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Heavy Mineral Associations Found in Sediments of the East China Sea and Adjacent Ryukyu and Taiwan Areas

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ABSTRACT

This paper dwells upon the composition of heavy residues found in the upper sediments of the active continental margin at the junction of the Euro-Asian and Philippine plates. It singles out and describes mineral provinces of this region. Values for discriminant functions of main mineral associations are presented. Using correlation and factor analyses, the authors distinguished mineral associations of provinces and described probable causes for their formation. The comparison has been carried out for the composition and structural parameters (granulometric fraction content, median diameter, sorting, kurtosis, skewness) of the provincial associations of the East China Sea shelf and slope. It has been found that the formation of the mineral associations in sediments of the transitional zone is mainly affected by the rock composition of source land and volcanism.

(Key words: Heavy mineral, East China Sea, Ryukyu, Taiwan, Sediment)

1. INTRODUCTION

Knowledge of a peculiar mineral composition of Quaternary deposits and its formation in different sedimentary basins is rather important for a better understanding of the evolution of sedimentation processes and reconstruction of tectonic situations (Markevich, 1985, Dickinson and Valloni, 1980; Nechaev, 1991; Nechaev and Isphording, 1993; Thornburg and Kulm, 1987; Valloni and Maynard, 1981). In this respect, the greatest morphostructures in the world such as continents and oceans appear to be rather interesting objects.

This paper dwells upon the mineral composition of the Holocene-late Pleistocene sediments found in the transitional zone with an active tectonic regime (active continental margin) including the shelf and slope of the East China Sea, Okinawa Trough, Ryukyu (Nansey) Island Arc, Ryukyu Trench and the north-western Philippine Sea with the adjacent rises (Figure 1). Geotectonically this area has settled down within the junction of the Euro-Asian and Philippine plates, where zones of subduction, collision, and active volcanic arcs are observed

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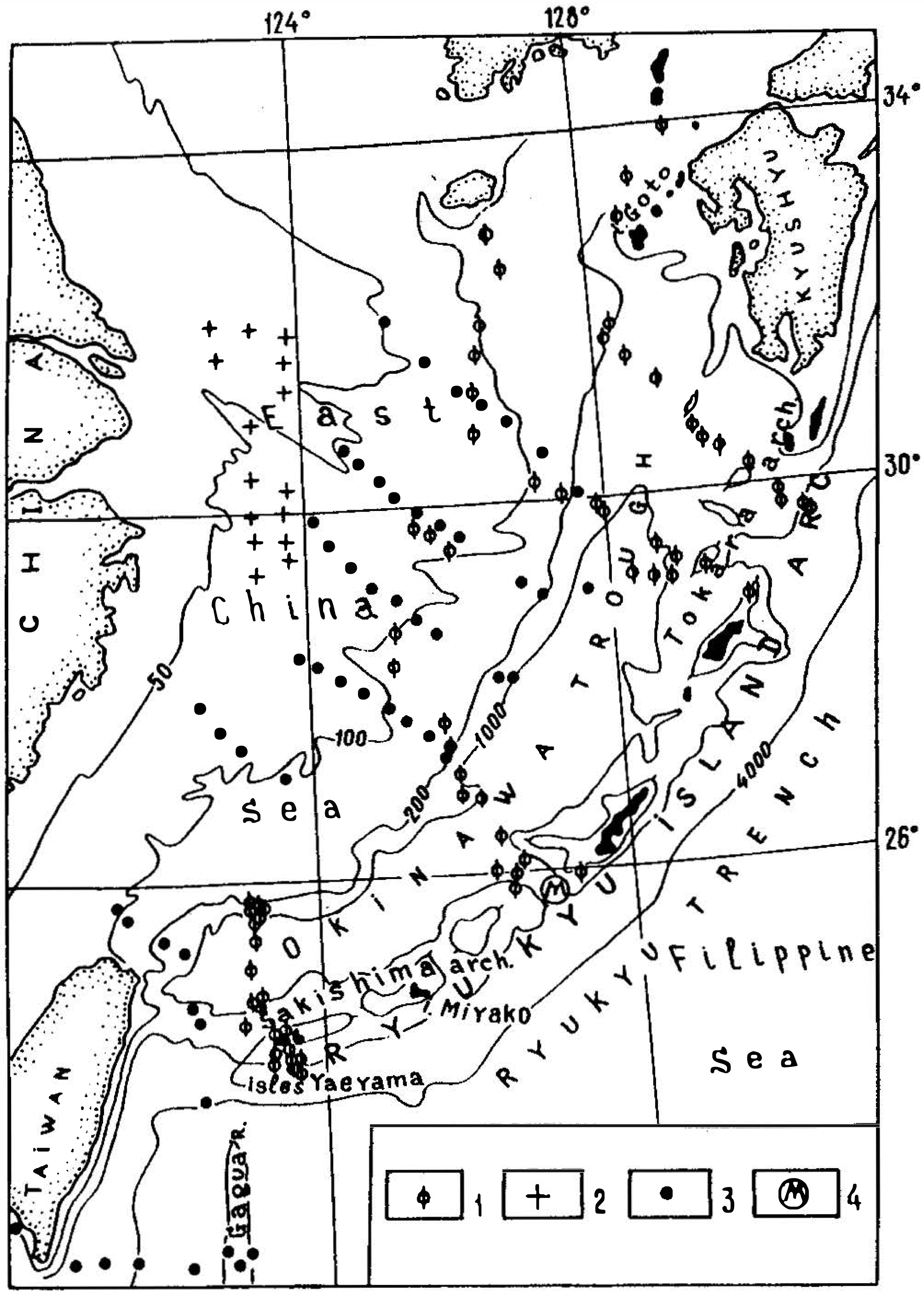

