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Short Articles

Zinc-bearing actinolite from the Kakkonda geothermal system, Iwate Prefecture, northeastern Japan

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Takayuki SAWAKI, Munetake SASAKI, Koichiro FUJIMOTO and Naoto TAKENO (2001) Zinc-bearing actinolite from the Kakkonda geothermal system, Iwate Prefecture, northeastrn Japan. *Bull. Geol. Surv. Japan*, vol. 52 (6/7), p. 315-320, 3 figs, 1 table.

Abstract: Zinc-bearing actinolite was found in a hydrothermal vein of a drill core retrieved at 1,223 m in depth of the deep research well, WD-1, which had been drilled in the Kakkonda geothermal area, northeastern Japan. Zinc-bearing actinolite is fibrous and occurs with sphalerite, chalcopyrite, pyrite, quartz, anhydrite, epidote and clay minerals in the vein. The ZnO content of actinolite ranges in 0.4-1.5 wt.%, relatively high compared with zinc-bearing calcic amphiboles in previous reports. The actinolite was possibly formed from zinc-rich hydrothermal fluid at early stage of geothermal activity in Kakkonda.

1. Introduction

The Kakkonda geothermal system in northeastern Japan is one of the active geothermal systems in Japan, and two geothermal power plants are in operation there (Kanazawa *et al.*, 1996). The New Energy and Industrial Technology Development Organization (NEDO) drilled a deep geothermal research well (WD-1), in order to confirm and promote utilization of deep geothermal resources within the "Deep-Seated Geothermal Resources Survey" (Sasada *et al.*, 1998). The well WD-1 was drilled through hydrothermally altered rocks and hornfelses, and encountered a Quaternary granitic rock (Kakkonda Granite: Kanisawa *et al.*, 1994) at 2,860 m in depth. In 1995, a temperature exceeding 500 °C was measured at the bottom of WD-1 (Muraoka *et al.*, 1998; Ikeuchi *et al.*, 1998).

Some drill cores were recovered from WD-1, including the altered rocks, hornfelses and granitic rocks (Uchida *et al.*, 1996). The authors found zinc-bearing actinolite in a hydrothermal vein of the core sample recovered from 1,220.8-1,223.5 m in depth of WD-1, and describe their petrography. The amphibole nomenclature conforms to that of Leake (1978).

Amphiboles of high zinc contents uncommonly occur. From the Franklin skarn, New Jersey, U.S.A., Palache (1935), Klein and Ito (1968) and Dorling and Zussman (1985) found tremolite-actinolite (4.3-9.45 wt.% ZnO), tirodite (6.95-10.8 wt.% ZnO), magnesian hastingsite (0.53 wt.% ZnO) and magnesio-riebeckite (7.84 wt.% ZnO). Other zinc-bearing amphiboles (ZnO > 0.1 wt.%) were described by Sundius (1946), Treloar (1987), Damman and Lustenhouwer (1992) and Oen and Lustenhouwer (1992) from Sweden, Borley (1963) and Butler and Thompson (1967) from Nigeria, De Keyser (1966) from Australia, Coleman and Papike (1968), Stull (1973) and Hawthorne *et al.* (1996) from U. S.A., Gulyaeva *et al.* (1986) from U.S.S.R., Schumacher and Czank (1987) from Finland, Caballero *et al.* (1998) and Oberti *et al.* (2000) from Spain, and Borg (1967) and Hawthorne *et al.* (1993) from various igneous rocks. Minor amounts of ZnO (< 0.1 wt.%) in amphiboles were reported by Engel and Engel (1962), Nambu *et al.* (1969), Graybeal (1973), Khitrunov and Dmitrenko (1975), Goto *et al.* (1977) and Hawthorne *et al.* (2000).

2. Geological setting

The geology of the Kakkonda area has been studied for geothermal exploitation (e.g. Doi *et al.*, 1998; Muraoka *et al.*, 1998). Figure 1 shows a cross section of the Kakkonda geothermal system (Doi *et al.*, 1998).

