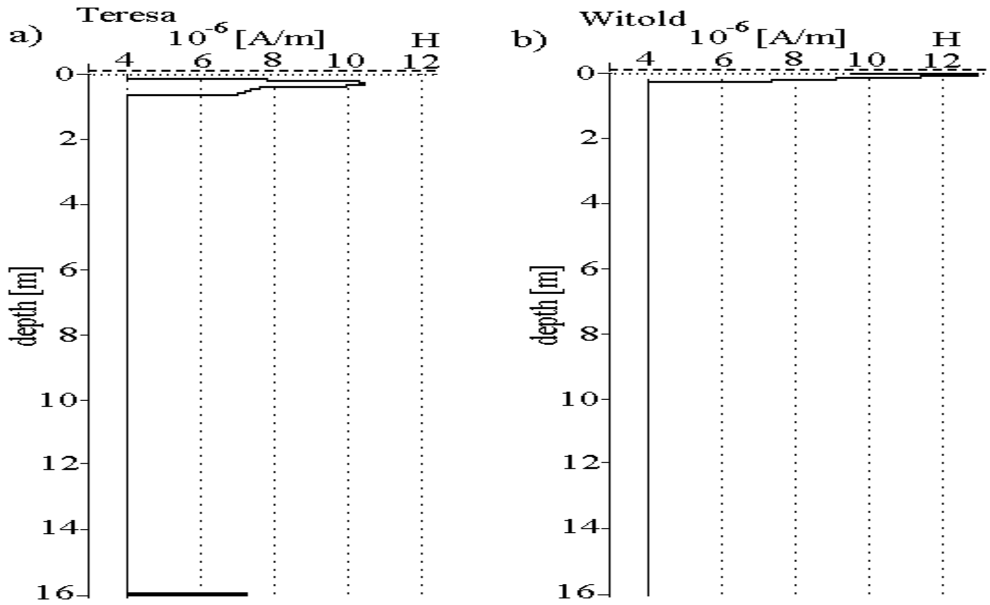

Fig. 5 Electromagnetic field emission along Teresa (a) and Witold (b) borehole.

tube, caused, for example, by electrification. In the case of a contact between plastic and soil, the problem (significant in the self-potential measurement method) of a parasitic potential at the electrode/earth contact, necessitating the use of special nonpolar electrodes, does not arise. The registered traces of magnetic field along the profiles of the boreholes named Teresa and Witold are shown in Fig. 5a, b. Then measurements were carried out in the SMZ Jelšava Magnesite Mine in Jelšava (Slovakia). The measurements were performed in boreholes drilled in the roof of a cave created when the magnesite deposit was worked out. The boreholes in Jeslava were also protected with PVC tubes. The roof is composed of mainly grey dolomite with inclusions in the form of small magnesite blocks or agglomerations of magnesite blocks. The measurements were carried out in a three-day period. No significant deviations of the electromagnetic emission of boreholes were observed over time. The results of the magnetic emission measurements presented in Fig. 6 a-d are supplemented with cross sections of the rock mantle surrounding the cave, made available courtesy of the SMZ Jelšava Mine. In both cases the test boreholes were located far from human settlements, roads, electric traction or other objects which might be a significant source of electromagnetic interference (e.g. transformers, high-voltage transmission lines, telecommunication lines, pipelines etc.) Measurements were performed in the absence of lightning discharges or other abnormal weather conditions. Neither were there any radio or television transmitting antennas nor radio-TV inverters. Therefore no additional electromagnetic spectrum tests on the measurement site were carried out, except for the observation of the resultant electromagnetic field by means of an auxiliary ground-based receiver being part of the measuring system.

4. DISCUSSION OF MEASUREMENTS

All the magnetic field traces registered on the Kawiory landslide and in the SMZ Jelšava Mine area show initial rapid increase in magnetic field strength, in the form of a rapidly falling impulse which already at a depth of 1-3 m decays and the registered magnetic field returns to the current background level, as evidenced by the traces for boreholes: Teresa, Witold, J43, J129, J133 and J135. The above phenomenon is a disturbance, which occurs in each measurement. It is due to the penetration of various overground electromagnetic fields into the ground. In this case, such interference is not eliminated to a substantial degree by the auxiliary overground receiver (see the description of the measuring system). The measurements carried out on the Kawiory landslide in Szymbark did not give positive results: only near-surface interfering signals were registered. The fact that no magnetic field emission was registered in the boreholes at the depths at which slip planes occur was due to two factors: 1) the Kawiory landslide is composed mainly of clays and 2) there are no large rock blocks in its body – the stresses generated in rock strata or blocks are the source of the most intensive magnetic field emission. This is corroborated by the measurements carried out in the magnesite mine in Jelšava where distinct magnetic emission of the rock strata in which stresses occurred was observed. Also the rate and continuity of flow of the landslide play a