Fig. 1. Scheme of mineralogical investigation of sediments. Stations: 1. the 14th and 17th cruises of the *R/V "Pervenets"* (1971- 1973) (Vasilyev and Derkachev, 1977; Markov *et al.*, 1979); 2. the 12th cruise of the *R/V "Akademik M. Lavrentyev"* (1988); 3. the 23rd cruise of the *R/V "Akademik A. Vinogradov"*, 4. the Miyako depression.

(Seno and Maruyama, 1984; Teng, 1990; Huang *et al.*, 1992). A number of publications are devoted to the investigation of sediment mineralogy in this region. Some of them consider the mineral composition of sediments as a constituent of complex characteristics of the deposits (Markov *et al*, 1979; Oshima *et al.*, 1982; Chen *et al.*, 1992; Boggs *et al.*, 1979; Chen and Chen, 1971); others comprehensively investigate most aspects participating in the formation of the mineral composition of sediments including the distribution of minerals and their connection with both supplying provinces and the factors of peculiar sedimentation environment (Chen *et al.*, 1986; Lee *et al.*, 1988; Shen *et al.*, 1984; Suzuki, 1975; Wang and Liang, 1982; Zhu and Wang, 1988), and separation of mineral associations (Zabelin and Vasilyev, 1975; Chen *et al.*, 1986; Lee *et al.*, 1988; Shen *et al.*, 1984; Boggs *et al.*, 1979). However, most publications investigate the composition of sediments found in individual ɜas of a transitional zone and do not consider the continent-ocean transitional zone as a ıitary object. Description of the mentioned mineral provinces and the analysis of heavy ineral paragenetic associations are given in one of the latest publications of the authors ıerkachev and Nikolayeva, 1992).

MATERIALS AND METHODS

The vast material used in this paper was collected onboard the 14 and 17 th Cruises of the /V *"Pervenets"* (1971, 1973) and the 12th Cruise of the *R/V "Akademik Lavrentyev"* 988) (Figure 1). The grab samples collected in 1992 on the 23d Cruise of the *R/V 4kademik Vinogradov"* organized within the ROC-Russia KEEP-MASS Project added ınsiderable information on the peculiar formation of mineral composition of sediments in e region under discussion. Mineralogically, the samples were analyzed by the immersion ethod: heavy residue of coarse aleuritic size (0.1-0.5 mm in size and specific weight > 89 g/cm^3) was investigated. Not less than 300 grains were determined in each sample. general, 149 samples were analyzed (Table 1). To obtain comparable data the results ' mineralogical analysis were recalculated excluding difficult for determination (changed) ains and rock fragments, authigenic and opaque minerals (ilmenite, hematite, leucoxene, ʼrite, iron and manganese oxides, collophane, glauconite). The sum of nonopaque clastic inerals was used as 100%, and the content of each individual mineral was recalculated :cordingly. The obtained data were used in the schemes of mineral distribution and in atistic calculations and generalizations. Having analyzed the schemes of contrast coefficient ⁅c) distribution, the authors distinguished the areas showing the accumulation or deficit of ıme individual minerals.

To determine formation regularities for mineral associations, together with traditional ımparisons of mineral distribution, the analysis of mineral paragenesis was also used as e main systematic approach to the problem (Derkachev, 1992; Derkachev and Nikolayeva, ›92). Such multivariant statistical methods as correlation and R-mode factor analyses were :tively applied (in modification of Davis, 1977) as well. Mineral paragenesis is understood significant positive correlations of several minerals composing the association as distinıished through the R-mode factor analysis. When interpreting linear paragenesis, the authors ɛed the known dependencies: heredity of mineral composition of sediments upon source land :trography (source land rock composition), processes of clastic mineral mobilization and ɜw association formation as the result of hydrodynamic mineral differentiation upon density, ability and migrating ability (Baturin, 1947, Kukharenko, 1961; Berger, 1986; Shumilov, ›81). Mineral provinces were distinguished with the help of cluster and Q-mode factor analɛes. To understand the interaction of mineral composition of sediments with their structural ırameters (granulometric fraction content, sorting, median diameter, kurtosis, skewness), ırrelation and regression analyses were used.