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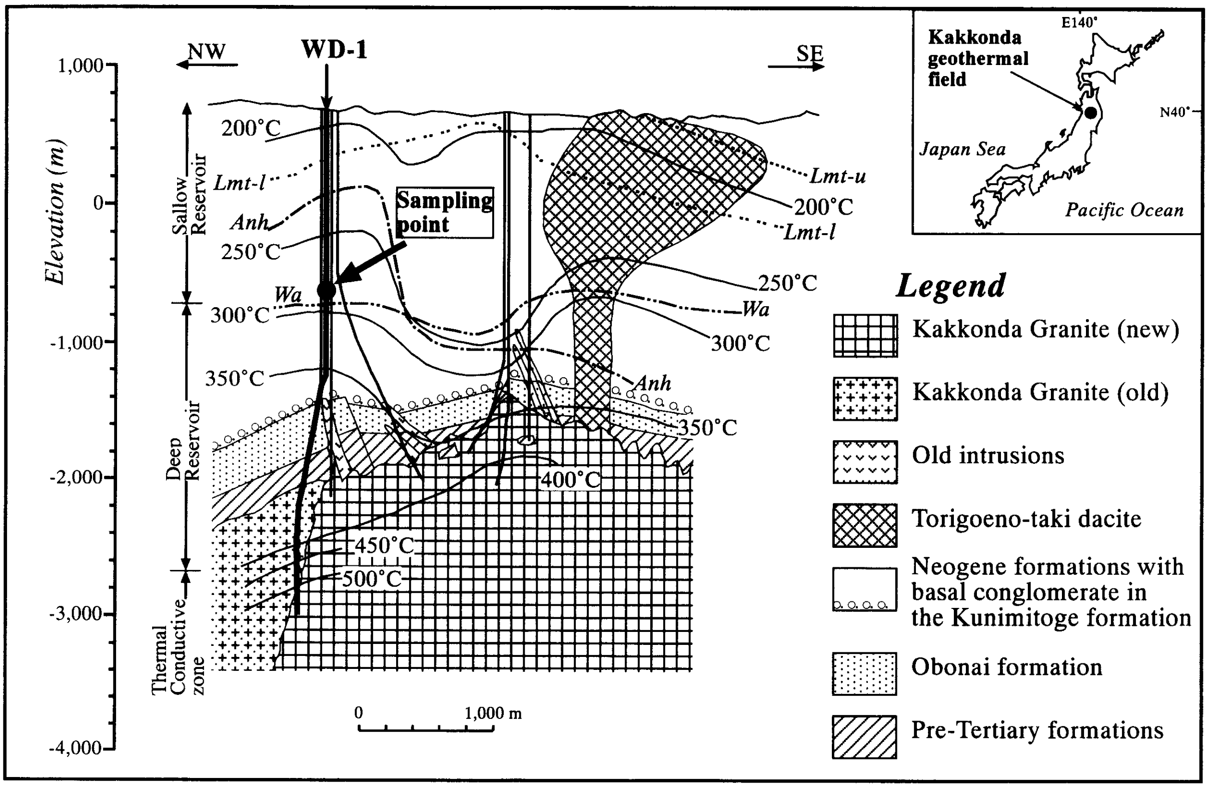

Fig. 1 Schematic cross section of the Kakkonda geothermal system, simplified after Doi *et al.* (1998). The studied sample was collected at 1,223 m in depth of WD-1.
Lmt-u, upper limit of laumontite; *Lmt-l*, lower limit of laumontite; *Anh*, upper limit of anhydrite; *Wa*, lower limit of wairakite.

The Kakkonda geothermal area is covered with volcanic and sedimentary rocks of Neogene (the Obonai, Kunimitoge, Takinoue-onsen and Yamatsuda formations) and Quaternary, and they are underlain by sedimentary rocks of pre-Tertiary. The geothermal reservoir of the Kakkonda geothermal system is divided into shallow and deep reservoirs, and their boundary is at about 1,500 m in depth, based on steep change of formation temperatures and permeability (Doi *et al.*, 1988, 1998). The sedimentary rocks of pre-Tertiary and a part of the volcanic and sedimentary rocks of Neogene are thermally metamorphosed by the Kakkonda Granite of Quaternary (Kanisawa *et al.*, 1994; Muraoka *et al.*, 1998; Doi *et al.*, 1998). The studied sample was from the shallow reservoir.

