

## Electromagnetic fields in the solid material neighbouring porous media Electromagnetic fields in the solid material neighbouring porous media

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Numerous studies reported that there are electromagnetic(EM) wave-fields associated with seismic waves. The electrokinetic effect, as one of the most possible mechanisms resulting in the coupling between the seismic and EM wave-fields, has attracted wide attention in the area of seismoelectromagnetism. The numerical experiments have confirmed that a finite fault in porous media can induce seismoelectromagnetic signals. The characteristics and the magnitude of amplitudes are consistent with those observed in natural earthquakes. However, all the used models consist of porous materials. In this work, we carried out numerical experiments to investigate the situation in the layered model composed of solid and porous materials together. It is found there are two kinds of EM waves in the solid material, the homogeneous and inhomogeneous EM waves. The former one is generated by the direct EM waves radiated from the source or the normal incident seismic waves at the interface between the solid and the porous media. The latter one is generated by the oblique incident seismic waves whose horizontal wavenumber is greater than the EM wavenumber in the solid media. The inhomogeneous EM waves propagate in the horizontal direction and decrease when the distance to the interface increases. For the solid area which is close to the interface (e.g., within 200m), the inhomogeneous EM waves behave very similar with the co-seismic EM signals in the pure-porous model.

キーワード: electrokinetic effect, the coupled seismic and electromagnetic fields, solid material neighbouring porous media, converted electromagnetic waves generated at the interface

Keywords: electrokinetic effect, the coupled seismic and electromagnetic fields, solid material neighbouring porous media, converted electromagnetic waves generated at the interface

## 岩石破壊に伴う電波放射実験における金属接触雑音の排除 Exclusion of metal contact noise in the experiment of radio wave emission due to rock fracture

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### 1. まえがき

以前、岩石破壊に伴って300 MHzから2.2 GHzの電波が、放射されることが観測された [1]。これは自然界で岩石が破壊する現象（地震や火山噴火）を、観測あるいは予知する手段として使える可能性があるため、注目を集めた [2][3]。

それに対し、実験系を構成する金属部が互いに当たって、電波が発生することが確認された [4] [5]。これは金属が衝突・接触により帯電し、放電するためと思われる。従って、この信号は岩石破壊による電気現象と本質的に関係ないので、識別が必要である。

最近我々は、実験系の中で衝突・接触する構成要素を、電氣的に短絡して再構築した、岩石破壊の過程で、要素が帯電し放電することを防ぐためである。本稿では、実験系の構成と実験結果について、報告する。

### 2. 実験系

実験系は、岩石破壊するための破壊系と電気信号測定系より成る。破壊系は油圧プレス機その他、土台や天板、それらを接続する支柱、ボルト、ナットなどで構成される。これらすべての部品に、太さ xx mm の撚り導線をねじ止めあるいはんだ付けして、結んだ。導線は撚り線で、その数は幅 5 mm 厚さ 1 mm が 24 本、幅 2 mm 厚さ 0.5 mm が 9 本である。

電気信号の測定系は、以前と同じである。1 MHz と 300 MHz、2 GHz、1.8 GHz を扱う。各周波数帯に対応して、アンテナと低雑音増幅器およびフィルタを設ける。データ量はデジタル化して、データ格納する。その際、メモリを駆動始めるためのトリガ信号が、測定上重要である。

岩石試料は以前と同じく、珪岩と花崗岩、斑レイ岩、玄武岩を用いた。

### 3. 測定結果

次のような結果を得られた。

- (1) すべての岩石で、破壊と同時に、300 MHz において電波の放射が観測された。
- (2) 特に珪岩では、300 MHz の他に 1.8 GHz 成分も検出できた。これらは同期している。
- (3) モルタルの円柱試料でも実験を行ったが、信号検出できなかった。
- (4) 岩石残滓あるいはブルーシート、ビニール被いなどが触れると、放射が観測された。それらの周波数帯は、300 MHz が主で、次に 2 GHz、そして 1.8 GHz と続き、岩石破壊の場合と異なる。原因としては、互いに帯電・放電するためと推測される。
- (5) 時間を外すと外来雑音も入るが、それらは 2 GHz や 1.8 GHz の高い周波数成分は無い。

### 4. まとめ

破壊系の金属をすべて短絡して、不要放射を防いだ。それに対しすべての場合で観測されたので、岩石破壊から電波が放射されることが確認された。

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会場:203

時間:5月24日 15:35-15:50

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キーワード: 岩石破壊, 電波放射, 金属接触, 雑音排除, 構成部品, 短絡  
Keywords: rock fracture, radio wave, metal contact, noise, parts, short

Medium effect on the characteristics of electromagnetic signals accompanying with seismic waves  
Medium effect on the characteristics of electromagnetic signals accompanying with seismic waves

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Recently developed numerical simulation technique can simulate the coupled seismic and electromagnetic signals for a double couple point source or a finite fault planar source. Besides the source effect, the simulation results showed that both medium structure and medium property could affect the coupled seismic and electromagnetic signals. The waveform of coupled signals for a layered structure is more complicated than that for a simple uniform structure. Different from the seismic signals, the electromagnetic signals are sensitive to the medium properties such as fluid salinity and fluid viscosity. The results may provide some insights of understanding the difference in the detectability of co-seismic electromagnetic signals in different geological regions.