RESULTS AND DISCUSSION

Cluster and Q-mode factor analyses of the sediments collected in the areas under study :lped to distinguish heavy mineral associations and to find out the main features of their gional changeability. Heavy mineral associations with similar composition united into ovinces and subprovinces (Table 2). Among these, well pronounced are two terrigenous

(East-China and Taiwan), two volcanoclastic (West-Philippine and Ryukyu Island-Arc) and one mixed volcano-terrigenous (Okinawa Trough) provinces (Figure 2). Taiwan Province (A) occupies the areas adjacent to Taiwan Island. It is characterized by a specific mineral assemblage with a great prevalence of mica (14.18% on average), chlorite and chlorite-mica aggregates (56.92% on average). Grains with numerous small inclusions of rutile are often observed in the sediments found there. The metamorphic rocks (mainly schists) of Taiwan Island which connect with the collision zone of the Philippine and Euro-Asian plates are the main source of the mineral group characteristics of this province (Biq *et al.*, 1985; Teng, 1990; Huang *et al.*, 1992). The underwater Gagua Ridge serves as a barrier preventing any eastward distribution of the discussed mineral associations. Mineral assemblage of the province includes a constant admixture of volcanoclastic components with a notable portion of hornblende (including brown and basaltic), biotite and clinopyroxene among them. A great part of the grains found in this area is covered by volcanic glass. The most probable source of this mineral assemblage is the explosive activity of the volcanoes of the Luzon Strait (Babuyan volcanic group) (Lelikov and Ostapenko, 1978). The same volcanoclastic association (IIA_3) but in a clear form is found in the sediments east off the Gagua Ridge and, as investigations this study revealed, occupies a great part of the West-Philippine Basin (Province D). Mica (17.48%) and the hornblende group (49.59%) prevail in its composition. The characteristic feature of the association under discussion is a relatively great content of basaltic hornblende (8.89%) and biotite (1.16%).

The Island-Arc Province (B) is represented by a typical volcanoclastic association. It occupies the north-eastern Okinawa Trough, northern Ryukyu Island Arc (up to the Sakishima Archipelago) and the adjacent Philippine Basin including the Ryukyu Trench (Figure 2). The mineral composition of the volcanoclastic association characteristic of province B differs greatly from the one typical of province D, particularly in the hornblende and pyroxene content (Table 2). Here the prevailing component is clino- and orthopyroxene making up 73.29% and 60.70% (on average it is 33.01% and 43.57%) respectively, while the hornblende content is small. Moreover, in the southern province their concentration increases sharply (subprovince B_3, association IVA) because of the diluting influence of another volcanoclastic source.

In terms of the morphological and optical characteristics, the hornblende of this province is identical to the one found in the mineral association of the western Philippine Province (D). The pyroclastic nature of most minerals is proven by their paragenesis with the acid volcanic glass and morphology of grains: fresh angular-clastic fragments and crystals often have a volcanic glass cover. The mineral composition of sediments of the province depends mainly upon the influence of the volcanoes of Kyushu Island and the inner zone of the Ryukyu Island Arc (the Tokara and Osumi Archipelagoes). In the composition of the pyroclastic material contributed by the volcanoes of the region, the ilmenite-bipyroxene association with hypersthene prevailing over augite predominates (Furuta *et al.*, 1986; Miyashi and Miyashi, 1988). Much of the acid pyroclastics was supplied to this area in the late Pleistocene when the formation of large calderas (Aira, Aso, Ata, and so on) took place (Furuta *et al.*, 1986; Machida and Arai, 1976, 1978).

The influence of the Ryukyu Island Arc basement on the mineral composition of sediments is not significant in this province. The sediments of the Okinawa area and Miyako depression show a relative enrichment in epidote, chlorite, actinolite, and, to a less extent, the stable mineral group (zircon, garnet, anatase). The Miyako depression divides into the southern (the Sakishima Archipelago) and northern groups of the Ryukyu Islands (subprovince B_2 with associations IB and IVC) (Table 2). The probable source of this mineral group is

Table 2. Mean content of sediment heavy mineral associations for the East China Sea (%).

