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The highest borehole temperature (449℃) determined by melting of pure metal tellurium ; WD-1 a, Kakkonda geothermal system, Japan

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1. Introduction

Melting of pure materials provides us with the most reliable temperature measurements in high temperature boreholes drilled in geothermal systems. Several pure materials were applied to determine the temperature at the bottom of well WD-1 a (Sasada *et al.*, 1993 ; Uchida *et al.*, 1996) at the Kakkonda geothermal system. The melting of metal tellurium (Te) indicates that the highest temperature in WD-1 a exceeds 449℃. Measurement techniques and data interpretation are described in the following chapters.

2. The deep geothermal well WD-1 a at Kakkonda

Kakkonda is one of the most productive geothermal fields in northern Honshu, where 80 MW geothermal power plants are currently in production (Fig. 1). Geothermal fluids are produced mainly from a reservoir shallower than 1,500 m, and were also recently discovered in deeper levels around the high-temperature Quaternary age pluton (Kato and Sato, 1995 ; Doi *et al.*, 1995).

WD-1 a was drilled to the depth of 3,729 m in June, 1995 (Fig. 2). It penetrates the granitic rocks at a depth of 2,860 m. Several types of

Fig. 1 Location of the Kakkonda geothermal field, northern Honshu, Japan.

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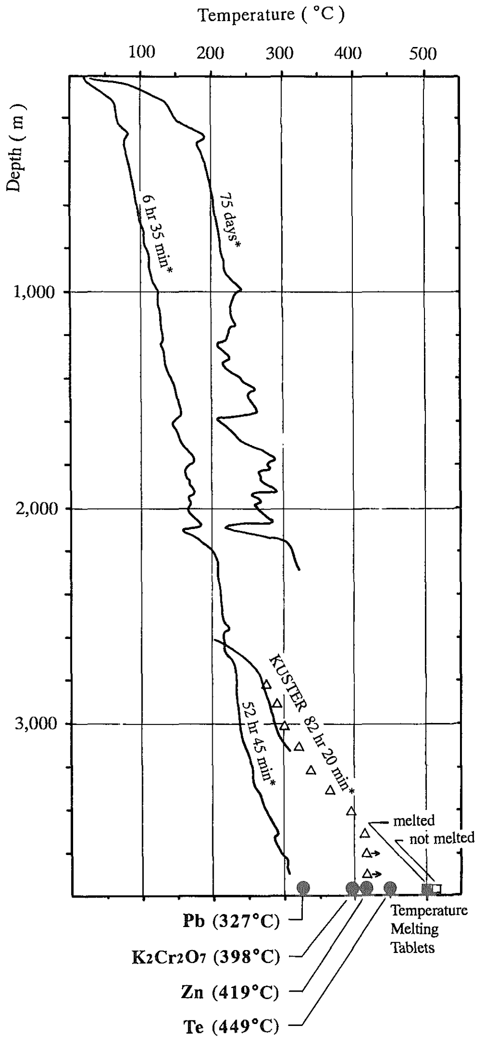

Fig. 2 Temperature profile of WD-1 a
* : Standing time after fluid circulation
Data from Yagi, *et al.* (1995), Uchida *et al.* (1996) and Kato *et al.* (1996).

temperature measurement systems were applied to the deepest levels. A maximum temperature of 414℃ was measured at 3,500 m using a Kuster temperature gauge. Moreover, temperatures greater than 414 ℃, which is the limit of the gauge, were confirmed at 3,600 m and 3,690 m. The temperature measurements at the bottom of the borehole was attempted using both pure materials and melting tablets (Yagi, *et al.*, 1995 ; Kato *et al.*, 1996).

3. Pure material melting method

The principle behind this method is simple, yet the reliability is high compared to other conventional methods. Pure materials of metal lead (purity : 99.999% ; melting point : 327℃), potassium dichromate (purity : 99.99% ; m.p. : 398℃), metal zinc (purity : 99.999% ; m.p. : 419℃) and metal tellurium (purity : 99.9999% ; m.p. : 449℃) were enclosed in Pyrex^{TM} capillary tubes filled with nitrogen gas to preserve the materials from oxidation (Fig. 3). Prior to the downhole measurements the melting behavior of these materials were observed with a microscopic heating stage in both nitrogen gas and air ambience. The melting behavior of lead, potassium dichromate and tellurium is quite sharp. Smoothly-curved surfaces on these three materials were easily observed on melting. In contrast, melting behavior was not observed in zinc at its melting point in air, with only a change of the color observed on the surface. However, very sluggish melting behavior of zinc was observed around its melting point in the nitrogen gas. Thus, all the four materials are applicable to temperature measurements when enclosed in nitrogen-filling tubes, although melting behavior of zinc is not as sharp.

