Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SCG10-01 Room:313 Time:May 2 09:00-09:24

Microcracks preceding ruptures: insights gained from laboratory acoustic emission study

LEI, Xinglin[1]*

[1]Geological Survey of Japan, AIST, Japan

Earthquakes in the crust are caused by the rapid shear fracture of a fault. Thus, understanding the source processes of earthquakes relies on the understanding of shear fracturing in rocks. Abundant experimental evidence shows that macroscopic shear fracturing within rocks and other brittle materials does not occur by the growth of a single shear crack in its own plane. Rather, it is preceded by a very complex pervasive evolution of some pre-failure damage. Therefore, studies focusing on both fracture dynamics and pre-failure damage are a subject of interest in seismology. Fracturing dynamics and the pre-failure damage can be inferred from AE statistics as the number of AE events is proportional to the number of growing cracks, and the AE amplitudes are proportional to the length of crack growth increments in the rock. Therefore, the AE technique, which monitors the spatiotemporal distribution of AE events, is applied to the analysis of the micro-cracking activity inside the sample space, and it can be performed under an artificially controlled pressure, which is very important for the simulation of underground conditions.

The fracture of intact rocks as well as rocks containing natural structures (joints, faults, foliations) under constant stress rate loading or creep conditions is generally characterized by typical stages with different underlying physics. Through an integrated analysis of several AE statistics obtained from AE data collected with the high-speed AE waveform recording system, a three-phase pre-failure-damage model has been proposed and further enforced with new data. The primary phase reflects the initial rupture of pre-existing microcrack population in the sample or in the fault zone. Sub-critical growth dominates the secondary phase. The third phases termed nucleation phase corresponds to the initiation and accelerated growth of the ultimate fracture. In earthquake seismology, researchers have a special interest with the nucleation phase since faulting nucleation governs the predictability of earthquakes.

Lithology, density and size distribution of pre-existing cracks, meso-scale and macro-scale heterogeneities all have an overall role in AEs. There are some cases in which some phases are not clear. In general, homogeneous (both fine-grained and coarse-grained) rocks with pre-existing cracks likely show all phases. Heterogeneous or weak rocks such S-C cataclasite normally show a lack of the primary phase. Samples with few pre-existing cracks and samples containing optimally oriented weak structures, likely show an unpredictable fracturing behaviour as well as a lack of primary and secondary phases, in addition the nucleation phase has a small number of AEs.

Rules obtained at the laboratory scale are helpful for understanding natural earthquakes on a significantly larger scale. However, we cannot simply bridge laboratory scale to a scale several orders larger. At every step up from a smaller scale to a larger scale, we encountered something different. The difference could be small for each step but, after many steps, we could see something quite different. Studies on all scales are important. Quantitative investigation of rock fracture using AE techniques is still an interesting field for the future. On one hand, it may shed some light on earthquake seismology. On the other hand, it may provide a fundamental technical background promoting applications including: enhanced geothermal systems (EGS), extraction of shale gas and core bed gas, and CO2 geological storage. The latter of which involves fluids being intensively pumped into the deep Earth under high pressure; injection-induced earthquakes would be a problem that must be well-addressed.

Keywords: Acoustic emission (AE), Microfracture, Pre-failure damage, Fault nucleation

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SCG10-02 Room:313 Time:May 2 09:24-09:39

Radio wave emission in friction or collision of various materials

TAKANO, Tadashi[1*] ; HANAWA, Rikuya[1] ; SAEGUSA, Saegusa[1]

[1]Nihon University

1. Introduction

In fracture of rock, radio wave emission was found experimentally [1]. This phenomenon could be used to detect a rock fracture during an earthquake or a volcanic activity [2] [3]. The cause of the radio wave is expected to be micro-discharges, which are generated by an inhomogeneous potential distribution around micro-cracks [4]. However, the theory of emission is not completely understood yet.

In order to clarify the cause of radio wave emission, we carried out experiments to detect the emission in the cases of friction or collision of various materials. This paper describes the experimental results, and a brief explanation of physical process.

2. Tested systems and experimental results

We tested the following systems using the manufactured measuring system at 1 MHz, 300 MHz, 2.0 GHz, and 18.8 GHz [5].

(1) A lighter using piezoelectricity

This device makes sparkles by knocking a mineral with piezoelectricity. Due to discharges, strong radio wave is emitted, and detected in our measuring system.

