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主 論 文

The Mesozoic Evolution of the Mino Terrane, Central Japan: A Geologic and Paleomagnetic Synthesis

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美濃地域の中生代地史: 地質学的 および 古地磁気学的考察

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THE MESOZOIC EVOLUTION OF THE MINO TERRANE, CENTRAL JAPAN: A GEOLOGIC AND PALEOMAGNETIC SYNTHESIS

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ABSTRACT

The Mino tectono-stratigraphic terrane, central Japan, underlain by Permian to Jurassic sedimentary and volcanic rocks of various origins, was formed through accretion processes associated with the Mesozoic sea-floor spreading. This conclusion has been reached mainly from the following reasoning; 1. the entire boundary of this terrane is defined by tectonic belts with high-pressure metamorphic rocks and serpentinzed ultramafic rocks, 2. the chemistry and petrology of the Permian greenstones demonstrate their affinity with abyssal tholeiitic and alkalic basalts, 3. the widespread, but chaotic, occurrence of Permian greenstones, Triassic cherts, and Jurassic siliceous shales in the younger Jurassic clastic rocks of this terrane suggests extensive post-depositional mixing of strata, 4. the sedimentology of the Jurassic sandstones strongly suggests that they are turbidity-current deposits supplied

from cratonic lands, 5. the South-Pacific type fossil assemblage in the Mino terrane shows strong contrast with the North-Pacific type fossil assemblage of the adjacent terranes, 6. the paleomagnetism of the Permian and Jurassic greenstones, the Triassic cherts, and the Jurassic siliceous shales implies long-distance northward drift in the Cretaceous time of these rocks from their original low latitudinal regions.

Along with this northward migration, the Mino terrane was accreted with extensive internal deformation to northeast Asia including the present Hida terrane. Recent accumulation of paleomagnetic and paleontologic data in the Pacific peripheral regions appears to support the existence of many allochthonous terranes which migrated from the equatorial regions. The Mino terrane may be regarded as one example of these Circum-Pacific allochthons.

INTRODUCTION

The recent success in plate tectonics brought the studies of ancient orogenic belts in the world from the realm of static explanation to that of dynamic one. The tectonic development of Japan also is currently reexamined from the plate tectonic viewpoint(Matsuda and Uyeda, 1970; Uyeda and Miyashiro, 1974). It is of great interest to know how far back in geologic history the model of plate tectonics can be successfully applied in Japan. A great deal of data and ideas are needed to elucidate the Japanese pre-Cenozoic geologic evolution, although some models have been constructed based on the analysis of greenstones and ophiolites(Ernst, 1972; Sugisaki et al., 1972).

Recently, we reported the paleomagnetic results from Permian greenstones in the Mino terrane, central Japan(Fig. 1), and reached the conclusion that they carry reliable magnetic records acquired in paleo-equatorial regions(Hattori and Hirooka, 1979). Based on this study, we proposed a hypothesis that the greenstones were possibly erupted during the disintegration of a continent which was situated in the tropical Pacific region in the late Paleozoic time. This hypothetical continent could have been the lost Pacifica continent, speculated originally by Nur and Ben-Avraham(1977, 1978). The author considers that such models as that of the Pacifica continent are viable for gaining a better understanding of the overall tectonic evolution of the Mino terrane, central Japan. In the following sections, the term "Pacifica" is applied in a loose sense to mean one or more cratonic lands which are assumed to have been situated to the south of the Mino terrane.

Fig. 1

Until some years ago, the Mino terrane was considered to be composed entirely of Paleozoic rocks deposited on a continental crust extended from the Precambrian Hida terrane(Fujimoto et al., 1962; Minato et al., 1965; Adachi, 1976)(Fig. 1). This view came mainly from the evidence that fusulina-bearing limestone bodies exist in undated sedimentary rocks. Recent geologic data, however, revealed that Jurassic rocks are predominant in the Mino terrane(Yao, 1972, 1979; Mizutani et al., 1981). It is now apparent that we have to revise the age of the Mino terrane and consequently the tectonic relation between this terrane and the Hida terrane. This paper attempts to synthesize, based on the plate tectonic viewpoint, the latest data into a coherent picture relevant to the Mesozoic evolution of the Mino terrane, emphasizing accretion and collision tectonics.

TERRANE ASSOCIATION

Central Japan, truncated to the east by a Cenozoic major fault called the Itoigawa-Shizuoka Tectonic Line, is geologically interpreted as a typical collage, a term defined by Helwig(1974), and the following tectonic, metamorphic, and stratigraphic terranes are differentiated (Fig. 1); The Hida metamorphic terrane, the Circum-Hida tectonic belt, the Mino terrane, and the Ryoke metamorphic belt in the Inner Zone, and the Sambagawa metamorphic belt, the Chichibu belt, and younger geologic belts in the Outer Zone. The boundary between the Inner and the Outer Zones is the most prominent fault belt in Japan called the Median Tectonic Line. The geology and tectonism of the Outer Zone is described by Minato et al.(1965) and Tanaka and Nozawa(1977). In this paper, only the Inner Zone is discussed.

The Hida metamorphic terrane is the apparent geologic nucleus of Japanese Islands. This terrane is dominated by pelitic to psammitic gneiss, amphibolite, and crystalline limestone. Part of them is obviously Paleozoic in origin (Hiroi et al., 1978). Many isotopic ages reported are clustered around 240 Ma and around 180 Ma(Nozawa, 1968; Shibata et al., 1970). These figures provide apparent measures for the ages of the latest two metamorphic events. Generally accepted by Japanese geologists is that the Hida terrane includes the oldest geologic entities in Japan.

The Circum-Hida tectonic belt, which is covered in part by Jurassic conglomeratic sedimentary rocks, sharply delineates the Hida terrane. The Ordovician(Adachi and Igo, 1980; Igo et al., 1980) to Permian rocks, having been squeezed tectonically into this belt, are sedimentary rocks of shallow sea origin and volcanic rocks of acidic to intermediate composition. Serpentinites are often developed along the entire length of this belt. Glaucophane schists also crop out in some place. These rocks give radiometric ages ranging from 300 Ma to 400 Ma(Shibata and Nozawa, 1968; Shibata et al., 1970; Shibata and Ito, 1978). This belt has all the attributes of a Paleozoic to early Mesozoic suture belt having resulted from a considerable amount of tectonic shortening. A paleogeographic region, having comprised rocks which are observed in the present Circum-Hida belt, is referred to in this paper as the ancestral Circum-Hida region. This hypothetical region existed between the Hida and the Mino terranes in the pre-early Mesozoic subduction period.

The geologic ages of the rocks composing the Mino terrane range from the latest Paleozoic to middle Mesozoic, and the stratigraphic, tectonic, and sedimentologic relations among individual members are complicated owing to extensive internal deformation, as will be described in the next chapter.

The Ryoke metamorphic belt, which is often regarded as the high-temperature counterpart to form the late Mesozoic metamorphic pair with the high-pressure Sambagawa metamorphic belt to the south, is a metamorphic derivative of the Mino terrane.

GEOLOGIC SUMMARY OF THE MINO TERRANE

The interpretation accepted widely until some years ago, that the Paleozoic sedimentary rocks in the Circum-Hida and Mino terranes were deposited successively on the cratonic Hida terrane and its extension(Kanuma, 1958; Fujimoto et al., 1962), has been rejected by the recent development of geochronology based on conodonts and radiolarians. A great deal of the micropaleontologic data are now available to determine precisely the ages of strata in the Mino terrane. Dramatic changes in assigning ages have occurred within the last several years. The most dramatic, with regard to the models of tectonic evolution of the Mino terrane, is the discovery that the most "Permian" sedimentary rocks are in fact Triassic to Jurassic(Igo and Koike, 1975; Igo, 1979; Nakaseko and Nishimura, 1979; Yao et al., 1980; Mizutani et al., 1981; Yoshimura et al., 1982). In assigning the ages of rock, the author refers to these recent paleontologic data as well as my own radiolarian data.

1. General Geology

The Mino terrane comprises typical rock-associations found in many orogenic belts such as greenstone, limestone, sandstone, shale, and chert. They are piled up on an unknown basement complex in a complicated style. No evidence has been available to determine whether they are indigenous or not. This situation introduces serious confusion regarding the geologic relation between the Paleozoic, Triassic, and Jurassic sedimentary rocks. Therefore, in the strict sense, the ancestral regions where the rocks of the present Mino terrane were deposited or erupted are referred to paleogeographically as the ancestral Mino terrane. Fossil chronology roughly indicates that this terrane comprises Permian limestones, Permian and late Triassic to early Jurassic greenstones, Triassic cherts, and Jurassic siliceous shales as well as sandstones. The sandstones range in age mostly from early to late Jurassic with the principal mode in the late Jurassic. Some sandstones associated with late Jurassic siliceous shales may be as young as or younger than the latter. To make a simplification, they are grouped into the late Jurassic strata.

The greenstones concerned in our earlier paper(Hattori and Hirooka, 1979) were all considered to be Permian in age based on the classical lithostratigraphic correlation. The radiolarian biostratigraphy reveals, however, that the greenstones in the Nanjo area of the northwestern Mino terrane are intercalated concordantly with the late Triassic to early Jurassic sedimentary rocks(Hattori and Yoshimura, in prep.).

Coherent successions from Permian strata to Triassic strata or from Triassic strata to Jurassic strata are rarely available in the Mino terrane. Generally speaking, the Permian and Triassic rocks are floating in the Jurassic sedimentary rocks, and no systematic distribution in age and lithofacies of sedimentary rocks is found at present.

2. Greenstones

The greenstones in the Mino terrane, some of which, especially the Permian ones, are associated with limestone bodies of a coral-reef type. They are the oldest geologic bodies in the Mino terrane and no rock underlying concordantly these rocks has been observed. The greenstones probably formed part of the basement of the ancestral Mino terrane. The greenstones are basaltic in origin and frequently show pillow structures. They are composed mineralogically of clinopyroxenes and plagioclases, albitized in varied degree, set in altered groundmasses. Fresh plagioclases which are often encountered in the zeolite-facies greenstones have labradorite composition(Fig. 2). The majority of clinopyroxenes are those in the fields of common augite and salite. Fig. 2

Chemical data on the Permian greenstons(Tanaka, 1970; 1975) follow the trends of abyssal tholeiitic basalts and alkalic basalts. According to Sugisaki et al.(1972) and

Kawabe et al.(1979), the Permian greenstones were erupted under the tensional environment between separating continental lands. On the other hand, the late Triassic to early Jurassic greenstones are alkalic basalts in origin. They interfinger with the late Triassic chert and the early Jurassic siliceous shales. Possibly, they could be products of submarine intraplate volcanism. The tectonic aspects of the Mesozoic greenstones, however, remain unsolved.

The Paleozoic and Mesozoic greenstones in the Mino terrane are weakly metamorphosed into the zeolite facies and prehnite-pumpellyite facies(Hashimoto and Saito, 1970; Hattori, 1978). The metamorphic series belongs to that of intermediate temperature and pressure. No paragenesis documenting high-pressure type metamorphism is recognized. This fact suggests that the rocks of the Mino terrane have not undergone extensive crustal subduction.

3. Sandstones

The sandstones occur mainly alternating with shales in turbidite successions, and often forming massive beds. They occur also as blocks in olistostrome sheets. Their modal compositions measured microscopically were described by Mizutani(1957), Hattori(1975, 1976), and Hattori and Yoshimura(1979). The early to middle Jurassic sandstones occur as distal to transitional turbidites and are mostly classified into fine to medium grained graywacke sandstone. The modal analysis showed that plagioclases generally exceed alkalic feldspars in amount (Fig. 3). The twin laws of clastic plagioclases determined by referring to the migration curves offered by Burri et al.(1967) are predominantly the albite and albite-Ala B laws which are diagnostic of metamorphic plagioclases(Fig. 4). The compositions of clastic plagioclases range from An 0 to An 50 with high concentration at the composition of sodic andesine and albite. The sandstones generally include a trace of rock-fragments of biotite schist, quartz schist, gneiss, and granite. Volcanic fragments are generally negligible in amount. This line of evidence suggests that the pre-late Jurassic sandstones were accumulated in off-shore basins where materials were supplied mainly from remote cratonic terranes.

Fig. 3
Fig. 4

The late Jurassic sandstones occur mainly as proximal turbidites. Mizutani(1957, 1959, 1975) and Hattori and Yoshimura(1979) attempted to find the provenance(Figs. 3 and 4), and concluded that the sandstones, in which alkalic feldspars(mainly microclines) are much predominant over plagioclases in amount, are composed of materials derived chiefly from a granitic and high-grade metamorphic provenance. They are generally classified into medium to coarse grained feldspathic or arkosic sandstones. Contribution from volcanic rocks to the late Jurassic Mino terrane is not significant. Based on a paleocurrent analysis, Adachi and Mizutani(1971) made clear that the Mino terrane received a number of turbidity currents from the north.

