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Knocker catalogue of the Mineoka ophiolite belt, Boso Peninsula, Japan

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Abstract

This paper summarizes the occurrence of knockers (exotic blocks standing above the local terrain in a fault zone) of the Mineoka ophiolite belt, Boso Peninsula, Japan, from published data, figures, references as well as some new data. Four areas in particular are described, the Kamogawa, the Mineoka-Sengen, the Hosono-Mt. Atago, and the Heguri-Yamada areas. Tables of knocker occurrences and chemistry data are provided as appendices. Interpretation and discussion of the analytical implications of the data presented, and age data, are projects for the future.

Key words: Mineoka belt, ophiolite, knocker, exotic block, mode of occurrence, chemical data

Introduction

A "knocker" is defined as an exotic, hard block of rock standing above the local terrain within a fault zone or chaotic zone. This term was first used in the geological description of the Franciscan mélange (Karig, 1980). It is used mostly for high pressure metamorphic rock blocks, but also for basalt and chert – limestone blocks, or even in some terrigenous sedimentary rocks. However, in the surface expression of ophiolite mélange belts, such blocks are unusual occurrences when compared to the usual sedimentary formations; they are so conspicuous that their mode of occurrence can provide a key to understanding the processes and mechanisms of deformation and emplacement of metamorphic and/or oceanic rocks on land.

The Mineoka belt (Fig. 1) is a mélange belt (Ogawa, 1983; Ogawa and Taniguchi, 1987, 1988) or a fault belt (Takahashi *et al.*, 2003; Ogawa and Takahashi, 2004) that is characterized by knockers. The rocks in the belt have been studied by many geologists (most of the relevant references are listed in Chiba Prefecture History Research Agency, 1997), but there are insufficient exposures to properly understand the tectonics of the belt. During the course of our research over the last thirty years, we have attempted to describe the structure, petrography, petrology, chemistry and age of these rocks (Hirano *et al.*, 2003; Sato and Ogawa, 2000; Sato *et al.*, 1999, and references provided above). Here, we revise these descriptions, and provide both previously published and new illustrations and data in a compilation of relevant data for use in future studies. We call this paper a catalogue: its primary purpose is to guide researchers to specific outcrops and to describe them, but without providing specific interpretations of the geology of those outcrops

To support our summaries of knocker occurrences, we provide maps, figures, and tables, and describe their basic characteristics (e.g., location, size, and lithology) (Table 1 in Appendix). The chemistry of igneous and metamorphic rocks has been analyzed for many of these knocker occurrences, and compositional tables of major, trace, and in some cases rare earth elements are included (Tables 2, 3, 4), but the interpretation of age data will be published elsewhere (Mori *et al.*, submitted; Hirano *et al.*, in preparation).

We used mainly 1:25,000-scale Geographical Research Institute maps for this project, supported by some GPS data. The size of individual blocks was determined either by measurements taken in the field, or from maps. For each area, the distributions of the blocks are shown in separate maps, but the 1:25,000 maps show the basic locations. Descriptions proceed from east to west, from the Kamogawa area (including Yo-oka Beach and Shinyashiki, and eastern Mineoka Hills), to the Mineoka-Sengen area (including middle Mineoka Hills, Shirataki and Nishi), to the Hosono-Mt. Atago area (including western part Mineoka Hills, Kobata and Hinata), and finally to the Heguri-Yamada area (including the golf course).

Schematic cross sections that were published in the 1980s are provided in Fig. 2, but note that these diagrams reflect the view at that time, and because the knockers are considered to be surrounded by a sheared

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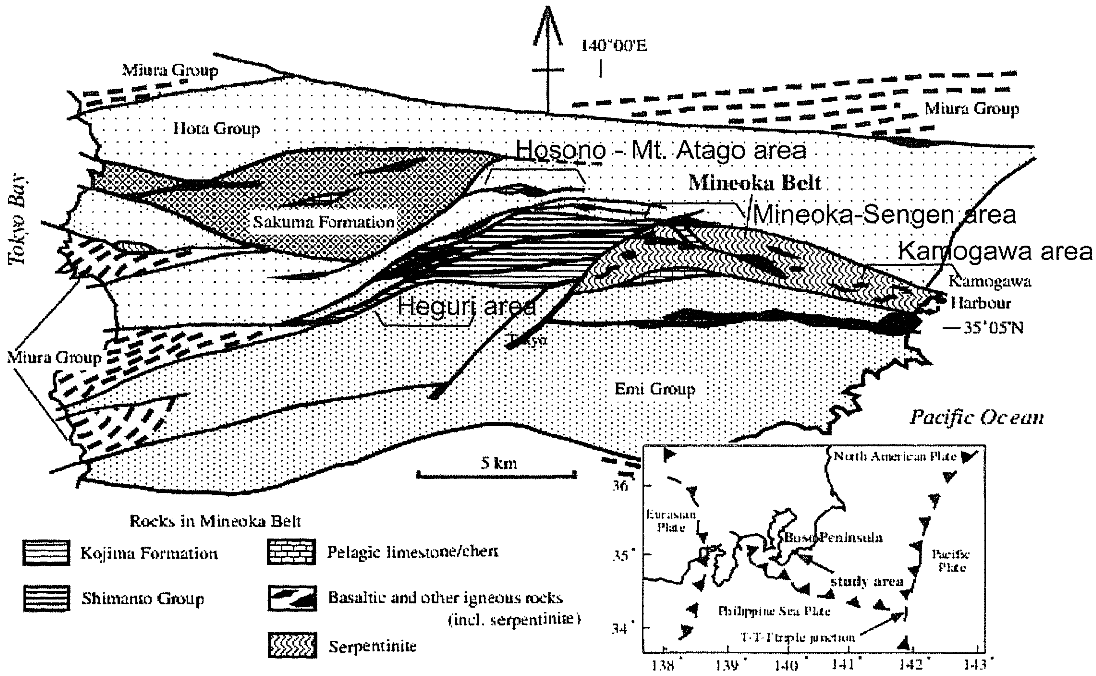

Fig. 1 Index map of the Mineoka belt (adopted from Takahashi *et al.* (2003) with some revisions), showing four representative areas in this paper.

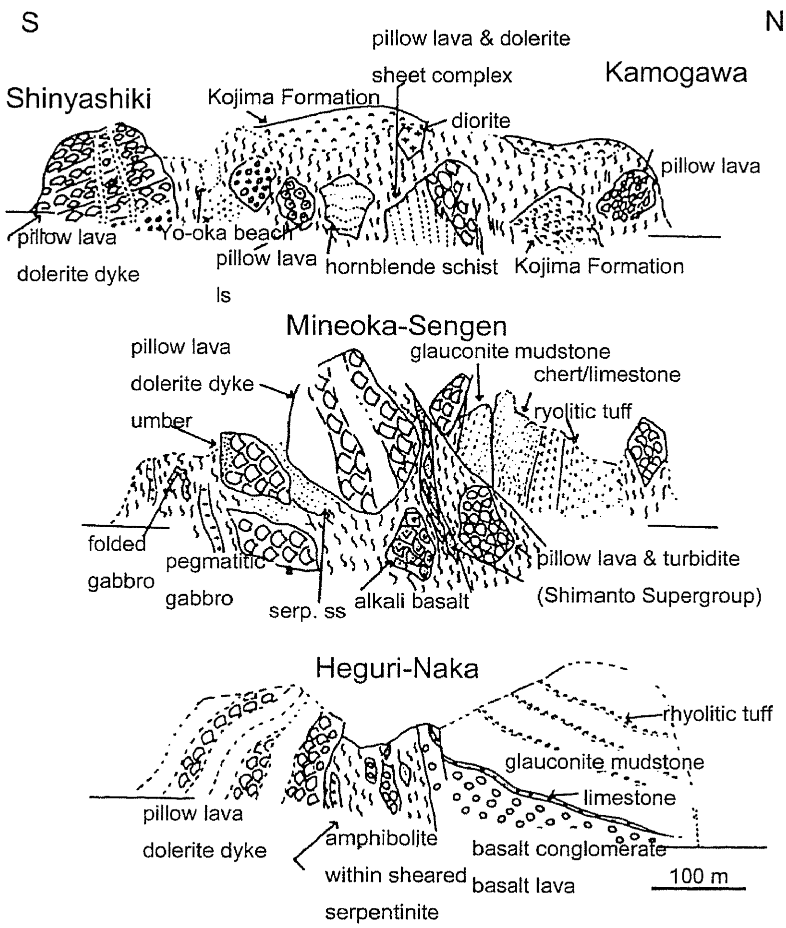

Fig. 2 Schematic cross sections of the representative areas of the Mineoka belt (mostly adopted from Ogawa and Taniguchi (1987, 1988) with some revisions, as observed in late 1980s). Attention, in these sections, serpentinite is shown as sheared but in fact mostly massive as blocks otherwise indicated (see also Fig. 4).

serpentinite matrix, the Mineoka belt is thought to be composed of ophiolite mélange (Ogawa, 1983). However, this view is now out of date. The serpentinite is now considered to also represent a block, as shearing within the serpentinite is evident only along the fault (Sato and Ogawa, 2000; Ogawa and Takahashi, 2004; Mori and Ogawa, 2005; Chiba, 2008MS). A schematic bird's-eye view of the main part of the Mineoka Hills, as viewed from the northeast, is shown in Fig. 3.

For description, one optional area is the Miura Peninsula, west neighborhood, and the maps will be added at last.

Description

Here, we provide a general description of each knocker, starting in the east of the Mineoka belt (Fig. 1).

Kamogawa area

The Kamogawa area includes both Kamogawa Harbor and its surrounds: from north to south, Kojima Island, Bentenjima Island, Yo-oka Beach, and Shinyashiki. It also extends onshore to the slope of Isomura to Shinganji in eastern Mineoka Hills (Fig. 4). This area was first mapped by Kanehira *et al.* (1968) and Kanehira (1976), and the precise rock distribution was mapped by junior high school pupils (referred to by Chiba Prefecture History Research Agency, 1997). The rocks offshore were detected from a boat (Mori and Ogawa, 2005). The general distribution of rocks is shown in Figs. 3 and 4.

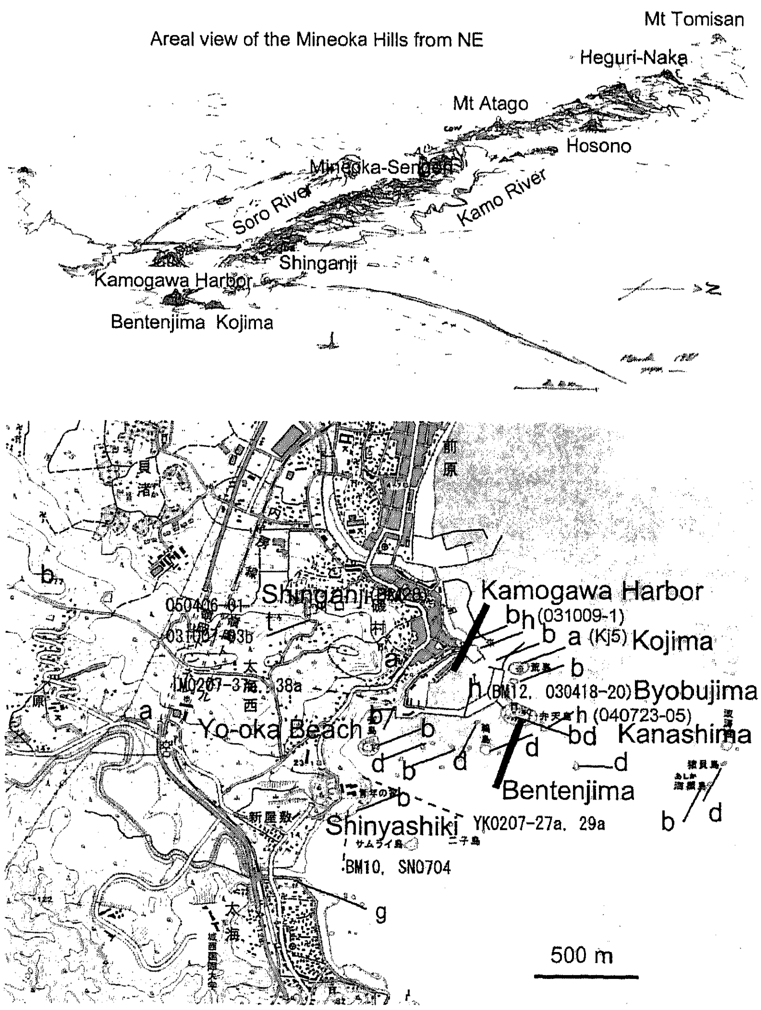

Fig. 3 Bird-eye view of the Mineoka Hills from NE (above), and the knocker distribution map in the Kamogawa Harbor and its vicinity with sample number (below). (see also Figs. 4 and 5). Abbreviation of rock type is as follows. a: andesitic pumice fall and tuff. b: basalt lava (tholeiitic)), d: dolerite dyke (tholeiitic), g: gabbro, h: hornblende schist, t: tonalite (diorite).

