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Japan Agency for Marine-Earth Science and Technology

The World's First Finding of Trace of High Temperature Fluid in the Fault Zone During Earthquakes

Outline

Tsuyoshi Ishikawa, Group Leader of Geochemical Research Group, Kochi Institute for Core Sample Research (KOCHI), Japan Agency for Marine-Earth Science and Technology (JAMSTEC; Yasuhiro Kato, President) and his colleagues, with the cooperation of Osaka University, Kobe University etc., have found traces of coseismic hydrothermal fluid in the Chelungpu fault which was active during the 1999 Chi-Chi earthquake (magnitude 7.6) in Taiwan.

It is assumed that high-temperature fluid generated by coseismic fault friction induces high pore pressure of rocks and causes easy slip of faults. However, such traces had not been identified until now.

Analysis of variation in trace-element concentrations and isotopic ratios of fault rocks were performed to estimate conditions that caused fluid-rock interaction, which is a new method to prove the presence of high-temperature fluid in the fault zone for the first time in the world. This finding is a significant contribution to understanding of seismic fault slip and its propagation mechanism including the reason why the maximum fault displacement occurred at the distant-location from the epicenter.

This achievement will be appeared on line version of "Nature Geoscience", the British science journal, on September 15.

Title: Coseismic fluid-rock interactions at high temperatures in the Chelungpu fault

Authors: Tsuyoshi Ishikawa, Masaharu Tanimizu, Kazuya Nagaishi, Jun Matsuoka, Osamu Tadai, Masumi Sakaguchi, Tetsuro Hirono, Toshiaki Mishima, Wataru Tanikawa, Weiren Lin, Hiroyuki Kikuta, Wonn Soh, and Sheng-Rong Song

Background

It is generally known that strength of a rock is largely influenced by pressure of pore fluid (pore pressure) within. And it is theoretically indicated that fault slip possibly be accelerated when hydraulic pressure increased by faults frictional heating during earthquakes. However, the evidence of presence of high-temperature fluid (*1) induced by frictional heating inside the fault zone during earthquakes had not been found. In the 1999 Taiwan Chi-Chi earthquake, although south to central part of Chelungpu thrust fault was closer to the epicenter, fault displacement was larger in the north part especially where the depth of the fault is less than 3 km, and fault displacement up to 8 m emerged in the surface. It is believed that it is because friction has decreased along the fault surface at shallow fault area in the north part. Influence of pore pressure was pointed out as one of the possible reasons for the friction drop.

Study method

The Taiwan Chelungpu-fault Drilling Project (TCDP) commenced in 2003 is a part of the International Continental Scientific Drilling Program (ICDP) which Japan participate in. The northern part of the fault was drilled since the fault displacement was larger (Fig.1 and 2). Among those boreholes, all core samples of Hole B were delivered to Kochi Institute for Core Sample Research (Nankoku City, Kochi Prefecture) and a series of nondestructive measurement (X-ray CT image analysis, magnetic susceptibility measurement, etc.,) was performed. Trace-elements and isotopes of cored earthquake fault were analyzed to elucidate each process occurred in the faults from chemical aspect.

The Chelungpu fault had developed in the Chinshui Shale which is composed of marine sediments. In Hole B, three significant active fault zones were recognized (Fig.2, 3). The fault zone around a depth of 1,136 m is likely to have been the main fault rupture during the Chi-Chi earthquake.

Samples with 3~5cm vertical thickness were cut out from each part of three fault zones, and quantitative determination of trace-element and measurement of isotope ratios were performed with use of mass spectrometers. The attained analysis values for each part of fault zones were compared each other, and variations in trace-element concentrations and isotope ratios were examined. Furthermore, model calculations were performed on correlation between these data and reported data obtained from hydrothermal (~350°C) experiments using sediment and pore water under conditions of high temperature and pressure.

Summary of result

All black gouge zones (which are likely to include coseismic fault slip zone) in three fault zones, which include the 1,136m depth zone, shows significant change in trace-element concentrations and strontium isotope ratios (Fig.3). Strontium, cesium, rubidium and lithium are known as mobile elements in hydrothermal environment. Variations of trace-element concentrations and isotope ratios seen in Fig.3 and Fig.5 are typical in high-temperature fluid-rock interactions.