It can be said to a first approximation, as formulated by Crook(1974), Dickinson and Suczeck(1979) and Dickinson and Valloni(1980), that the change in modal composition of sandstones with time recognized in the Mino terrane resulted from successive erosional stripping of adjoining cratonic terranes with minor volcanic, sedimentary, and low-grade metamorphic accessaries. In other words, the Mino terrane was gradually approaching a cratonic terrane and came to receive cratonic debris from the onset of Jurassic.

4. Other Rocks

There exists a considerable amount of Triassic cherts and Jurassic siliceous shales in the Mino terrane. The latter contain abundant remains of radiolarians and are sometimes called radiolarites. They are commonly interpreted to have been deposited in areas where or when any clastic materials from cratonic terranes could not reach. High content of silica and no trace of carbonate are reminiscent of their deep-sea origin. Since they give geochemical indication of cratonic influences such as high content of Cerium(Shimizu and Masuda, 1977) and $^{87}Sr/^{86}Sr$ (Shibata and Mizutani, 1980), however, very fine grained materials from cratonic lands might have contaminated them; suggesting their accumulation in the distal environments with a continental provenance.

Limestones are restricted in the Permian age and are mainly associated with greenstones. They carry fossil fauna of the tropical origin, the Tethyan fauna. The majority of limestone as well as of greenstone are allochthonous in the Triassic and Jurassic strata.

A lesser amount of conglomerate of Jurassic age carries clasts of gneiss whose ages have been determined by radiometric methods to be approx. 2000 Ma, indicating Precambrian provenance of the Jurassic sedimentary rocks in the Mino terrane(Shibata et al., 1971; Shibata and Adachi, 1974; Adachi, 1973).

The geologic analysis described above enables us to reconstruct the late Paleozoic to middle Mesozoic overall framework of the Mino terrane as follows. The Mino terrane, underlain by Paleozoic greenstones in part, was gradually covered by the Triassic cherts and subsequently the Jurassic siliceous shales. Clastic sediments supplied from cratonic lands began to be deposited at the onset of the Jurassic in the Mino terrane. Syn- and post-depositional deformation completely disorganized the original successions.

RELATION TO THE ADJACENT TERRANES

The evolution of the Mino terrane can not be understood without taking its relation with the Hida terrane and the Circum-Hida tectonic belt into account. The distribution of pre-Cenozoic rocks in the Hida and Mino terranes is illustrated in Fig. 5, and their spatial and chronologic relation is summarized in Fig. 6. The following discussion is based on the data published by many investigators which can be found in the summaries by Minato et al. (1965), Matsumoto and Kimura (1974) and Matsumoto (1978). Fig. 5 Fig. 6

As the Circum-Hida tectonic belt contains Permian rocks and is locally overlain by Jurassic molasse facies sedimentary rocks, the main phase of tectonic consumption of the ancestral Circum-Hida region is considered to have occurred during the Triassic time. Accompaning this event, granite and granodiorite were intruded widely in the Hida terrane and the Circum-Hida region in part, and pervasive deformation forming tectonic slivers and slices of early to middle Paleozoic rocks proceeded in the ancestral Circum-Hida region. This crustal consumption continued until the late Mesozoic and formed the Circum-Hida tectonic belt. During the same period, on the other hand, sedimentation of cherts continued in the main domain of the Mino terrane. This remarkable contrast is considered to have been produced from the difference in tectonic settings, and suggests a distal nature of the Mino terrane.

During the early to middle Jurassic time, marginal regions in the Hida terrane were covered by thick molasse facies sedimentary rocks with well-known fauna and flora called the Boreal-North Pacific type. The clastic materials were delivered not only from the Hida terrane but also from missing acidic volcanic and plutonic masses and orthoquartzite-bearing cratonic masses(Tokuoka and Okami, 1979; Shibata, 1979) probably of the ancestral Circum-Hida region. In fact, recent tectonic correlation between central Japan and Korea suggests a missing cratonic massif between the Hida and the Mino terranes(Hiroi, 1981). This massif is considered to have undergone extensive deformation and erosion and the record is found only as clasts in the Jurassic molasse facies sedimentary rocks which have characters of late-orogenic and post-orogenic successor basin deposits. A major domain of the Mino terrane of this period was, in contrast, under the condition of sedimentation of siliceous shales, distal turbididtes, and olistostrome sheets and of basic volcanism in places along with the mixing of the Permian to Triassic rocks with the Jurassic rocks. Not only the sedimentologic contrast, that is, the distal facies in the Mino terrane and the conglomeratic facies in the Hida terrane, but also the paleontologic contrast between the North-Pacific type fauna and flora of the Hida terrane and the South-Pacific type fauna of the Mino terrane strongly lead credence to the allochthonous concept of the Mino terrane.

Post-middle Jurassic sedimentary rocks found in part of the Mino terrane somewhat resemble the coeval molasse facies sedimentary rocks in the Hida terrane. Clastic chloritoids probably supplied from the Circum-Hida tectonic belt are discovered in the sandstones of the Mino terrane (Adachi, 1977). These facts suggest a great amount of clastic materials began to be delivered from the Circum-Hida belt and the Hida terrane into the Mino terrane at this time with the tectonic and erosional consumption of the ancestral Circum-Hida region in between

In the early to middle Cretaceous, no sedimentary rock was deposited in the Mino terrane. Extensive folding in the Mino terrane, thrusting in the Circum-Hida belt, and high-temperature metamorphism in the southern margin of the Mino terrane proceeded along with the late Mesozoic subduction of the Outer Zone under the Inner Zone. In the late Cretaceous, acidic volcanic and plutonic rocks were erupted on and intruded into both of the Mino and Hida terranes; indicating the completion of welding between both terranes. The geologic structure observed at present was essentially constructed by the late Cretaceous tectonism.

Through the Jurassic to Cretaceous compression tectonics, the Mino terrane with the South-Pacific type fossils and the Hida terrane with the North-Pacific type fossils, originally separated by a great distance, were completely junctured forming the suture belt of the Circum-Hida tectonic belt, and subsequently the whole region was uplifted and covered by late Cretaceous volcanic rocks. The Outer Zone separated by the Median Tectonic Line from the Inner Zone can be regarded as peripheral slices added subsequently to the Inner Zone during the late Cretaceous.

PALEOMAGNETISM OF MESOZOIC ROCKS

Diagrams illustrating the Phanerozoic age-versus paleolatitude of Japan were offered by Fujiwara(1968) and Sasajima(1981). Paleomagnetic data for the Mesozoic rocks in the Mino terrane, however, have been so scarce and so fragmentary as to preclude any systematic tracing of the Mesozoic evolution of the Mino terrane. The author has conducted paleomagnetic measurements on some of the Permian and Mesozoic sedimentary rocks in the Mino terrane which should have recorded the motion of this terrane (Fig. 7), and confirmed that some red cherts, red siliceous shales, and green to gray siliceous shales carry weak but measurable magnetic remanence(ca. 0.1-1.2 x 10^{-5}emu/gr.). The ages of sedimentary rocks were assigned by referring to radiolarian data by Nakaseko and Nishimura(1979), Yao et al.(1980), and Mizutani et al.(1981) and by the author's unpublished data. The ages of rocks which can not be precisely ascertained were determined on litho-stratigraphic correlation.

Fig. 7

1. Paleomagnetic Measurements

The paleomagnetic measurements were made for individual site-sets of samples by the following procedures.

1. The directions of the natural remanent magnetization (nrm) for all samples were measured. 2. One to two pilot samples were cleaned stepwise in the alternating fields (af-demagnetization) to define one or two optimum demagnetization fields(ODF). ODF was defined as the field intensity at which no abrupt change in magnetic intensity and/or magnetic direction was recognized. When no suitable ODF could be defined by the stepwise af-demagnetization(Fig. 8), the site-set was eliminated(e.g. Sites 12 and 17). 3. The remaining samples, excluding one for heating experiment(Procedure 4), were demagnetized in the ODF, and the site-mean of magnetization direction of the residual remanence and Fisher's parameters were calculated. When the result gave α_{95} larger than 25° and k smaller than about 10, it was concluded to be unreliable(e.g. Sites 2, 8, 9, 14 and 15). Sites 1, 4, 6, 7, and 18 showed that the magnetization directions of the pilot samples did not migrate from the nrm direction, and the precision parameter(k) of nrm for the site-sets was larger than those after demagnetization in the ODF. 4. At least one pilot sample from individual site-sets which met the criterion of procedure 3 was heated stepwise in air to ascertain the thermal stability. For comparison, the thermal stabilities of the site-sets eliminated by procedure 3 were also examined.

Fig. 8

Greek Alpha

Fig. 9

The following examples are typical results of af- and thermal demagnetization. OM 76 and OM 80A in Fig. 9 are the pilot samples from Site 2 which was eliminated. This site-set appears stable in the alternating fields (OM 76), but unstable thermally(OM 80A). KM 20 and KM 16 in Fig. 10 are the pilot samples of red cherts from Site 15. KM 16 showed thermally stable nature, but no suitable ODF could be defined for KM 20. This site-set was also discarded. Fig. 11 illustrates a typical example of red siliceous shales and red cherts. OM 31 and OM 27 are representative of Site 1. The demagnetization experiments revealed the stability of the nrm. In fact, k for nrm is larger than that after cleaned in the ODF. The intensity of magnetization decreased gradually with increasing temperature up to 650 °C. This is also the case for red cherts of Sites 6 and 7. Fig. 12 shows another type of the intensity reduction, which shows a step at 500 °C in the temperature-intensity curves. N7-1 and OM 108 are red tuffaceous cherts from Sites 4 and 3, respectively. In Site 4, no directional change between the nrm direction and the direction after cleaning was observed until the intensity decreased to the noise level. Thus, the nrm direction was accepted as the reliable one. In Site 3,

Fig. 10

Fig. 11

Fig. 12

the characteristic direction of the magnetization was obtained by cleaning in the ODF of 200 Oe and such was the case for Sites 5, 13, and 16.

Fig. 13

The green to gray siliceous shales obtained from the other sites displayed a different mode of thermal reduction in magnetization intensity. S-2-6 and JS 70-2 are the pilot samples from Site 11(Fig. 13). The thermal stability of JS 70-2 is obvious. The intensity dropped down to null values at 500 °C; suggesting that the chief magnetic contributor is magnetite. This site-set was cleaned in the ODF of 300 Oe and 400 Oe, and the former result was accepted. Siliceous shales which were eliminated by procedure 3, for example, Site 17, showed abrupt increase in the intensity at temperature higher than 400 °C, and no unique direction was calculated. This phenomenon results possibly from mineralogic alteration such as dehydration and oxidation.

Through this series of stability examination of magnetization, more than one third of the site-sets collected were eliminated. The reliable results are listed in Table 1.

2. Structural Correction

The structural correction of paleomagnetic directions is not simple and not easy for rocks from orogenic belts. In this study, the following procedure was applied taking the structural evolution in the Mino terrane into account. The sedimentary rocks in this terrane were folded with almost horizontal fold axes with E-W direction during the Cretaceous period(Mizutani, 1964). By the Cenozoic structural disturbance, local blocks were rotated about the vertical axes, and the resultant bedding attitudes became deviated considerably from the overall fold geometry.

The practice of the correction is to rotate the strikes of bedding planes so as to make them parallel with the E-W direction(strike correction) and to tilt the bedding planes to the horizontal(dip correction). The selection of sense of rotations depends merely on the smallness of rotation angles. In Table 1, the paleomagnetic directions of in-situ means(D, I) and after the structural correction (Dc-A, Ic) are listed with Fisher's parameters. The couples of Dc and Ic are the paleomagnetic directions after simple dip correction. Great care must be taken to the fact that the restored mutually antipodal paleomagnetic directions can not be differentiated, because sedimentary structures generally do not tell the bottom and the top of the cherts and the siliceous shales, and because the beds stand nearly vertical.

Fig. 14

Fig. 15

The in-situ and corrected paleomagnetic directions are illustrated in Figs. 14 and 15. Despite wide variation of geologic structures, the paleomagnetic directions shown with couples of Dc-A and Ic seem to cluster better than those of the other couples. This result indicates the acquisition of characteristic magnetization before the structural disturbance. The dispersion found in Fig. 15B owes partly to probable rotation along bedding planes occurring on the occasion of the mixing of strata and during the late Cretaceous deformation, and partly to the imprecise understanding of local geologic structure.