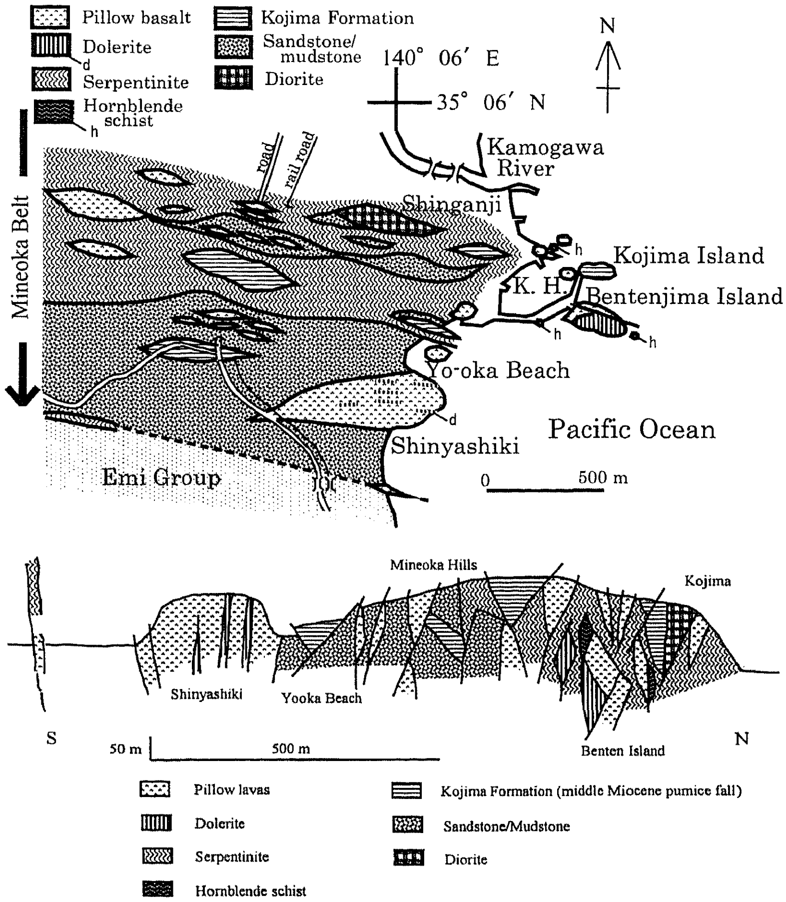

Fig. 4 Lithology map and cross section in the Kamogawa Harbor and its vicinity. Adopted from Takahashi *et al.* (2003) with some revisions.

Within the harbor, a metamorphic block some tens of meters in size (Byobujima Island) was first found by Kanehira *et al.* (1968), and was extensively studied by Hiroi, (1995a), and Ogo and Hiroi (1991). The conspicuous Bentenjima Island, in the center of the Kamogawa Harbor, is well mapped (Ogawa and Takahashi, 2004) (Fig. 5), and each rock type on the island has been chemically analyzed for major, trace, and rare earth elements. Some of these data have been interpreted by Hirano *et al.* (2003) and Ogawa and Takahashi (2004). The chemical data are listed in Tables 2, 3 and 4.

A very strange fossil was found in a siliceous matrix within pillow lavas at the northern end of Bentenjima Island (Fig. 6). The genus has not been determined, but the fossil possibly represents a type of tube worm.

The geology of Kojima Island, the northernmost island in Kamogawa Harbor, has not been described in detail, but is briefly described in a field guidebook (Ogawa, 2005) (Fig. 7). It is composed entirely of andesitic pumiceous fall deposits – the Kojima Formation. Strata on the island dip gently north. No strong deformation or alteration is evident, except for some faults and zeolite veins, which suggest that this formation was emplaced after the main stage of deformation of the rocks in the Mineoka belt. The age of this formation is not accurately known, but K-Ar dating suggests an age of around 5.8 +/− 0.3 MaBP (by Geochronology and Isotopic Geochemistry).

Two interesting masses of metamorphic rock, Byobujima Island and Kanashima Island, were mapped by Mori and Ogawa (2005) (Fig. 8). The present-day characteristics of these two islands are critical to understanding the geological history and mechanism of formation of the Mineoka ophiolite belt (Mori *et al.*, submitted). Another metamorphic knocker, some meters in diameter of round shape, is known in the northern corner of the harbor, the Sumoba-ishi (sumo as in Japanese wrestling). All of the metamorphic rocks of these islands are hornblende schist (with some minor retrograde or hydrothermal metamorphism to epidote–amphibolite or greenschist facies) and are extensively foliated, suggesting that they are products of a subduc-

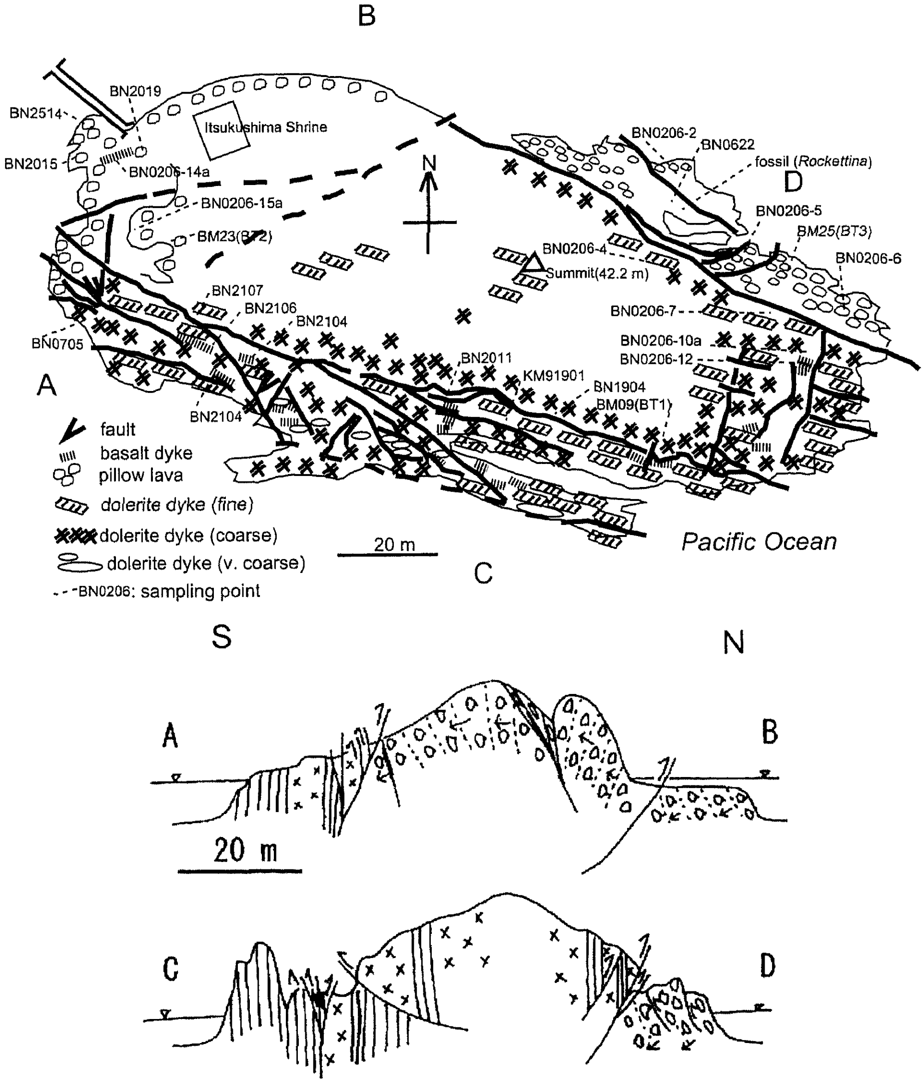

Fig. 5 Lithology map (above) and cross sections (below) of the Bentenjima Island with sample number.

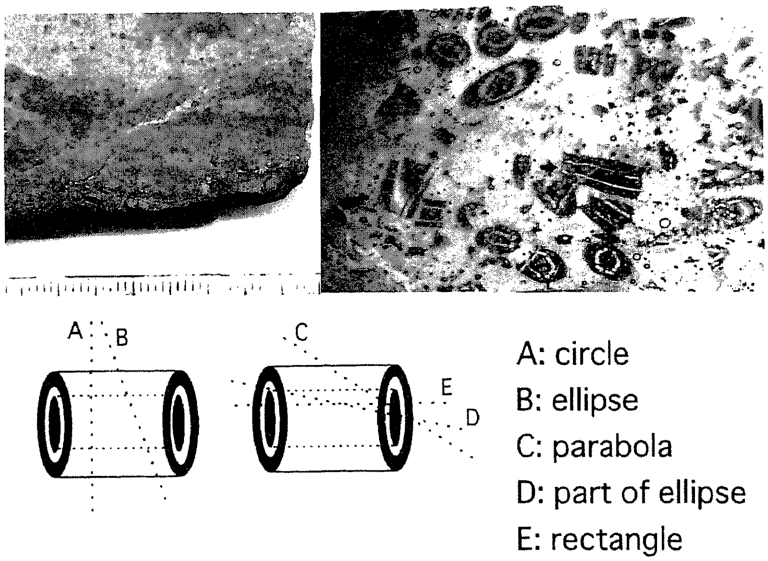

Fig. 6 New fossil sample from the north of the Bentenjima Island (above), and supposed restored shape from thin section (below).

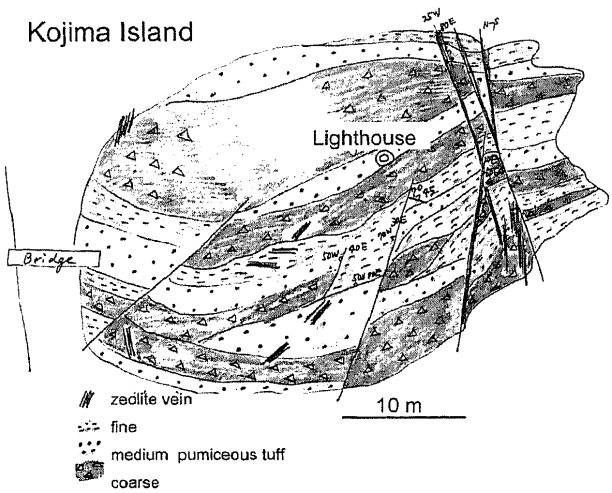

Fig. 7 Lithology map of the Kojima Island, showing bedded and mostly graded pumiceous fall deposits (Kojima Formation).

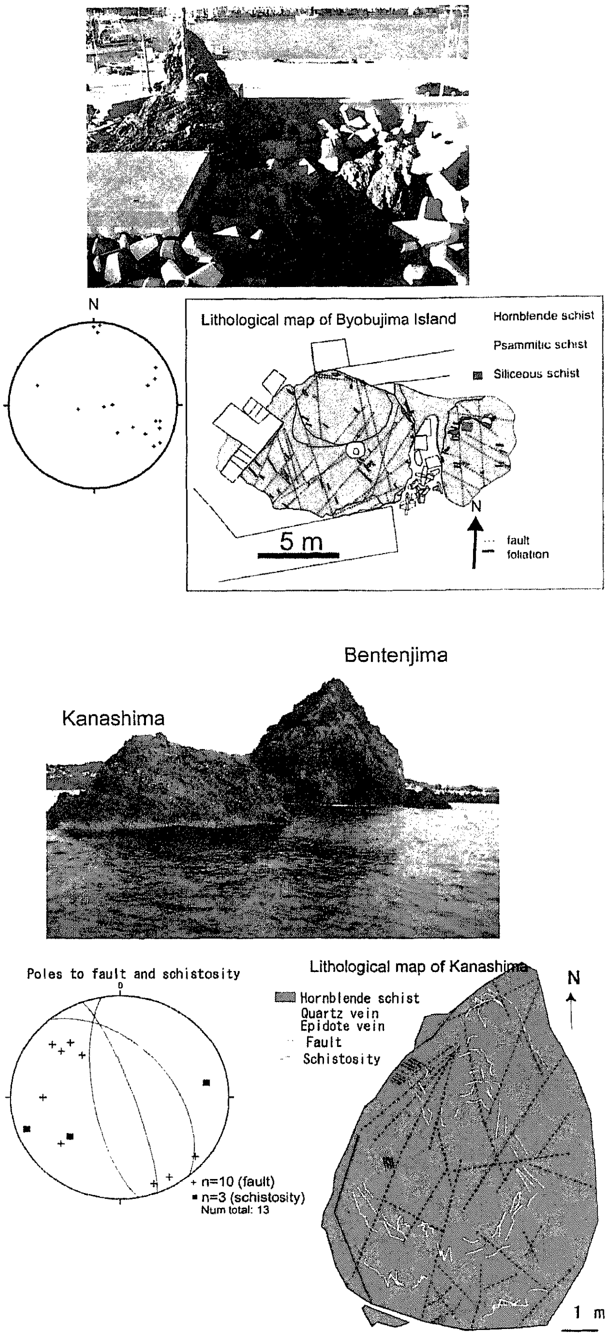

Fig. 8 Two metamorphic rock blocks, the Byobujima Island with stereographic projection of schistosity pole (above), and the Kaneshima Island with stereographic projection of fault and schistosity (below). Adopted from Mori and Ogawa (2005) with some revisions.

