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Title	North-South Upper Crustal Profile of the Central Fossa Magna Region Deduced from Xenoliths of the Yatsugatake Volcanic Chain, Central Japan
Author(s)	Kawachi, Shimpei
Citation	北海道大学理学部紀要, 19(1-2), 19-28
Issue Date	1979-03
Doc URL	https://hdl.handle.net/2115/34862
Type	departmental bulletin paper
File Information	19_1-2_p19-28.pdf

Hokkaido University Collection of Scholarly and Academic Papers : HUSCAP

Jour, Fac. Sci., Hokkaido Univ., Ser. IV,
vol. 19, nos. 1-2, March, 1979, pp. 19-28.

NORTH-SOUTH UPPER CRUSTAL PROFILE OF THE CENTRAL FOSSA MAGNA REGION DEDUCED FROM XENOLITHS OF THE YATSUGATAKE VOLCANIC CHAIN, CENTRAL JAPAN

by

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(with 3 text-figures and 4 tables)

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Abstract

A north-south upper crustal profile of the central Fossa Magna region is presented based mainly on characteristic occurrence of schist xenoliths in the eruptive volcanic rocks of the Southern area and the contrasting lack of those in the Northern area, of the Yatsugatake Volcanic Chain.

Introduction

The Yatsugatake Volcanic Chain (Fig. 1; Highest point at Mt. Akadake, 2,899 m, A in Fig. 2) is one of the major volcanic massifs in Japan and is situated near the junction of the NE and SW Japan. It consists of over twenty centers of volcanic activities aligned on two major NS arcs of about 21 km in length convex to the east. All of the volcanoes of the volcanic chain reach over 2,000 m a.s.l.. They have been active since middle Pleistocene. Thick coarse-grained materials erupted from the volcanic chain cover an area of 1,900 km^2 (60 km in NS by 35 km in EW at maximum dimensions).

The geology of the volcanic chain has been described in detail in Kawachi (1961, 1972, 1974–75, 1977). According to the above studies, the volcanic chain can be subdivided into different units based on various criteria: i.e.,

a) Older (middle Pleistocene) and Younger (post middle Pleistocene to Recent) periods separated by an erosional hiatus.

b) The Northern and Southern areas at Natsuzawa Pass (n in Fig. 2) in the middle of the volcanic chain: The older period of the Yatsugatake Volcanic Chain consists of stratovolcanoes of basaltic and andesitic compositions, whereas the Younger period of the same area is characterized by many lava cones of rhyolites, dacites, hornblende andesites and pyroxene andesites. Both the Older and Younger periods of the Southern areas comprize stratovolcanoes of pyroxene andesites with two pyroxene andesite lava cones in the Younger period.

c) Eastern and Western arcs of aligned volcanoes: Eastern arc consists of stratovolcanoes whereas Western of lava cones.

The relative ages of activities show a youngling trend from north to south during the Older period while they show contrasting trends of from south to north and from east to west during the Younger period.

Difference in the types of xenoliths between the Northern and Southern areas has been