MINE-	Mineral associations																
RALS	IA	IB	IIA_1	IIA_2	IIA_3	IIA_4	IIB	$IIIA_1$ 1	$IIIA_1$ 2	$IIIA_2$ 1	$IIIA_2$ 2	$IIIA_2$ 3	IIIB	IVA	IVB	IVC	V
Ol	-	-	**0.71**	-	**0.10**	-	0.05	-	-	-	-	-	-	**0.13**	-	-	-
Cpx	5.48	**15.45**	**48.73**	**18.33**	10.07	**14.84**	6.82	5.43	5.24	5.71	5.79	3.70	**11.42**	**29.90**	**33.10**	**34.35**	6.17
Opx	0.30	**16.88**	3.08	**21.47**	4.08	6.42	6.17	2.75	1.99	3.44	1.71	1.33	**9.48**	**33.48**	**47.49**	**29.72**	6.62
Hb	11.60	9.69	**39.40**	24.79	**49.59**	**34.72**	17.93	**33.38**	**27.19**	**30.49**	**25.94**	**25.66**	12.50	19.33	6.63	8.43	8.12
bgHb	7.50	3.70	**25.68**	11.08	**39.96**	15.96	14.90	**27.65**	**19.92**	**27.01**	**23.29**	**24.55**	4.58	15.61	4.32	5.65	6.55
bHb	**1.54**	-	**4.75**	0.18	0.60	-	0.21	0.17	0.26	0.20	0.30	0.14	0.13	0.27	0.03	-	0.29
gHb	-	**5.99**	2.20	**11.17**	0.15	**18.49**	2.29	**5.53**	**6.90**	3.18	2.20	0.97	**7.56**	1.98	1.41	2.53	0.87
OHb	**2.60**	-	**6.77**	**2.36**	**8.89**	0.27	0.54	0.03	0.11	0.10	0.16	-	0.24	**1.47**	0.87	0.25	0.40
Ep	8.62	17.74	3.17	13.08	6.39	**18.44**	10.97	**25.69**	**32.80**	**19.39**	**20.24**	16.64	**40.22**	5.15	5.12	10.56	5.14
Gar	0.53	0.69	0.06	**4.71**	1.06	**7.48**	1.70	**5.53**	**5.41**	**4.17**	3.04	2.47	**5.44**	0.59	1.09	**4.59**	**12.17**
Zi	0.63	0.11	0.27	1.70	0.12	**6.74**	0.72	2.21	**3.18**	2.05	1.28	1.25	**3.06**	0.34	0.27	**3.10**	**26.82**
Ap	-	1.12	0.21	2.00	1.38	**2.41**	1.13	**2.47**	**2.80**	**2.82**	1.94	1.68	1.77	1.26	1.16	1.07	**7.18**
Sph	-	1.27	0.21	2.34	0.89	1.17	0.72	**3.25**	**3.34**	**3.34**	**2.87**	**2.72**	**3.24**	0.46	0.27	0.96	**7.61**
Tou	0.21	0.28	0.32	**1.05**	**1.48**	0.51	0.66	0.90	**1.13**	**1.09**	**1.02**	0.94	0.31	0.14	0.12	0.54	**4.43**
An	0.32	0.30	0.06	**1.39**	0.52	**1.17**	0.42	0.47	0.56	0.46	0.38	0.19	**1.19**	**0.80**	0.13	**1.05**	**6.64**
Chl	**56.92**	**19.86**	0.30	0.93	2.47	1.30	2.91	**6.63**	4.80	4.21	4.77	4.34	3.54	1.11	1.85	0.64	0.30
Me	0.11	0.21	-	0.09	0.18	0.31	0.31	**0.55**	**0.48**	**0.62**	**0.64**	**0.59**	**0.40**	0.13	-	-	0.09
Act	0.53	**10.78**	1.12	4.05	3.42	1.91	3.35	**6.26**	6.13	**8.00**	**8.35**	**7.19**	3.15	2.00	1.17	0.95	1.25
Mi	**14.18**	2.86	2.19	3.94	**17.48**	2.03	**44.04**	3.65	4.01	**12.59**	**19.50**	**28.27**	4.06	4.70	1.57	3.62	7.19
cMi	**10.48**	0.99	0.42	0.33	**2.40**	0.43	**6.92**	0.41	0.56	1.40	1.40	**2.64**	-	0.52	0.39	0.83	0.81
gMi	2.54	1.77	0.76	3.29	**12.79**	1.54	**35.51**	3.02	3.24	**11.03**	**17.92**	**25.21**	1.00	4.12	0.85	2.49	5.99
bMi	**1.16**	0.10	**1.01**	0.32	**2.28**	0.06	**1.60**	0.22	0.21	0.16	0.18	0.42	**3.06**	0.06	0.33	0.29	0.40
Ca	0.52	**2.75**	0.12	0.13	0.67	0.47	**1.96**	0.78	0.90	**1.57**	**2.43**	**3.03**	0.22	0.39	0.03	0.23	0.11
NaHb	-	-	**0.06**	-	**0.10**	**0.09**	**0.13**	**0.07**	0.03	0.03	**0.10**	-	-	**0.07**	-	**0.13**	**0.17**
Number of analyses	3	3	4	5	6	4	7	15	21	26	12	11	5	5	11	3	5

Notes for this table are given in table 1.