(2) A lighter using friction of OL metal

Formerly, this type of a lighter was widely used for igniting cigarettes. The alloy metal of cerium and iron rubs a revolving drum so that sparkles are made changing the friction power to thermal energy. Despite significant sparkles, radio wave could not be detected in this case.

(3) Igniter using a flint stone

A flint stone is struck against iron pyrites so that small flakes of iron are scattered being made hot. The flint stone is mostly chart In Europe, and quartz, sanukite, or obsidian in Japan. Sparkles cannot be made by striking two bulks of flint each other. Radio wave is not emitted in this case.

(4) Striking a steel lump with a steel hammer

Radio wave is emitted in this case. Probably, the kinetic energy is converted not to thermal energy but to the excitation of electrons or atoms so that inhomogeneous potential distribution is realized.

3. Conclusions

In general, sparks are not the origin of radio wave emission. This emission is esteemed a non-thermal phenomenon. An inhomogeneous potential distribution makes micro-discharges that emit radio waves. In some cases, the cause of an inhomogeneous potential distribution makes the sparks.

Further study is needed to clarify the mechanism of the energy transfer to electron excitation.

References

[1] Ken-ichiro Maki, Tadashi Takano, Eriko Soma, Kentaro Ishii, Shingo Yoshida and Masao Nakatani, "An experimental study of microwave emission from compression failure of rocks" (in Japanese), Jour. of the Seismological Society of Japan, vol.58, no.4, pp.375-384, 2006.

[2] Tadashi Takano, Takashi Maeda and Shingo Yoshida, "Experiment and Theoretical Study of Earthquake Detection Capability by Means of Microwave Passive Sensors on a Satellite", IEEE Trans. Geoscience And Remote Sensing, Vol.6, No.1, pp.107-111, 2009.

[3] T. Maeda and T. Takano, "Discrimination of Local and Faint Changes from Satellite-borne Microwave Radiometer Data", IEEE Trans. on Geoscience and Remote Sensing, vol 46, issue 9, pp. 2684-2691, 2008.

[4] K. Maki and T. Takano, "Analysis of the microwave radiation field from the discharge due to an impact destruction", National Convention of the Institute of Electrical Engineers of Japan (IEEJ), 1-081, p.87, March 2004.

[5] T. Takano, J. Kato, M. Hirashima and K. Saegusa, "Radio wave emission from 1 MHz to 18 GHz due to rock fracture and the estimation of the emitted energy", EEIS'12, 978-1-4673-0335-4/12/IEEE, pp.300-303, Cape Town, September 2012.

Keywords: radio wave, friction or collision, various materials, electrical discharge, micro-crack, non-thermal phenomenon

SCG10-03 Room:313 Time:May 2 09:39-10:03

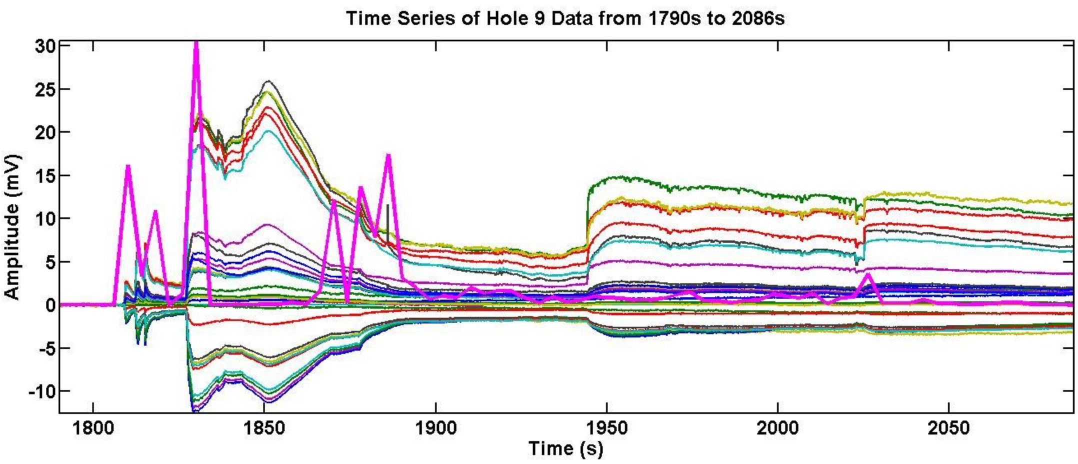
Seismoelectric phenomena of electrokientic nature associated with the formation of cracks in porous media