Table 1

3. Paleomagnetic Interpretation.

The same operation of structural correction was applied to the paleomagnetic results from the Permian and Jurassic greenstones described in our previous paper(Hattori and Hirooka, 1977, 1979) to compare both the paleomagnetic directions of the sedimentary and volcanic rocks(Fig. 16). For the paleomagnetic directions from the Permian to Jurassic rocks of the Mino terrane, high concentrations are found in the shallow direction of N-S to NNE-SSW regardless of the lithologic types. This means that the greenstones, cherts and siliceous shales in this terrane originated from low latitudinal regions and were not rotated so randomly along the bedding planes after their magnetization. Fig. 16

The shallow paleomagnetic inclinations of the late Paleozoic and older Mesozoic rocks described by Hattori and Hirooka(1977, 1979) and in this paper differ widely from the late Cretaceous paleomagnetic inclinations of Southwest Japan summarized by Yaskawa and Nakajima(1974). Fig. 17 is the pre-Cenozoic inclination-versus-age diagram on the basis of the paleomagnetic results expressed in this paper and reported by Shibuya and Sasajima(1980) and Katsura et al.(1980). There appears to be no major inconsistencies between this figure and the observation by Fujiwara(1968) and Sasajima(1981), and the large-distance northward drift of the Mino terrane is strongly supported. The juxtaposition of the Mino terrane carrying the Tethyan fauna with the Hida terrane carrying the North-Pacific fauna and flora was completed during the latest Jurassic to the late Cretaceous, and subsequently both terranes are covered by late Cretaceous acidic volcanic rocks. The collision between both terranes followed by the Cenozoic southward motion of Japan marks the terminal of the Mesozoic orogeny in the Japanese Islands.

Fig. 17

DISCUSSION AND SUMMARY

The geologic and paleomagnetic data available in the Mino terrane demonstrate that this terrane comprises greenstone, chert, siliceous shale, and limestone of the Permian to Jurassic oceanic elements generated in low latitudinal regions and Jurassic clastic rocks whose consituents were delivered from cratonic lands including the Hida terrane. Since the former occur in a chaotic fashion in the latter, scarce evidence is available on which to determine the original stratigraphic relation between the former and the latter. One probable explanation for the chaotic situation is that the two distinct lithofacies, one oceanic and the other continental, were mixed by the middle to late Mesozoic accretion processes to the Hida terrane after their deposition in different regions. It is likely that sediments deposited to the south of the Hida terrane were scraped together around the Hida terrane in the middle Mesozoic. During this accretion process, a great deal of materials of the ancestral Circum-Hida region were probably lost.

Recent paleomagnetic study by McElhinny et al.(1981) revealed that Asia is a composite continent formed by many crustal blocks which travelled from the south.

Supporting this idea, the author suspects that the Hida terrane is possibly the very fragment dismembered from "Pacifica" and that this terrane proceeded at rapid rates in the late Paleozoic to the early Mesozoic and at slow rate in the middle to late Mesozoic relative to the rates of the Mino terrane. The Mino terrane can be regarded as an allochthonous terrane accreted around the Hida terrane, and the latter also appears to be an accreted one around the Asian continent. This interpretation leads to a probability that there exist two types of accreted terranes. One is of allochthonous terranes such as the Hida terrane and the other is of allochthonous terranes composed of marine sedimentary rocks and greenstones such as the Mino terrane. The probable modern analogy of the latter type is recognized as moving oceanic plateaus(Ben-Avraham et al., 1981).

The allochthonous terrane concept derived from the Mino terrane appears to be applicable to some geologic provinces around Japan. The Sikhote Alin to the northeast of Japan serves well as the example. This province with tropical fauna experienced the Paleozoic and Mesozoic geologic evolution resembling that of Japan(Beznosov et al., 1978; Matsumoto, 1978). The allochthonous explanation of this province dates back to the paleomagnetic measurements of its Mesozoic rocks by McElhinny(1973). According to Frakes et al.(1975), Permian glacial sedimentary rocks are developed along the upper reach of the Omolon River. If the age is correctly assigned, this formation shows strong contrast with the tropical Tethyan fauna observed in the Mino terrane and Sikhote Alin, substantiating the allochthonous nature of the latter.

The tropical faunal realm, called the Tethyan faunal realm(Ross, 1967) around the Pacific, is in clear contrast with the Eurassian-Arctic, Midcontinent-Andean, and middle Cordilleran faunal realms and is important in understanding the Paleozoic to early Mesozoic paleogeography in the Pacific region(Danner, 1977). Churkin and Eberlein(1977), Hamilton(1978), Monger(1977), and Monger and Ross(1977) concluded that the terranes with the Tethyan fauna are allochthonous blocks having collided with the American continent, and Alexander and Wrangellia are well-known examples(Jones et al., 1977; Davis et al., 1978; Plafker and Judson, 1980). According to Sengör et al.(1980), Sengör and Yilmaz(1981), and Ridd(1980), the same situation is noted to the south of Japan. The Tethyan faunal zone in the south and middle east Asia continent is allochthonous to the Eurassian continent.

The Paleozoic and Mesozoic rocks in the orogenic belts around the Pacific provide magnetized volcanic and sedimentary rocks, and recent paleomagnetic measurements of these rockc(Packer and Stone, 1974; Hillhouse, 1977; Stone and Packer, 1979; Beck, 1980; Schwarz et al., 1980; Yole and Irving, 1980) all meet the interpretation that the southern part of Alaska, Vancouver Island, and adjacent areas migrated northward from the early Mesozoic equatorial regions.

Although the allochthonous terranes have been shown to vary greatly in size and shape, the characters of the accretion processes on them seem comparable. According to Engel and Kelm(1972), the post-Permian orogeny in the Circum-Pacific region resulted from the collision of many continental fragments dispersed from Pangea, possibly comprising "Pacifica" as part. After the Permian to Triassic breakup of the continent, many continental fragments, oceanic plateaus, and submarine sediments were transported toward present sites, and subsequently were added as peripheral slices of the major continents(Churkin et al., 1979; Irving, 1979; Coney et al., 1980; Plafker and Hudson, 1980; Ben-Avraham et al., 1981).

The view deduced from the Mino terrane puts interpretation of tectonic processes in different segments of the Circum-Pacific more in accord. The late Paleozoic to late Mesozoic evolution of the Mino terrane revealed in this paper is probably one of the typical examples of the accretion processes with respect to the Circum-Pacific allochthonous terrane belt.

ACKNOWLEDGEMENTS

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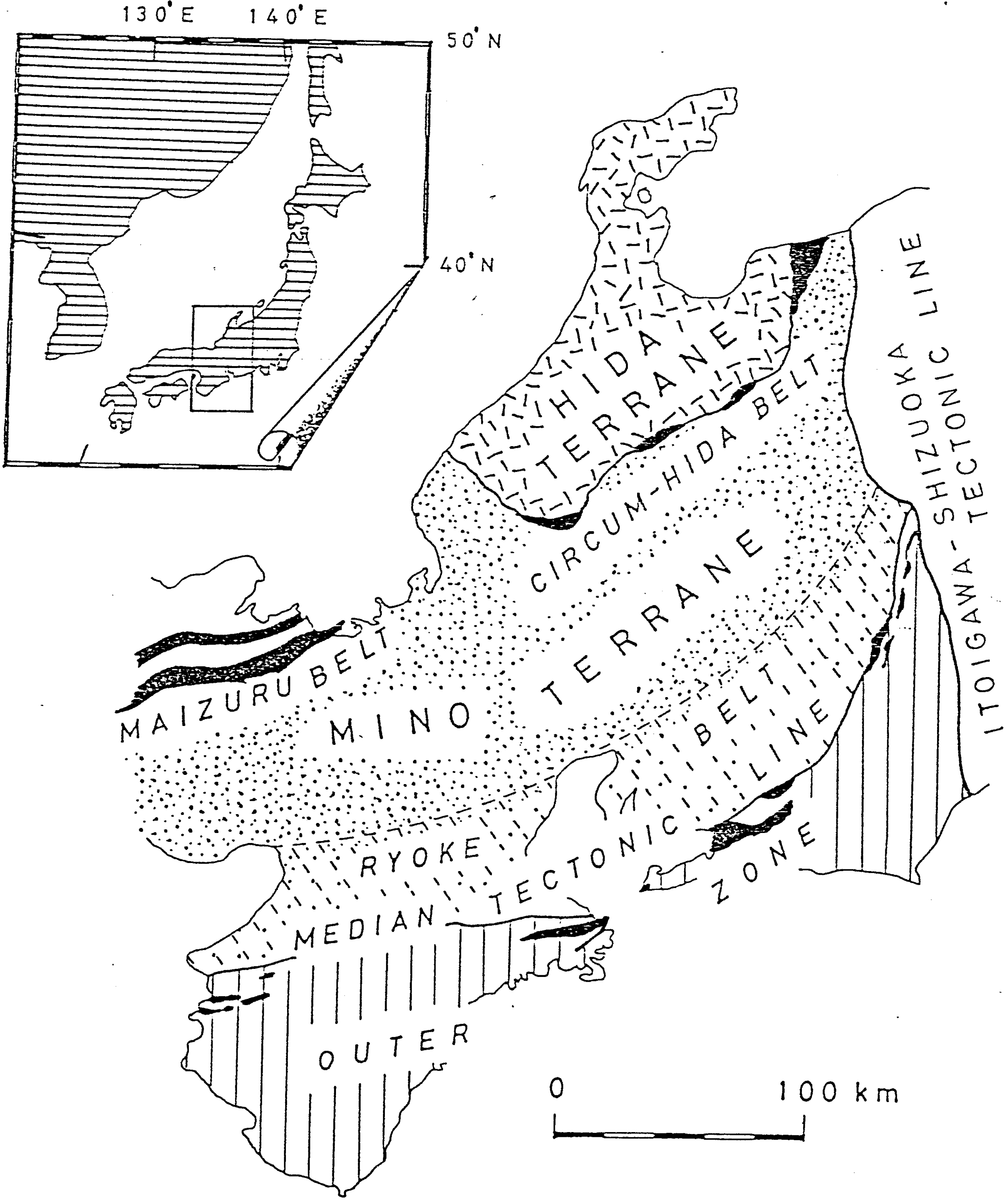
I. HATTORI
Fig. 1



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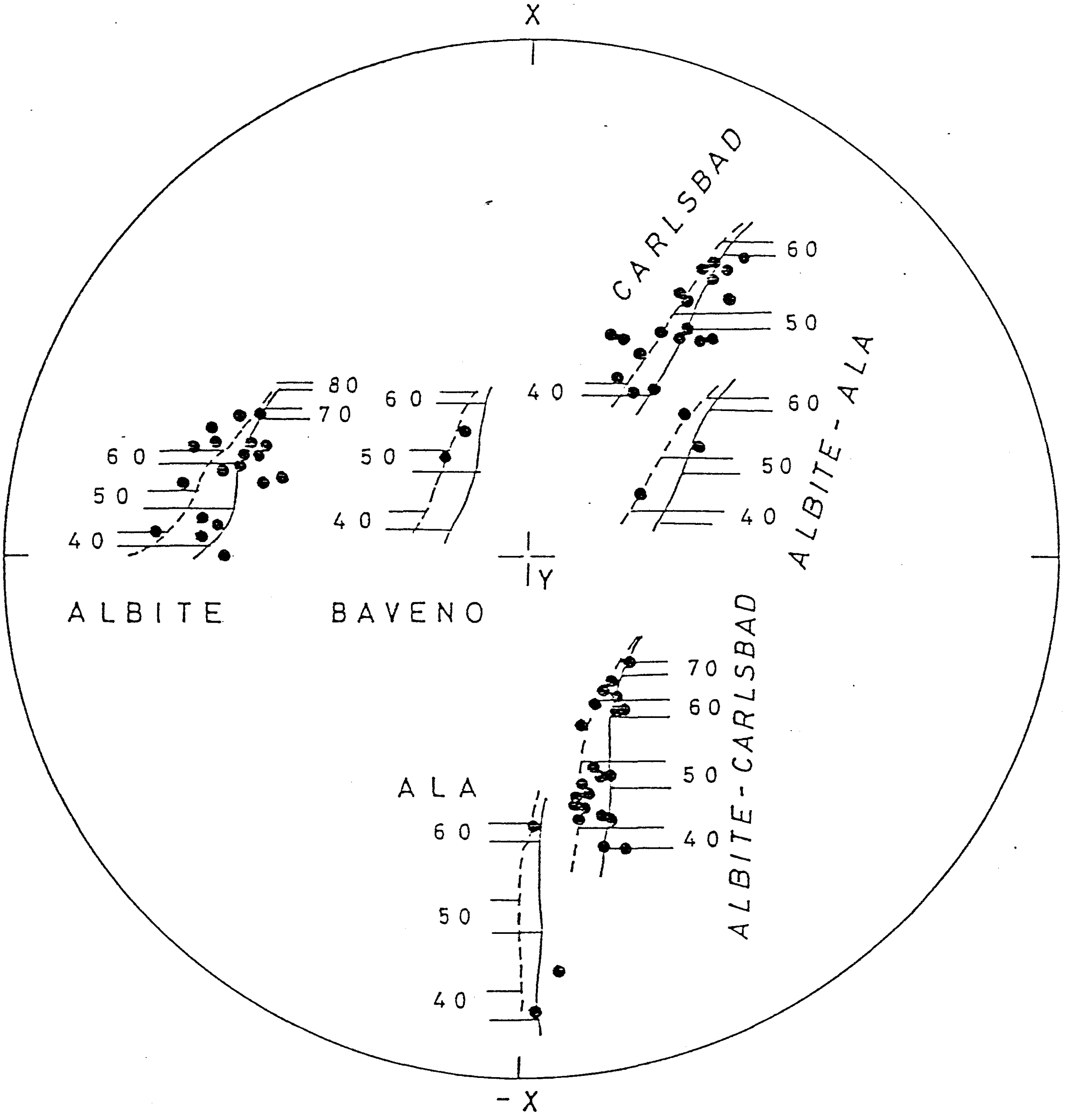