Cretaceous-Eocene rocks of the Shimanto Supergroup metamorphosed into green schist facies (Hashimoto, 1978; Kizaki, 1986; Letouzey and Kimura, 1986).

The East China Province (E) occupies the vast areas of the continental shelf and slope of the East China Sea. In general, the composition of mineral associations characteristic of this province is uniform with prevailing mica (up to 60.2%, and 11.45% on average), epidote (up to 60.2%, and 24.25% on average) and hornblende (up to 39.5%, and 27.8% on average). High concentrations have been registered for actinolite (up to 18.6% and 6.9% on average) and the stable mineral group (14.2% on average). However, on the basis of the content of the main minerals, this province could be divided into 5 subprovinces. The differences in their mineral composition are not important (Figure 3, Table 2). The subprovince E_1

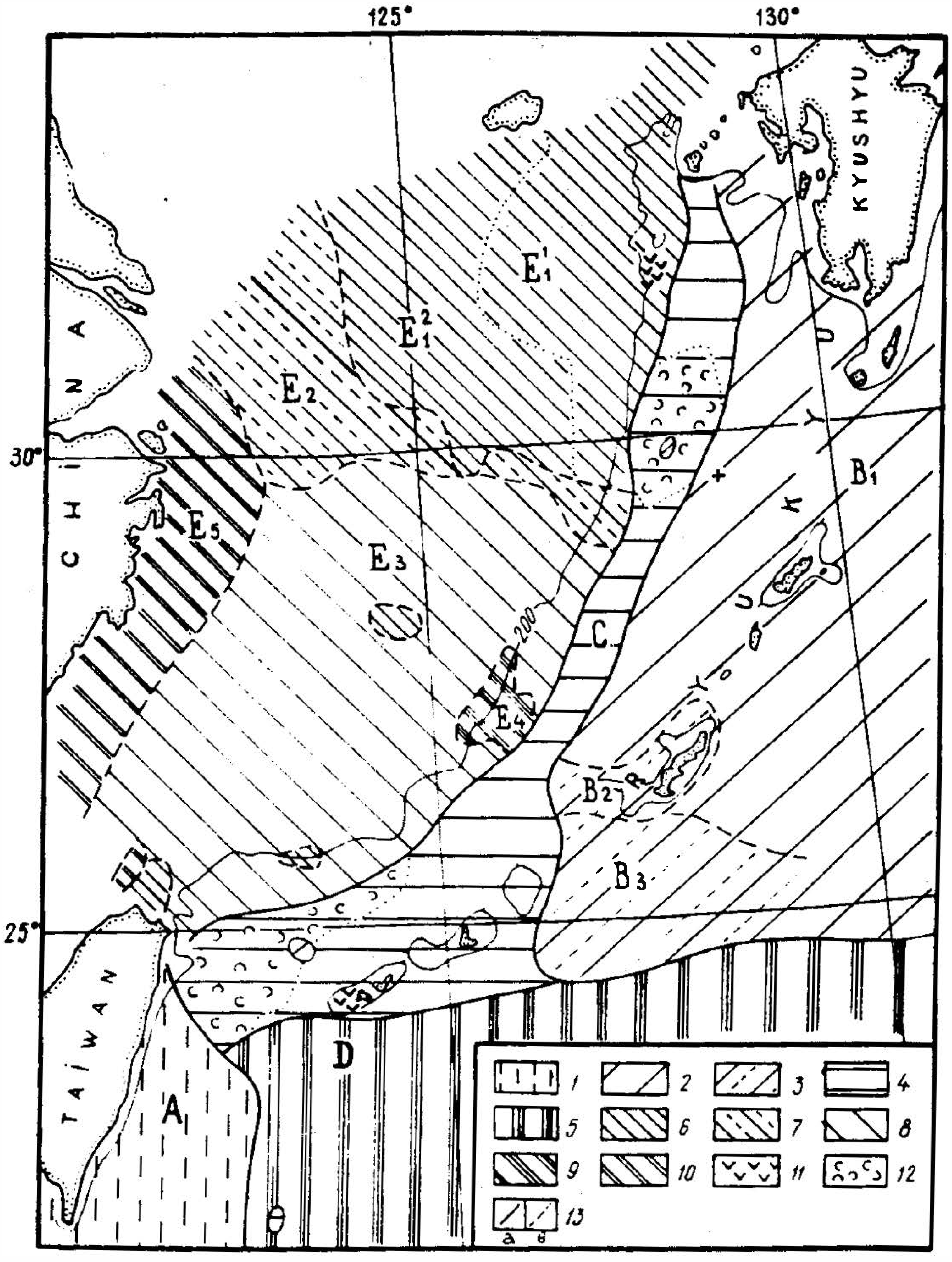

Fig. 2. Scheme of mineralogical provinces. Provinces: 1. Taiwan (A), association IA (hornblende-mica-chlorite); 2-3. Island-Arc (B), subprovinces - B_1: association IVB (clino,- ortopyroxene), B_2: associations IB and IVC (actinolite-clino,- orthopyroxene-epidote-chlorite), B3: association IVA (hornblende-clino,-orthopyroxene); 4. the Okinawa Trough (transitional) (C), associations: IIA_1 (hornblende-clinopyroxene), IIA_2 (epidote-clino,-ortopyroxene-hornblende), IIA_4 (clinopyroxene-epidote-hornblende), IIB (epidote-hornblende-mica); 5. West-Philippines (D), association IIA_3 (clinopyroxene-mica-hornblende); 6-10. East China (E): 6-subprovinces E_1^1-E_1^2, associations $IIIA_1^1$-$IIIA_1^2$ (epidote-hornblende), 7-subprovince E_2, association $IIIA_2^1$ (mica-epidote-hornblende), 8-subprovince E_3, associations $IIIA_2^2$-$IIIA_2^3$ (epidote-mica-hornblende), 9-subprovince E_4, association IIIB (pyroxene-hornblende-epidote), 10-subprovince E_5 (hornblende-mica); 11. 12-distribution areas of: 11-stable association (V), 12. mica ones; 13. boundaries for: a-provinces, b-subprovinces, c-associations.