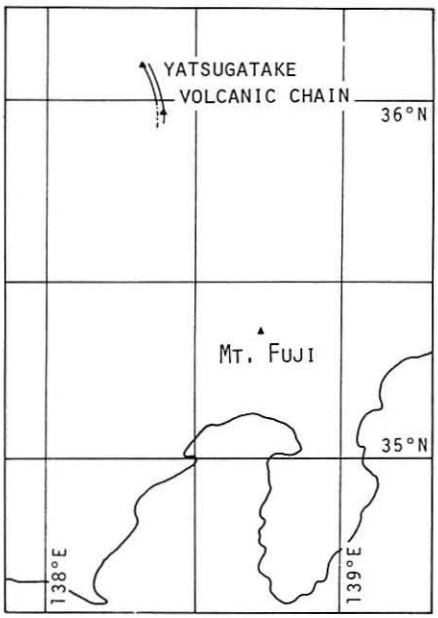
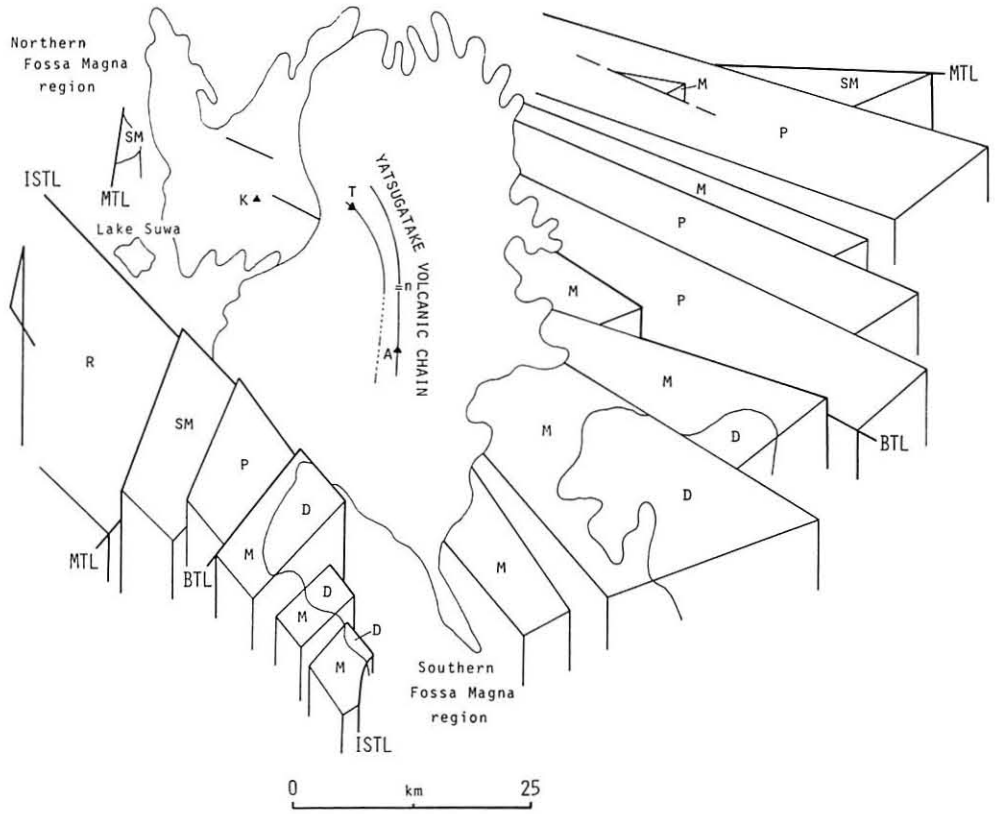


Fig. 1 Locality map

Fig. 2 Schematic tectonic map of the basement around the Yatsugatake Volcanic Chain
D: Tertiary quartz-diorites M: Jurassic, Cretaceous, and Paleogene formations P: Carboniferous, Permian, and Triassic formations R: Ryoke metamorphic rocks SM: Sambagawa metamorphic rocks MTL: Median Tectonic Line B: Butsuzo Tectonic Line ISTL: Itoigawa-Shizuoka Tectonic Line K: Mt. Kirigamine T: Mt. Tateshinayama A: Mt. Akadake n: Natsuzawa Pass



pointed out (Kawachi, 1976).

Due to the geographic-geologic position of the Yatsugatake Volcanic Chain, the study of the xenoliths in the volcanic rocks is important in that it would not only give information concerning magma chamber but also that on the relationship between NE and SW Japan, Outer and Inner zones of SW Japan and their extension in NE Japan, and Northern and Southern Fossa Magna regions.

Over 4,000 xenoliths (weigh about 2 tons) have been collected from all over the Yatsugatake Volcanic Chain, so far, among which over 1,000 have been studied under the microscope. The relation between the types of xenoliths and the historical development of the Yatsugatake Volcanic Chain, petrography of the volcanic chain, distribution of volcanoes, and detailed petrography of the xenoliths will be discussed in separate papers.

Acknowledgement

Sincere thanks are due to Prof. Hideo Kobayashi, Shimane University, who helped me in identifying minerals under the microscope. Profs. Seiji Hashimoto and Yoshio Katsui and many other colleagues of Hokkaido University are thanked for their help and discussion. Many thin sections essential to this study were made by Thin Section Laboratory of the Hokkaido University. Miss Chiaki Sato helped me in typing of the manuscript.

Geologic setting of the Yatsugatake Volcanic Chain

A highly schematic block diagram of the basement rocks of an area surrounding the Yatsugatake Volcanic Chain is shown in Fig. 2. The diagram is constructed on the following assumptions.

1. The horizontal widths of various parallel belts (shown in blocks) in the east (Kanto Mountains) and west (Akaishi Mountains) of the Yatsugatake Volcanic Chain are drawn in proportion to those measured on the published geologic maps while irregular boundaries are being smoothed out.