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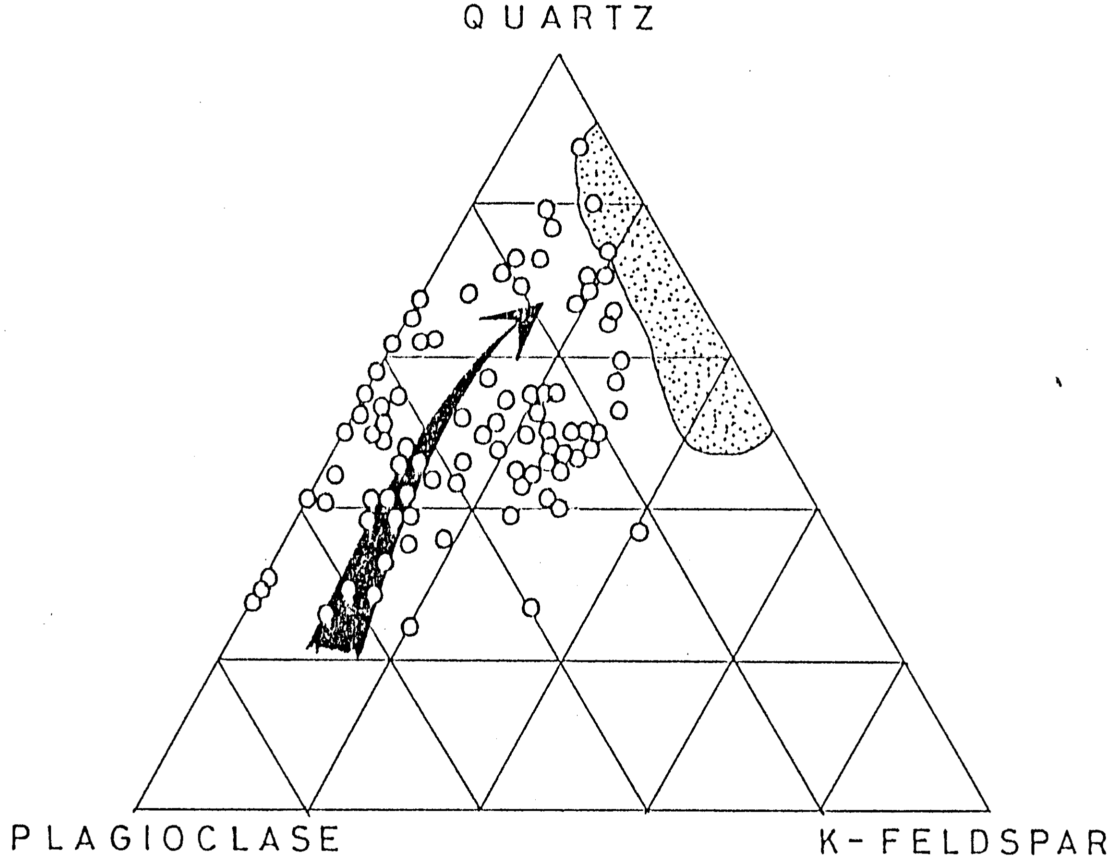

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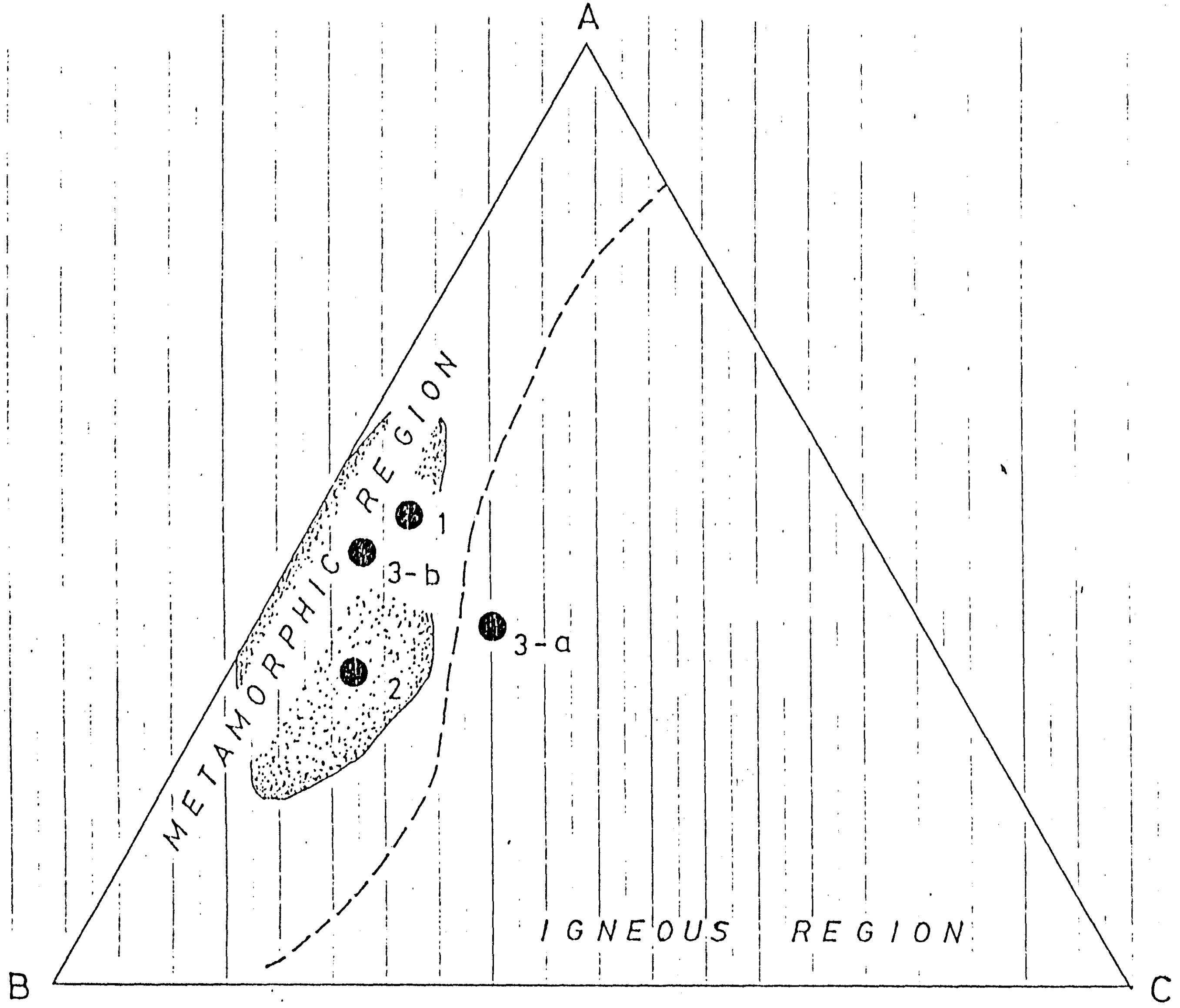

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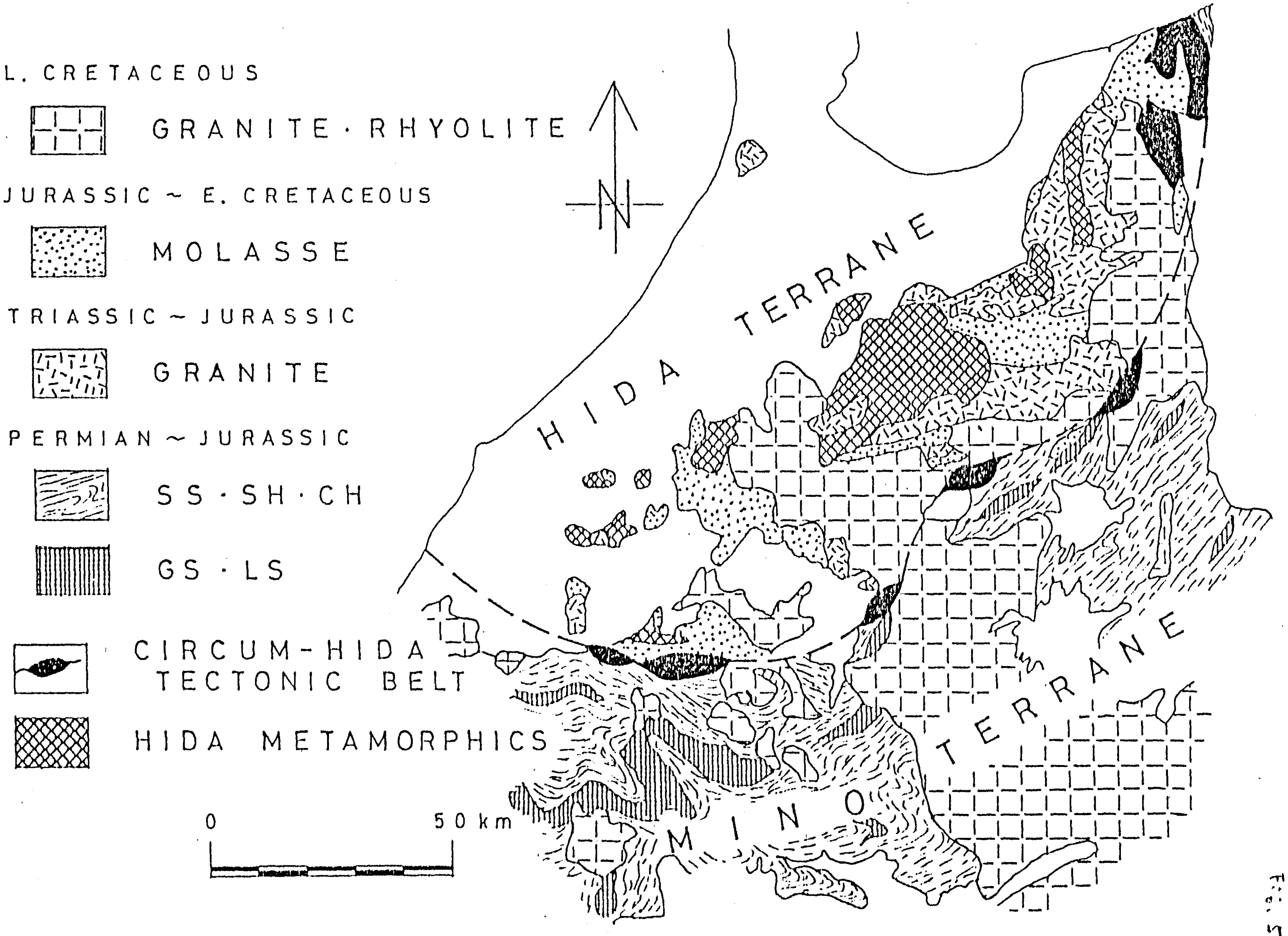