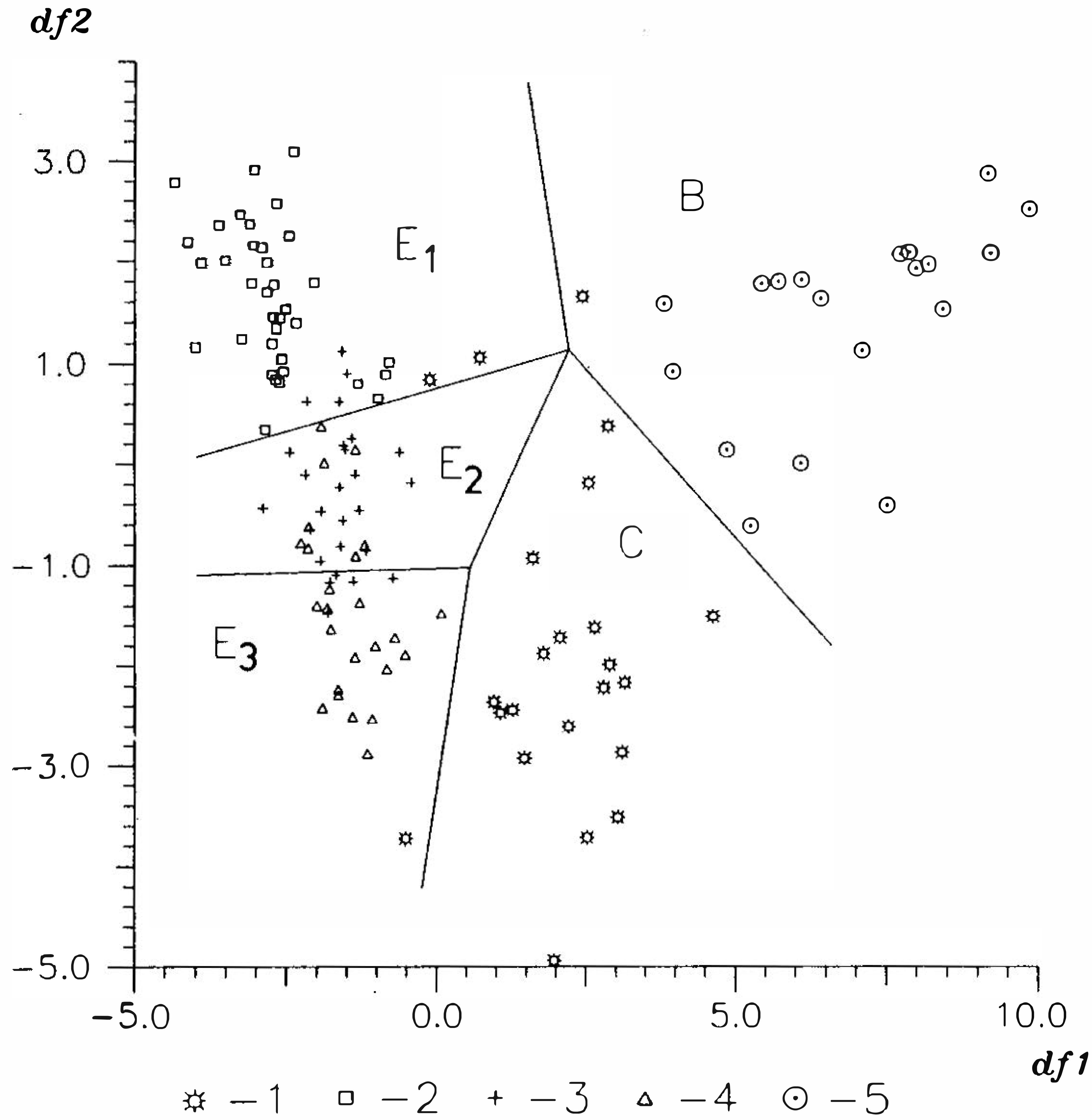

Fig. 3. Plot of the first and second discriminant functions for mineral associations of the East China Sea. Heavy mineral associations for provinces: 1. Island-Arc (B), 2. Okinawa Trough (C), 3-5 East China (E): 3. subprovince E_1, 4 subprovince E_2, 5 subprovince E_3. Field boundaries separating the groups were determined as the perpendicular to the midpoint of a line connecting any two groups (Stokes and Lowe, 1988).

(associations $IIIA_1^1$-$IIIA_1^2$) is characterized by the increased epidote and stable mineral group and decreased mica contents when compared with the other shelf zones of the East China Sea. Probably this is due to the influence of Korea. The absolute maximum of stable mineral group is registered on the shelfbreak (station 777). Shelf sediments found in the areas south off 30°N (subprovinces E_2, E_3, E_5), in the coastal areas and in the Changjiang River mouth show the increased content of more hydraulic active minerals of the tabular type (mica, actinolite, chlorite). The most remarkable increase in their content occurs in the zone where fine suspended material transported by the Changjiang River has accumulated. Its position is easily identified by the distribution of fine muddy sediments in the coastal zone of mainland China south off the Changjiang River mouth (Zhu and Wang, 1988; Li *et al.*, 1985). Besides mica, the increased content of carbonate fragments (associations $IIIA_2^1$, $IIIA_2^2$, $IIIA_2^3$) which is characteristic of the loess deposits of China is observed here (Sun, 1987).

Some stations, namely 904, 905, 909, located on the shelf break and continental slope differ from the above description of mineral associations of sediments. Instead, they are characterized by an increased content of epidote and pyroxene (by 1.5-3.0 times) and a decreased mica content (subprovince E_4, association IIIB). Single stations with similar compositions were found around the Goto Islands (station 769) and in the Okinawa Trough (station 897).

The similarity in the mineral composition of sediments found in the East China province is natural as it is composed mainly of the clastic material contributed by the same two major sources: the Changjiang and Huanghe Rivers, characterized by similar minerals in relatively the same quantities (Wang *et al.*, 1984; Wang and Liang, 1982). The main factor responsible for the different content of minerals in sediments observed in the various shelf zones is the sorting effect of the hydrodynamic characteristics of the environment where these sediments were formed.