REVIL, Andre[1]*

[1]Colorado School of Mines, department of Geophysics

I will describe the physics of the generation of electromagnetic disturbances associated with the formation of cracks in porous media. The mechanism is electrokinetic in nature (i.e., associated with the flow of the pore water with respect to the solid phase of a porous material). I will describe the occurrence of these electromagnetic signals and how they can be inverted jointly with seismic signals to determine the position of the hydromechanical disturbance and its moment tensor. I will also demonstrate that electrical fields of electrokinetic nature are associated with the formation of crack through a set of laboratory experiments (see figure below showing the fluctuation in the electrical potential on the surface of the block and the amount of recorded acoustic emissions). The associated electrical field fluctuations can be remotely monitored and the resulting signals used to localize their causative source. The technique is similar to what is performed in electroencephalography (in the medical world) in which an electrical field (associated with the opening of ionic channels at the synapses between the neurons) can be measured on the scalp of a patient and inverted to localize and monitor brain activity. A laboratory experiment shows how these electrical fields can be recorded at the surface of a cement block during the fracking of the block. The measurements are performed with a research-grade medical electroencephalograph and inverted using the genetic algorithm to localize the causative source of electrical current and therefore localize the evolution of the crack. Two snapshots of electrical signals are used to show how the breakage evolves over time. A second experiment is performed to see if we could localize a pulse water injection from a shallow well in field conditions and in the case of a heterogeneous subsurface.

Keywords: electrokinetic, streaming current, self-potential, moment tensor, source localization, electromagnetic phenomena



SCG10-04 Room:313 Time:May 2 10:03-10:18

Waveform analysis of seismo-magnetic signals in Boso, Japan

HAN, Peng[1*] ; HATTORI, Katsumi[1] ; FEBTY, Febriani[1] ; HIROKI, Yamaguchi[1] ; CHIE, Yoshino[1]

[1]Graduate School of Science, Chiba University

To clarify the seismo-magnetic phenomena, it is essential to establish theoretical models to explain how the phenomena come out. A reliable model should coincide with field observations. Thus, the fundamental part is to find out what are the signals associated with earthquakes. Therefore, in this study we have checked detailed waveform of seismo-magnetic signals observed in Boso, Japan. Our preliminary results indicate that there are mainly two kinds of seismo-magnetic signals: one is noise-like signals; the other is transient/quasi-rectangular signals. The former are mainly detected before the 2005 M6.1 Boso earthquake; the latter is observed mainly during slow slip events.

Keywords: ULF seismo-magnetic phenomena, waveform analysis, slow slip events

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SCG10-05 Room:313 Time:May 2 10:18-10:42

Quantitative evidence of the coupling between seismic and electromagnetic signals

HUANG, Qinghua[1*]

[1]Peking University

There are some reports of the coupling between seismic and electromagnetic signals from both the natural earthquakes and the active field experiments. Such coupling effect may provide some useful information of earthquake process and/or oil exploration. Although the coupling mechanisms are not well understood at the current stage, there are some candidate mechanisms, such as the electrokinetic effect and piezoelectric effect. We focused this study on seismic and electromagnetic coupling for the data observed during earthquakes or synthesized from our numerical simulation method based on electrokinetic effect and earthquake models. We presented a quantitative analysis method of the correlation between seismic and electromagnetic signals. As an example of the field data, we investigated the data recorded during the Ms5.7 Ningqiang earthquake, China. The results indicated that there is a clear coupling between seismic and electromagnetic signals. As a further example of the synthetic data of seismic and electromagnetic signals, we obtained the synthetic seismic and electromagnetic signals using our numerical simulation method and confirmed the existence of coupling between the seismic and electromagnetic signals in the synthetic data.
This study is supported by the National Natural Science Foundation of China (41025014, 41274075).

Keywords: Co-seismic electromagnetic signals, Rupture model, Source time function, Electrokinetic effect

SCG10-06 Room:313 Time:May 2 11:00-11:15

The Development of self-potential tomography to estimate the ground water condition

OTSUBO, Hiroshi[1] ; HATTORI, Katsumi[1] ; YMAZAKI, Tomohiro[1*]

[1]Graduate school of science, Chiba University

Landslides are one of the most severe natural disasters in the world and there are two types; rainfall induced landslides and landslides triggered by an earthquake. In this research, basic study on early warning system for landslides will be performed to understand rainfall-induced landslide process by hydrological and electromagnetic changes. The final goal of this research is to develop a simple technology for landslide monitoring/forecasting using self potential method. The advantages of this method are lower cost and easier to set up than the hydrological approaches using pore pressure sensors. The laboratory experiments show that the self-potential variation has relationship with the water and soil displacements. But, we can not estimate the ground water condition by self-potential yet. So, in this study, we developed self-potential tomography to estimate the ground water condition.