2. The height of each block is drawn to represent the idealized height of the actual topography. For example, the maximum and minimum heights of the blocks representing the Akaishi Mountains are 3,100 and 1,200 m, respectively, while those of the Kanto Mountains being 2,500 and 800 m, respectively.

3. The boundaries between the blocks are assumed to be vertical. This seems to be justified in most cases judging from known stratigraphy and structure of rocks in most belts.

From Fig. 2, the geologic setting of the Yatsugatake Volcanic Chain is summarized as follows.

a) The Yatsugatake Volcanic Chain is situated at the junction of SW and NE Japan which are separated by the Itoigawa-Shizuoka Tectonic Line.

b) The Yatsugatake Volcanic Chain is also situated near the junction of the Outer and Inner zones which are separated by the Median Tectonic Line.

The exact location of the Median Tectonic Line beneath the Yatsugatake Volcanic Chain is not clear. However, to the west of Kirigamine Volcano, northwest of the Yatsugatake Volcanic Chain (Y, Kawachi et al., 1966) and in the Kanto Mountains to the northeast of the Yatsugatake Volcanic Chain, outcrops of the Sambagawa metamorphic

rocks are known. Therefore the Median Tectonic Line is expected to be not far away to the north of the Yatsugatake Volcanic Chain. The Yatsugatake Volcanic Chain is, therefore, positioned in the Outer zone.

c) The Outer zone of SW Japan is clearly (and that of NE Japan less clearly) separated by the Butsuzo Tectonic Line into the Chichibu Terrane (inner side) and the Shimanto Terrane (outer side). The Yatsugatake Volcanic Chain is straddling over the Butsuzo Tectonic Line.

d) The Yatsugatake Valcanic Chain is placed in the central Fossa Magna region. The southern and northern Fossa Magna regions are separated roughly by a broad zone of basement high around the Yatsugatake Volcanic Chain.

e) The general trend of the basement rocks on both sides of the Yatsugatake Volcanic Chain is almost at right angles to each other forming a syntaxis at around the place where the Yatsugatake Volcanic Chain is. The age of syntaxis formation is believed to be sometime during Paleogene.

It should be born in mind that the correlation of individual beds on both sides of the syntaxis is not simple. However, it is suffice to say here that the overall structure of the region can be described by a large-scale fold structure closing northward with a vertical axis and the location of the Yatsugatake Volcanic Chain is nearly in the axial plane.

Types of xenoliths

There are a number of varieties of xenoliths under the microscope. For the estimation of the types of basement rocks, care must be exercised on the following points. Firstly, when the xenoliths show recrystallization textures, the origin of such textures must be evaluated carefully whether or not the texture is a modification resulted from incorporation into the magma. The size of xenoliths are between 5 and 10 cm but in some cases up to 20 cm. Smaller ones, (though increasingly hard to recognize as the size diminishes, do exist) should be taken into account to interpret the particular type of xenoliths to occupy as a significant geologic body beneath the volcanoes. Classification of xenoliths solely based on consisting minerals should be avoided as it is well known that non-equilibrium assemblages such as occurrence of glass, and juxtaposition of incompatible minerals are common and widespread among volcanic xenoliths.

Taking above points into consideration, a classification of xenoliths based on the original lithologies is presented in Table 1. In Table 2 is shown a list of characteristic mineral assemblages of hornfelses. Detailed description of these assemblages will be given elswhere.

Among the various types of xenoliths, finely and coarsely foliated xenoliths have to be derived directly from preexisting rocks as it is most unlikely that an incorporation of any rock types into magma to produce such texture. To attribute foliated xenoliths to conglomerates bearing such rocks is equally unlikely as conglomerates are extremely rare if not absent among basement rocks.

The observed mineral assemblages of schists are listed in Table 3.

Table 1 Types of xenoliths

chert (white, red, black, and radiolarian chert)		
quartz rock and quartzite		
magnetite or maghemite (3 x 4 x 7 cm)		
pyrite (4 cm)	hornblendite	
mudstone	hornblendite	
sandstone	Pl hornblendite	
diabase	pyroxenite	
dolerite	Pl pyroxenite	
granite	peridotite	
Bi granite	Pl websterite	
diorite	Pl harzburgite (cumulate)	
gabbro	anorthosite	
Ol gabbro	Ol-Opx-Cpx anorthosite	
Ol gabbro (cumulate)	spessartite	
Opx-Cpx gabbro	serpentinite	
Opx gabbro	pelitic hornfels	(see Table 2)
Cpx gabbro	calcareous hornfels	
Q gabbro	basic hornfels	
Ho gabbro	slate	
Opx-Cpx gabbro porphyrite	phyllite	
volcanics	schist (see Table 3)	