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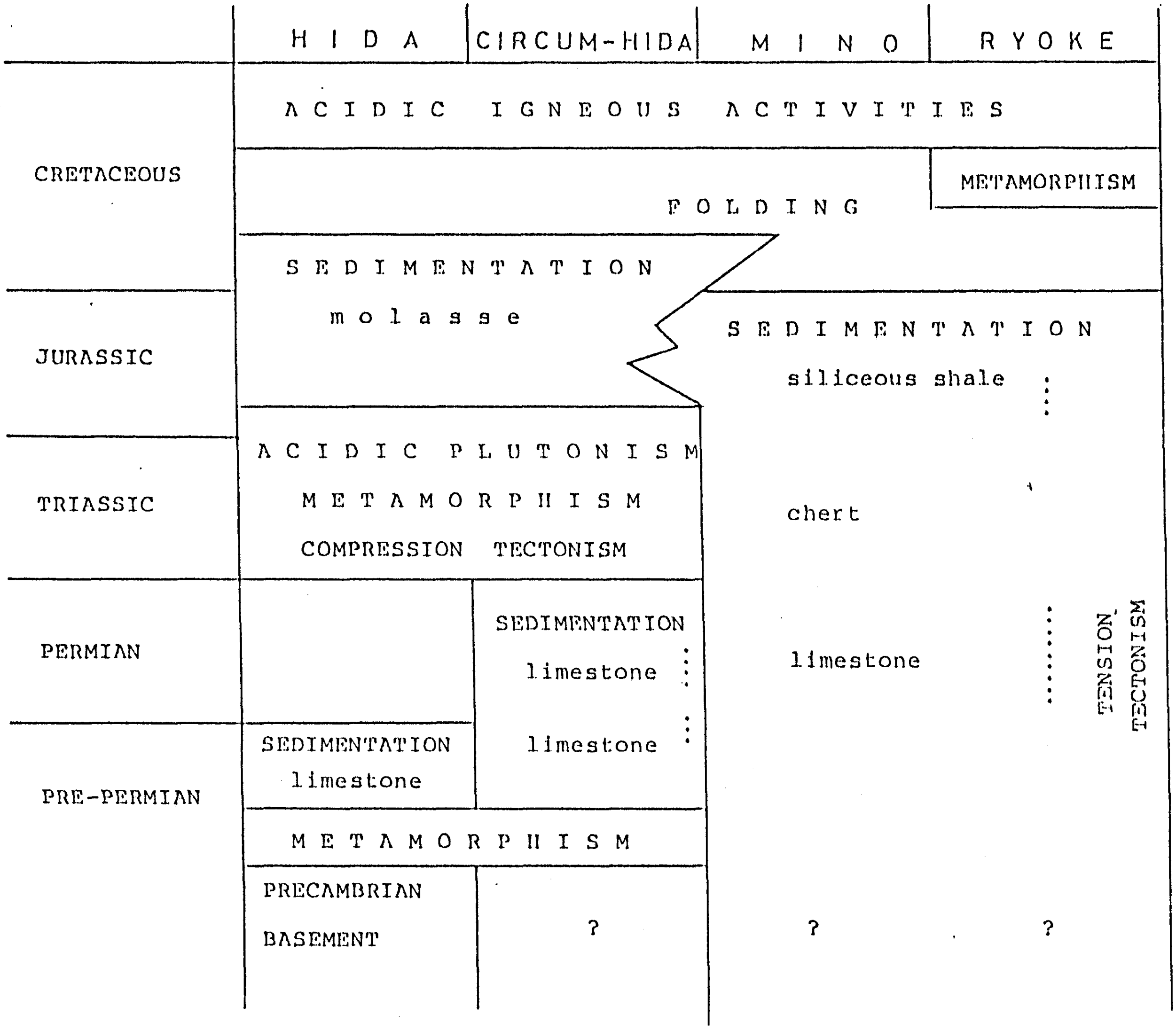

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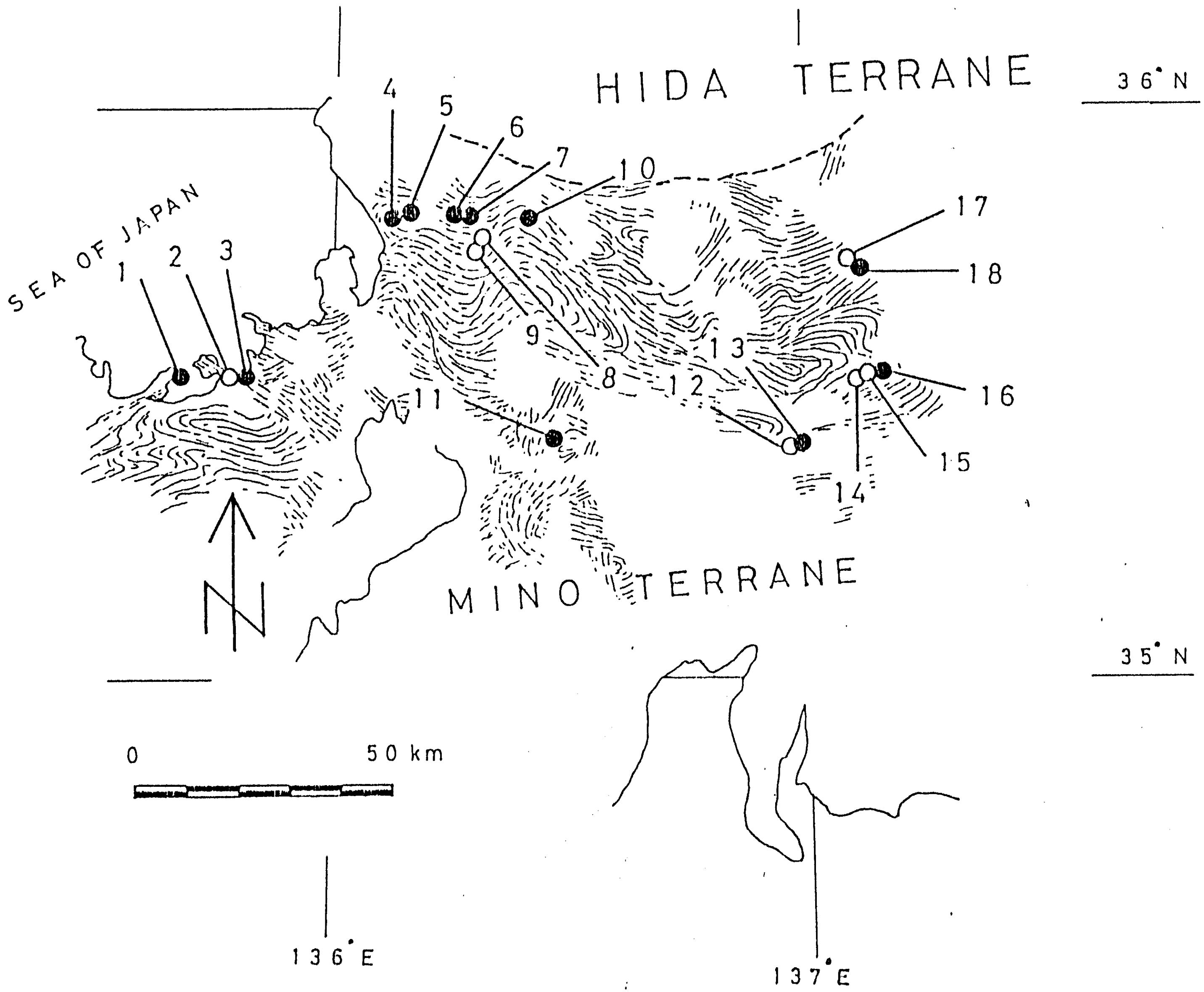

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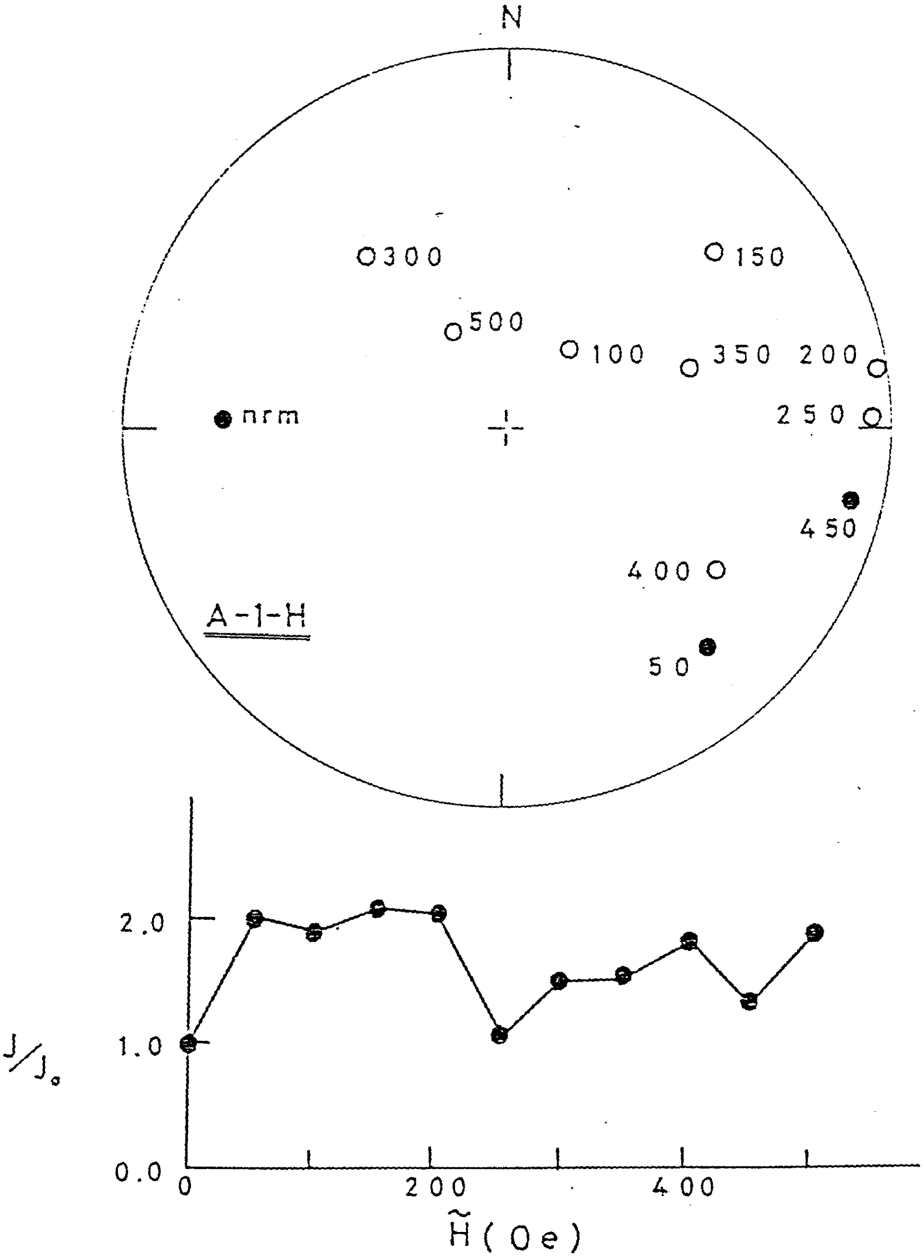

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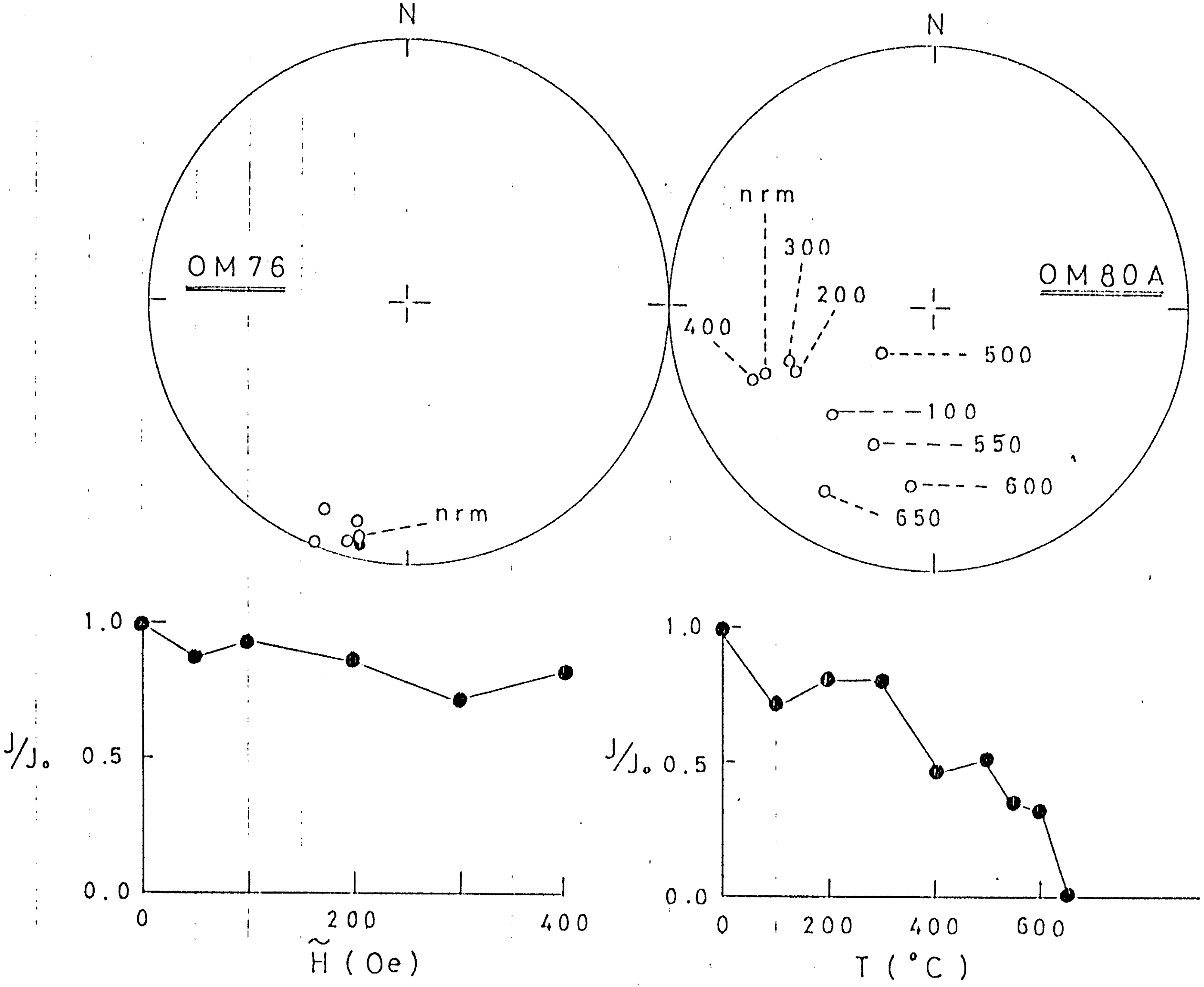