3. Petrography of the sample

The core sample at 1,220.8-1,223.5 m in depth of WD-1 is andesitic tuff with pyroclastic textures of the middle Kunimitoge formation, and is cut by a number of hydrothermal mineral veins (NEDO, 1995). Zinc-bearing actinolite occurs in a hydrothermal vein over 10 cm wide with 70° dip at 1,223.0-1,223.5 m deep. The core is remarkably altered around the vein. The vein consists of chalcopyrite, pyrite, sphalerite, quartz, anhydrite, epidote, actinolite and clay minerals (NEDO, 1995), accompanied by fractured and altered rock fragments. The vein is subdivided into two parts under the microscope: one is composed of coarse sphalerite, chalcopyrite, pyrite and quartz with small amounts of anhydrite and epidote, and the other is of coarse sphalerite, chalcopyrite and pyrite which are embedded in matrix of fine actinolite and epidote. The later part may be extremely altered host andesitic tuff.

Actinolite occurs as fibrous crystals less than 0.3 mm in length. Around coarse sphalerite, fibrous actinolite pierces sphalerite (Fig. 2), without reaction relations. Compositional zoning in actinolite was not observed, because of its small size. Pyrite, chalcopyrite and sphalerite are euhedral to subhedral of several millimeters in size. Epidote occurs as pools in the matrix, and possibly replaced original volcanic textures: for example, amygdules.

4. Mineral chemistry and paragenesis

Chemical analyses of actinolite around sphalerite and epidote were performed on the JEOL JCXA-8800 electron-probe microanalyzer at the Geological Survey of Japan. The accelerating voltage, specimen current and beam diameter were 15 kV, 1.2-1.3x10^{-8} A and 3 μm, respectively. Analytical data were reduced

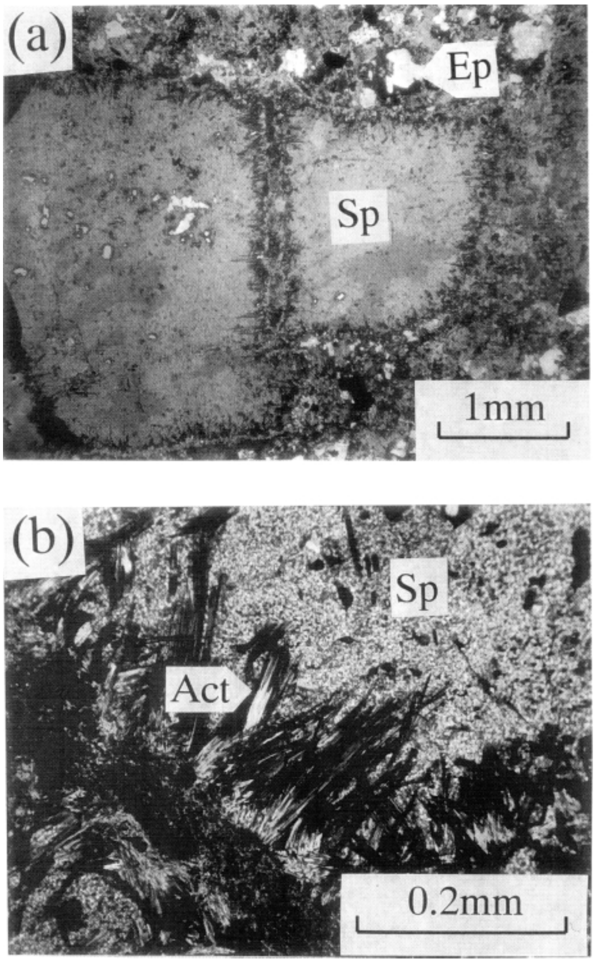

Fig. 2 Photomicrographs of minerals in the sample.
(a) Sphalerite (Sp) embedded in matrix of epidote (Ep) and actinolite (Act).
(b) Fibrous actinolite with which sphalerite is pierced.

using the method of Bence and Albee (1968). Selected results are given in Table 1. The actinolite contains 0.45-1.45 wt.% ZnO (0.05-0.15 per formula unit for O=23). The $Mg/(Fe^{2+}+Mg)$ ratios are 0.79-0.87, and MnO contents are 1.2-3.2 wt.%. Coexisting epidote contains no valuable ZnO.