Bi: biotite Cpx: clinopyroxene Ho: hornblende
Ol: olivine Opx: orthopyroxene Pl: plagioclase
Q: quartz

Difference in types of xenoliths between the rocks of the Northern and Southern Yatsugatake Volcanic Chain

The most striking difference in the types of xenoliths between the Northern and Southern areas is in that the schists occur only in the Southern area. Schists are not known from surface geology corresponding to the area covered by the Yatsugatake Volcanic Chain. Other difference includes that sandstone*, peridotite and calcareous hornfels with melanite tend to occur in the Southern area, although number of thin sections other than sandstone is less than ten in each case.

Coarse-grained schists (total number of thin sections about 30) and fine-grained schists (about 100) are restricted to the Southern area.

Therefore, if the depths of the magma chambers are assumed to be constant throughout, there must be a contrasting difference in the nature of basement rocks between the Southern and Northern areas.

* Total number of xenoliths identified to be sandstone is 170 among which the ones from the Southern area are 4.4 times more numerous than those from the Northern area.

North-south upper crustal profile of the central Fossa Magna region

Matsuda (1968) proposed a N-S profile of the Fossa Magna region synthesizing stratigraphic as well as explosion seismicity, and gravity data. The stratigraphic data he used were:

Table 2 Mineral assemblages of pelitic, calcareous, and basic hornfelses*

Pelitic hornfels	Calcareous hornfels
biotite-plagioclase-quartz	calcite-quartz
biotite-plagioclase	calcite-garnet-clinopyroxene-corundum
biotite-cordierite-quartz	calcite-garnet-corundum
biotite-cordierite-plagioclase-quartz	calcite-garnet-corundum-tremolite
biotite-cordierite-plagioclase	calcite-wollastonite
biotite-cordierite-sillimanite-plagioclase-quartz	calcite-wollastonite-grossularite
biotite-cordierite-andalusite-plagioclase-quartz	calcite-wollastonite-grossularite-clinopyroxene
biotite-cordierite-andalusite-sillimanite-plagioclase-quartz	calcite-wollastonite-grossularite-clinopyroxene-tremolite-spinel
biotite-cordierite-andalusite-hercynite-corundum-clinopyroxene-plagioclase	calcite-wollastonite-clinopyroxene
biotite-cordierite-hercynite-plagioclase	clinozoisitite-wollastonite-garnet-tremolite
biotite-cordierite-microcline-corundum-plagioclase	sphene-clinopyroxene-hedenbergite
biotite-andalusite-plagioclase-quartz	sphene-clinopyroxene-plagioclase
biotite-andalusite-hercynite-corundum-plagioclase	sphene-clinopyroxene-plagioclase-garnet
biotite-andalusite-sillimanite-quartz	sphene-clinopyroxene-plagioclase-melanite
biotite-sillimanite-quartz	sphene-hedenbergite-melanite-andradite-corundum
biotite-garnet-plagioclase	sphene-clinozoisite-tremolite-wollastonite-melanite-andradite
biotite-hercynite-plagioclase	sphene-hedenbergite-plagioclase-garnet-corundum
biotite-corundum-plagioclase	sphene-hedenbergite-grossularite-spinel-plagioclase
cordierite	Basic hornfels
cordierite-quartz	hornblende-orthopyroxene-clinopyroxene-plagioclase-quartz
cordierite-plagioclase	biotite-hornblende-orthopyroxene-clinopyroxene-plagioclase
cordierite-plagioclase-quartz	biotite-orthopyroxene-plagioclase
cordierite-andalusite-plagioclase-quartz	biotite-orthopyroxene-clinopyroxene-plagioclase
cordierite-sillimanite-quartz	biotite-orthopyroxene-clinopyroxene-plagioclase-quartz
cordierite-sillimanite-plagioclase	biotite-clinopyroxene-plagioclase
cordierite-sillimanite-plagioclase-quartz	orthopyroxene-plagioclase
cordierite-sillimanite-garnet-plagioclase-quartz	orthopyroxene-clinopyroxene-plagioclase
cordierite-sillimanite-hercynite-plagioclase	orthopyroxene-clinopyroxene-plagioclase-quartz
cordierite-hercynite-plagioclase	orthopyroxene-clinopyroxene-plagioclase-garnet
andalusite-plagioclase-quartz	clinopyroxene-plagioclase
andalusite-plagioclase	clinopyroxene-garnet-epidote-corundum
andalusite-sillimanite-quartz	sphene-orthopyroxene-clinopyroxene-plagioclase
andalusite-sillimanite-hercynite-corundum-plagioclase	sphene-clinopyroxene-plagioclase-quartz
andalusite-hercynite-corundum	sphene-clinopyroxene-plagioclase
sillimanite-plagioclase-quartz	sphene-hedenbergite-diopside-orthopyroxene-plagioclase
sillimanite-microcline-quartz	sphene-hedenbergite-diopside-plagioclase
sillimanite-microcline-garnet-hercynite-plagioclase	sphene-biotite-garnet-hedenbergite-diopside-plagioclase
sillimanite-garnet-plagioclase	
garnet-hercynite	
hercynite-corundum-plagioclase	
hercynite-plagioclase	