The Okinawa Trough Province (transitional) (C) occupies the foot of the continental slope including the bottom of the Okinawa Trough together with the adjacent southern areas of the Ryukyu Island Arc (Sakishima Archipelago). The mineral complex of this province is represented, on one hand, by hornblende, mica, and epidote typical of supplying continental provinces, and, on the other hand, by the pyroxene group being the characteristic products of island-arc volcanism (Table 2). Mineral associations (IIA_1, IIA_2, IIA_4, IIB) found here are mixed volcano-terrigenous with variable contents of composing minerals (Table 2). The hornblende-pyroxene association (IIA_1) discovered around the Gagua Ridge (stations T9, T10) and, sporadically, the southern Sakishima Archipelago contains increased contents of both brown and basaltic hornblende and biotite (a concentration coefficient -Kk>1.0).

The association IIA_2 clearly reveals the properties of the East China Sea (with the increased background of hornblende and the stable mineral group) and the Island-Arc (with a clino-, orthopyroxene association) provinces, and it is most characteristic of the Okinawa Trough. Some areas of the Okinawa Trough are characterized by an increased mica content (association IIB) (Figure 2), while the sediments taken near the Yaeyama Islands (Sakishima Archipelago) have a mixed mineral composition: along with mica associations they also include sediments enriched with stable minerals: zircon - up to 32.6%; sphene - up to 13.3%; tourmaline - up to 8.6%; anatase and rutile - up to 12.7%. This is Association V. The increased concentration of stable minerals is registered in coarse-grained carbonate sediments of the Pleistocene age (Q_2-Q_3) 400 m deep in the area near Iriomoto Island (Markov *et al.*, 1979; Derkachev and Nikolayeva, 1992). It should be noted as characteristic features that the association with high concentrations of stable minerals is accompanied by high concentrations of iron hydroxides. Clastic minerals also have a brown cover of iron hydroxides. Most grains of the stable minerals are round or semiround. The mineral association being discussed is composed of the products of the weathering crust destruction which has taken place on the adjacent islands and of the sandstones of the Yaeyama group containing many stable minerals (Kizaki, 1986). The characteristic feature of the Sakishima Archipelago is the relative enrichment of its sediments with actinolite, chlorite and epidote. Here the authors also observed alkaline hornblende (glaucophane), its quantity ranging between single signs to 1%. The main supply of this group of minerals is the Paleozoic-Mesozoic metamorphic Yaeyama rocks that also include glaucophane-bearing schists and conglomerates of the Tomura Formation (Kizaki, 1986).