Measured self-potential value under the ground and charge distribution to estimate is given by the Coulomb's law. Therefore, this is inverse problem. To solve the inverse problem, we adapt Phillips-Tikhonov regularization with Generalized Cross Validation (GCV). To evaluate the reconstructed charge distribution and investigate the relationship with the ground water condition, computational simulations and applications to practical data by using the sandbox experiment has been examined.

It is found that the developed algorithm is effective through numerical simulations. Results of application to sandbox experiments show good performance but there are some problems to solve.

The details will be given in our presentation.

Keywords: landslide, self-potential

SCG10-07 Room:313 Time:May 2 11:15-11:30

Induced seismicity due to fluid injection at a deep well in Youngstown, Ohio, USA

KIM, Won-young[1*]

[1]Lamont-Doherty Earth Observatory, Columbia University, [2]Earthquake Research Institute, University of Tokyo

Over 100 small earthquakes (Mw 0.4-3.9) were detected during January 2011- February 2012 in the Youngstown, Ohio, USA area, where there were no known earthquakes in the past. These shocks were apparently close to a deep fluid injection well, and hence, were immediately suspected as induced by the fluid injection. This 14-months seismicity included a half-dozen felt earthquakes and culminated with a Mw 3.9 shock on 31 December 2011, about 24 hours after the fluid injection ceased in the deep well in Youngstown. Among the 109 shocks, 12 events greater than Mw 1.8 were detected by regional network, whereas 97 small earthquakes (0.4 $<$Mw $<$1.8) were only detected by using the waveform correlation detector.

Among these shocks, 21 earthquakes were accurately located by using the local portable station data. All of the accurately located earthquakes were distributed along a set of subsurface faults striking N265 (due East-west) and dipping steeply to the north – consistent with the focal mechanism of Mw 3.9 mainshock on 31 December 2011. All of the well-located earthquakes have occurred at depths ranging from 3.5 to 4.0 km in the Precambrian crystalline basement.

We conclude that the recent earthquakes which occurred during 2011 - 2012 in Youngstown, Ohio were indeed induced by the waste fluid injection at a deep injection well due to increased pore pressure along the preexisting East-west trending faults located close to the wellbore in the Precambrian basement. We found that the earthquakes are located along a 1.2 km-long, East-west trending subsurface en echelon fault, and that the seismicity initiated at the eastern end of the subsurface fault – close to the injection point, and migrated toward the west – away from the wellbore, indicating that the expanding high fluid pressure front increased the pore pressure along its East-west trending path and progressively triggered the earthquakes. Further, we observe that the occurrence of these earthquakes is generally correlated to the total daily injection volume and that several sharp peaks in the daily injection volume correlate with the occurrence of earthquakes. We observed that several periods of quiescence of seismicity follow gaps in surface injection volumes and pressure (sudden drops in injection pressure followed by prolonged low pressure), which may indicate that the earthquakes were directly caused by the pressure buildup in the fractured Precambrian basement and stopped when pressure dropped. Geohydrologic properties of the Youngstown, Ohio area behaved as a fractured Precambrian rock similar to the Rocky Mountain Arsenal, Colorado, USA site of induced earthquakes during 1960s.

Keywords: Induced seismicity, Fluid pore pressure, Shale gas extraction, Space and tme migration of earthquakes

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SCG10-08 Room:313 Time:May 2 11:30-11:45

Characteristics of Microcracks in the Nucleation Stage of Natural Earthquake

FUJINAWA, Yukio[1*] ; NODA, Yoichi[2] ; TAKAHASHI, Kozo[3]

[1]MierukaBosai Inc., [2]Tierra Tecnica Ltd., [3](former) Communication Research Laboratory

At the last JpGU meeting we reported that a deep underground electric field measurement using special antenna could detect micro-cracks appearing in the nucleation stage of the Tohoku Earthquake (Fujinawa et al., 2013). Here we report several results of further analysis on the characteristic pulse-like phenomena.