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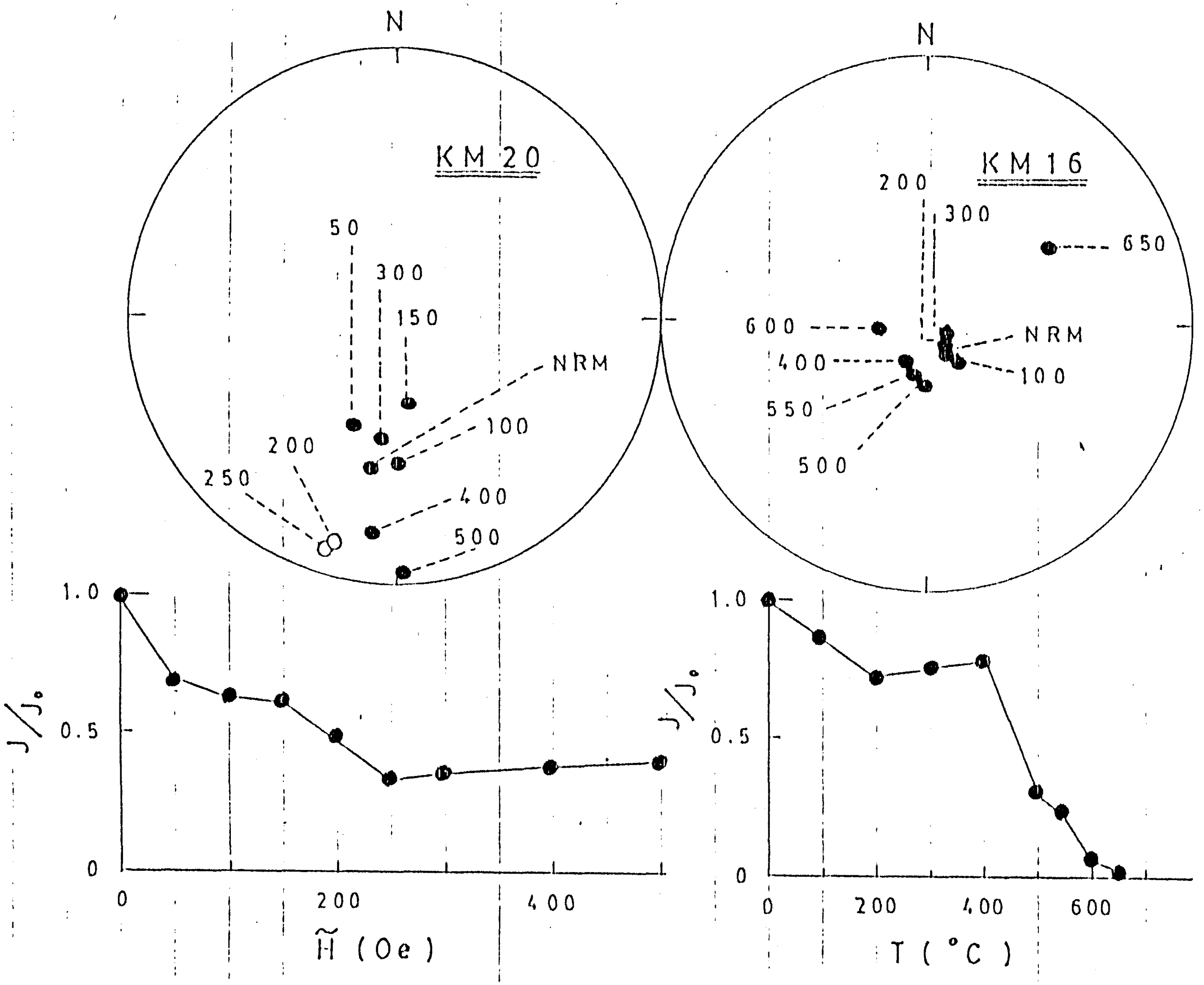

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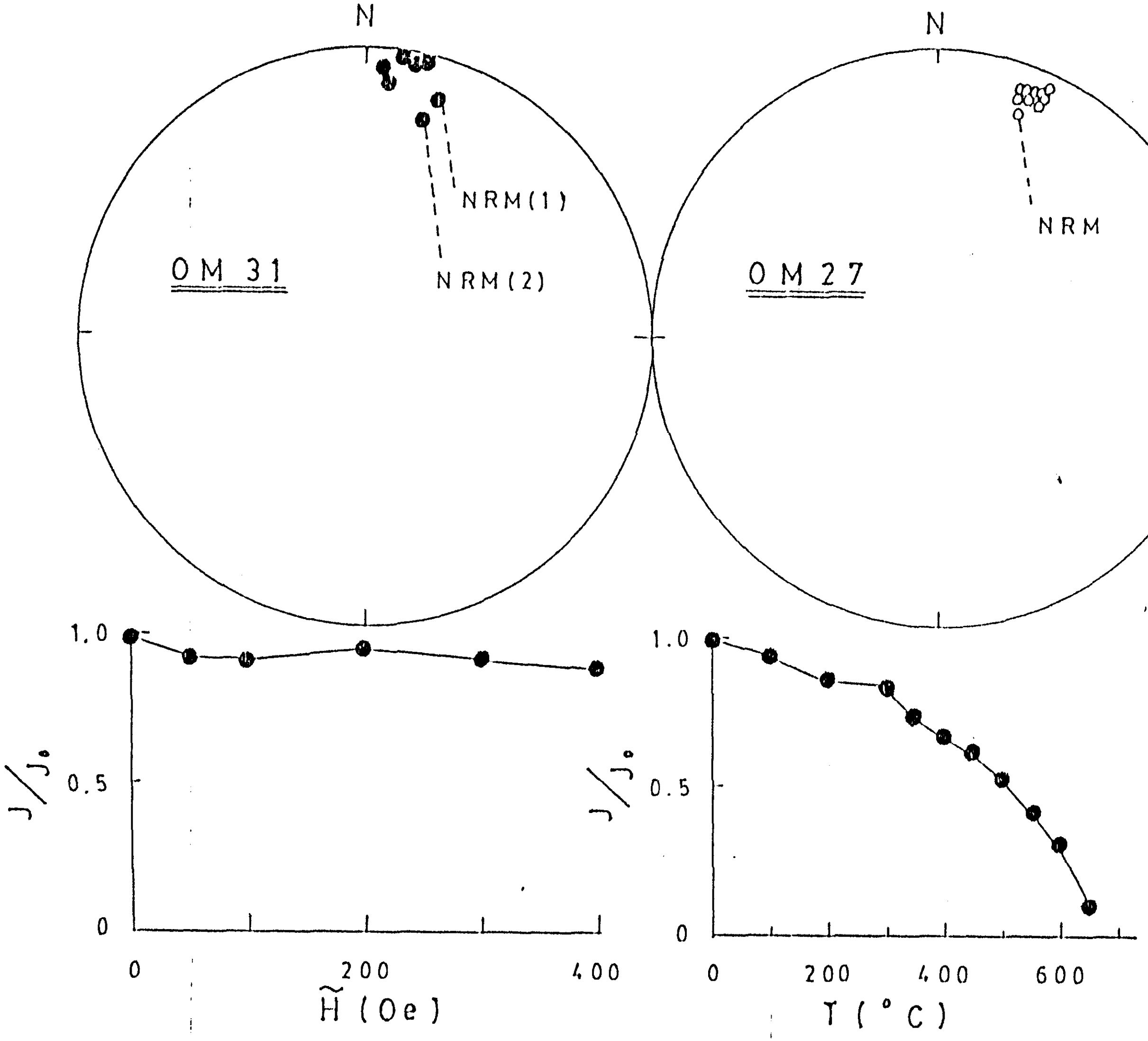

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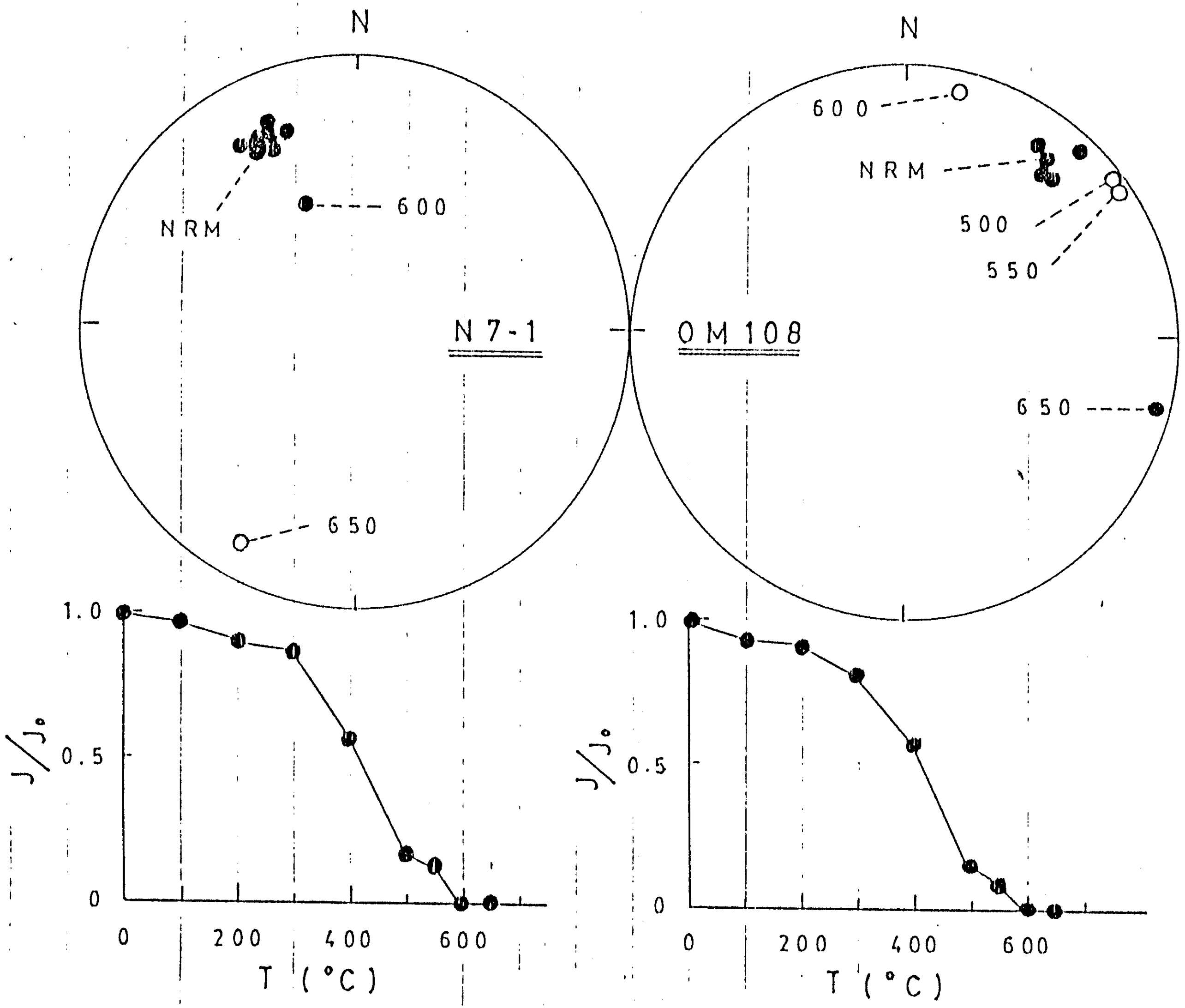