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キーワード: Electrokinetic effect, co-seismic electromagnetic signals, medium effect, a double couple point model, a finite fault planar model

Keywords: Electrokinetic effect, co-seismic electromagnetic signals, medium effect, a double couple point model, a finite fault planar model

## 地震直前の微小クラックに伴う電界現象の特性 Properties of seismo-electric variations induced by microcracks in the nucleation stage of earthquake occurrence

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Characteristics of dominant three phases ( $P_f$ , S, EM) of seismoelectrical waves have been investigated using waveform which are suggested to be induced by microcrack in the nucleation stage of the 2011 Tohoku Earthquake (Fujinawa *et al.*, 2013). Twelve B-type events having clear P, S phases and apparent EM phase with dominant frequency 500 Hz have been selected from the catalog of B type events. Slight traces of EM phases are searched at around the origin time. We estimated focal distances of those events using S-P time assuming the P and S wave velocity, which are corrected on the basis of arrival time of the identified EM phase. The corrected velocities are well in agreement of the measured logging data at the borehole. The accumulated number of events is found to follow the Gutenberg- Richter relation with the  $b$  value equal 0.7, indicating that the B-type events are of natural micro-earthquake. We can conclude that the seismoelectric mode of the SES related with natural earthquake can be observed by using high sensitive sensor.

The electric strength of fast- P, S, and EM modes of the shear tensile type events are compared with each other. Averages of observed amplitude order as  $A_s > A_{pf} > A_{em}$ , which is partly different from those of previous numerical simulations (e.g., Gao and Hu, 2010). Those amplitudes are analytically estimated on the basis of the seismo-electromagnetic formulation of Pride (1994) assuming the isotropic homogeneous medium filled with confined solvent. The force field is the double couple model of Gao and Hu (2010) in consistent with the hypothesis that the source is microcrack. The typical value for physical parameters of elastic material, solvent and the streaming coefficient for seismic frequency result in the ordering  $A_{pf} > A_s > A_{em}$ , a little bit different from the observational result. The contradictory relation between the observed result and numerical simulation may be attributed to the assumed whole space model other than the half space model.

Overall agreement between the observed and estimated results suggest that, 1) pulse-like events of B-type detected before the Tohoku Earthquake are induced by rupture of microcrack in the nucleation period of main shock, 2) observed phases of waveform ( $P_f$ , S, and EM) are corresponding to co-seismic  $P_f$ , S and free electromagnetic wave in the unified formulation, 3) the SES phenomena in the field can be analyzed by the formation.

Precursory phenomena of earthquake have been investigated by analyzing seismic activity, crustal deformation, groundwater anomalies, and electromagnetic anomalies. Present finding of the overall agreement of the observation and estimation on suggests that those multiple kind of phenomena can be discussed by means of the Pride's formation of on the basis of concept that those phenomena are induced by variety of the cracks taking place in the nucleation period. We have already impressive observation of magnetic ULF band anomalies (Han, 2012) occurred simultaneously with the slow slip at deep plate boundary by means of high sensitive seismometer (Ozawa *et al.*, 2003). Many of observational electric anomalies (Hayakawa and Fujinawa, 1994) can be more satisfactory interpreted on the basis of the unified scheme. Multidisciplinary approach on the basis of the unified theory is expected to open new window for practical earthquake prediction methods as well as for geophysical survey. For instance we can investigate the fluid motion associated with fracture in a porous medium as conducted in the laboratory (Haas *et al.*, 2013).

Keywords: seismo-electromagnetics, short-term forecasting, micro-crack, porous medium, Electrical properties, Acoustic property