1) Detection Distance:

Some events of B-type variation have clear first and second phases (Figure 1). The S-P time is 25ms corresponding to about 180m of the epicentral distance. Majority of events have no apparent P phases due to the small strength of the P phase and/or large dissipation. The detection distance of P phase is about 200m. On the other hand the S phase of the frequency of some 100Hz and amplitude of 2mV suggests detection distance of some 10km, much larger than that of the acoustic emission signal of order several hundred meters by elastic observation.

The characteristic electric field variation induced by crack through electro-kinetic mechanism have been discussed by systematic formulations (Pride, 1994; Revil and Leroy, 2004). As to the wave mode, there are four kinds of wave, slow P and fast P wave (ordinary p wave), S-wave (ordinary S wave) and electromagnetic wave (EM). Events containing P phase have occasionally small forerunners at about the origin time possibly corresponding to (see Fig.1).

2) Correspondence to main shock:

The seismological approaches (e.g., Kato et al., 2012) showed that there were two slow seismic slip events from mid-February to the Tohoku Earthquake and microearthquake activities around the foreshocks and mainshocks. Those activities were whole around the epicentral zone, about 300 km northeast from the observation site. The detection distance of the electric field change by the borehole antenna is at most 100 kilometer. Our observational evidence including temporal evolution of the microcrack activity and b value of 0.7 suggest that the micro-cracks of B-type are related to the nucleation process of the main shock, though they occurred at the edge of the giant rupture area. We propose that the nucleation process is not limited at around the asperity, but extends to whole rupture zone. More extensive monitoring of the microcrack of magnitude less than -5 can provide clue to this question.

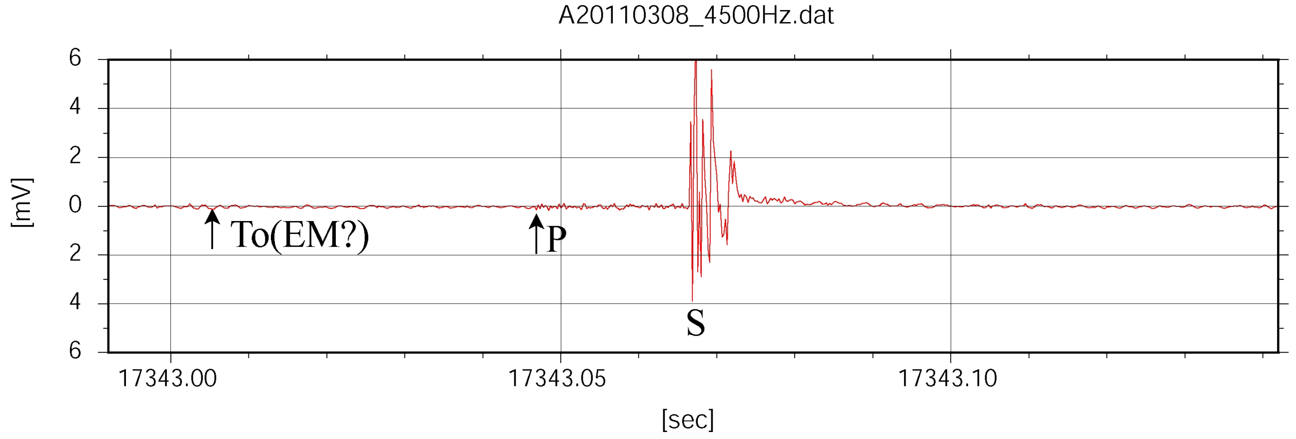
3) Intermittent Criticality

There appeared undulation of microcrack activity after the most active period around 9th March , 2011. The undulation has been suggested to reflect the intermittent criticality indicating another phase of nucleation (Sornette and Sammis, 1995; Kapiris et al., 2005). As approaching to the main shock there appeared two kinds of events. One kind is a superposition of several smaller events. It is interpreted that small events substantially increased with the result of picking up more smaller events in the time interval of data length of 100ms. The second kind is like a long chain of small events. These feature suggest that microcrack activity has changed at the last stage of nucleation stage.

4) It is well known that the crust of the earth is elastic-porous medium filled with fluid as water. The research on the rupture of such kind of medium had a remarkable development in early 1990 contributing to interpret the mysterious seismo-electric phenomena associated earthquakes enabling systematic treatment and suggesting new method of geophysical prospecting. The formulation of Pride and Revil have been used to interpret the phase of faster propagation of EM signal with velocity much larger than the p-wave speed (Fujinawa et al., 2011), the ULF band anomalies associated the slow-slip (Han, 2013) . And, our electromagnetic method has been suggested to detect micro-cracks preceding natural earthquakes to identify the nucleation stage providing a break-through for the short term prediction method. The converted electromagnetic mode at the material contrast from elastic seismic wave has been proved to be profitable means to survey for oil and gas.