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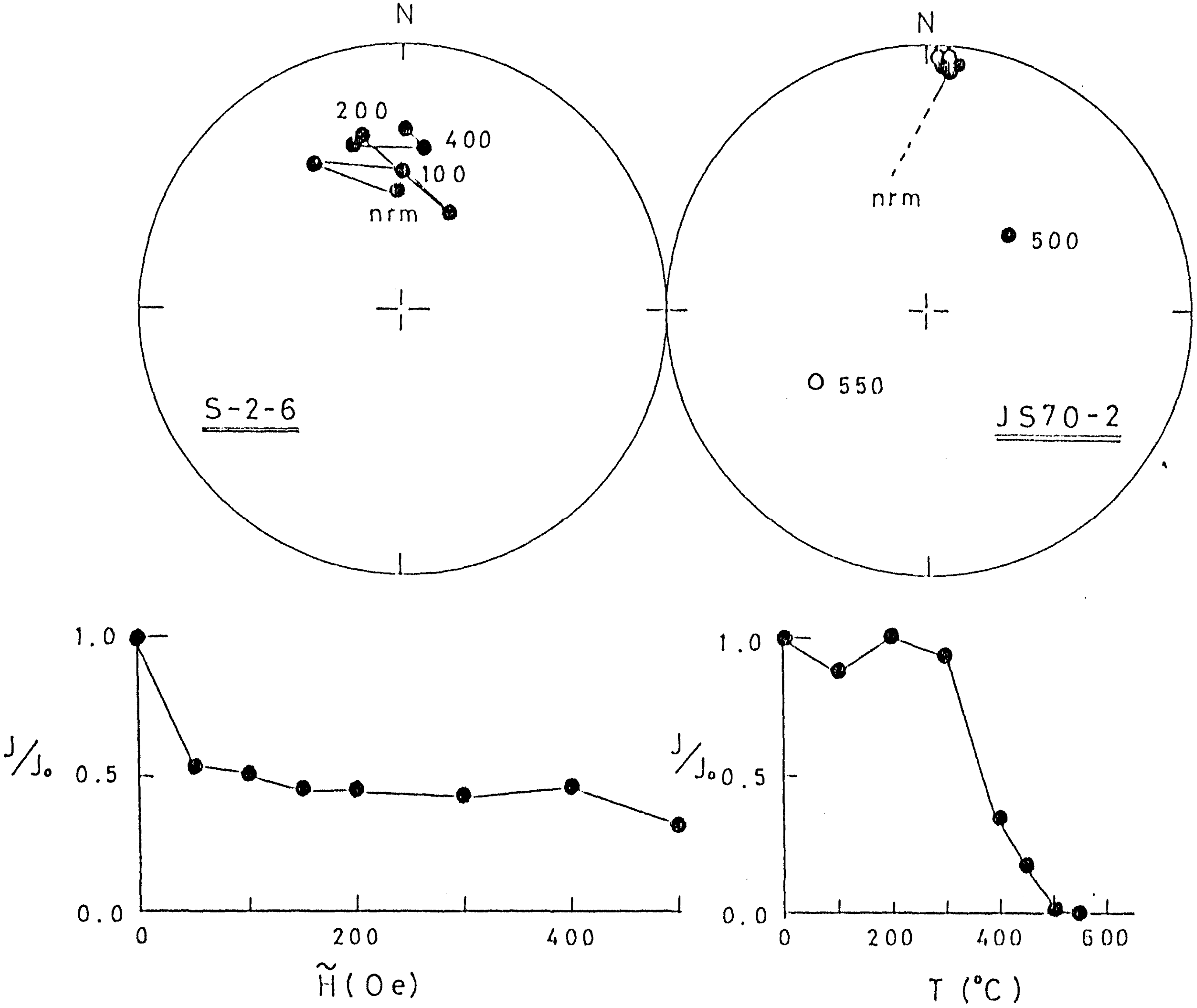

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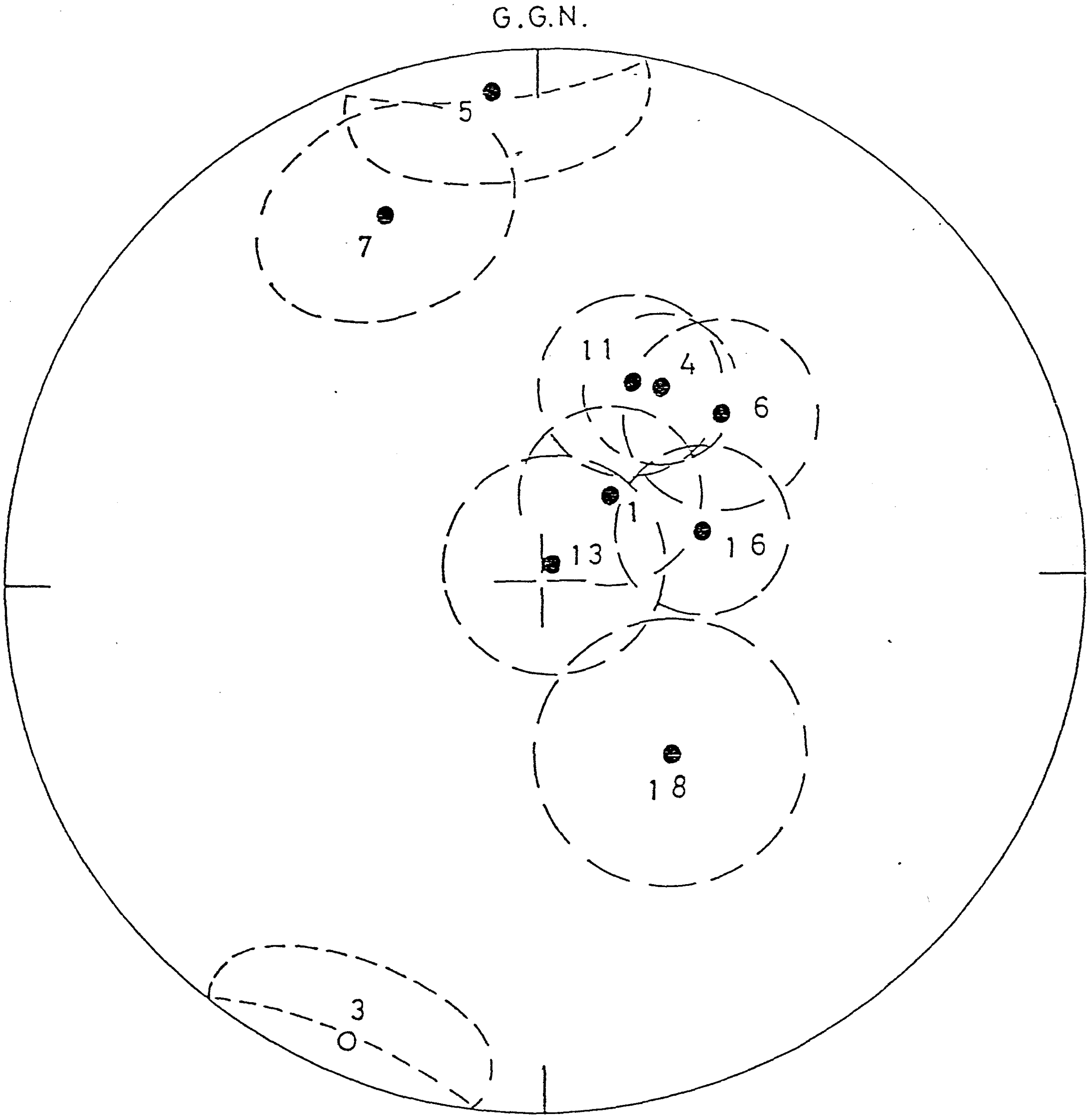

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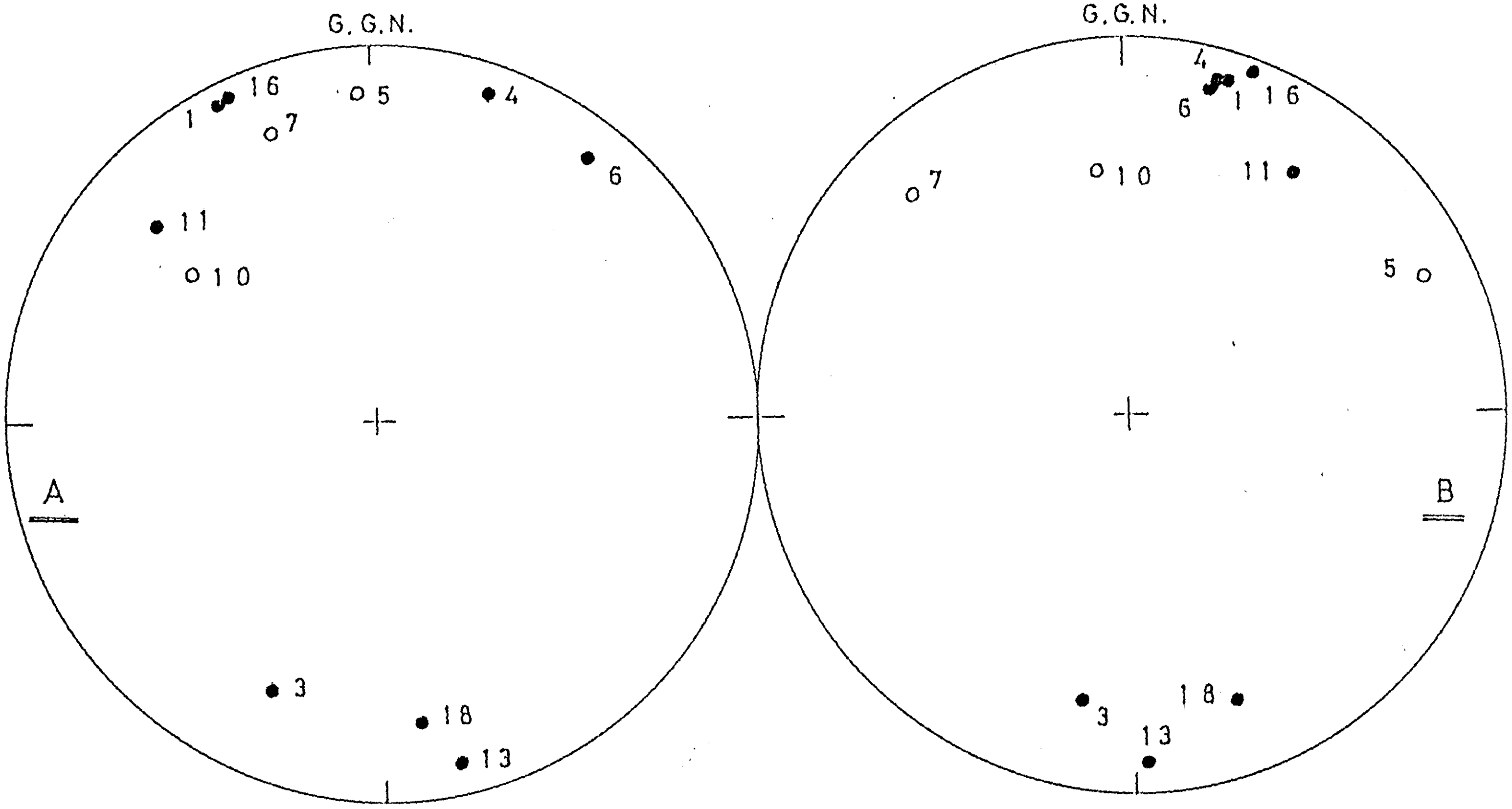