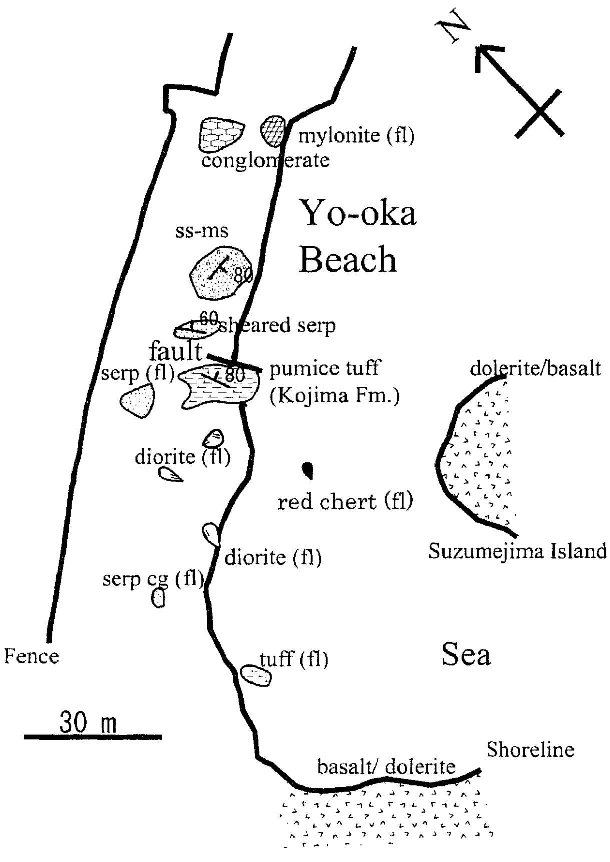

Fig. 9 Lithology map of the Yo-oka Beach. Adopted from Ogawa and Sashida (2006) with some revisions.

tion zone. They have later been mylonitized and brecciated (Mori and Ogawa, 2005).

Yo-oka Beach comprises several rock types; some are floats and some are *in situ* outcrops (Fig. 9). In particular, radiolarian fossils in bedded chert were described and dated as Albian (Early Cretaceous) by Ogawa and Sashida (2006), providing the first evidence of rocks of Cretaceous age in the Mineoka belt.

A serpentinite body is in faulted contact with the Kojima Formation, just offshore and close to Suzume-jima Island. There are outcrops of conglomerate and arkosic sandstone and mudstone at the northern end of Yo-oka Beach (Fig. 9). The mudstone is not highly indurated and has yielded middle Miocene foraminifers (by M. M. Mohiuddin), which suggests that the Mineoka belt fault zone affected these relatively young sedimentary rocks.

The Yo-oka Beach shore extends to the south to the small Shinyashiki Peninsula, which is composed of tholeiitic pillow basalts. A detailed discussion of the rock distribution and structures of the Shinyashiki Peninsula is provided by Takahashi *et al.* (2003) (Fig. 10). In the 1980s, a good outcrop was exposed that shows gently southwestward dipping pillow lavas intruded by five dolerite dykes. There were good exposures of ropy lava. Ophicalcite is developed in some horizons, as pillow breccias. The pillow lava on the beach has been designated as a natural monument by the Chiba Prefecture.

Many more small outcrops are known inland near the shore of Kamogawa Harbor (Fig. 4), but most of them are now buried or covered. Along the coastal side of the harbor, basaltic rocks crop out in the cliffs, but in the uplands of Isomura, andesitic tuff that is equivalent to the Kojima Formation is widely distributed, extending west to the Kamogawa logging road, probably covering the other rocks unconformably (Fig. 2). Tholeiitic basalt and alkali basalt crop out on the shoreward side of western Isomura, just north of Yo-oka Beach.

Some of the subsurface distribution of these rocks has been determined during tunnel construction near the center of the Mineoka Hills. The rock distribution described by Yoshida (1974) was referred to and revised by Takahashi *et al.* (2003) on the basis of these data (Fig. 10). Among the rocks of this area, a diorite (or tonalite) body behind the Shinganji Temple is remarkable. Outcrops of the same rock type are known in several places, but they may represent parts of a single body of rock.

Further landward, bedded volcanic sandstone of andesitic composition is exposed. This may be equivalent to the Kojima Formation, or possibly correlatable to the Yabe Group in the Miura Peninsula, which is of the middle Miocene, approximately 11–12 MaBP (Kanie and Asami, 1995). Similar volcaniclastic rocks are distributed between the area south of the Mineoka Hills and the Sorogawa Fault (an active fault), but they are not well exposed (Fig. 11). Conglomerates with chert and sandstone rounded pebbles are also found in this area. Along the Sorogawa Fault, several blocks of gabbro, basalt, dolerite, and serpentinite are sporadically distributed, for instances at Furubo and Igarashi. At Hashimoto, and further southeast at Arato, there are large tholeiitic basalt blocks.

Mineoka-Sengen area

Mineoka-Sengen is the name of a shrine that marks the highest mountain (altitude 335 m) in central

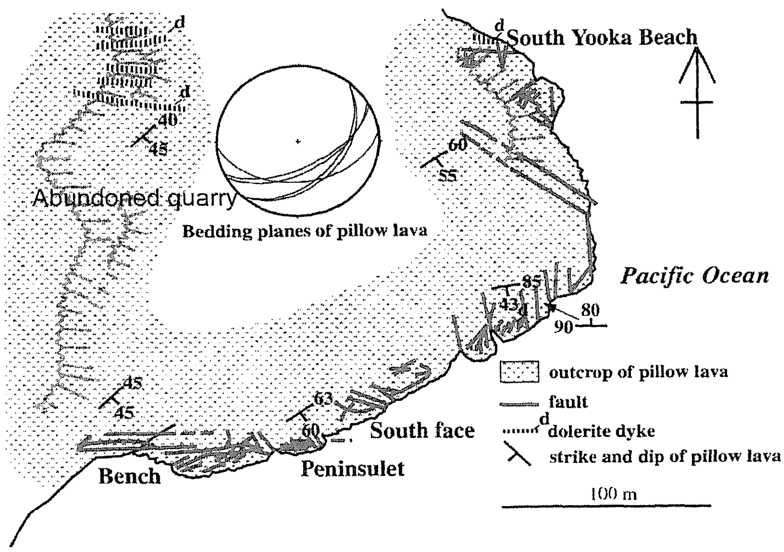

Fig. 10 Lithology map of a large basaltic rock block at Shinyashiki. Adopted from Takahashi *et al.* (2003).

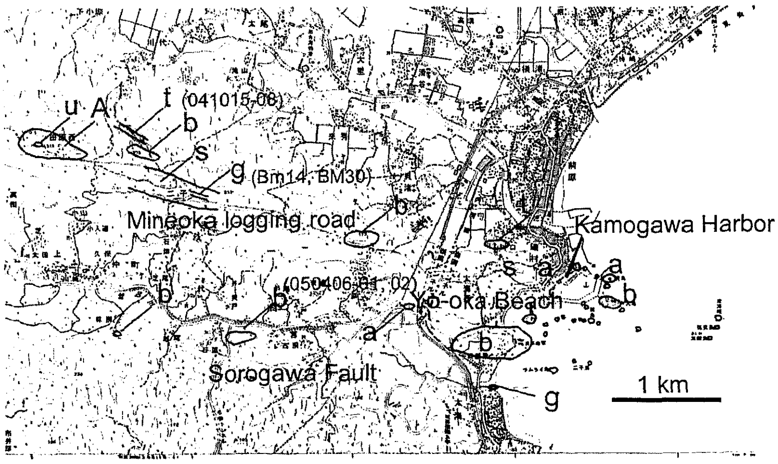

Fig. 11 Knocker distribution map in the Kamogawa area with sample number. Abbreviation of rock type other than in Fig. 3 is as follows. A: alkali basalt, s: serpentinite, u: umber.

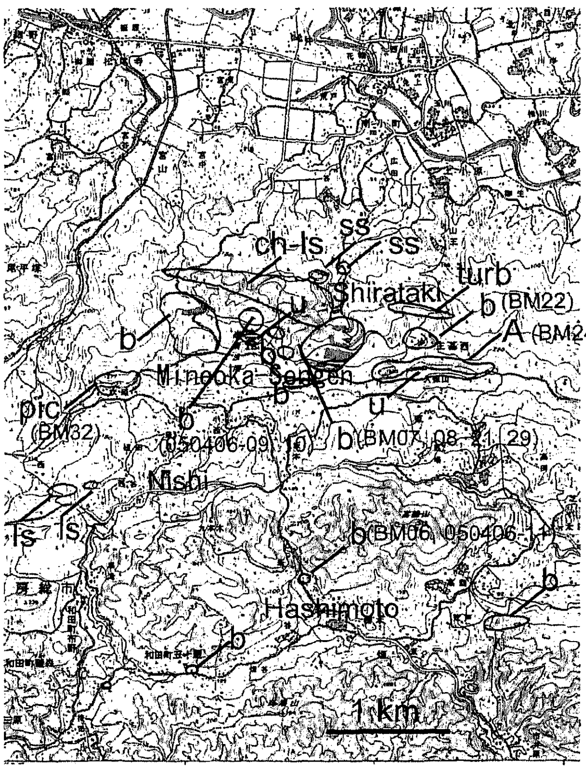

Fig. 12 Knocker distribution map in the Mineoka-Sengen area with sample number. Abbreviation of rock type other than in Figs. 3 and 11 is as follows. ch-ls: alternation of chert and limestone, ls: limestone, pic: picrite, ss: sandstone, turb: turbidite (part of the Shimanto Supergroup).

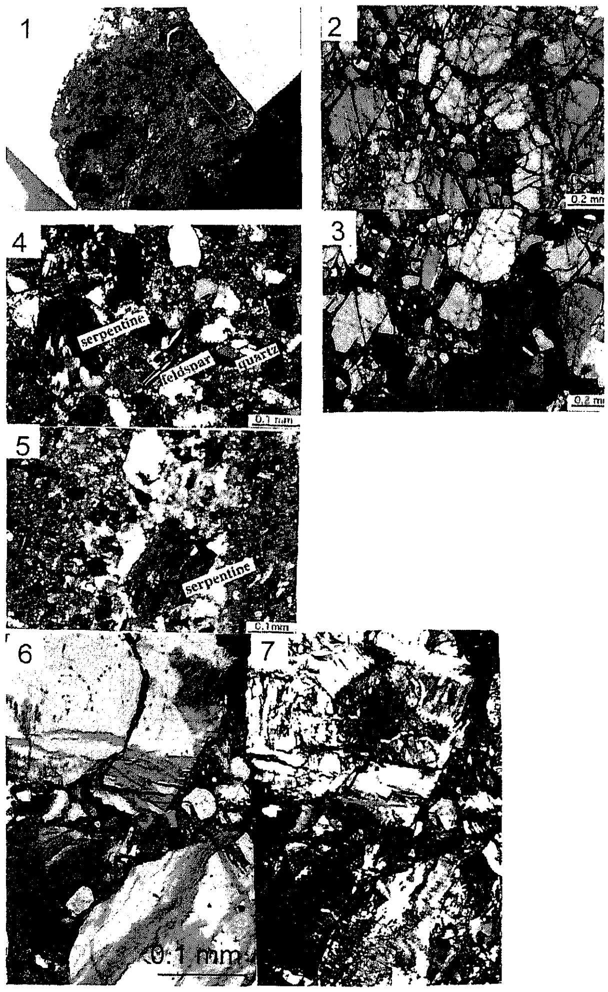

Fig. 13 Examples of serpentine-bearing rocks. 1, 2, 3 are serpentinite breccia with jigsaw puzzle structure (not of sedimentary origin). 4, 5 are serpentine sandstone with quartz and feldspar grains (of sedimentary origin). 6, 7 are serpentine micro-breccia (not of sedimentary origin).

Mineoka Hills. Until the 1980s, there were numerous basaltic knockers, mostly around 100 m in diameter, but most of them have since been quarried for use as road ballast and fill (Figs. 2 and 12). Most of the basaltic rocks exhibit pillow basalt of tholeiite chemistry, but some are alkalic. Serpentinite provides a matrix around the basaltic rocks, but it is not penetratively sheared; zones of shearing and brecciation are apparent only at the boundaries between the basalt and serpentinite and are some tens of centimeters wide at most. We thus consider that the serpentinite rocks are also fault zone knockers. In some places, both serpentinite and soft, unindurated sandstone are found surrounding the pillow basalts (Arai *et al.*, 1983) (Fig. 13). Brecciated serpentinite is common in many parts of the Mineoka-Sengen area (Fig. 13). However, in general, most of the brecciated, pebbly, or sandy serpentinite is not of sedimentary origin but is the result of deformation, that is, they are tectonic breccias.

Other common rock types within the serpentinite matrix are blocks or dykes of gabbro (mostly gabbro pegmatite) and diorite (tonalite). The dykes occur even in brecciated serpentinite, where they are in some places affected by brecciation or shearing. Two outcrops of Cyprus umber, a form of ochre, cover pillow lavas: one

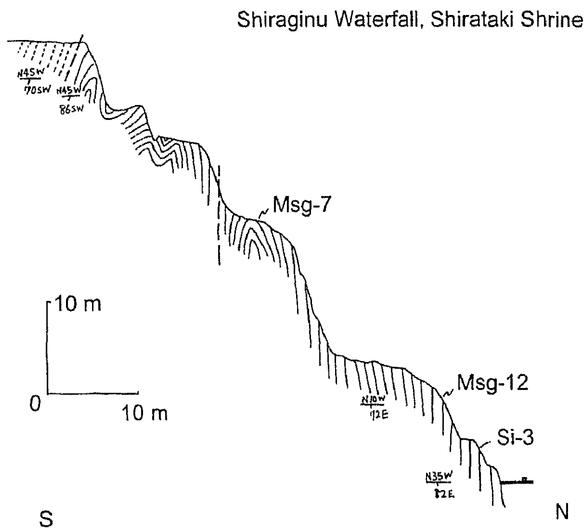

Fig. 14 Cross section of the alternations of chert and limestone beds at Shiraginu Waterfall, north of Mineoka-Sengen.