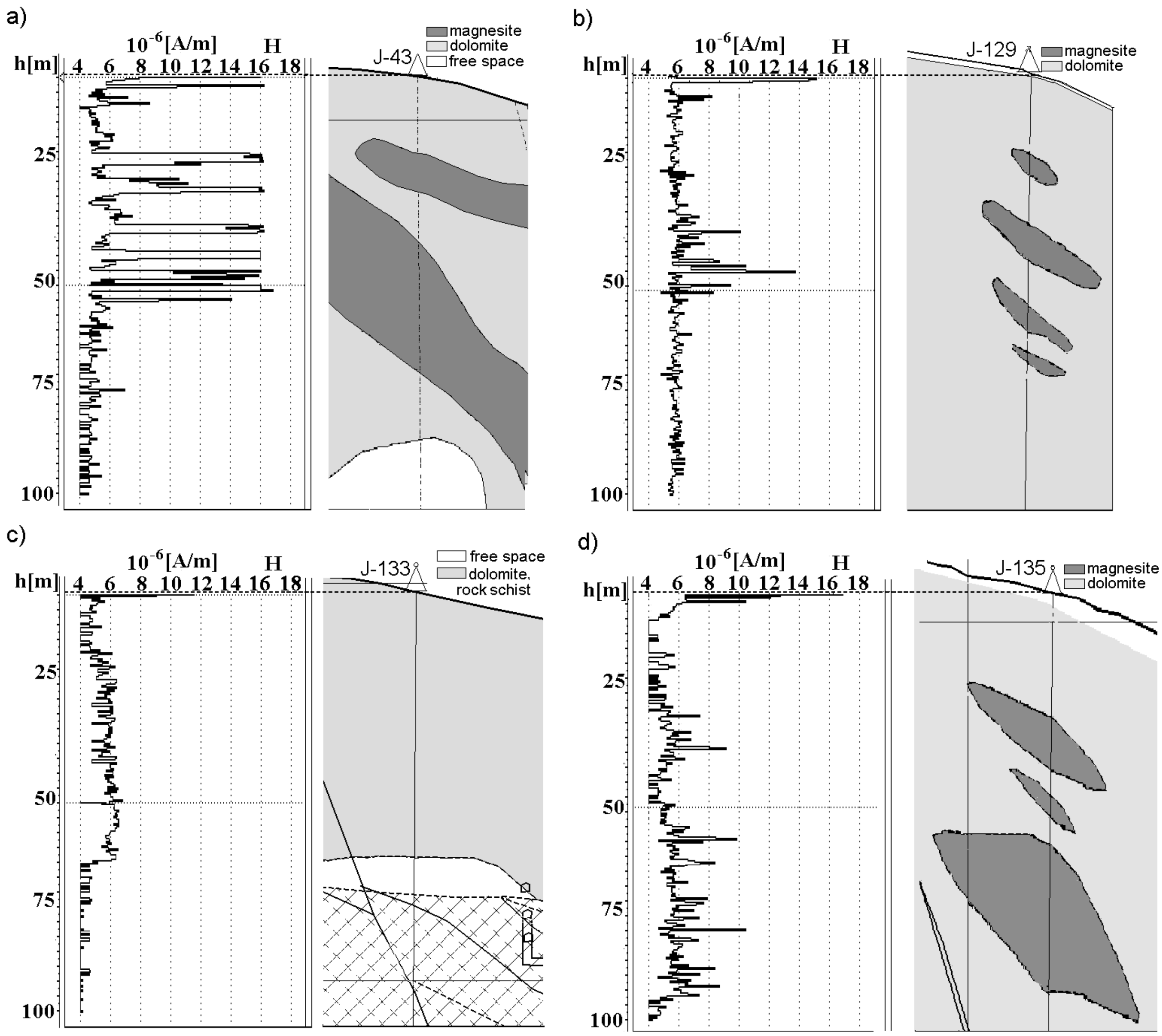

Fig. 6 Electromagnetic field emission along J43 (a), J129 (b), J133 (c) and J135 (d) borehole.