* Glass is excluded from the list.

Table 3 Mineral assemblages of fine-grained and coarse-grained schists*

Fine-grained schist
quartz
biotite-cordierite-orthopyroxene-plagioclase-quartz
biotite-cordierite-orthopyroxene-clinopyroxene-plagioclase-quartz
biotite-garnet-orthopyroxene-clinopyroxene-plagioclase-quartz
biotite-orthopyroxene-plagioclase-quartz
biotite-orthopyroxene-clinopyroxene-plagioclase-quartz
biotite-clinopyroxene-plagioclase-quartz
hornblende-cordierite-orthopyroxene-clinopyroxene-plagioclase-quartz
hornblende-clinopyroxene-plagioclase-quartz
sphene-hornblende-hedenbergite-plagioclase-quartz
sphene-orthopyroxene-clinopyroxene-plagioclase-quartz
sphene-clinopyroxene-plagioclase-quartz
sphene-clinopyroxene-wollastonite-plagioclase-quartz
garnet-orthopyroxene-clinopyroxene-plagioclase-quartz
garnet-clinopyroxene-quartz
garnet-clinopyroxene-plagioclase-quartz
orthopyroxene-plagioclase-quartz
orthopyroxene-clinopyroxene-plagioclase-quartz
clinopyroxene-plagioclase-quartz
Coarse-grained schist
hornblende-orthopyroxene-clinopyroxene-plagioclase
sphene-orthopyroxene-clinopyroxene-plagioclase-quartz
sphene-clinopyroxene-quartz
sphene-clinopyroxene-plagioclase-quartz
sphene-garnet-orthopyroxene-clinopyroxene-quartz
orthopyroxene-clinopyroxene-quartz
orthopyroxene-clinopyroxene-plagioclase-quartz
clinopyroxene-plagioclase-quartz

* Glass is excluded from the list.

1. The Paleozoic rocks are relatively thick in the central Fossa Magna region while they become thin towards south.

2. The Mesozoic and lower Tertiary rocks are thick in the southern Fossa Magna region while they rapidly thin out towards the northern Fossa Magna region.

Xenoliths occurring in eruptive volcanic rocks must have been derived from pre-existing rocks between magma chamber and the surface of the earth. Examples of the various estimated depths of magma chambers are shown in Table 4. Among them Vesuvius volcano studied by Rittmann (1962) is best known as a classic example of estimation using xenolith data. However, basement rocks beneath Vesuvius are flat-lying and consisting of contrasting lithologies, while they are not so in the Yatsugatake Volcanic Chain. Reliable estimations of the depth of magma chambers for the Yatsugatake Volcanic Chain would be very difficult, but not impossible. Based on the assumptions listed below, a N-S upper crustal profile of the

Table 4 Depth of magma chamber in literatures

Locality	depth (km)	remarks
Kilauea	3 – 4	above sea level
Avachinsky	3	1.5 x 5 km in size
Sakurajima	3 and 10	
Vesuvius	5.6	
Hakone	10 (?)	
Atlantic Ocean	10	
Katmai	10 – 40	Many known in vertically spheroids. Directly connected to the volcano when shallower than 20 km
Bezymianny	50 – 60	Lens-shaped in NS

After Macdonald (1972, p.396-399) except for Hakone (Oki et al., 1978, p.71). Yoder (1976, p.2) believes that most magma chambers are between 2 and 6 km deep.

region can be drawn as shown in Fig. 3.