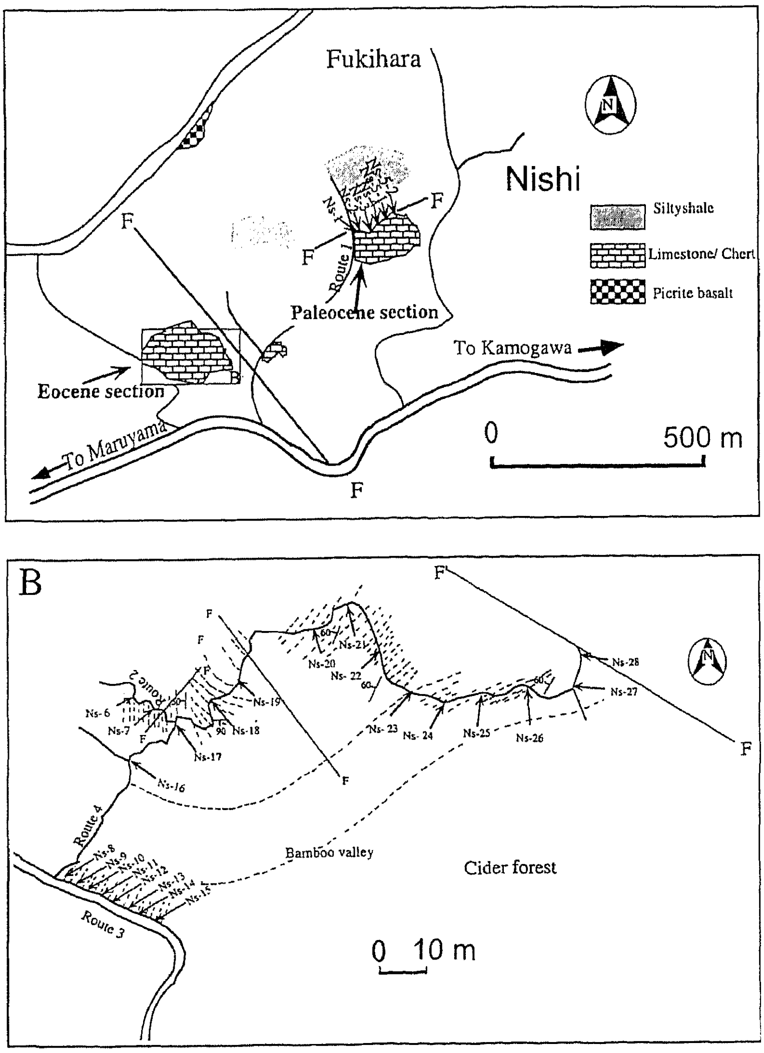

Fig. 15 Lithology map of the Nishi area, indicating the Paleocene and Eocene limestone sections after Mohiuddin (1997MS).

instance at Futago, another in the west of the Mineoka-Sengen area (Fig. 12).

There is a huge slab of chert–limestone in the northern Mineoka-Sengen area, near the Shirataki Shrine, where it forms a body of rock associated with the Shiraginu Waterfall (Fig. 14). Rhyolitic tuff layers are found south of the waterfall. Eocene to Oligocene radiolarian fossils have been found in the chert–limestone (referred to by Ogawa and Taniguchi, 1987), but Mohiuddin and Ogawa (1998a) reported middle Miocene foraminifers from some of these rocks. Therefore, some of the chert-limestone may be of Paleogene age, and some of Miocene age.

Blocks of chert–limestone, other than those at the Shiraginu Waterfall, are known at Nishi (Fig. 15) and Osato. There are also some layered deposits of chert –limestone at Heguri-Naka and Okuyama as shown later. The foraminifer biostratigraphy of these has been extensively studied by Mohiuddin (1997MS) and Mohiuddin and Ogawa (1998a,b), who determined the age of most of the these outcrops to range from Paleocene to early or middle Miocene (Mohiuddin, 1997MS; Mohiuddin and Ogawa, 1996, 1998a,b). Such total pelagic sequences of chert–limestone beds are nominated as the Kamogawa Group (Mohiuddin and Ogawa, 1998a). The chert–limestone outcrop at Shiraginu Waterfall was mapped by Y. Ogawa (Fig. 14), and those at Nishi by Mohiuddin (1997MS) and Mohiuddin and Ogawa (1998a) (Fig. 15).

There are some intercalations of emerald-greenish tuff in some chert–limestone sequences, probably of rhyolitic chemistry, but they have not yet been dated. There are similar limestone–chert blocks included within a conglomeratic formation of early Miocene Emi Group to the south of Mineoka belt (Takayama, 1999MS; Kawakami, 2004). Some radiolarians from the limestone (which is intercalated with rhyolitic tuff layers) have been dated as Paleogene. A siliceous mudstone within the conglomeratic formation was dated by Kawakami (2004) as middle Eocene (reworked-derivatives of secondary origin) and Oligocene (*in situ*). If this lithological interpretation is accepted, some rhyolitic tuff beds in the Mineoka belt may be of Paleogene age.

Hosono and Atago area

The Hosono and Atago area is in the western part of the Mineoka Hills, and it is in an en echelon position relative to the eastern part of the Mineoka Hills (Fig. 16). The area was extensively mapped by Chiba (2008MS). Most of the knockers are small, tens of meters at maximum, and they are probably in fault

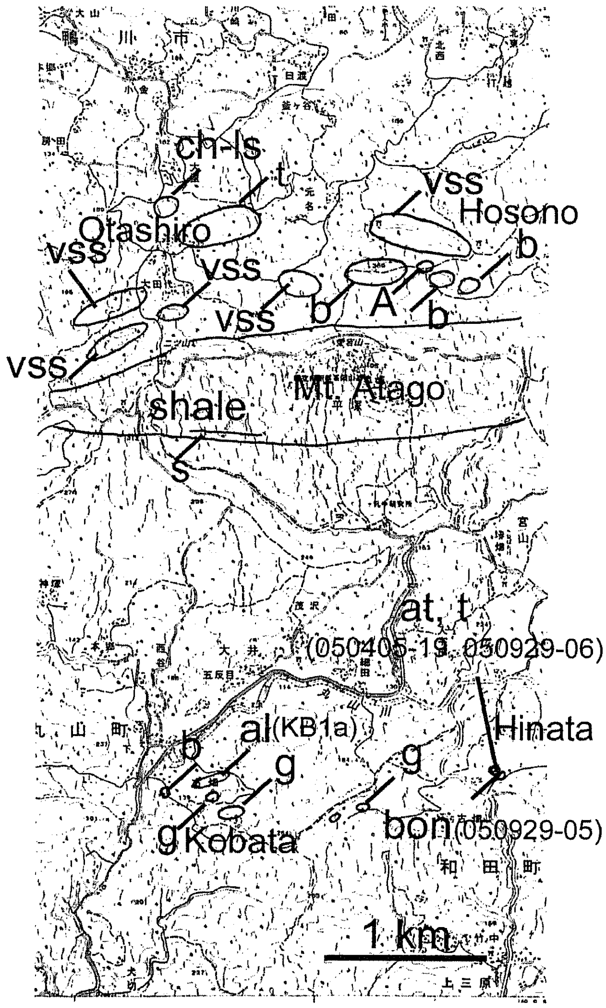

Fig. 16 Knocker distribution map in the Hosono-Mt. Atago area with sample number. Abbreviation of rock type other than in Figs. 3, 11 and 12 is as follows. al: andesite lava, at: andesitic tuff breccia, bon: boninitic rock clast-bearing tuff breccia, vss: volcanic sandstone.

contact with serpentinite or sandstone and mudstone. From Hosono to Motona, there are several small knockers of basalt; these are mostly tholeiitic, but one is alkalic basalt (Fig. 17). Other blocks are composed of gabbro, diorite, chert, or very coarse volcanic sandstone (Fig. 16).

There is a serpentinite layer within a fault between mudstone (or claystone) and a turbidite sequence to the south of Atagoyama Mountain (Fig. 18). The surrounding formation correlates well with the Shimanto Supergroup (the claystone correlates with the Hatcho or Atagoyama Formation, and the turbidite correlates with the Enokibatake or Kozuka Formation; Nakajima *et al.*, 1981; Ogawa and Taniguchi, 1987). From the former claystone Kawakami (2004) found middle Eocene

Fig. 17 Hosono knockers, back and forward two peaks are of tholeiitic basalt. View from E. Alkali basalt knocker is behind them.

radiolarians. This is one of the easternmost extensions of the Shimanto Supergroup, which stretches from Shikoku to the Kanto Mountains. Figure 18 summarizes the outcrop occurrences of these beds and provides cross sections with each outcrop sketch. Flexural-slip folds are common in the sandy turbidite formation.

Because exposures of the rocks surrounding the ophiolites are poor, the distribution of the Shimanto Supergroup equivalent is not well known. However, taking into consideration the distribution of floats, the Shimanto Supergroup is extensive, occurring almost everywhere to the north of the area between Hosono and Heguri, and also north of Toriikawa (Chiba, 2008MS).

Considering the distribution of these rocks in this area, it is clear that the exotic rocks are found mainly along faults. Therefore, we do not know the original relationship of the exotics to the country rock. Such occurrences may extend farther to the west, to the Heguri area.

Scattered knockers are found in the Kobata-Hinata area to the south of Mt. Atagoyama (Fig. 16). There are blocks of gabbro, basalt, tonalite, and andesite in the Kobata area. Well-jointed, fresh andesitic lava is observed on the banks of a small river in this area (Fig. 19). This outcrop is possibly important for understand-

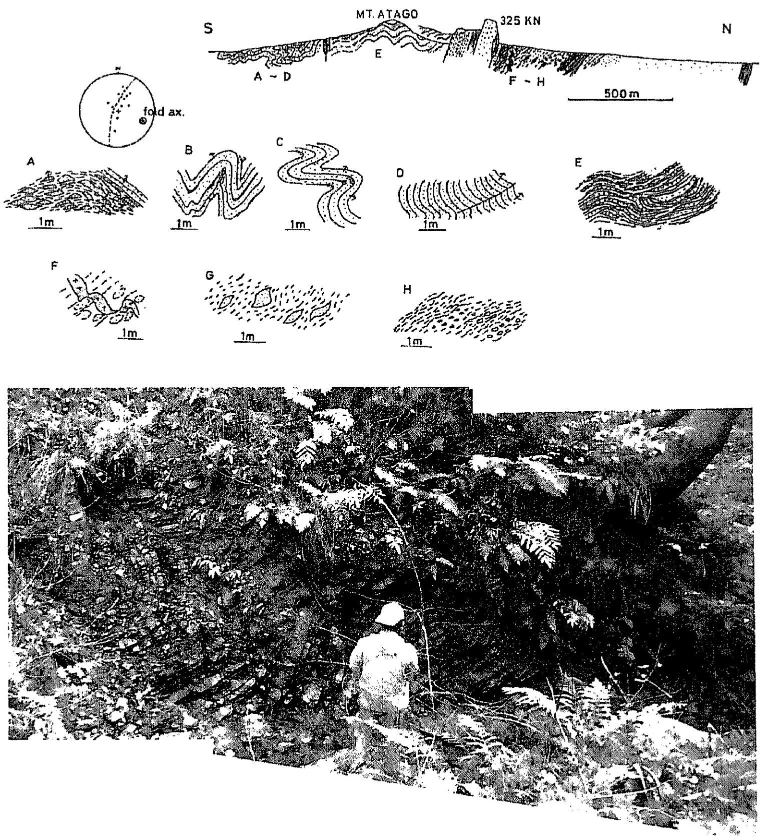

Fig. 18 Cross section and outcrop sketches (part of the Shimanto Supergroup) around Mt. Atago in1980s (above), and the outcrop photo of folded turbidite of the Kozuka Formation (part of the Shimanto Supergroup) in 2005 (view from W).

Fig. 19 Outcrop photo at Kobata; andesite lava (view from S) (above), and gabbro breccia (of sedimentary origin) (view from E) (middle). Thin sections of gabbro breccia (below).

Fig. 20 Photos of floats (according to the local people these are *in situ*) at Hinata (above), and surface of andesitic tuff breccia which includes a boninitic rock clast (below).

ing the geologic history of the Mineoka belt.

To the west, around Kobata, there is a 10 m-scale gabbro conglomerate of sedimentary origin in a paddy field (Fig. 19). In total, three gabbroic or tonalitic blocks are known in the Kobata area. Some of these are brecciated, and some are mylonitized. These gabbroic to tonalitic rocks may suggest a tectonic history associated with a transform fault at an oceanic ridge, such as a core complex.