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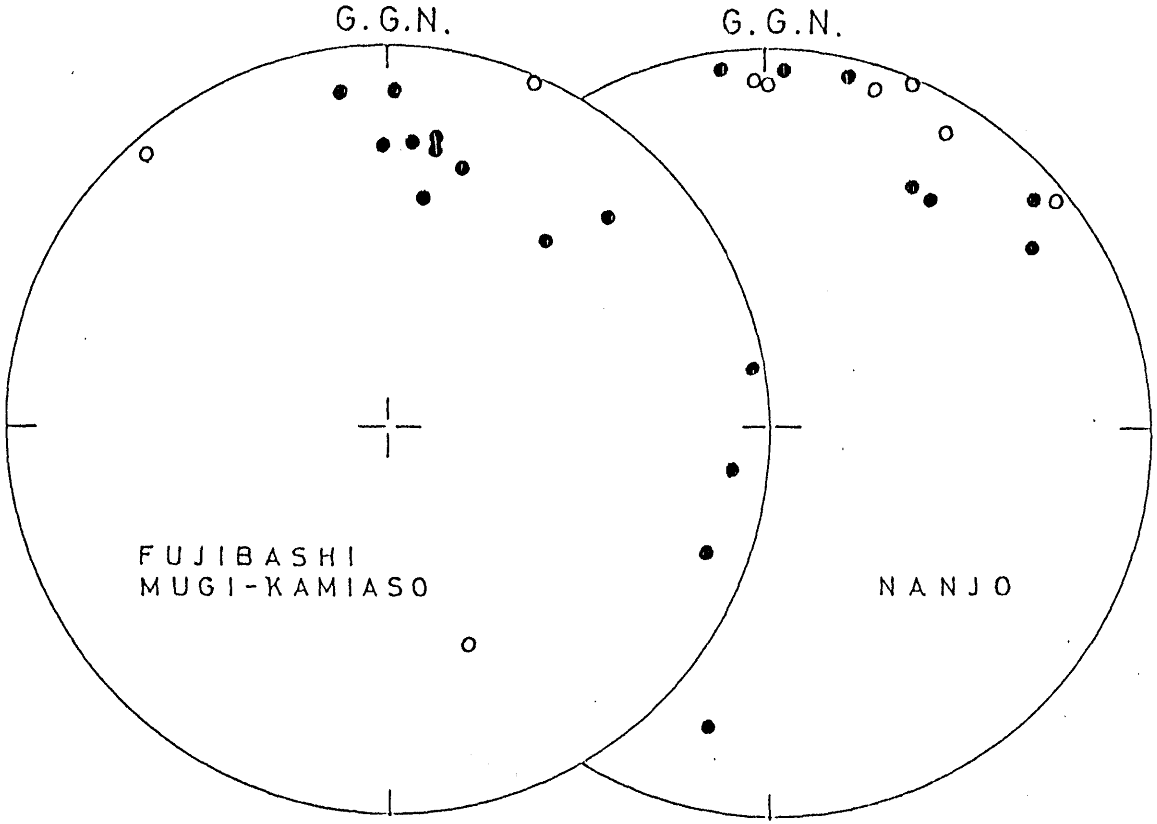

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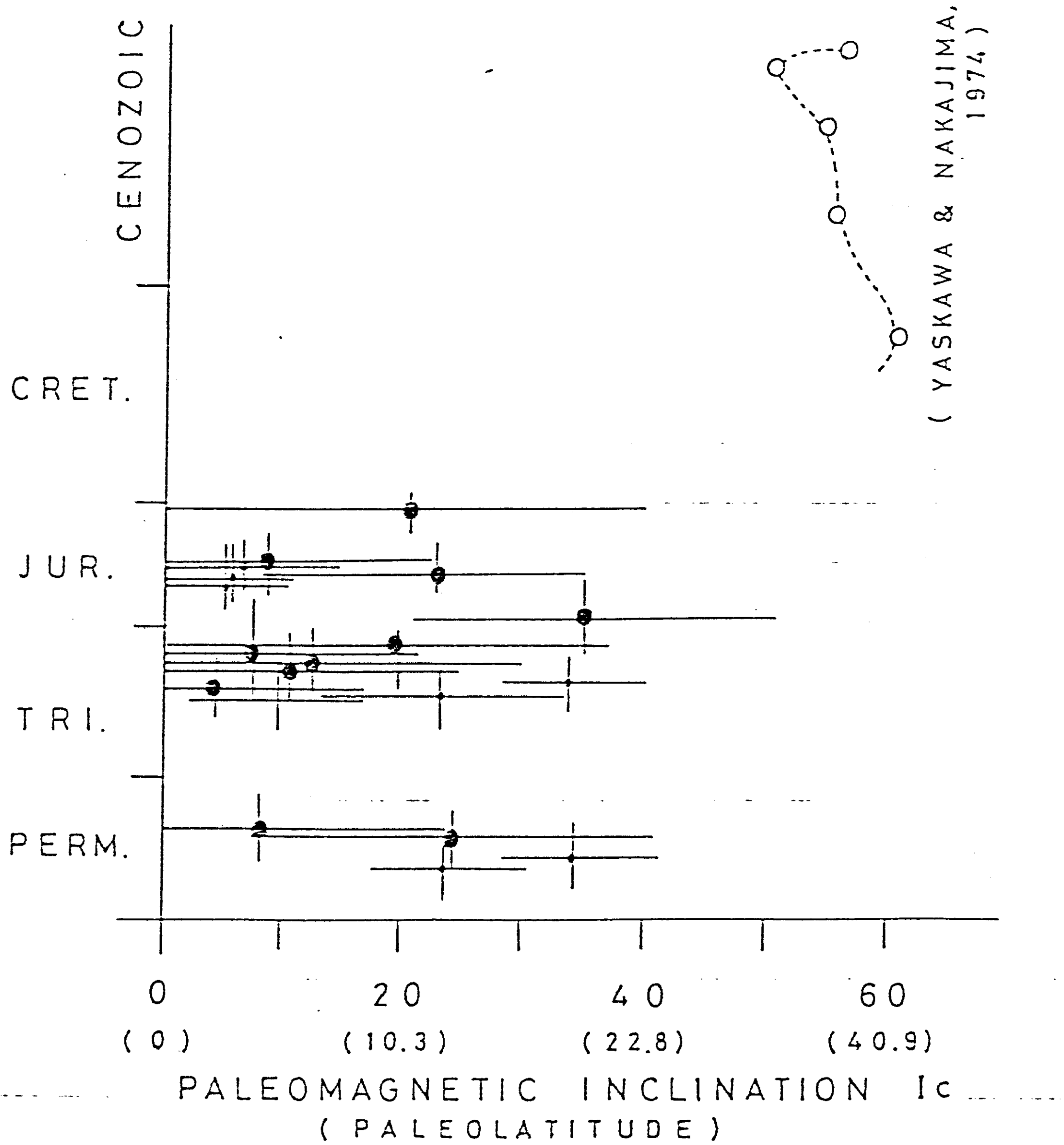

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Fig. 17

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Table 1

SITE	N	α_{95}	k	J	D	I	Dc	Dc-A	Ic	remarks
1	11	15.0	10.2	1.6	39.0	73.0	-26.3	17.0	7.3	Tr, rsh, nrm
3	5	17.3	16.0	0.9	-157.6	-7.2	-156.7	-169.4	24.3	Pm, rc, 200 Oe
4	7	11.4	24.8	1.5	32.1	54.6	19.8	16.7	7.7	Pm, rc, nrm
5	8	18.3	10.1	0.9	-5.5	6.2	-3.2	67.1	-12.5	L. Tr, rc, 200 Oe
6	8	15.2	14.2	0.4	49.8	52.4	39.6	15.9	10.9	L. Tr, rc, nrm
7	9	18.4	16.8	1.3	-22.8	26.0	-20.0	-43.9	-19.9	L. Tr, rc, nrm
10	10	15.1	11.2	0.3			-53.5	-6.5	-36.3	E. Jr, ssh, 300 Oe
11	8	15.6	13.6	0.1	24.3	55.2	-48.4	35.9	22.9	M. Jr, ssh, 300 Oe
13	9	17.2	10.0	0.4	15.2	86.0	166.9	178.2	8.6	M. Jr, rsh, 100 Oe
16	7	13.3	21.4	0.6	72.9	63.7	-26.0	22.3	4.0	L. Tr, rc, 150 Oe
18	7	20.7	9.5	0.4	143.4	57.7	173.3	160.6	20.4	L. Jr, ssh, nrm

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Figure 1: Terrane association in central Japan.

Figure 2: Compositions and twin laws of some plagioclases in the greenstones of the Mino terrane plotted on the migration diagram by Burri et al.(1967). Solid line; low temperature form, broken line; high temperature form. Figures imply anorthite content of plagioclases.

Figure 3: Diagram illustrating modal ratios among quartz, plagioclase, and K-feldspar in the sandstones of the Mino terrane. General change in mineral composition with time is expressed by the solid arrow. Open circles; the modal ratios reported by Hattori(1975, 1976) and Hattori and Yoshimura(1979). The dotted area; the ratios of the late Jurassic sandstones in the central Mino terrane reported by Mizutani(1957).

Figure 4: Distribution of twin laws of clastic plagioclases plotted on the diagram proposed by Suwa(1956). Solid circles are obtained from sandstones of different areas. 1; southern Mino(Eigenji) area(36 plagioclases), 2; western Mino(Fujibashi) area(51 plagioclases), 3; two subareas in northern Mino(Nanjo) area(a, 136 plagioclases, b, 54 plagioclases).

3-b is derived from the lithic sandstones associated with the Jurassic greenstones. The dotted area; distribution of twin laws of clastic plagioclases in late Jurassic sandstones of the central Mino terrane(Mizutani, 1959). A; albite, pericline, and acline laws, B; albite-Ala B, Manebach, and Baveno laws, C; albite-Carlsbad, Carlsbad, and Ala laws.

Figure 5: Generalized geologic map of central Japan. Strong contrast between the Hida and Mino terranes is clearly noticed. It is obvious that both terranes were completely amalgamated by the late Cretaceous time.

Figure 6: Summary of the pre-Cenozoic evolution of the Hida, Circum-Hida, and Mino terranes. The differentiation of the Ryoke belt from the Mino terrane occurred in the late Cretaceous time. Blank boxes show tectonic and sedimentary hiatus. Dotted lines show periods of basic volcanism. Of sedimentary rocks, only characteristic ones are expressed.

Figure 7: Sampling stations from which the sedimentary rocks for paleomagnetic measurements were collected. Thin lines illustrate the overall structural trends of the strata in the Mino terrane.

Figure 8: Stepwise af-demagnetization of red siliceous shale from Site 12. As no characteristic direction was detected through the demagnetization, this site-set was eliminated from the further measurement. Solid and open circles show positive and negative inclinations, respectively. Equal-area projection. These symbols are used in the following figures.

Figure 9: Thermal and af-demagnetization of the pilot samples from Site 2. OM 76 is stable in the af-demagnetization but OM 80A is thermally unstable. This site-set was eliminated.

Figure 10: Thermal and af-demagnetization of the pilot samples from Site 15. KM 16 is thermally stable relatively, but no characteristic direction was defined in the af-demagnetization. This site-set was eliminated.

Figure 11: Thermal and af-demagnetization of the pilot samples from Site 1. This result shows that the magnetic remanence is strongly stable and the direction of nrm is reliable.

Figure 12: Thermal demagnetization of the pilot samples of red cherts, N7-1 from Site 4 and OM 108 from Site 3. At 500°C, the magnetization intensity of OM 108 reduced to 8.1×10^{-9}emu/gr. The migration of the direction beyond 500°C results from this low intensity. Refraction points on the curves are observed at 500°C.

Figure 13: Thermal and af-demagnetization of gray siliceous shales of Site 11. The shales are thermally stable. From the af-demagnetization, the ODF was defined to be 300 Oe and 400 Oe. CDF of 300 Oe gave α_{95} for this site set samller than that of 400 Oe. did. Note that the blocking temperature is considerably lower than that of red cherts and red siliceous shales.

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Figure 14: In-situ site mean directions of characteristic magnetization. α_{95}'s are shown by broken ovals. Open circles; negative inclination, solid circles; positive inclination. Equal area projection.

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Figure 15: Paleomagnetic directions derived from the Permian to Juraasic sedimentary rocks of the Mino terrane. A; after simple dip correction(Dc, Ic), B; after dip and strike corrections(Dc-A, Ic). The magnetization directions in B are more systematic than those in A and in Fig. 14, and general concentration in the direction of NNE is found in B. Symbols are same as Fig. 14.

Figure 16: Paleomagnetic directions of the Permian greenstone of the Fujibashi and the Mugi-Kamiaso areas and the Jurassic greenstones of the Nanjo area. The directions are derived by restoring our early data(Hattori and Hirooka, 1977, 1979) according to the operation described in this paper.

Figure 17: Illustration showing change in the absolute paleomagnetic inclinations with time obtained from the Permian to Jurassic sedimentary rocks. The horizontal and vertical error bars correspond with α_{95} and probable errors in assigning ages of rocks, respectively. The small dots are cited from the reports by Shibuya and Sasajima(1980) and Katsura et al.(1980). Data of the late Cretaceous and Cenozoic inclination are cited from the summary by Yaskawa and Nakajima(1974).

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Table 1: Paleomagnetic results from the Mino terrane. N; number of samples measured, α_{95} and k; Fisher's parameters, J; mean intensity($\times 10^{-5}$emu/gr.) of the characteristic magnetization, D and I; in-situ paleomagnetic direction, Dc and Ic; paleomagnetic direction after simple dip correction, Dc-A; paleomagnetic declination after strike correction.
Pm, Tr, and Jr; Permian, Triassic, and Jurassic.
rsh, rc, and ssh; red siliceous shale, red chert, and green to gray siliceous shale. Figures in remarks show the optimum demagnetization fields. In this table, for Site 10, D and I are not expressed because bedding orientation is not uniform within the sampling station.

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