By using distribution coefficients of trace-element (*2) estimated based on hydrothermal experimental data, element concentrations and isotope ratios in fault rocks were calculated when fluid and rock interact at 250, 300 and 350°C individually. Calculated value at 350°C agree well with measured chemical compositions in black gouge zones (Fig.5).

This means that black gouge zone interacted with hydrothermal fluid of 350°C or above. The present ambient temperature in the fault zones is less than 50°C. It seems unlikely that a high-temperature was generated by other than coseismic frictional heating. Thus, presence of hydrothermal fluid at higher than 350°C generated by frictional heating in the fault zone during the earthquake was convinced.

Future prospective

It is known that the black gouge zone is composed of impermeable clay. So that when higher than 350°C hydrothermal fluid generated, fluid was not able to diffuse outside easily, and that made pore pressure jump.

Therefore, it is highly possible that the large fault displacement seen in shallow zone of the northern Chelungpu fault was formed by dynamic decrease of friction along the fault surfaces induced by increase of pore pressure.

Presence of high-temperature fluid in the fault zone during earthquakes has been proved. That is highly significant in understanding of rupture propagation and its relation with fluid in earthquake faults all over the world. Also, this result is important on the point of presenting the method to determine occurrence of high-temperature fluid-rock interactions based on trace element and isotope analysis of fault samples.

Occurrence of high-temperature fluid and increase of pore pressure in fault zones may involve in tsunami generation and its magnitude that caused by fault displacement on the sea-floor. More investigations will be performed for earthquake fault samples in the deep sea to be collected by drilling vessels such as the Deep-sea Drilling Vessel *Chikyu*.

*1 fluid

Various elements and components dissolved in aqueous fluid in the deep underground, so that it is not pure water. In geoscience field, it generally called “fluid”.

*2 distribution coefficient of trace-element

When a rock and fluid (of high-temperature) are in chemical equilibrium, the ratio of concentration for a given trace-element in a rock to that in fluid (trace-element concentrations in a rock/ trace-element concentrations in fluid) should be constant under the same temperature and pressure. It is called bulk distribution coefficient between rock and fluid. The distribution coefficient, togher with initial trace-element concentrations in fluid and rock, is important parameter to the control of migration of trace-element induced by fluid-rock interaction. In this study, distribution coefficients of trace-elements at each temperature was estimated based on the data reported in the hydrothermal experiments using the same kind of sediment and pore fluid as collected by TCDP.