At Hinata, there are several floats beside the river. The local people believe that they have been there for a long time, which suggests that they come from upstream outcrops. The lithologies range from tonalite (very fresh) to andesitic breccia (Fig. 20). The latter is of similar lithology of the Yabe Group in the Miura Peninsula, and is dated by K-Ar method as 15.6 +/– 0.5 MaBP (by Geochronology and Isotopic Geochemistry). One of the floats of the andesitic brecccia includes one high-magnesian (boninitic) andesite clast of several centimeters diameter. This suggests that boninitic rocks underlay the area at the time when the andesitic breccias were extruded or intruded.

Heguri-Yamada area

This area is the western continuation of west Mineoka Hills. Lithologies in the Heguri-Yamada area are conspicuously different from those of the eastern and central Mineoka belt, and are characteristic of the western part of the belt. Some linear belts of basalt and serpentinite are recognized in this area and they contain several knockers (Fig. 21). There was a good outcrop of alkalic basalt with limestone at Heguri-Naka, until it was removed by quarrying in the 1980s (Fig. 22).

A glauconite-bearing mudstone formation (Arakawa Formation, early Miocene; Mohiuddin and Ogawa, 1996, 1998b) was originally interpreted to conformably overlie the alkalic basalt and a basaltic conglomerate with limestone intercalations. Later, they were interpreted to be in faulted contact, but their stratigraphic relationships are still not clear (Fig. 22). Today, these important outcrops cannot be investigated further because they have been excavated. Limestone blocks were biostratigraphically dated by Mohiuddin and Ogawa (1996, 1998b) (Fig. 22). This work suggested

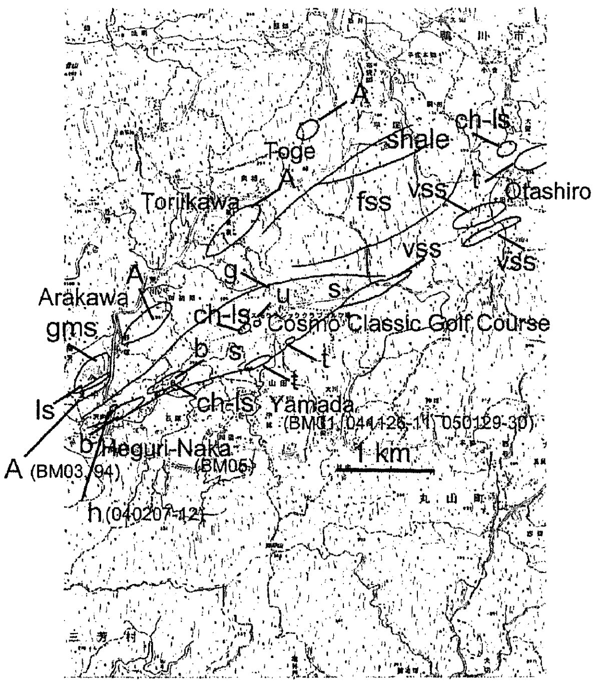

Fig. 21 Knocker distribution map in the Heguri area with sample number. Abbreviation of rock type other than in Figs. 3, 11, 12 and 16 is as follows. fss: fine sandstone (part of the Shimanto Supergroup), gms: glauconitic mudstone.

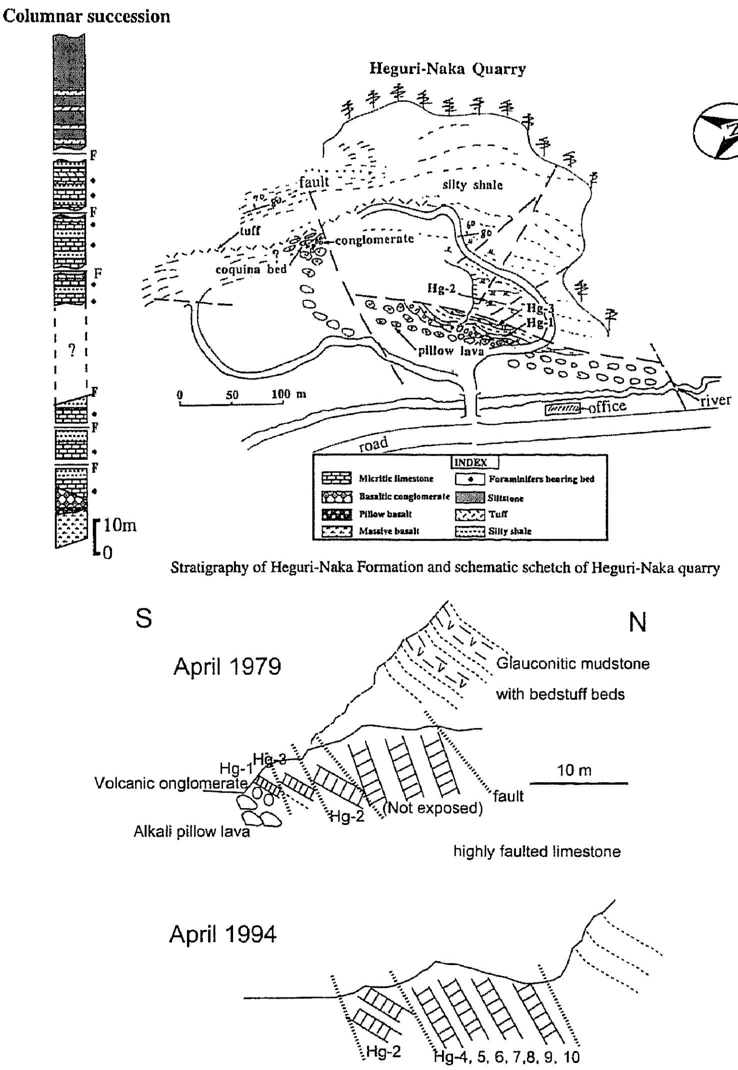

Fig. 22 Lithology map of the Heguri-Naka quarry in 1979 (above) (Adopted from Mohiuddin and Ogawa (1998b)), and the change of the outcrop situation for cross sections from 1979 to 1994. Numbers are for the samples in Mohiuddin and Ogawa (1998b). Hg-1 is P11 of Blow's zone (middle Eocene), Hg-2 P16/17 (late Eocene), Hg-3 P18/19 (early Oligocene), Hg-4 and Hg-5 N4 (early Miocene), and Hg-8, 9, 10 N8 (early Miocene).

Fig. 23 Outcrop photos of the metamorphic rock block in sheared serpentinite at Heguri-Naka (above) (view from W), and alternation of limestone and chert at Uenodai (below) (view from S).

that there was a long, but possibly intermittent, period of limestone deposition through the Eocene, Oligocene, and Miocene.

There are alkalic basalt knockers of some hundreds of meters in size in three places within the Heguri area (Fig. 21); one of these has been excavated by a local quarry company. The alkalic basalt at Toge was dated by the Ar-Ar method at approximately 20 Ma (Hirano and Okuzawa, 2002).

Because of the complicated structure and distribution of rocks in this area, we cannot reconstruct the original disposition of the rocks. However, many of these formations are different from those characteristic of other areas of Japan, so the depositional environments for the Eocene to Miocene formations of this area are different to those that are common elsewhere in Japan.

There is an amphibolite facies garnet amphibolite knocker within sheared serpentinite to the south of the alkalic basalt block at Heguri-Naka (Hiroi, 1995b) (Fig. 10). The metamorphic conditions deduced from the mineral chemistry of hornblende and plagioclase in this rock is listed by Mori (2006MS) and Mori *et al.* (submitted). The modes of occurrence of other metamorphic blocks in the Kamogawa Harbor are unknown, but that at Heguri-Naka is known to have been injected into sheared serpentinite via faults (Fig. 23).

In the Yamada area, tonalite (diorite) bodies (and others such as gabbro and sandstone) are known to be in contact with sheared serpentinite. One of these is an enormous knocker; it stands prominently above the surrounding terrain at Yamada, and is known as

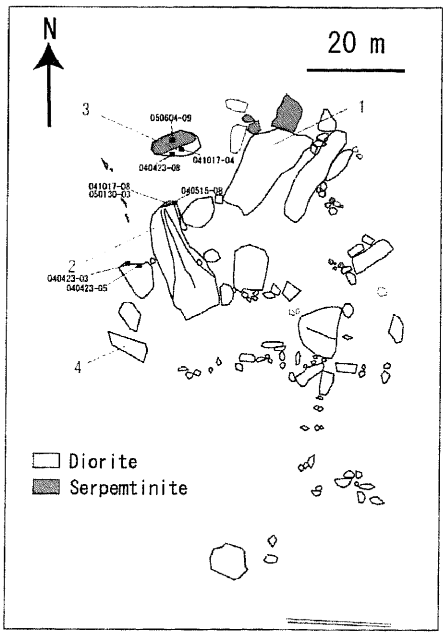

Fig. 24 Rock distribution at the Yamada knocker (left) (mostly composed of land slid bodies) and photo of the peak #1 (right) (view from SW).

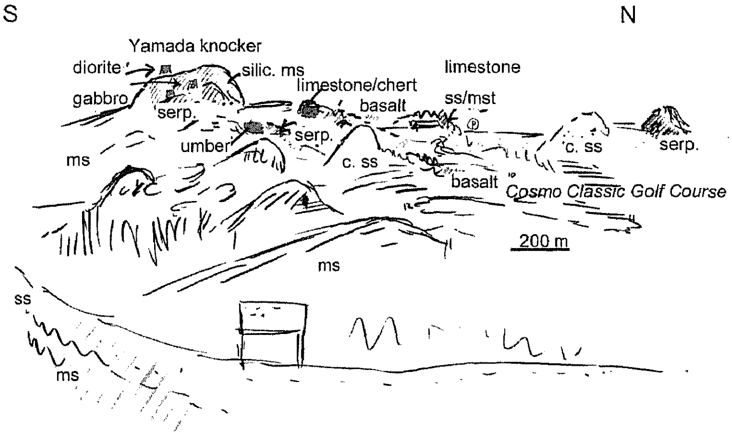

Fig. 25 Schematic view of the Yamada knocker and Cosmo Classic Golf Course from E.

the Yamada knocker (Fig. 24) (Mori, 2006MS). These blocks originate from farther north. Mudstone and fine sandstone, probably of the Shimanto Supergroup (Kozuka and Atagoyama Formations), are in faulted contact with the knockers, and may extend from Yamada to the golf course (Fig. 25). Considering the distribution pattern of rocks in the golf course, it must extend to the east as far as the Hosono area, which is characterized by much serpentinite together with a coarse volcaniclastic sequence. The lithology of the latter suggests that it might be a component of the Hota Group, and may, therefore, be of early or middle Miocene age.

Other areas

There is a large block of alkalic basalt (100-m scale) at Homyo, to the north of the Heguri area. It is relatively isolated compared to other such blocks, and was probably injected within a fault zone in the middle Miocene Sakuma or Hota Group.

There is a 100-m-scale bedded limestone, which yielded middle Miocene foraminifers (Mohiuddin and Ogawa, 1998a), at Okuyama (Fig. 26), and which is in possibly fault contact with the middle Miocene Okuyama Conglomerate. This conglomerate contains abundant cobbles and pebbles of limestone, chert, and alkalic basalt that are derived from Mineoka belt rocks. The limestone block itself might also be derived from the Mineoka belt. Blocks such as these, and their associated formations, provide evidence of the first landward emplacement of ophiolitic rocks during the middle Miocene.

To the west, serpentinite and basaltic and peridotitic rocks are poorly exposed in the Katsuyama area,

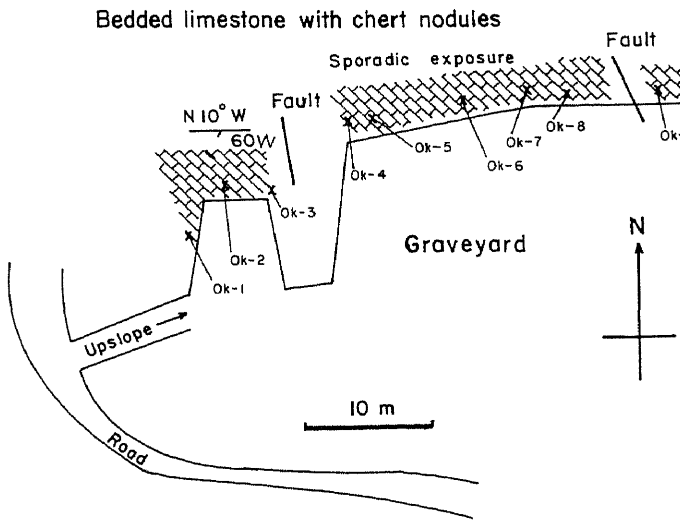

Fig. 26 Rock distribution of the bedded limestone knocker at Okuyama, showing the sample number for Mohiuddin and Ogawa (1998a).