4. Downhole measurements

The above described pure materials were installed in a steel vessel. The vessel was sealed and lowered to the depth of 3,700 m in WD-1 a. Downhole measurements were carried out twice on July 23 and 24, 1995. The first measurement was performed 129 hours after fluid circulation in the borehole was stopped, and the second one 159 hours after. The first vessel was filled with nitrogen gas and the second with air. All the pure materials in the vessel were melted on both the runs (Fig. 3).

The melting point of pure materials is also dependent on pressure. The inner pressure of the vessel is not hydrostatic, but is estimated to be from the characteristic equation for gases, since the pure materials are placed in gases

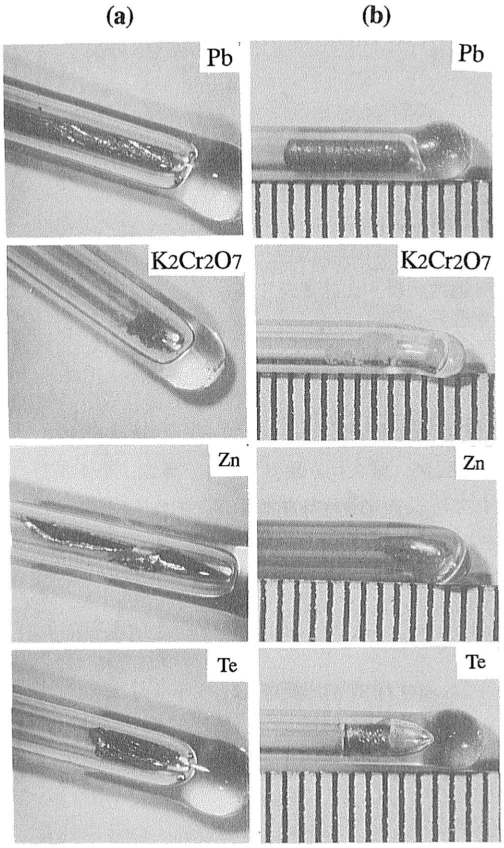

Fig. 3 (a) The pure materials before downhole measurement.
The four kinds of pure materials, lead (Pb), potassium dichromate ($K_2Cr_2O_7$), zinc (Zn) and tellurium (Te) are placed in fused silica capillary tubes filled with nitrogen gas.
(b) The pure materials after downhole measurement.
The rugged lumps of lead and zinc are more rounded, and their surfaces became smooth after the downhole measurement. The inner wall of the zinc tube is coated by dark material. All the tellurium and a considerable amount of potassium dichromate moved to the corner and filled the inner spaces of the tubes. All of these changes of the pure materials indicate melting. Graduated measure in mm.

completely enclosed by the steel vessel. The pressure in the vessel at 449℃ is calculated to be approximately twice atmospheric pressure, thus the pressure correction is negligible for the melting point determination.

Based on metal tellurium's melting point, the maximum temperature of well WD-1 a exceeds 449 ℃. This is the highest drillhole temperature determined with high reliability in exploited geothermal areas in the world. The previous record in geothermal drillholes was 419 ℃, which was determined by the melting of zinc in San Vito, Italy (Bruni *et al.*, 1983).

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葛根田地熱系 WD-1a 坑井において金属テルルの溶融により求められた最高温度 449℃

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要　旨

岩手県葛根田地熱地域において NEDO により掘削された深部坑井 WD-1a（3,729 m）の坑底温度を純物質の融点を用いて測定した．極めて高純度の物質 4 種類（鉛，重クロム酸カリウム，亜鉛，テルル）を窒素ガス置換したキャピラリーに封入し，ゾンデにいれて坑底まで降ろしたところ，すべての物質に溶融が認められた．これらのうち最も高い融点がテルルの 449℃であることから，WD-1a は坑底でこの温度を上回っていることになる．これまで地熱坑井で記録された温度は亜鉛の溶融による 419℃であるので，WD-1a は世界で最も高い温度を記録した坑井といえる．

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