Fig.1 Drilling operation of the Chelungpu fault

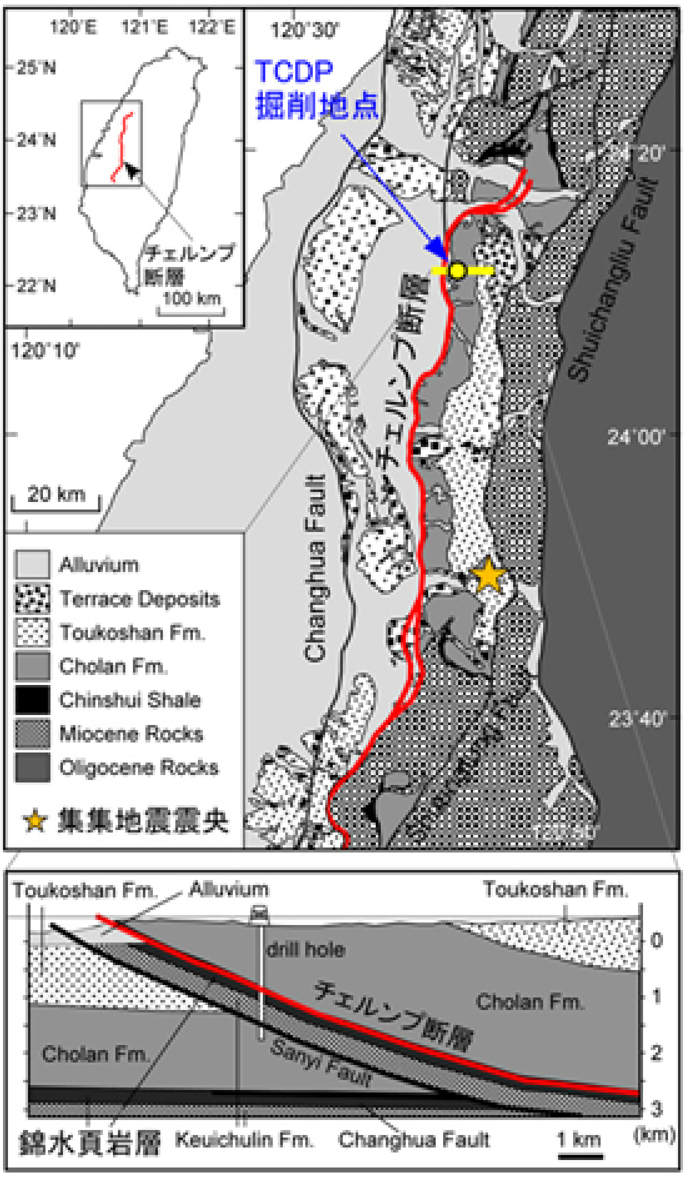

Fig.2 Geological map of central Taiwan, with the site of TCDP. Drilling was operated at 2km east of the surface rupture and reached the Chelungpu fault at a depth of about 1km.

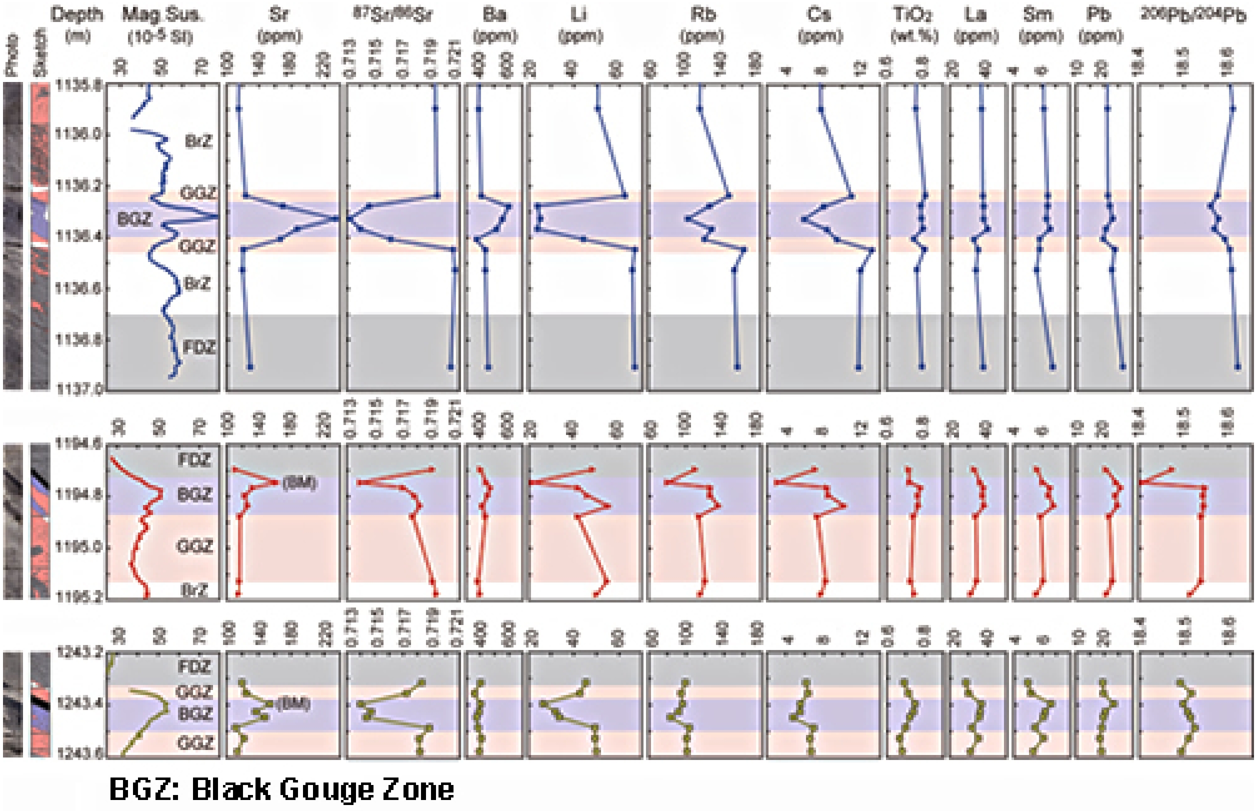

Fig.3 Depth profiles of magnetic susceptibility, trace-element concentrations and isotope ratios across the three fault zones of TCDP Hole B. Fault zones are recognized at depth of 1,136m, 1,194m, 1,243m. In the black gouge zone of the fault zones, trace-element concentrations and isotope ratios are significantly changed.