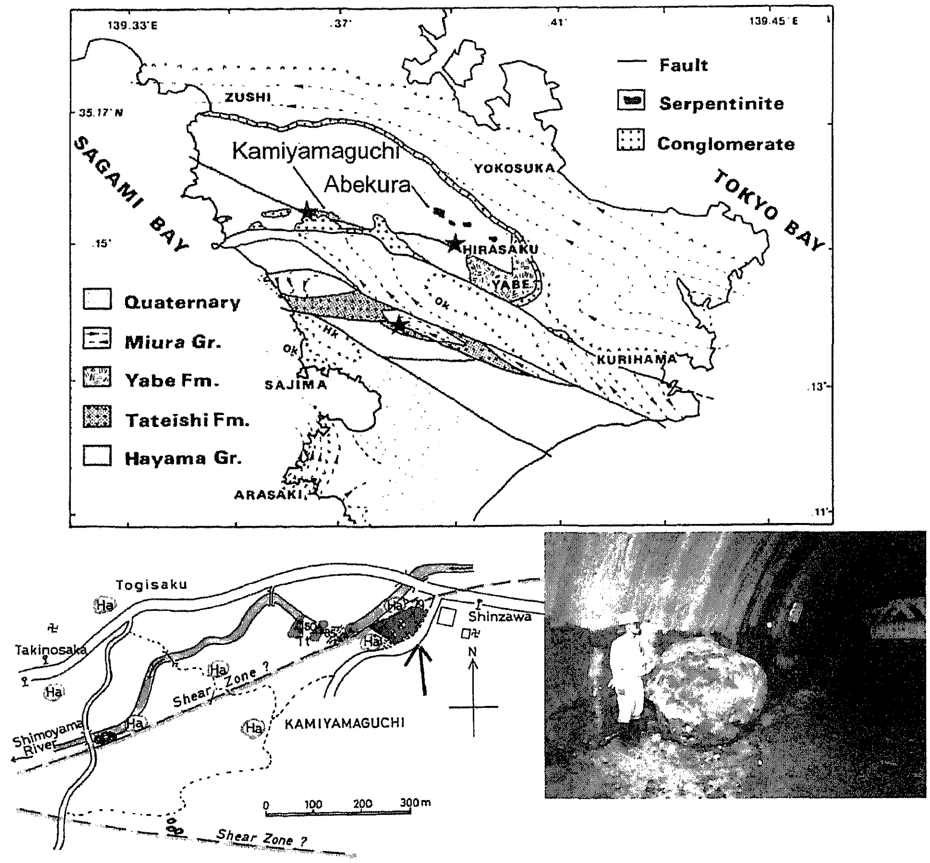

Fig. 27 Lithology map of the Miura Peninsula (adopted from Taniguchi and Ogawa (1990)) with some additional place of knockers (above), andesite location at Kamiyamaguch (below left), and sandstone block (part of the Shimanto Supergroup) from a fault between brecciated serpeninite and the Hayama Group, obtained during the Abekura tunnel construction (presented by Maeda Corporation).

but their precise distribution has not been determined. These rocks may represent fault zones.

The western extension of the Mineoka belt can be traced on the Miura Peninsula. In this area, there are three or four lines of faults, within which are serpentinite, alkalic basalt, and dolerite rocks (Taniguchi and Ogawa, 1990). There is also some fresh andesite within the faults. An equivalent andesite intrudes the early Miocene Hayama Group (Taniguchi *et al.*, 1988) (Fig. 27). The andesite was dated as 19.5 +/– 0.70 and 19.8 +/– 0.60 MaBP by Imanaga and Yamashita (1999).

A meter-scale medium-grained quartzo-feldspathic sandstone block was recently excavated during tunnel construction at Abekura (Fig. 27). It was observed to be in faulted contact with brecciated serpentinite. This sandstone might be equivalent to the Kozuka Formation of the Shimanto Supergroup in the Mineoka Hills.

Summary

This paper summarizes the distribution and lithology of rocks of the Mineoka ophiolite belt. Important bodies are listed in Table 1, and some of the chemical data are listed in Tables 2, 3 and 4.

Acknowledgments

This paper summarizes the results of our field work over the last several years. However, the work began in the 1970s, and, since then, we have been supported by the following people, both in the field and in the laboratory: Takanori Nakano, Teruaki Ishii and Satoru Haraguchi (chemical analysis), Naoki Takahashi and Satoru Muraoka (field survey and occurrence of knockers), and Ryo Anma and Koichi Okuzawa (field survey and structural and chemical analysis). We are indebted to many people for discussions of ophiolitic rock occurrences during field trips. These include Alastair H. F. Robertson, Yildirim Dilek, Makoto Arima, Kantaro Fujioka, Anthony J. Barber, Julian Pearce, Brian F. Windley, Darrel S. Cowan, Stephen Phipps, Nicholas W. Hayman, Kurtis C. Burmeister, Henry Dick, Jonathan Snow, and many others. We acknowledge the contributions of all these people.

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Table 1 Representative knocker factors. Longitude and latitude are by GPS. Sizes are length, width and height in m.

Name	Area	Latitude	Longitude	Rock name	Size (m)	Remarks	Reference
	East Kamogawa						
Bentenjima	Kamogawa Harbor	35 05.452	140 06.523	Basalt, dolerite	200×100×50	Fig. 5	Ogawa & Takahashi (2004), Ogawa (2005)
Byobujima		35 05.443	140 06.418	Hornblende schist	10×10×30	Fig. 8	Ogo & Hiroi (1991), Mori & Ogawa (2005)
Kojima				Andesitic pumice tuff	50×60×30	Fig. 7	Ogawa (2005)
Kanashima				Hornblende schist	8×11×5	Fig. 8	Mori & Ogawa (2005)
Somobaishi				Hornblende schist	5×8×10		
Isomura				Basalt, limestone	5×5×20		
Isomura				Alkali basalt	10×10×20		
Yo-oka	Kamogawa south			Chert	2×3×3	Fig. 9	Ogawa & Sashida (2005)
				Sandstone/mudstone	small	*ibid.*	
				Kojima Formation	small	*ibid.*	
Suzumijima				Basalt, dolerite	50×50×100	*ibid.*	
Shinyashiki	Shinyashiki (Futomi)			Basalt, dolerite	500×200×100	Fig. 10	Takahashi et al. (2003)
	Kamogawa Hills						
Shinganji		35 05.764	140 05.889	Diorite (tonalite)	10×50×100		Hirano et al. (2003)
Mineoka-Sengen		35 06.388	140 01.683	Basalt (many blocks)	100×100×200		
Fukihara				Picrite	100×40×20		Tazaki & Inomata (1980)
Shirataki				chert, limestone, tuff	150×2000	Fig. 14	Mohiuddin & Ogawa (1998a)
Hashimoto		35 05.380	140 01.673	Basalt	10×20×10		
S. Hashimoto		35 05.343	140.02.631	Basalt, dolerite	100×50×10		
Nishi				Limestone (2)	100×50×40		Mohiuddin & Ogawa (1998a)
Futago		35 05.970	140 04.254	Gabbro, serpentinite	1×2×5		
	Hosono-Atago						
Hosono				Basalt (2)	10×10×40	Fig. 17	Chiba (2008MS)
				Alkali basalt	5×10×10		
Osato (W. Motona)		35 07.482	139 58.345	Chert	20×30×100		
		35 07.194	139 58.853	Coarse sandstone			
S. Atagoyama		35 06.502	139 58.708	Harzburgite	5×10?		
S. Atagoyama		35 06.555	139 58.778	Turbidite	5×10?	Fig. 18	
S. Otashiro				Volcanic sandstone	800×100×50		
Hinata		35 05.451	139 59.774	Andesitic tuff breccia, diorite, boninitic andesite	2×2×3	Fig. 20	Mori (2006MS)
Kobata		35 05.418	139 58.641	Andesite (jointed)	50×10×10	Fig. 19	
		35 05.384	139 58.597	Gabbro breccia	10×10×10	Fig. 19	
		35 05.369	139 58.753	Gabbro, limestone	small float		
		35 05.234	139 58.646	Serpentinite breccia	*ibid.*		
		35 05.200	139 58.831	Gabbro	*ibid.*		
		35 05.236	139 58.674	Red chert, dolerite	*ibid.*		
		35 05.300	139 58.484	Harzburgite, gabbro	*ibid.*		
		35 05.180	139 58.641	Blueschist (float)	0.1×0.1×0.1	(Not *in situ*)	
E. Kobata		35 05.338	139 59.223	Diorite, gabbro inter-layered			
		35 05.372	139 59.226	Glauconite ss, gabbro, diorite			
	Heguri-Yamada						
Yamada		35 06.306	139 56.639	Diorite	10×10×20	Fig. 24	
		35 06.443	139 56.710	Serpentinite			
		35 06.458	139 56.806	Serpentinite, shale, limestone, sandstone	small block		
		35 06.329	139 56.764	Gabbro	*idid.*		
Golf Course	Gate of golf club	35 06.687	139 57.368	Serpentinite	20×30×50		
	Club house & course	35 06.630	139 57.018	Basalt, gabbro etc.	small float		
				Chert/limestone	30×20×10	Fig. 25	
Uenodai		35 06.172	139 56.100	Limestone/chert	2×2×2	Fig. 23	
		35 07.562	139 57.140	Alkali basalt	5×5×5		
		35 07.541	139 57.124	Basalt, dolerite	30×200×40		
Heguri-Naka		35 06.078	139 55.850	Garnet-amphibolite	2×3×5	Fig. 23	Mori & Ogawa (2005)
		35 06.096	139 55.834	Sheared serpentinite			
				Limestone	20×20×20	Fig. 22	Mohiuddin & Ogawa (1996, 1998a,b)
		(Arakawa	Formation)	Glauconite mudstone	200×200×100	Fig. 22	
Ohatsubata				Alkali basalt	100×50×30		
Toriikawa		35 06.880	139 56.570	Alkali basalt	50×100×20		
Toge				Alkali basalt	100×300×50		Hirano & Okuzawa (2002)
Homyo				Alkali basalt	10×30×20		
Okuyama				Bedded limestone	40×20×20	Fig. 26	Mohiuddin & Ogawa (1998a)

Table 2 Representative rock analysis of knockers (samples collected by N. Hirano) for major and trace (analysit, N. Hirano; by XRF), adopted from Hirano et al. (2003). RE elements (analyst, M. Kurosawa; by LAM-ICP-MS). trace and RE elements, precision (1σ) approximately ±10%. See Kurosawa *et al.* (2002). For detail locality see Hirano *et al.* (2003).

	Locality	Rock	SiO2	TiO2	Al2O3	Fe2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Total	Sc	Rb	Sr	Y	Zr	Nb
BM09-BT	Benten	Basalt	49.82	1.71	14.65	3.34	7.74	0.19	8.29	9.82	4.02	0.27	0.16	100.00	39	2.4	179	32	99	4.2
BM23-BT	Benten	Basalt	49.32	1.67	15.00	7.21	3.62	0.18	8.02	11.41	3.32	0.11	0.15	100.00	54	29.5	131	54	209	6.0
BM25-BT	Benten	Basalt	50.92	1.63	15.37	6.17	4.06	0.16	6.74	10.14	4.39	0.30	0.12	100.00	41	2.4	171	30	99	4.5
BM10-SY	Shinyashiki	Basalt	51.00	2.31	14.72	5.82	4.33	0.19	6.79	10.77	3.46	0.39	0.21	100.00	46	5.8	129	42	142	5.0
BM07-SG	Sengen	Basalt	51.91	2.14	13.63	5.81	5.15	0.19	6.64	9.85	3.90	0.56	0.22	100.00	43	8.5	162	41	136	6.3
BM08-SG	Sengen	Basalt	50.09	1.76	14.02	6.65	4.77	0.23	6.48	11.79	3.44	0.61	0.16	100.00	41	16.6	114	36	97	2.5
BM22-SG	Sengen	Basalt	50.16	2.06	14.91	6.21	2.96	0.41	8.86	10.74	3.41	0.10	0.19	100.00	45	0.4	172	36	120	5.1
BM24-SG	Sengen	Basalt	50.44	2.19	14.36	6.86	5.37	0.22	6.40	9.37	3.23	1.31	0.25	100.00	33	0.5	114	24	77	3.0
BM21-SG	Sengen	Basalt	50.63	2.40	12.22	8.05	5.48	0.25	6.76	8.77	4.62	0.56	0.25	100.00	45	13.7	126	45	131	4.5
BM32-NSGM	Fukihara	PicBasalt	44.68	1.67	7.89	7.50	4.86	0.17	26.39	6.17	0.37	0.11	0.19	100.00	20	5.2	91	13	93	10.6
BM06-HS	Hashimoto	Basalt	50.88	1.78	14.18	4.14	6.38	0.29	8.20	9.70	4.22	0.08	0.15	100.00	42	0.7	125	33	98	2.4
BM29-SG	Sengen	Basalt	50.47	1.66	15.17	4.89	3.69	0.15	6.65	12.38	3.87	0.94	0.13	100.00	45	10.3	282	30	89	2.2
BM03-HG	Heguri	Basalt	44.92	3.00	12.68	7.17	6.04	0.29	12.66	10.10	2.51	0.29	0.34	100.00	32	0.6	221	22	152	20.8
BM04-HG	Heguri	Basalt	48.90	3.32	13.98	4.67	7.09	0.16	8.32	8.28	3.93	0.96	0.38	100.00	32	11.9	385	25	184	25.6
BM05-HG	Heguri	Basalt	49.94	2.18	14.45	5.07	6.33	0.21	7.58	9.54	4.34	0.12	0.24	100.00	42	0.7	251	41	132	4.9
BM26-SK	Sakuma	Basalt	50.35	1.80	15.00	6.17	3.44	0.15	7.86	10.55	3.91	0.61	0.16	100.00	47	10.1	130	35	107	3.0
BM14-FG	Futago	Gabbro	49.25	0.34	26.75	1.78	2.38	0.07	5.09	9.55	4.26	0.53	0.01	100.00	30	4.1	625	8	10	0.2
BM28-SNJ	Shinganji	Diorite	60.81	0.55	17.30	2.15	3.33	0.10	3.83	6.51	4.90	0.47	0.06	100.00	22	3.6	211	15	67	1.0
BM31-YD	Yamada	Diorite	59.31	0.38	19.02	3.02	2.34	0.08	3.87	7.49	3.95	0.49	0.04	100.00	24	4.5	280	9	43	0.8
BM30-RS	Raishu	Gabbro	51.52	1.07	14.88	3.30	5.49	0.16	9.11	9.55	4.65	0.26	0.02	100.00	44	2.3	337	29	37	0.6
BM12-GSCH	Byobujima	Schist	49.42	1.33	14.85	5.04	5.64	0.17	8.52	11.71	2.78	0.45	0.10	100.00	42	8.2	118	27	68	1.9

