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# Compositional variation and morphological characteristics of amphibole grains in the Wakurayama andesite from Omisaki, Matsue

by

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## Introduction

One of the authors (K. YOKOYAMA) has collected brown amphibole crystals of a few millimeters in length from cavities in the Wakurayama andesite at Omisaki, north-eastern part of Matsue city. He is aware of at least two types of amphibole grains with different morphologies those which are needle like and those which are short and columnar. Furthermore, we notice that the short columnar type amphibole grains are often sector zoned. In this paper we describe the compositional variation within the amphibole grains with respect to different morphological types.

## Occurrence of amphibole

The Wakurayama andesite outcrops on the eastern hill side of Matsue city (Fig. 1) and overlies Miocene rocks (MIYAJIMA *et al.*, 1972 ; YAMAUCHI & TAKAYASU 1987). The whole rock K-Ar age is about 5 Ma (MORRIS *et al.*, 1990).

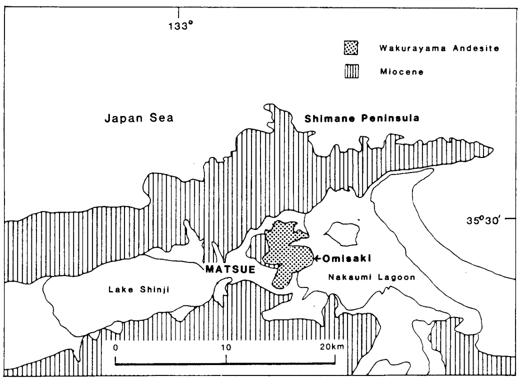


Figure 1 Distribution map of the Wakurayama andesite and sampling locality (Omisaki).

MORRIS (1986) describes the andesite as follows ; This weakly porphyritic rock has flow-banded, simple twinned laths of feldspar occasionally enclosing subhedral clinopyroxene (? rare orthopyroxene) with accessory biotite and opaque oxide. Based on form, rare aggregates of opaque oxide are the result of replacement of amphibole phenocrysts.

Along the weak flow layering described above by MORRIS (1986) small cavities (a few mm × a few cm) are sometimes observed, especially at Omisaki. Amphiboles occur within the cavities with tridymite, ilmenite (altered to an amorphous phase) and minor plagioclase.

## Chemical compositions of amphibole crystals

We chose three crystals for analysis (Plate 1), i. e., needle type, short columnar type (a) and (b) - sector zoned amphiboles (Plate 1d).

The amphiboles were analysed by EPMA (JEOL 733) and the chemical variation in each amphibole grains was examined. Analytical data are listed in Table 1. F and Cl were not analysed. Ferric iron contents are calculated on the basis of X+Y+Z=13 (when the amphibole formula is $A_{0-1}X_2Y_5Z_8O_{22}(OH)_2$). Fig. 2 shows all amphibole analyses plot nicely on a line with a slope of 1 : 1, proving that analytical data are rather precise and the presence of cunmmingtonite molecule is negligible.

As shown in Fig. 3, Ti content is well correrlated with $Al^{iv}$ as compared with othcr elements. Fig. 3 also indicates rythmical chemical variation within the short columnar type amphiboles (tremolitic hornblende) and only the outermost part rapidly

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Table 1 Chemical compositions and the mineral formulas for amphiboles. Analysing positions correspond to those in Plate 1b, c, and d.