Zn vs Fe[total]/(Fe[total]+Mg+Mn+Zn) ratios for calcic amphiboles in this study and previous reports (Palache, 1935; Borley, 1963; Klein and Ito, 1968; Stull, 1973; Treloar, 1987; Damman and Lustenhouwer, 1992; Oen and Lustenhouwer, 1992) are plotted on Fig. 3. Actinolite from the Franklin skarn (Palache, 1935; Klein and Ito, 1968) is exceptionally rich in ZnO, and is classified into "zinc-actinolite" (Leake, 1978). The studied actinolite from Kakkonda is second to that from Franklin as for ZnO content.

Bulk rock compositions of cuttings from the well WD-1 were reported by NEDO (1996) and Muraoka and Ohtani (2000), and the data show that zinc is enriched around 1,200-1,300 m deep. Hydrothermal veins of zincian minerals and sulfides are localized at

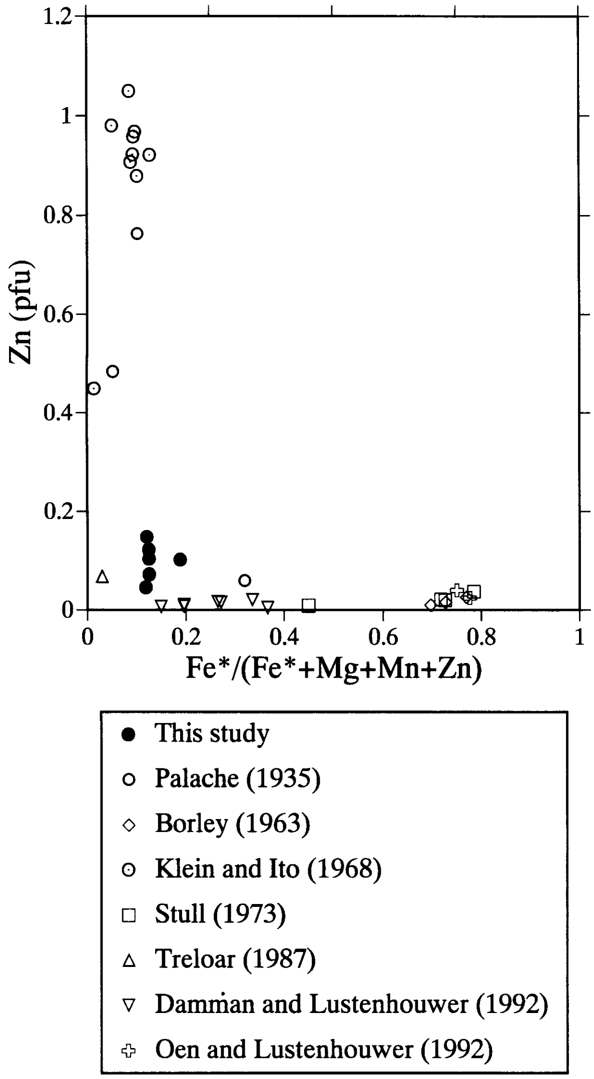

Fig. 3 Plots of Zn per formula unit (pfu) vs Fe*/(Fe*+Mg+Mn+Zn) for zinc-bearing Ca-amphiboles of this study and previous reports. Fe*: total iron.

the level, and heavy metals (Mn, Pb, Zn, Ba, V and Cu) are concentrated there. However, Muraoka and Ohtani (2000) suggests that the concentrated zone of the heavy metals does not correspond to present-day lost circulation zones. and the veins were probably formed prior to formation of the present permeable fractures. Thus, the zinc-bearing actinolite and other sulfides in the vein may be product of hydrothermal activity, in which geothermal fluid was enriched in the heavy metals, at early stage in the Kakkonda geothermal system.

5. Summary

Fibrous zinc-bearing actinolite occurs accompanied by sphalerite in a hydrothermal vein of a core sample at 1,223 m deep of the deep geothermal research well in Kakkonda. The ZnO content ranges from 0.4-1.5

Table 1 Chemical compositions of actinolite and epidote in the sample from 1,223 m deep of WD-1.
* Total iron as Fe_2O_3, ** Total iron as FeO.