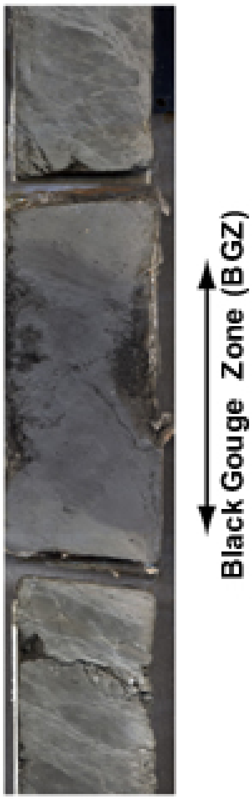

Fig.4 Closeup of the central part of the fault zone at a depth of about 1,136m. (FZB1136)The black gouge zone (BGZ) is likely to contain the slip zone associated with the Chi-Chi earthquake.

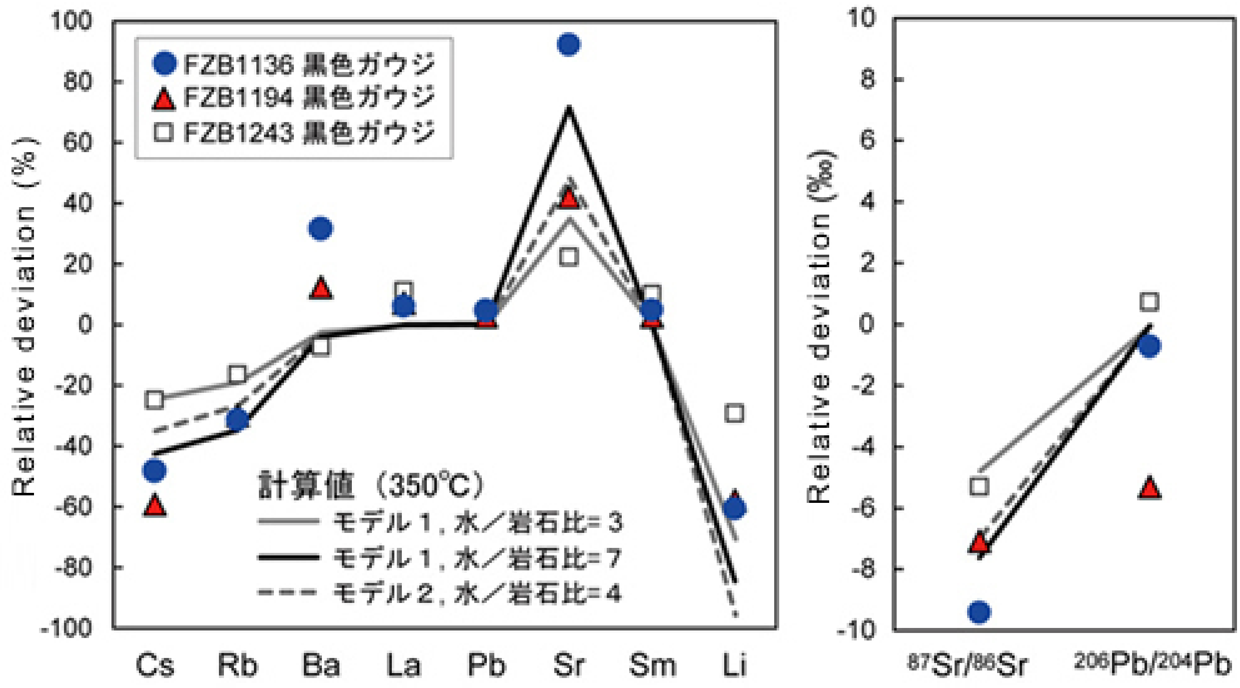

Fig.5 Variation of element content and isotope ratios in the black gouge of three fault zones were showed by relative deviation. Solid line and dotted line indicate calculated value of chemical composition in black gouge when fluid-rock interaction occurs at 350°C.

Contacts:
(For the study)
Tsuyoshi Ishikawa
Group Leader, Geochemical Research Group
Kochi Institute for Core Sample Research (KOCHI)
Japan Agency for Marine-Earth Science and Technology

(For publication)
Noriyuki Murata e-mail: press@jamstec.go.jp
Manager, Planning Office Press Office
Japan Agency for Marine-Earth Science and Technology