needle type hornblende

| No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $SiO_2$ | 51.57 | 52.13 | 52.68 | 53.34 | 54.07 | 55.50 |
| $Al_2O_3$ | 4.53 | 4.18 | 3.67 | 3.44 | 3.02 | 2.15 |
| $TiO_2$ | 0.83 | 0.82 | 0.65 | 0.50 | 0.38 | 0.21 |
| $Fe_2O_3$ | 3.98 | 3.94 | 4.37 | 3.83 | 3.42 | 3.91 |
| FeO | 4.66 | 4.37 | 3.98 | 3.97 | 4.26 | 3.72 |
| MnO | 0.22 | 0.21 | 0.18 | 0.20 | 0.11 | 0.17 |
| MgO | 18.84 | 19.10 | 19.20 | 19.48 | 19.56 | 20.10 |
| CaO | 11.36 | 11.23 | 11.04 | 11.16 | 11.20 | 11.45 |
| $Na_2O$ | 2.42 | 2.38 | 2.28 | 2.21 | 2.07 | 1.72 |
| $K_2O$ | 0.72 | 0.77 | 0.72 | 0.63 | 0.57 | 0.39 |
| Total | 99.13 | 99.13 | 98.77 | 98.79 | 98.66 | 99.32 |
| O | 23 | 23 | 23 | 23 | 23 | 23 |
| Si | 7.229 | 7.288 | 7.370 | 7.442 | 7.531 | 7.647 |
| $Al^{IV}$ | 0.748 | 0.689 | 0.605 | 0.558 | 0.469 | 0.349 |
| $Al^{IV}$ | – | – | – | 0.007 | 0.027 | – |
| Ti | 0.088 | 0.086 | 0.068 | 0.052 | 0.040 | 0.022 |
| $Fe^{3+}$ | 0.420 | 0.415 | 0.460 | 0.402 | 0.358 | 0.405 |
| $Fe^{2+}$ | 0.546 | 0.511 | 0.465 | 0.463 | 0.496 | 0.429 |
| Mn | 0.026 | 0.025 | 0.021 | 0.024 | 0.013 | 0.020 |
| Mg | 3.937 | 3.981 | 4.004 | 4.049 | 4.062 | 4.129 |
| Ca | 1.706 | 1.682 | 1.655 | 1.667 | 1.672 | 1.690 |
| Na | 0.658 | 0.645 | 0.618 | 0.597 | 0.559 | 0.459 |
| K | 0.129 | 0.137 | 0.129 | 0.112 | 0.101 | 0.069 |
| Total | 15.487 | 15.459 | 15.395 | 15.373 | 15.328 | 15.219 |

short columar type (a) hornblende

| No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 51.96 | 51.87 | 52.74 | 52.74 | 51.83 | 51.99 | 52.63 |
| $Al_2O_3$ | 4.13 | 4.39 | 3.78 | 3.76 | 4.29 | 4.38 | 3.82 |
| $TiO_2$ | 0.86 | 0.84 | 0.70 | 0.69 | 0.91 | 0.75 | 0.62 |
| $Fe_2O_3$ | 3.98 | 4.84 | 3.88 | 4.34 | 4.10 | 3.57 | 2.97 |
| FeO | 4.39 | 4.00 | 4.47 | 3.92 | 4.31 | 4.55 | 4.95 |
| MnO | 0.14 | 0.21 | 0.21 | 0.19 | 0.17 | 0.19 | 0.19 |
| MgO | 18.92 | 18.86 | 19.04 | 19.11 | 18.85 | 18.87 | 19.06 |
| CaO | 11.12 | 10.89 | 11.02 | 10.80 | 10.98 | 11.21 | 11.19 |
| $Na_2O$ | 2.30 | 2.55 | 2.44 | 2.41 | 2.38 | 2.24 | 2.38 |
| $K_2O$ | 0.78 | 0.74 | 0.66 | 0.69 | 0.77 | 0.78 | 0.72 |
| Total | 98.58 | 99.19 | 98.73 | 98.65 | 98.59 | 98.53 | 98.53 |
| O | 23 | 23 | 23 | 23 | 23 | 23 | 23 |
| Si | 7.299 | 7.252 | 7.363 | 7.380 | 7.284 | 7.306 | 7.392 |
| $Al^{IV}$ | 0.684 | 0.723 | 0.624 | 0.620 | 0.711 | 0.694 | 0.610 |
| $Al^{IV}$ | – | – | – | – | – | 0.032 | 0.022 |
| Ti | 0.091 | 0.088 | 0.074 | 0.073 | 0.096 | 0.079 | 0.065 |
| $Fe^{3+}$ | 0.421 | 0.509 | 0.409 | 0.457 | 0.434 | 0.378 | 0.314 |
| $Fe^{2+}$ | 0.515 | 0.468 | 0.524 | 0.459 | 0.507 | 0.534 | 0.581 |
| Mn | 0.017 | 0.025 | 0.025 | 0.023 | 0.020 | 0.023 | 0.023 |
| Mg | 3.962 | 3.931 | 3.979 | 3.986 | 3.949 | 3.953 | 3.990 |
| Ca | 1.674 | 1.631 | 1.655 | 1.619 | 1.653 | 1.688 | 1.683 |
| Na | 0.626 | 0.691 | 0.663 | 0.654 | 0.651 | 0.610 | 0.648 |
| K | 0.140 | 0.132 | 0.118 | 0.123 | 0.138 | 0.140 | 0.129 |
| Total | 15.429 | 15.450 | 15.434 | 15.394 | 15.443 | 15.437 | 15.457 |