Minerals	Act	Act	Act	Act	Act	Act	Ep	Ep	Ep	Ep	Ep
SiO2	55.24	56.54	55.90	57.14	55.11	55.30	37.76	37.35	37.55	36.96	37.44
TiO2	0.00	0.00	0.01	0.01	0.00	0.03	0.00	0.01	0.08	0.13	0.00
Al2O3	0.67	0.37	1.10	0.54	0.67	1.61	23.81	21.62	23.52	20.72	24.55
Cr2O3	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe2O3*							11.68	14.91	12.91	15.99	10.54
FeO**	5.30	5.45	5.15	5.39	8.05	5.43					
MnO	1.26	1.21	2.42	1.61	3.15	2.53	0.47	0.16	0.28	0.22	0.55
MgO	19.51	20.18	19.74	20.33	17.05	19.39	0.25	0.08	0.05	0.16	0.22
ZnO	0.98	1.19	0.45	1.45	0.97	0.70					0.02
CaO	13.11	13.17	12.76	12.35	13.02	12.71	22.89	22.92	23.15	22.93	23.13
Na2O	0.03	0.03	0.09	0.03	0.04	0.15	0.00	0.00	0.00	0.00	0.00
K2O	0.01	0.01	0.06	0.06	0.08	0.10	0.02	0.00	0.00	0.00	0.02
Total	96.11	98.15	97.67	98.92	98.15	97.93	96.88	97.06	97.53	97.09	96.48
O=	23	23	23	23	23	23	12.5	12.5	12.5	12.5	12.5
Si	7.889	7.909	7.856	7.926	7.873	7.784	3.023	3.020	2.999	3.005	3.004
Ti	0.000	0.000	0.001	0.001	0.000	0.003	0.000	0.001	0.005	0.008	0.000
Al	0.113	0.060	0.182	0.089	0.113	0.267	2.247	2.061	2.214	1.985	2.322
Cr	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe^{+3}*							0.704	0.907	0.776	0.978	0.636
Fe^{+2}**	0.632	0.638	0.605	0.626	0.962	0.639					
Mn	0.152	0.143	0.288	0.190	0.381	0.301	0.032	0.011	0.019	0.015	0.038
Mg	4.153	4.207	4.136	4.204	3.632	4.069	0.030	0.010	0.006	0.019	0.027
Zn	0.104	0.122	0.046	0.148	0.102	0.072	0.000	0.000	0.000	0.000	0.001
Ca	2.006	1.975	1.921	1.836	1.993	1.917	1.964	1.986	1.981	1.997	1.989
Na	0.008	0.009	0.024	0.009	0.010	0.040	0.000	0.000	0.000	0.000	0.000
K	0.002	0.001	0.011	0.010	0.015	0.017	0.002	0.000	0.000	0.000	0.002

wt.%, relatively high. The actinolite was possibly formed from zinc-rich hydrothermal fluid which infiltrated and fractured the host andesitic tuff at early stage in the Kakkonda geothermal system.

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References

Bence, A. E. and Albee, A. L. (1968) Empirical correction factors for the electron microanalysis of silicates and oxides. *J. Geol.*, **76**, 382-403.

Borg, I. Y. (1967) Optical properties and cell parameters in the glaucophane-riebeckite series. *Contrib. Mineral. Petrol.*, **15**, 67-92.

Borley, G. D. (1963) Amphiboles from the Younger Granites of Nigeria. Part I. Chemical classification. *Mineral. Mag.*, **33**, 358-376.

Butler, J. R. and Thompson, A. J. (1967) Cadmium and zinc in some alkali acidic rocks. *Geochim. Cosmochim. Acta*, **31**, 97-105.

Caballero, J. M., Monge, A., La Iglesia, A. and Tornos, F. (1998) Ferri-clinoholmquistite, $Li_2(Fe^{2+}, Mg)_3Fe^{3+}{}_2Si_8O_{22}(OH)_2$, a new ^{B}Li clinoamphibole from the Pedriza Massif, Sierra de Guadarrama, Spanish Central System. *Am. Mineral.*, **83**, 167-171.

Coleman, R. G. and Papike, J. J. (1968) Alkali amphiboles from the blueschists of Cazadero, California. *J. Petrol.*, **9**, 105-122.

Damman, A. H. and Lustenhouwer, W. J. (1992) Manganese-rich calcic amphiboles of the tremolite-ferro-actinolite series. *Mineral. Mag.*, **56**, 391-398.