	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
BM09-BT	0.09	201	5.0	12.9	2.0	10.9	3.5	1.3	4.6	0.9	5.7	1.2	3.4	0.50	3.5	0.49	2.5	0.26	0.67	0.32	0.15
BM23-BT	0.58	243	7.4	20.4	3.4	20.0	6.8	2.2	8.6	1.5	10.1	2.1	5.9	0.82	5.7	0.81	5.5	0.34	0.84	0.49	0.23
BM25-BT	0.06	1818	4.4	11.6	1.9	10.0	3.4	1.3	4.2	0.8	5.4	1.1	3.2	0.50	3.4	0.50	2.5	0.25	0.66	0.35	0.13
BM10-SY	0.12	36	5.9	16.9	2.7	15.2	5.1	1.8	6.4	1.2	7.8	1.7	4.7	0.68	4.8	0.70	3.6	0.32	0.88	0.37	0.33
BM07-SG	0.19	40	6.9	17.2	2.7	15.1	4.8	1.6	6.2	1.1	7.2	1.6	4.4	0.62	4.4	0.63	3.5	0.33	1.07	0.48	0.18
BM08-SG	0.44	46	4.1	10.8	1.9	11.1	3.8	1.4	5.0	1.0	6.4	1.4	3.9	0.56	3.9	0.52	3.0	0.15	0.76	0.16	0.14
BM22-SG	0.03	32	5.8	15.1	2.4	13.1	4.2	1.6	5.4	1.0	6.5	1.4	3.8	0.58	4.1	0.58	3.3	0.29	1.11	0.43	0.18
BM24-SG	0.11	42	3.7	9.7	1.5	8.5	2.9	1.1	3.6	0.7	4.4	1.0	2.7	0.38	2.7	0.39	2.1	0.18	0.36	0.22	0.12
BM21-SG	0.27	42	5.4	15.5	2.6	14.7	5.2	1.8	6.5	1.2	8.2	1.8	4.9	0.71	5.2	0.71	3.6	0.25	0.88	0.35	0.20
BM32-NSGM	0.35	44	9.8	22.4	3.0	13.7	3.1	1.1	3.2	0.5	2.7	0.6	1.4	0.18	1.2	0.16	2.3	0.63	0.92	0.79	0.25
BM06-HS	0.32	41	3.2	10.1	1.7	9.8	3.7	1.4	4.7	0.9	6.2	1.3	3.7	0.55	3.9	0.54	2.7	0.15	0.25	0.17	0.17
BM29-SG	0.15	42	3.3	10.4	1.6	9.8	3.5	1.3	4.4	0.9	5.4	1.2	3.3	0.47	3.3	0.47	2.4	0.13	0.59	0.17	0.15
BM03-HG	0.20	190	16.8	36.8	4.8	22.2	5.6	1.9	5.3	0.8	4.6	0.9	2.2	0.29	1.9	0.27	3.9	1.15	1.30	1.50	0.25
BM04-HG	0.19	338	20.6	45.1	5.8	27.6	6.4	2.3	6.2	1.0	5.5	1.0	2.5	0.35	2.2	0.29	4.7	1.46	1.62	1.91	0.60
BM05-HG	0.05	50	5.9	16.2	2.6	14.3	4.7	1.8	6.2	1.2	7.4	1.7	4.5	0.63	4.7	0.64	3.7	0.29	0.71	0.40	0.12
BM26-SK	0.20	78	4.6	12.6	2.1	11.8	4.0	1.5	5.3	0.9	6.2	1.4	3.8	0.56	3.8	0.55	2.8	0.20	0.57	0.25	0.48
BM14-FG	0.05	33	0.7	1.8	0.3	2.0	0.9	0.5	1.2	0.2	1.4	0.3	0.9	0.13	0.9	0.13	0.4	0.02	0.47	0.05	0.05
BM28-SNJ	–	106	3.1	7.9	1.2	6.4	1.9	0.7	2.2	0.4	2.7	0.6	1.6	0.26	1.8	0.27	1.9	0.08	0.58	0.43	0.15
BM31-YD	0.06	96	2.1	5.0	0.7	3.9	1.2	0.5	1.4	0.3	1.6	0.3	0.9	0.15	1.1	0.16	1.3	0.06	1.36	0.44	0.11
BM30-RS	0.42	98	1.5	5.6	1.2	7.4	3.2	1.1	4.4	0.8	5.5	1.1	3.1	0.44	3.1	0.44	1.3	0.03	0.33	0.09	0.05
BM12-GSCH	0.16	41	2.9	8.3	1.4	8.2	2.8	1.1	3.8	0.7	4.9	1.0	2.9	0.41	3.1	0.44	1.9	0.12	0.71	0.14	0.11

Table 3 Representative rock analysis of knockers (samples collected by A. Takahashi and Y. Ogawa) for major (analyst, T. Nakano by XRF), trace and RE elements (analyst, M. Kurosawa; by LAM-ICP-MS). For trace and RE elements, precision (1σ) approximately ±10%. See Kurosawa *et al.* (2002).

Sample No.	Locality	Rock	SiO2	TiO2	Al2O3	FeO*	MnO	MgO	CaO	Na2O	K2O	P2O5	Total	Sc	Rb	Sr	Y	Zr	Nb
BN2015	BentenNW	BasDyke	46.7	1.81	14.25	11.22	0.44	8.61	8.63	3.13	0.2	0.12	95.11	41	3.7	90	35	103	3.1
BN2109	BentenNW	Pillow	51.40	2.75	13.93	10.46	0.20	6.20	8.09	4.83	0.69	0.21	98.76	49	11.1	154	56	176	5.8
BN2514	BentenNW	Pillow	48.61	2.33	15.15	14.12	0.13	7.09	6.30	4.08	1.84	0.30	99.95	19	3.3	27	22	64	1.9
BN2106	BentenC	Dolerite	48.32	2.45	12.43	12.96	0.21	7.01	7.75	4.91	0.16	0.30	96.50	44	3.1	86	49	146	4.7
BN2107	BentenC	Dolerite	49.75	2.24	13.90	12.50	0.21	7.21	8.75	4.25	0.35	0.17	99.33	43	4.3	213	43	131	4.8
BN1904	BentenC	Dolerite	49.91	1.55	14.35	9.81	0.17	8.33	8.39	4.93	0.20	0.11	97.75	36	2.6	109	28	94	5.0
BN0705	BentenC	Dolerite	49.11	2.45	13.86	14.41	0.28	7.10	8.07	3.95	0.43	0.30	99.96	41	2.3	149	48	145	4.3
KM91901	BentenC	Dolerite	47.83	2.45	13.73	13.11	0.22	7.91	8.47	3.08	0.09	0.18	97.07	45	0.4	106	52	157	4.1
BN1901	BentenC	Dolerite	47.82	2.53	13.51	13.61	0.23	7.08	9.19	3.64	0.13	0.14	97.88	46	1.4	149	51	155	4.8
BN2104	BentenC	BasDyke	48.51	2.69	12.52	14.30	0.23	7.44	8.01	4.94	0.06	0.22	98.92	48	5.7	27	53	161	5.0
BN2011	BentenC	BasDyke	50.37	2.73	11.47	14.34	0.30	6.43	9.35	3.78	0.14	0.22	99.13	44	1.0	98	57	172	7.4
BN31921	BentenN	Pillow	48.46	3.35	13.48	14.71	0.31	6.04	8.64	3.49	0.76	0.26	99.50	43	22.6	131	75	254	11.6
BN0622	BentenN	Pillow	46.21	2.28	14.13	15.05	0.19	6.01	9.43	5.30	1.04	0.30	99.94	46	36.1	234	47	135	4.5
SN0704	Shinyashiki	Pillow	49.94	2.36	14.19	13.23	0.19	6.26	7.58	3.81	1.95	0.45	99.96	43	44.9	230	41	137	4.0
YB1106	Yo-oka	Pillow	52.54	0.83	7.13	20.49	0.12	7.00	2.40	1.16	8.10	0.18	99.95	16	259.0	38	18	54	1.6
Kj5	Kojima	Pumice	59.28	0.73	13.14	6.57	0.15	2.40	3.35	3.94	0.67	0.11	90.34	27	7.8	1408	28	48	0.5

Sample No.	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
BN2015	0.26	147	4.2	12.1	2.0	11.6	3.8	1.5	5.0	0.9	6.3	1.4	3.9	0.56	3.9	0.56	2.7	0.17	0.84	0.21	0.70
BN2109	0.20	249	7.4	21.2	3.5	19.9	6.6	2.3	8.4	1.6	10.1	2.2	6.1	0.91	6.3	0.90	4.9	0.34	1.13	0.44	0.59
BN2514	0.04	74	2.4	7.1	1.2	7.1	2.6	0.9	3.1	0.6	3.9	0.8	2.4	0.34	2.5	0.34	1.3	0.08	0.81	0.12	0.16
BN2106	0.08	60	6.2	17.2	2.8	16.3	5.5	2.0	6.9	1.3	8.7	1.9	5.3	0.77	5.4	0.81	4.1	0.26	3.50	0.35	0.20
BN2107	0.09	2129	5.8	16.2	2.6	14.3	4.9	1.7	6.2	1.1	7.7	1.7	4.6	0.67	4.8	0.69	3.5	0.25	0.65	0.33	0.12
BN1904	0.13	74	5.2	13.4	2.0	10.5	3.4	1.3	4.2	0.8	5.2	1.1	3.0	0.44	3.0	0.43	2.5	0.29	0.73	0.38	0.16
BN0705	0.03	174	5.9	16.9	2.8	16.0	5.4	1.9	6.9	1.3	8.6	1.9	5.1	0.76	5.2	0.76	4.1	0.25	0.69	0.30	0.13
KM91901	–	19	6.2	17.3	2.9	16.7	5.8	2.0	7.4	1.4	9.2	2.0	5.5	0.82	5.8	0.85	4.2	0.25	2.72	0.32	0.13
BN1901	0.04	60	6.3	18.0	3.0	16.7	6.0	2.0	7.5	1.4	9.1	2.0	5.5	0.80	5.7	0.79	4.2	0.29	0.76	0.35	0.11
BN2104	0.09	35	6.5	18.9	3.1	17.4	6.3	1.8	7.5	1.4	9.4	2.1	5.8	0.85	6.2	0.85	4.4	0.29	1.07	0.39	0.37
BN2011	0.02	41	6.3	18.7	3.1	18.4	6.2	2.2	8.0	1.6	10.1	2.2	6.1	0.90	6.2	0.89	4.6	0.32	1.12	0.40	0.20
BN31921	0.26	254	13.0	34.2	5.3	28.7	9.2	2.8	11.1	2.0	13.2	2.9	7.8	1.15	7.9	1.14	6.7	0.66	2.51	0.86	0.82
BN0622	1.34	201	6.0	16.1	2.7	15.4	5.3	1.9	6.7	1.2	8.4	1.8	5.0	0.77	5.0	0.74	3.7	0.26	1.70	0.33	0.91
SN0704	0.38	32	5.2	15.2	2.5	14.0	4.8	1.7	6.0	1.1	7.4	1.6	4.4	0.67	4.6	0.64	3.8	0.24	2.55	0.30	0.17
YB1106	1.02	20	2.5	5.9	0.9	5.3	1.8	0.6	2.5	0.4	3.1	0.7	1.9	0.29	2.1	0.34	1.3	0.08	0.81	0.12	0.16
Kj5	0.14	233	2.7	7.2	1.2	6.9	2.8	1.0	3.4	0.7	4.7	1.0	3.1	0.47	3.4	0.49	1.6	0.03	4.76	0.35	0.23

Table 4 Representative rock analysis of knockers (samples collected by R. Mori and Y. Ogawa) for major and trace elements (analysit, S. Haraguchi and T. Ishii; by XRF), some trace and RE elements (analyst, M. Kurosawa; by LAM-ICP-MS). For trace and RE elements, precision (1σ) approximately ±10%. See Kurosawa *et al.* (2002).