short columar type(b) hornblende

| No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 54.27 | 53.98 | 53.00 | 53.17 | 52.77 | 52.53 | 52.84 | 52.02 | 52.17 | 52.03 |
| $Al_2O_3$ | 2.74 | 2.81 | 3.66 | 3.41 | 3.62 | 4.00 | 3.59 | 3.92 | 4.06 | 4.09 |
| $TiO_2$ | 0.30 | 0.28 | 0.48 | 0.47 | 0.55 | 0.62 | 0.60 | 0.71 | 0.71 | 0.80 |
| $Fe_2O_3$ | 3.01 | 2.12 | 4.19 | 4.05 | 4.07 | 4.01 | 3.31 | 3.84 | 4.39 | 3.77 |
| FeO | 4.79 | 5.60 | 4.05 | 4.05 | 3.99 | 4.36 | 4.71 | 4.35 | 4.18 | 4.34 |
| MnO | 0.19 | 0.17 | 0.19 | 0.18 | 0.22 | 0.19 | 0.11 | 0.24 | 0.24 | 0.20 |
| MgO | 19.44 | 19.25 | 19.24 | 19.20 | 19.11 | 18.92 | 18.88 | 18.75 | 18.85 | 18.81 |
| CaO | 11.42 | 11.55 | 11.10 | 11.03 | 10.89 | 10.97 | 10.88 | 10.86 | 10.74 | 10.94 |
| $Na_2O$ | 1.88 | 1.92 | 2.23 | 2.11 | 2.23 | 2.37 | 2.23 | 2.31 | 2.48 | 2.27 |
| $K_2O$ | 0.54 | 0.58 | 0.68 | 0.67 | 0.64 | 0.67 | 0.70 | 0.75 | 0.78 | 0.76 |
| Total | 98.58 | 98.26 | 98.82 | 98.34 | 98.18 | 98.64 | 97.85 | 97.75 | 98.60 | 98.01 |
| O | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 |
| Si | 7.575 | 7.576 | 7.404 | 7.452 | 7.414 | 7.363 | 7.451 | 7.362 | 7.328 | 7.342 |
| $Al^{IV}$ | 0.425 | 0.424 | 0.596 | 0.548 | 0.586 | 0.637 | 0.549 | 0.638 | 0.672 | 0.658 |
| $Al^{IV}$ | 0.026 | 0.041 | 0.006 | 0.016 | 0.014 | 0.024 | 0.048 | 0.016 | – | 0.022 |
| Ti | 0.031 | 0.030 | 0.050 | 0.050 | 0.058 | 0.065 | 0.064 | 0.076 | 0.075 | 0.085 |
| $Fe^{3+}$ | 0.316 | 0.224 | 0.440 | 0.427 | 0.430 | 0.423 | 0.351 | 0.409 | 0.463 | 0.400 |
| $Fe^{2+}$ | 0.559 | 0.658 | 0.473 | 0.474 | 0.468 | 0.511 | 0.556 | 0.515 | 0.492 | 0.512 |
| Mn | 0.022 | 0.020 | 0.022 | 0.021 | 0.026 | 0.023 | 0.013 | 0.029 | 0.029 | 0.024 |
| Mg | 4.045 | 4.028 | 4.007 | 4.012 | 4.003 | 3.954 | 3.969 | 3.956 | 3.947 | 3.957 |
| Ca | 1.708 | 1.737 | 1.661 | 1.656 | 1.639 | 1.648 | 1.644 | 1.647 | 1.616 | 1.654 |
| Na | 0.509 | 0.522 | 0.604 | 0.573 | 0.632 | 0.644 | 0.610 | 0.634 | 0.675 | 0.621 |
| K | 0.096 | 0.104 | 0.121 | 0.120 | 0.115 | 0.120 | 0.126 | 0.135 | 0.140 | 0.137 |
| Total | 15.312 | 15.364 | 15.384 | 15.349 | 15.385 | 15.412 | 15.381 | 15.417 | 15.437 | 15.412 |