De Keyser, F. (1966) Arfvedsonite in granites of the Ingham district, North Queensland. *Contrib. Mineral. Petrol.*, **12**, 315-324.

Doi, N., Muramatsu, Y., Chiba, Y. and Tateno, M. (1988) Geological analysis of the Kakkonda reservoir. Proceedings of "*International Symposium on Geothermal Energy, Exploration and Development of Geothermal Resources*", Kumamoto and Beppu, 1988, 522-525.

Doi, N., Kato, O., Ikeuchi, K., Komatsu, R., Miyazaki, S., Akaku, K. and Uchida, T. (1998) Genesis of the plutonic-hydrothermal system around Quaternary granite in the Kakkonda geothermal system, Japan. *Geothermics*, **27**, 663-690.

Dorling, M. and Zussman, J. (1985) Zincian actinolite asbestos. *Mineral. Polonica*, **15**, 11-19. (cited in Deer, W. A., Howie, R. A. and Zussman, J., 1997: *Rock-Forming Minerals, Vol. 2B, second edition, Double-Chain Silicates*, The Geological Society, London, pp. 764.)

Engel, A. E. J. and Engel, C. G. (1962) Hornblendes formed during progressive metamorphism of amphibolites, northwest Adirondack Mountains, New York. *Geol. Soc. Am. Bull.*, **73**, 1499-1514.

Graybeal, F. T. (1973) Copper, manganese, and zinc in coexisting mafic minerals form Laramide intrusive rocks in Arizona. *Econ. Geol.*, **68**, 785-798.

Goto, H., Kanisawa, S. and Katada, M. (1977) Zinc, lead, copper, nickel, cobalt, chromium, vanadium, and lithium contents of some Ryoke granites, and their constituting biotites and hornblendes, central Japan. *Bull. Geol. Surv. Japan*, **28**, 103-113. (in Japanese with English abstract)

Gulyaeva, T. Ya., Gorelikova, N. V. and Karabtsov, A. A. (1986) High potassium-chlorine-bearing hastingsites in skarns from Primorye, Far East USSR. *Mineral. Mag.*, **50**, 724-728.

Hawthorne, F. C., Cooper, M. A., Grice, J. D. and Ottolini, L. (2000) A new anhydrous amphibole from the Eifel region, Germany: Description and crystals structure of obertiite, $NaNa_2(Mg_3, Fe^{3+}, Ti^{4+})Si_8O_{22}O_2$. *Am. Mineral.*, **85**, 236-241.

Hawthorne, F. C., Ungaretti, L., Oberti, R., Bottazzi, P. and Czamamske, G. K. (1993) Li: An important component in igneous alkali amphiboles. *Am. Mineral.*, **78**, 733-745.

Hawthorne, F. C., Oberti, R., Ungaretti, L., Ottolini, L., Grice, J. D. and Czamamske, G. K. (1996) Fluor-ferro-leakeite, $NaNa_2(Fe^{2+}{}_2, Fe^{3+}{}_2, Li)Si_8O_{22}F_2$, a new alkali amphibole from the Canada Pinabete pluton, Questa, New Mexico, U.S.A.. *Am. Mineral.*, **81**, 226-228.

Ikeuchi, K., Doi, N., Sakagawa, Y., Kamenosono, H. and Uchida, T. (1998) High-temperature measurements in well WD-1a and the thermal structure of the Kakkonda geothermal system, Japan. *Geothermics*, **27**, 591-607.

Kanazawa, Y., Sato, K. and Akeno, T. (1996) Geothermal development in the Kakkonda II area. *Geothermal Energy*, **21**, 244-255. (in Japanese)

Kanisawa, S., Doi, N., Kato, O. and Ishikawa, K. (1994) Quaternary Kakkonda Granite underlying the Kakkonda Geothermal Field, northeast Japan. *J. Mineral. Petrol. Econ. Geol.*, **89**, 390-407. (in Japanese with English abstract)

Khitrunov, A. T. and Dmitrenko, S. M. (1975) Geochemistry of zinc in granitoids. *Geochem. Inter.*, **11**, 804-812.

Klein, Jr., C. and Ito, J. (1968) Zincian and manganoan amphiboles from Franklin, New Jersey. *Am. Mineral.*, **53**, 1264-1275.