Sample No.	Locality	Rock	SiO2	TiO2	Al2O3	FeO*	MnO	MgO	CaO	Na2O	K2O	P2O5	Total	H2O(-)	LOI	Co	Cr	Ni	Ba	Nb
050405-19	Kobata	Tuff	60.73	0.81	16.13	8.53	0.16	1.81	5.29	3.93	1.80	0.24	99.43	1.76	3.09	75	3	20	595.2	5.6
050929-05	Kobata	Basaltic andesite	54.76	0.61	14.19	9.30	0.16	9.04	8.77	3.31	0.27	0.01	100.41	0.51	1.75	71	353	102	69.7	0.0
050929-06	Kobata	Granitic rock	75.66	0.21	13.16	3.21	0.08	0.71	3.66	2.87	0.59	0.00	100.14	0.27	0.66	151	−1	11	101.1	0.2
030418-20	Byobujima	Hornblende schist	50.60	1.52	16.06	11.99	0.18	6.12	10.45	3.06	0.52	0.06	100.56	0.43	1.2	84	316	85	41.9	1.1
040723-05	Kanashima	Hornblende schist	50.52	1.86	14.70	12.90	0.18	6.67	9.24	3.99	0.61	0.07	100.75	0.67	0.97	76	236	66	60.5	1.4
050129-30	Yamada	Diorite	58.65	0.43	18.75	6.33	0.08	4.67	5.07	3.98	1.64	0.00	99.60	0.78	2.4	79	12	40	114.6	0.2
041015-08	Kawashiro	Diorite	57.60	0.60	15.26	6.55	0.11	5.98	6.50	6.11	0.06	0.01	98.77	0.48	1.54	56	108	79	27.9	0.2
050929-03	Shinganji	Diorite	53.76	0.74	18.87	7.29	0.12	5.07	6.73	6.17	0.56	0.01	99.32	0.45	2.57	87	23	66	183.7	0.2
051007-03	Shinganji	Diorite	61.18	0.44	16.85	5.41	0.09	4.24	6.89	3.70	0.61	0.00	99.40	0.28	0.77	78	27	60	162.4	0.4
041126-11	Yamada	Gabbro	44.03	1.36	16.61	9.78	0.19	7.91	20.19	0.04	0.01	0.09	100.21	1.35	6.04	59	206	46	44.7	4.1
050406-01	Furubo	dolerite	50.66	1.60	13.57	12.49	0.18	8.35	8.59	4.50	0.10	0.06	100.10	1.11	3.97	69	122	62	50.8	0.8
050406-02	Furubo	Pillow	50.04	1.74	13.08	13.73	0.20	7.55	8.50	4.62	0.09	0.07	99.61	1.10	3.22	87	139	64	112.5	0.9
050406-11	Hashimoto	Pillow	51.14	1.82	14.47	10.69	0.21	7.69	10.03	3.68	0.10	0.08	99.93	2.27	1.97	55	180	66	138.1	2.0
031009-1a	Sumobaishi	Hornblende schist	49.01	2.56	12.96	14.92	0.26	8.01	8.70	2.92	0.12	0.19	99.65	0.66	1.69	72	96	49	12.8	4.01
040207-12a	Heguri-Naka	Garnet amphibolite	44.51	1.92	12.61	13.32	0.25	10.38	14.47	1.12	0.16	0.13	98.87	2.12	2.96	457	122	41	12.2	1.52
KB-1-a	Kobata	Andesite	57.35	1.35	15.04	8.67	0.12	4.94	6.90	4.25	0.68	0.22	99.52	1.14	0.75	101	124	113	279.27	9.54
SG2003-3	Sengen	Pillow	49.58	1.65	14.64	11.07	0.24	9.09	9.79	3.19	0.15	0.12	99.52	2.46	2.47	51	312	85	59.2	3.78
SN0207-25a	Shinyashiki	Pillow	49.91	1.51	14.30	11.20	0.19	7.49	11.22	3.39	0.10	0.10	99.41	2.64	1.98	52	294	80	37.9	1.96
SN0207-26a	Shinyashiki	Dolerite	49.37	1.63	13.93	12.04	0.20	7.93	11.04	3.56	0.09	0.09	99.88	1.87	2.40	59	214	54	31.6	2.54
YK0207-27a	Yoka Beach	Pillow	49.04	1.42	15.10	11.28	0.21	6.54	12.49	3.38	0.12	0.12	99.70	1.98	2.15	57	308	87	36.8	1.78
YK0207-29a	Yoka Beach	Dolerite	49.72	2.39	14.02	12.33	0.25	6.33	10.13	3.19	0.60	0.18	99.14	1.24	0.67	64	107	48	56.2	4.36
IM0207-37a	Isomura	Pillow	48.72	2.59	12.74	13.01	0.17	8.84	10.05	3.87	0.13	0.20	100.32	1.01	2.47	68	399	171	395	17.7
IM02007-38a	Isomura	Pillow	49.54	1.52	14.04	12.39	0.20	5.93	10.96	4.34	0.94	0.12	99.98	1.22	4.25	54	198	49	337	2.32
BN0206-14a	BentenNW	Pillow	47.94	2.30	15.24	15.75	0.17	4.80	7.74	4.65	1.34	0.23	100.16	1.83	4.68	55	148	53	404	4
BN0206-15a	BentenNW	Pillow	48.17	2.47	15.17	15.69	0.16	5.53	8.31	3.11	1.37	0.25	100.23	1.72	2.20	62	164	57	184	4.73
BN0206-16a	BentenNW	BasaltDyke	47.76	2.36	14.10	14.56	0.18	6.33	8.61	4.66	1.05	0.24	99.85	1.81	5.00	53	176	53	209	4.68
BN0206-17a	BentenNW	Pillow	49.09	2.30	14.68	13.58	0.15	5.78	9.42	3.16	1.33	0.21	99.70	1.26	2.40	62	122	55	319	4.46
BN0206-4	BentenC	Dolerite	51.04	2.44	12.04	14.76	0.22	6.57	8.31	4.94	0.21	0.21	100.74	0.54	3.06	53	102	44	44.9	4.5
BN0206-7	BentenC	Dolerite	48.45	2.40	13.14	14.57	0.22	7.01	9.30	3.28	0.42	0.18	98.97	0.59	1.84	55	105	43	2372	4.59
BN0206-10a	BentenC	Dolerite	48.90	3.00	12.37	16.58	0.24	6.71	8.23	3.65	0.30	0.22	100.20	0.78	1.46	60	79	41	233	5.49
BN0206-12	BentenC	BasaltDyke	47.63	3.25	12.44	18.41	0.25	6.01	7.84	4.22	0.26	0.27	100.58	0.52	1.97	52	45	21	39.5	6.7
BN0206-18a	BentenC	Pillow	49.64	1.39	15.87	10.17	0.16	8.92	10.13	3.60	0.24	0.09	100.21	1.18	2.76	63	355	129	153	3
BN0206-2	BentenNW	Pillow	52.10	2.86	12.95	14.79	0.27	4.58	7.70	4.33	0.41	0.50	100.49	1.14	0.24	51	66	26	291	11.4
BN0206-5a	BentenNW	Pillow	49.41	1.53	15.68	9.96	0.20	7.12	12.84	2.77	0.14	0.12	99.77	1.76	1.41	81	397	161	120	4.65
BN0206-6	BentenNW	Pillow	51.17	2.70	12.52	13.08	0.27	6.68	7.76	4.85	0.46	0.23	99.72	1.80	1.18	51	186	62	256	9.28

Sample No.	Pb	Rb	Sr	Th	Y	Zr	Hf	Eu	Ta	Sc	Cs	La	Ce	Pr	Nd	Sm	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	U
050405-19	6.6	32.8	558	2.86	37	101																			
050929-05	0.4	2.6	141	0.53	15	43																			
050929-06	1.4	10.6	106	0.59	19	46																			
030418-20	0.7	7.9	113	0.61	30	90																			
040723-05	0.4	4.4	103	0.55	37	110																			
050129-30	0.4	8.3	232	0.50	10	26																			
041015-08	0.0	0.0	122	0.77	15	56																			
050929-03	0.5	1.2	200	0.31	19	31																			
051007-03	0.2	4.5	224	0.84	12	57																			
041126-11	0.3	0.0	70	0.66	19	91																			
050406-01	0.0	0.0	149	0.72	32	89																			
050406-02	0.1	2.0	87	0.20	34	95																			
050406-11	0.1	0.0	166	0.53	34	116																			
031009-1a	2.52	0.46	110	0.33	52	153	4.4	2.1	0.23	43	–	6.2	18	3.0	16.8	6.0	7.7	1.37	9.2	2.01	5.7	0.83	5.6	0.84	0.13
040207-12a	–	1.89	118	0.11	42	113	3.3	1.6	0.09	40	–	3.5	11	2.0	12.1	4.7	5.6	1.09	7.5	1.62	4.6	0.68	5.0	0.68	0.06
KB-1-a	2.67	9.83	602	1.38	17	103	2.5	2.0	0.48	12	–	13.8	30	4.3	23.4	6.3	5.1	0.73	3.7	0.65	1.5	0.20	1.2	0.15	0.31
SG2003-3	–	1.1	140	0.29	31	98	2.6	1.4	0.23	40	0.33	4.7	13	2.0	10.9	3.8	4.7	0.83	5.5	1.22	3.3	0.52	3.5	0.48	0.12
SN0207-25a	–	1.01	141	0.15	31	85	2.1	1.3	0.13	40	–	3.6	10	1.7	9.9	3.5	4.6	0.85	5.6	1.23	3.3	0.51	3.6	0.51	0.19
SN0207-26a	–	1.41	194	0.20	33	95	2.8	1.4	0.15	42	–	3.9	11	1.8	10.3	3.8	4.6	0.90	5.9	1.28	3.5	0.50	3.8	0.55	0.55
YK0207-27a	–	1.96	126	0.13	29	81	2.2	1.1	0.12	42	–	3.1	9	1.6	9.1	3.4	4.1	0.77	5.3	1.11	3.3	0.48	3.2	0.43	–
YK0207-29a	1.22	12.8	127	0.33	48	148	3.8	2.0	0.27	46	0.30	6.4	18	2.9	16.0	5.2	7.1	1.26	8.5	1.89	5.2	0.73	5.4	0.75	0.44
IM0207-37a	1.68	1.24	532	1.30	22	143	3.8	2.0	1.00	35	0.16	15.9	37	4.7	22.0	5.3	5.1	0.82	4.6	0.89	2.3	0.27	2.0	0.26	0.24
IM02007-38a	0.81	23.5	135	0.19	32	88	2.4	1.3	0.14	44	0.91	4.0	11	1.8	10.5	3.7	4.5	0.85	5.8	1.31	3.5	0.51	3.7	0.52	0.25
BN0206-14a	–	28.4	393	0.28	46	128	3.9	1.9	0.27	46	0.87	5.8	16	2.6	14.7	5.2	6.5	1.22	8.0	1.82	4.9	0.74	4.9	0.73	0.50
BN0206-15a	–	30.8	138	0.34	49	140	3.9	2.1	0.34	46	0.64	6.5	18	3.0	17.4	5.9	7.1	1.36	8.6	1.94	5.6	0.79	5.6	0.86	0.43
BN0206-16a	–	22.7	158	0.28	48	136	4.0	1.9	0.28	44	0.64	6.3	17	2.8	16.3	5.5	6.9	1.26	8.5	1.86	5.5	0.75	5.5	0.79	0.38
BN0206-17a	–	24.6	125	0.37	50	152	4.3	2.2	0.26	47	0.52	7.0	19	3.1	16.9	5.2	6.9	1.33	8.6	2.06	5.6	0.81	5.4	0.78	0.49
BN0206-4	0.7	7.47	55	0.40	48	147	3.9	1.8	0.25	42	0.17	6.3	18	2.9	16.1	5.7	7.1	1.30	8.7	1.89	5.3	0.80	5.6	0.81	0.25
BN0206-7	1.84	10.4	179	0.30	46	140	3.8	2.1	0.24	43	0.20	6.0	18	2.8	15.8	5.3	6.5	1.27	8.4	1.85	5.1	0.72	5.4	0.76	0.25
BN0206-10a	1.45	3.13	112	0.41	56	171	4.8	2.2	0.30	44	0.08	7.2	21	3.4	20.0	6.5	8.2	1.55	10.5	2.2	6.2	0.89	6.4	0.94	0.25
BN0206-12	2.73	8.47	74	0.50	68	201	5.7	2.7	0.35	44	0.12	8.6	25	4.0	22.8	7.7	9.8	1.81	11.9	2.59	7.4	1.05	7.6	1.09	0.48
BN0206-18a	–	4.41	132	0.16	24	74	2.0	1.1	0.19	37	0.20	3.8	11	1.6	8.9	3.0	3.4	0.67	4.5	0.99	2.8	0.39	2.7	0.42	0.17
BN0206-2	2.13	9.26	106	0.94	97	344	9.1	3.8	0.65	35	–	15.5	45	6.9	38.4	12.4	14.9	2.70	18.1	3.83	10.4	1.55	10.9	1.46	0.40
BN0206-5a	1.25	1.04	168	0.37	29	96	2.5	1.4	0.28	38	–	5.5	14	2.1	11.8	3.7	4.4	0.80	5.4	1.12	3.1	0.47	3.5	0.49	0.10
BN0206-6	0.62	9.8	111	0.77	48	176	4.6	2.1	0.56	39	0.19	9.4	26	3.9	21.1	6.7	7.9	1.41	8.9	1.93	5.2	0.74	4.9	0.73	0.37