role. The Kawiory landslide periodically (mainly after prolonged rainy periods) exhibits increased activity. The inclinometric measurements show that the rate of flow of the landslide is low – maximum 70 mm per annum. For the last three years the annual average rate of flow of the landslide strata has been about 25 mm. This means that the flow of the landslide is too slow for the method to be effective. According to (Mastow et al., 1989), the minimum rate of flow of a landslide composed of clayey materials needed to generate a magnetic field emission measurable by equipment with a sensitivity similar to that one used in the measurements should be about 8 mm per 24 h. Further magnetic emission measurements are to be performed on the Kawiory landslide after a prolonged rainy period after which landslide activity is likely to be higher. An analysis of appropriate series of measurements carried out in Jelšava reveals that each borehole is characterized by a peculiar trace of magnetic field intensity trace versus depth. Within the measurement series for each borehole one can notice recurring anomalies which are the basis for the further interpretation of the results. Single peaks against stabilized electromagnetic emission are often observed. As a rule, the peaks are not registered in the next measurement. They are caused by strong impacts of the probe against the borehole's wall or its bottom (see Fig. 5), producing the well-known coil micro-phonic effect. An analysis of the results for borehole J135 shows a sharp increase in magnetic field emission activity at depths 30-40 m and 55-75 m. The geological section shows that magnesite blocks occur in the dolomite at the above mentioned depths. On the basis of intensity of the registered emission one can conclude about the size of the inhomogeneities in the rock mantle. An analysis of the magnetic field emission in borehole J129 also shows that at a 35-55th meter of its depth there is a distinct anomaly attributable to the occurrence of four magnesite blocks situated close to each other. Whereas comparing the measured magnetic emission profiles with the geological section of borehole J43 one can see that the boundaries between the magnetic field emissions originating from magnesite layer situated close to each other become blurred. This may be also caused by substantial levels of magnetic field emissions originating from rock blocks lying close to each other. The emission for borehole J133 is clearly divided into two zones. One zone, extending from the surface of the ground down to about the 55th meter, exhibits magnetic emission corresponding in the geological structure mainly to dolomite with small inclusions of other rock materials. No magnesite blocks occur here. The other zone is practically devoid of emission, which is due to the presence of a large post-extraction recess originating at the 55th meter of borehole J133. Generally, all the measurements show the absence of magnetic emission in empty post-extraction spaces. This seems to be natural for the considerable, at such low magnetic field intensities, distances from the emission sources, i.e. the rock strata. The cause of the magnetic emission may be the mutual pressure exerted by rock blocks of different types, e.g. a magnesite block compressed by dolomite strata. The registered increased magnetic emission of compressed magnesite blocks confirms the observations made during laboratory tests in which magnesite specimens being crushed exhibited higher emission levels than those exhibited by dolomite specimens subjected to crushing. The knowledge of the distribution of stresses in the rock strata along the profiles of the investigated boreholes would be very helpful. Then one could determine the relationship between the stresses in the magnesite strata and in the dolomite strata and the intensity of the magnetic field emitted by them. It should be noted that the presence in the ground of magnetic field components originating from other sources (not directly connected with the activity of the investigated rock strata) cannot be excluded. The presence of such fields should be treated as an additional source of interference. This problem is considered in (Singh et al., 2003) and (Tsutsui, 2002). As regards the influence of the tube lining on the distribution of forces and stresses in the landslide body and their transfer to the adjacent layers, this problem was not considered. A clear answer to this question can be obtained only if the basic parameters of the slide are known before boreholes are drilled. Such investigations had not been made in the case of the considered landslides. Since tubed boreholes also occur in other commonly used landslide condition assessment methods (e.g. the inclinometric method) the authors think that an influence of tubed measuring boreholes should not be a deciding factor in an evaluation of the usefulness and reliability of the method presented in this paper.

5. CONCLUSIONS

In this paper electromagnetic phenomena occurring during landslides activity are presented, and their characteristics and measurement methods are analysed in details. In this context pulsed electromagnetic fields appeared crucial. Investigations are conducted in boreholes lined with nonmetal (e.g. plastic) tubes, which do not damp the electromagnetic field. Such boreholes are used in standard inclinometric examinations of landslides. The emitted electromagnetic field has impulse (expressed in impulses per second) or continuous character and its maximum intensity occurs in a frequency range of up to 50 kHz. As the rate of creep of the landslide increases, so does the number of registered impulses or electromagnetic field intensity. Electromagnetic radiation, which occurs in a landslide is associated with the mechanical stresses and the friction resulting from the displacement of the landslide's layers under sliding-down force. The problem of the influence of electromagnetic interference on measurement accuracy can on its own constitute a separate field of electromagnetic compatibility research. But such research would be laborious, one would need a series of boreholes located close to each of the above interference sources (roads, power networks, human settlements, etc.). Because of the small number of measuring boreholes in the landslides this seems to be rather impractical. One can only say that an increased level of electromagnetic emission is observed in landslides containing blocks or slabs or rock, which under pressure become sources of strong electromagnetic radiation. This may be caused by piezoelectric phenomena. The landslides electromagnetic emission measurements will be developed in the future.

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