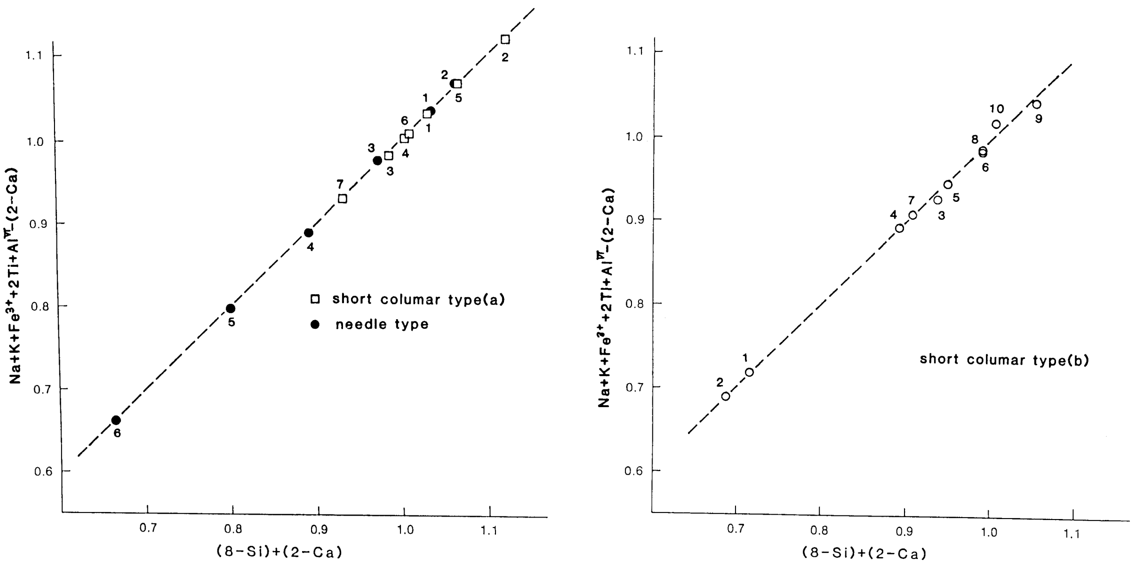


Figure 2 Diagram showing relationship between (8−Si)+(2−Ca) versus Na+K in A site $+Fe^{3+}+2Ti+Al^{VI}$ for amphiboles.

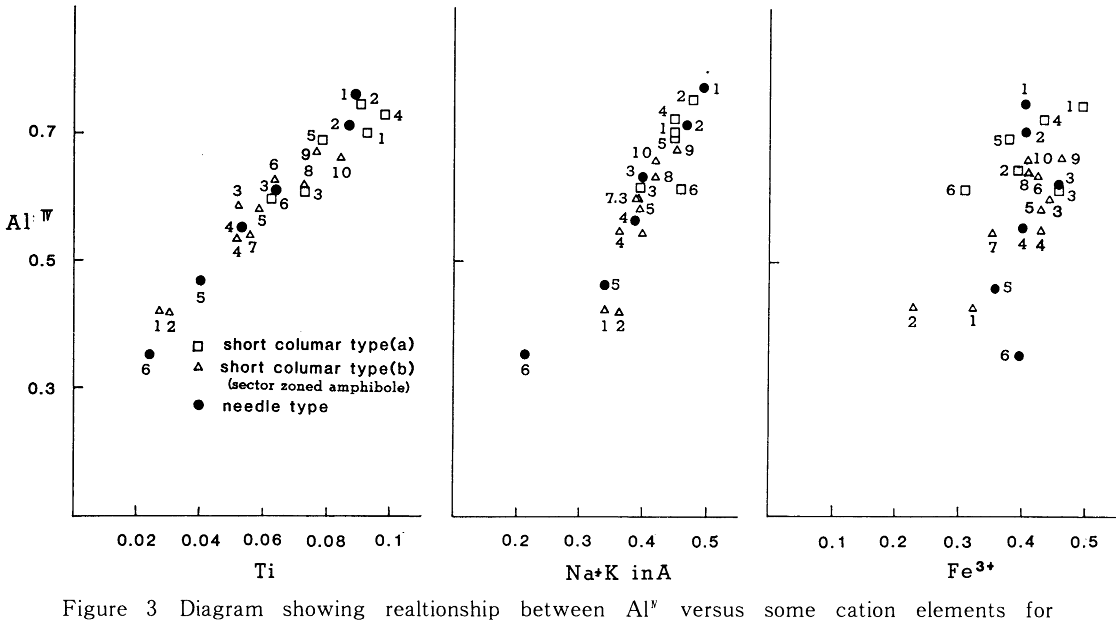


Figure 3 Diagram showing realtionship between $Al^{IV}$ versus some cation elements for amphiboles.

becomes tremolitic. The rythmic chemical variation may be attributed to repeated growth of hornblende under the influence of multiple circulation of fluids with rythmic change of composition at the final magmatic stage, as already interpreted for successive zoned amphibole on a granitic complex by KAWAKATSU and YAMAGUCHI (1987). In needle type amphiboles, Si increases monotonously towards the rim. Si contents in the needle type attain 7. 6 at the outermost rim, suggesting rapid increase in silica activity during the formation of needle type amphiboles.