a) The depths of the magma chambers are assumed to be constant throughout the Yatsugatake Volcanic Chain. Considering the examples given in the literatures the depths are fixed at 10 km for drawing purpose.
b) Matsuda's (1968) profile is modifed to conform to the data obtained in this study.
c) Each column of strata bounded by faults on both sides in Fig. 3 is extended vertically from generallized surface geology.
d) Regionally metamorphosed Paleozoic rocks must occur beneath the Southern area above the magma chambers. On the other hand, they should not occur beneath the Northern area down to the depths of magma chambers despite widespread occurrence of unmetamorphosed Paleozoic rocks on the surface geology. The relative depth of each column is thus fixed.
e) A major tectonic break is expected between the basement rocks of the Northern and Southern areas. As far as judged by the surface geology, it could be an extension of the Butsuzo Tectonic Line. A broken line representing a transition from unmetamorphosed to metamorphosed Paleozoic rocks is shown in Fig. 4.
f) If the assumption of constant depth of magma chambers is valid, the difference in depth would only shift the whole columns up or down, but would not affect the overal shape of cross section so much.

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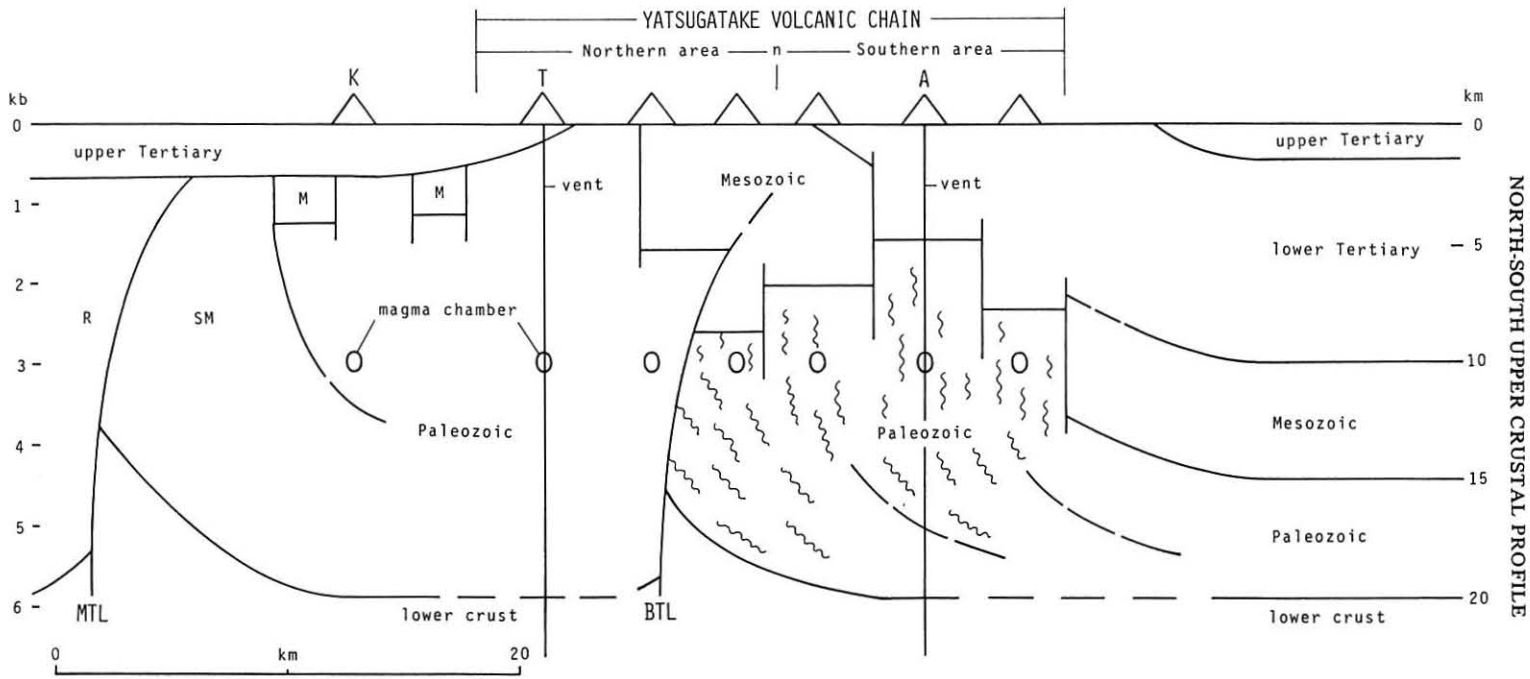

Fig. 3 N-S upper crustal profile of the central Fossa Magna region. Wavy lines under the Southern area show regionally metamorphosed rocks. Other symbols are same with Fig. 2.

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(Received on Sept. 11, 1978)