Keywords: Microcrack, Earthquake Prediction, Nucleation Stage, Seismo-electric- signal, Electrokinetic effect, Tohoku Earthquake

SCG10-08 Room:313 Time:May 2 11:30-11:45



Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SCG10-P01 Room:Poster Time:May 2 16:15-17:30

Electromagnetic emissions from fracture of semiconductor pyrite

OZAWA, Mitsuyuki[1*] ; MUTO, Jun[1] ; NAGAHAMA, Hiroyuki[1] ; NAGASE, Toshiro[2]

[1]Department of Geoenviromental Sceinces, Graduate School of Science, Tohoku University, [2]The Tohoku University Museum

Introduction

When elastic waves propagate in orebodies composed of semiconductor minerals, electromagnetic (EM) radiation with radio frequency occurs. Its frequencies were 10-100 times higher than those of the elastic waves. They were observed by geophysical exploration surveys and laboratory experiments. These previous studies suggested that generation of radio waves is closely related to the rectifying property of orebodies which is attributed to semiconductor minerals. Semiconductor minerals are divided into p- or n-type conductivity by its charge carrier. When p- and n-type are joined, the resulting junction (p-n junction) has the rectifying property. Because many p-n junctions of semiconductor minerals exist as which connect in parallel and in series in the orebody, they also show rectifying property. Previous research measured only large scale rectifying property of orebody to understand the generation mechanism of radio wave. However, due to the lack of the measurement of rectifying properties of each micro p-n junction in semiconductor minerals, quantities evaluation was difficult.

Composition of semiconductor minerals is heterogeneous due to the presence of impurities and lattice defects. Because rectifying property depends crucially on the composition, clarifying the composition at each micro region is needed. In this research, we measured the composition and rectifying property of semiconductor pyrite to discuss the possibility of EM emission from the ore bodies.

Methods

Semiconductor pyrite sample was obtained from Waga-Sennin mine, Akita prefecture, Japan. It was cut into slabs with a thickness of about 0.38 cm and an area of 1.4 cm^2.

We obtained composition of the sample surface by electroetching method and SEM-EDS. Thermal probing method allowed us to discriminate between p- and n-type conductivity. By electrical probing, we quantified the rectifying properties.

Results

After the electrolytic etching, heterogeneity of composition in the sample surface was emerged as the difference in solubility. The difference of soulubility caused etching figure and zonal structures. Thermal probe method revealed that the differences of p-n type regions corresponded to the difference in solubility of each region. P-types regions showed a higher solubility than n-type regions. According to the SEM-EDS analysis, about 1.0 wt.% of Pb inclusions were precipitated parallel to crystallographic planes in the p-type regions.

In the electrical probing method, rectifying effects were observed at p-n junctions. We obtained the current and voltage characteristic of p-n junction. The reverse and forward breakdown voltages were estimated to be 1.5 V and 0.3 V, respectively.

Discussion and conclusion

When two types of rocks make contact, electrons move between the surfaces of rocks, producing the potential difference between them. This electrification becomes a possible source of EM radiations during separating rocks. If we regard p- and n-type semiconductor minerals as the two types of rocks, the contact potential is given by the forward breakdown voltage of p-n junction. When the junction is split into two pieces, separated surface can be regarded as capacitance plates. If the surface charge density of plates reaches the Paschen's minimum charge density of breakdown (e.g. air 5.0×10^{-5} C/m^2), corona discharge occurs. We estimated the charge density of separated plates at p-n junction to be 2.7×10^{-4} C/m^2. Given the effect of charge relaxation, we must take into account separation velocity of plates. In this case the critical separation velocity to cause corona discharge is estimated to be 2.0 km/s. Therefore, it is expected that the pyrite fractured by propagation speed higher than 2.0 km/s can cause corona discharge.

In conclusion, the fracturing of pyrite becomes a possible source of EM radiations. Further investigation is needed to clarify the properties (e.g. frequency) of EM radiations from the orebodies.

Keywords: Seismic electromagnetic signals, Semiconductor minerals, Radio wave, P-n junction