## Conclusion

Chemical variations of the tremolitic hornbleде of three different morphological and textural types are studied by EPMA. Rhythmical variation, mainly by Si and Ti, within hornblende grains is apparent in the short columnar types. Simple increases in Si are recognized in needle type tremolitic hornblende beyond the core.


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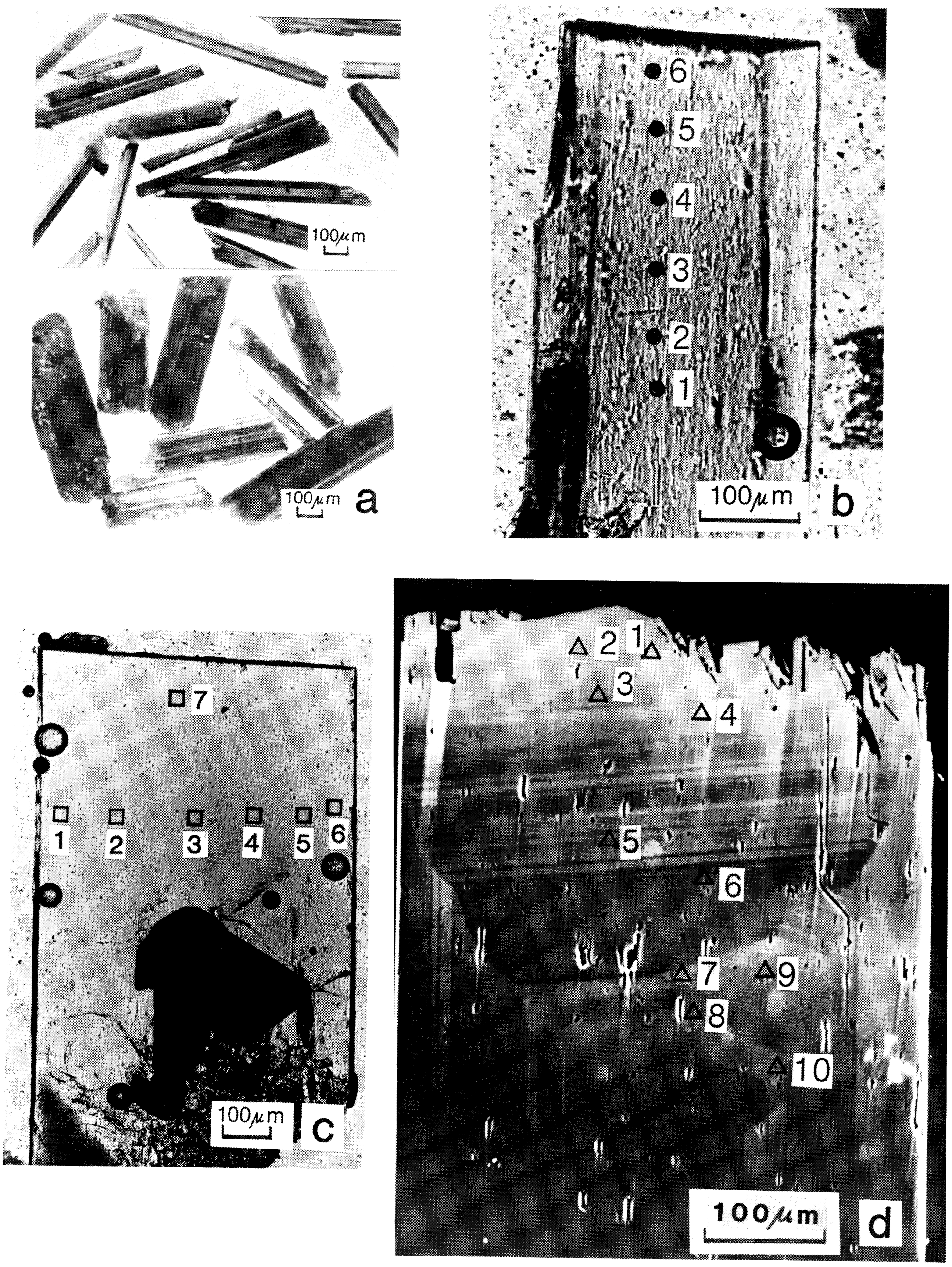


Plate 1a Photograph showing two diffrent morphological types of amphibole granis.
Plate 1b, c, and d Photomicropictures of analysed amphibole grains and analysing positions ; b=neeedle type, c=short columnar type (a), d=short columnar type (b) with sector zoning.