Leake, B. E. (1978) Nomenclature of amphiboles. *Am. Mineral.*, **63**, 1023-1052.

Muraoka, H. and Ohtani, T. (2000) Profiling of the Kakkonda geothermal system by bulk rock chemistry of the well WD-1a. *Report Geol. Surv. Japan*, No. 284, 35-55. (in Japanese with English abstract)

Muraoka, H., Uchida, T., Sasada, M., Yagi, M., Akaku, K., Sasaki, M., Yasukawa, K., Miyazaki, S., Doi, N., Saito, S., Sato, K. and Tanaka, S. (1998) Deep geothermal resources survey program: igneous, metamorphic and hydrothermal processes in a well encountering 500 °C at 3729 m depth, Kakkonda, Japan. *Geothermics*, **27**, 507-534.

Nambu, M., Tanida, K. and Kitamura, T. (1969) Kozulite, a new alkali amphibole, from Tanohata Mine, Iwate Prefecture, Japan. *J. Japan. Assoc. Mineral. Petrol. Econ. Geol.*, **62**, 311-328. (in Japanese with English abstract)

New Energy and Industrial Technology Development Organization (NEDO) (1995) *A report on a "Deep-Seated Geothermal Resources Survey" project during FY 1993.* pp. 518. (in Japanese)

New Energy and Industrial Technology Development Organization (NEDO) (1996) *A report on a "Deep-Seated Geothermal Resources Survey" project during FY 1995.* pp. 887. (in Japanese)

Oberti, R., Caballero, J. M., Ottolini, L., López-Andrés, S. and Herreros, V. (2000) Sodic-ferripedrizite, a new monoclinic amphibole bridging the magnesium-iron-manganese-lithium and the sodium-calcium groups. *Am. Mineral.*, **85**, 578-585.

Oen, I. S. and Lustenhouwer, W. J. (1992) Cl-rich biotite, Cl-K hornblende, and Cl-rich scapolite in meta-exhalites: Nora, Bergslagen, Sweden. *Econ. Geol.*, **87**, 1638-1648.

Palache, C. (1935) The minerals of Franklin and Sterling Hill, Sussex County, New Jersey. *U.S.G.S Professional Paper*, No. 180, pp. 135.

Sasada, M., Doi, N. and Hedenquist, J. W. (1998) Preface. *Geothermics*, **27**, 505.

Schumacher, J. C. and Czank, M. (1987) Mineralogy of triple- and double-chain pyriboles from Orijärvi, southwest Finland. *Am. Mineral.*, **72**, 345-352.

Stull, R. J. (1973) Calcic and alkali amphiboles from the Golden Horn Batholith, North Cascades, Washington. *Am. Mineral.*, **58**, 873-878.

Sundius, N. (1946) The classification of the hornblendes and the solid solution relations in the amphibole group. *Sver. Geol. Unders. Årsbok*, Ser. C, **40**, No. 4, pp. 36.

Treloar, P. J. (1987) The Cr-minerals of Outokumpu — Their chemistry and significance. *J. Petrol.*, **28**, 867-886.

Uchida, T., Akaku, K., Sasaki, M., Kamenosono, H., Doi, N. and Miyazaki, S. (1996) Recent progress of NEDO's "Deep-seated Geothermal Resources Survey" Project. *Geothermal Resources Council Trans.*, **20**, 643-648.

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東北日本岩手県葛根田地熱系に産する含亜鉛アクチノ閃石

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要　旨

葛根田地熱系に掘削された深部調査井 WD-1 の，深度 1,222 m より回収されたコア試料を切る熱水性鉱物脈中に，含亜鉛アクチノ閃石が見い出された．含亜鉛アクチノ閃石は繊維状のものであり，閃亜鉛鉱，黄銅鉱，黄鉄鉱，緑簾石，硬石膏，石英，粘土鉱物と共に産する．その亜鉛含有量は 0.4-1.5 wt.%であり，これまでに報告されている含亜鉛カルシウム角閃石と比べると，亜鉛含有量が高い方に入る．この含亜鉛アクチノ閃石は，おそらく，葛根田地熱系の熱水活動の初期段階に存在していた亜鉛に富む流体から形成されたと考えられる．