## The Mechanism of the Pre-seismic Changes of the Tidal Deviation of Groundwater Level in Hualien City, Taiwan

### The Mechanism of the Pre-seismic Changes of the Tidal Deviation of Groundwater Level in Hualien City, Taiwan

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The different response by various natural stimuli and processes (tidal force, barometric loading, ground shaking and crustal strain) were used as the elements of the hydraulic information in the earthquake induced groundwater level changes. Using the ocean tidal force to act as naturally recurring stimuli to provide a sufficiently varied distribution of excitations in time and space, and represented the hydro-geological changes responses to the earthquake processes. The purposes of this study are to analyze the recently observation results of the earthquake induced tidal deviation of groundwater level in observation wells around Hualien city, eastern Taiwan. The analysis of the tidal responses and the atmospheric pressure responses also will be used to estimate the mechanical properties of the aquifer. Comparison the observation between the sea level and the groundwater level changes in the each event, offers the opportunity to discussion the possible mechanism of the hydrologic response to earthquake. Curiously pre-seismic groundwater level changes in the pattern of tidal deviation occurred repeatedly in several local seismic events nearby the Hualien City. Poroelastic model been used to act as the simulation tool to fit to the pre-seismic groundwater level changes. The results shows groundwater preseismic change could be simulated by a recharge or discharge at a fault zone with poroelastic model. The numerical results could support our conceptual model with a permeable fault zone between sea loading and groundwater responses. Our numerical model provides some information for the preseismic mechanism but more investigations are required.

キーワード: Groundwater, Permeability Structure, Pre-seismic  
Keywords: Groundwater, Permeability Structure, Pre-seismic

## Seismoelectric Interferometry Seismoelectric Interferometry

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The seismoelectric effect is a very interesting and complex physical phenomenon, dealing with the subsurface coupling between mechanical poroelastic wavefields and electromagnetic diffusive fields. Therefore, the seismoelectric method can provide us with both seismic resolution and electromagnetic sensitivity at the same time. In addition, several studies have shown that the seismoelectric method can provide supplemental information about porosity and permeability, or on pore-fluid properties such as viscosity. These features do not only make seismoelectrics a worthwhile phenomenon to study for exploration purposes, but also for e.g. the field of earthquake mechanisms and risk analysis. Two types of seismoelectric coupling can be distinguished:

- 1) localized coupling generating an electromagnetic field that is present inside the seismic wave and travels with seismic velocity, the so-called coseismic field.
- 2) An independently diffusing electromagnetic field with electromagnetic velocity, providing us with information at depth. This is referred to as the seismoelectric conversion (or interface response).

At present, the key challenge for seismoelectrics is its measurability in the field. Due to the very weak signal to noise ratio of especially the second-order seismoelectric conversion, the events are often not detectable. In order to make seismoelectrics applicable in the field, we need to find ways to improve the signal to noise ratio of this second order effect. From seismic interferometry, we know that by cross-correlating recorded fields, virtual source responses can be simulated. In this process, stacking inherently takes place thereby possibly enhancing the signal-to-noise ratio of the records. We here present initial results of applying interferometric principles to seismoelectric phenomena. Can we indeed retrieve the desired seismoelectric virtual source responses that we are after, by cross-correlating selected responses due to boundary sources of a certain type (mechanical or electrical)? We explore the area of seismoelectric interferometry using our analytically based, numerical modeling code ESSEMOD (ElectroSeismic and Seismoelectric Modeling). Acknowledgements: Shell-FOM project, 'Innovative physics for oil and gas'.

キーワード: Seismoelectric, Electroseismic, Interferometry, cross-correlation  
Keywords: Seismoelectric, Electroseismic, Interferometry, cross-correlation

## Feasibility study of characterizing crustal cracks by EMR in the VLF band using interferometry

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In this paper we present the three-dimensional (3D) numerical simulation results aimed to shed a light on the feasibility of mapping the density and orientation of crustal cracks by looking into the features of electromagnetic radiation (EMR) from cracks using interferometry from a surface observation array. We use 3D finite difference time domain (FDTD) technique to conduct the numerical modeling. The cracks are statistically generated with specified density, size, orientations, and electromagnetic (EM) properties. The measuring points are placed on the earth surface and can be distributed in any arbitrary fashion to investigate the optimistic configuration of the field observation arrays. The objective of this numerical test is two-fold:

1) Investigate the EMR efficiency on the surface by looking into different physical mechanisms (such as charge separation processes between (O'Keefe and Thiel, 1995) or along (Gershenzon et al., 1986) the crack walls associated with micro-cracking; 2) crack-induced movement and reorientation of dislocations (Misra and Gosh, 1980; Slifkin, 1993); 3) the surface vibrational-wave model of Frid et al. (2003) and Rabinovitch et al. (2007)).

2) Investigate the influence of strong radiation from VLF transmitters on using EMR for tectonic and earthquake studies.

As the existing preliminary observations (e.g., Krumbholz, 2010; Krumbholz et al. 2012) have shown, the hope of using EMR to determine the horizontal principal stress orientation at one location by looking into the EM amplitude from a single station alone is diminished. This motivates us to look into the interferometry approach to eliminate the strong influence of active VLF transmissions.

キーワード: seismoelectric, crustal cracks, interferometry, VLF, electromagnetic radiation, numerical simulation  
Keywords: seismoelectric, crustal cracks, interferometry, VLF, electromagnetic radiation, numerical simulation