Discriminant analysis results showed a rather high efficiency (88-100%) of executed separation of provincial mineral associations. A more distinct isolation of the associations for the East China, the Okinawa Trough and the Island-Arc provinces is traced by two first discriminant functions (Figure 3). From this, whether certain regional sediments belong to different mineral association may be determined with a high degree of probability. The values of the first two discriminant functions follow:

D_1= -0.92+0.064 Cpx+0.139 Opx+0.014 bgHb-0.082 Ep+0.062 Gar+0.028 Zi+0.07 Ap-0.255 Sph+0.309 An-0.234 Me-0.082 Act+0.131 cMi+0.044 gMi+0.093 bMi-0.063 Ca+2.173 NaHb-0.007 Tou;

D_2=0.413-0.031 Cpx+0.054 Opx-0.028 bgHb+0.109 Ep-0.074 Gar+0.003 Ap+0.031 Sph-0.438 An+0.267 Me-0.038 Act+0.095 cMi- 0.118 gMi-0.244 bMi-0.114 Ca+0.337 NaHb-0.0556 Tou.

The schemes of mineral distribution and the results of Q-mode factor analysis show that the sediments of the East China Sea have been formed by clastic material contributed by two major regional sources: continental (materials discharged by the Changjiang and Huanghe Rivers) supplying the derivatives of granitic-metamorphic rocks and volcanic contributing the volcanoclastic material of the Ryukyu and Luson Island arcs.

The Q-mode factor analysis revealed five factors responsible for 96.7% of the total variability of the mineral sediment composition. The contribution of the first three factors into total depression is the most prominent, making up 44.6%, 18.4%, and 23.9% respectively. The first and second factors refer to mineral associations made of granitic-metamorphic rocks in which hornblende, mica, epidote and a relatively high content of stable minerals predominate. The share of bipyroxene island-arc association in total dispersion is less than 25% (it comprises the mixed the hornblende-clinopyroxene association singled out by the fourth factor).

Having analyzed the dependence of mineral correlations upon the distance from the Ryukyu Island and the coast of China, the authors understood that the mineral composition of sediments is connected to a certain supplying province. Accordingly, the following minerals may be considered closely associated with the supplying provinces of the continental margin (listed in increasing values of correlation coefficient): brown-green hornblende, mica, actinolite, calcite, metamorphic mineral group, sphene, epidote, tourmaline. With increasing distance from the Ryukyu Island-Arc, the content of clino- , orthopyroxene, alkaline hornblende, basaltic hornblende and anatase decreases. However for brown and green hornblende, chlorite, garnet, zircon and apatite, no distinct correlation of content with distance has been revealed. Such a distribution of stable minerals is easily explained, as can be seen in Figure 4, by the increased background of these minerals in the sediments of the outer shelf of the East China Sea deposited approximately at the same distance both from the continental and island coasts.

Besides the regional differences conditioned mainly by the homogeneous geological structure of the source land, the mineral composition of sediments is also affected by other factors. Among them the most prominent are hydrodynamic processes (waves, tidal and drift currents) differentiating clastic material in density, size, and the shape of grains. Evidently, the sorting of clastic material is the responsibility of factors 3 and 5 (contributing 23.9% and 3.5% respectively). The third factor unites the mineral complex of those stations which is characterized by a great number of highly mobile grains, mica and actinolite above all (stations T21, E46, E46A) (Table 1). Figure 5 represents the areas where this mineral group is accumulated and the routes of its migration. The association with quite the opposite mineral properties is determined by factor 5 (station 777 is a standard). Its main feature is great contents of stable minerals: garnet, zircon, sphene, anatase, tourmaline and ilmenite. This association is found in relict Pleistocene sediments of the outer shelf and, locally, near Sakishima Island (Figure 4). In general, its location coincides with the zones of erosion and mixed sediments singled out by Chinese geologists (Wang and Liang, 1982; Li *et al.*, 1985; Zhu and Wang, 1988).

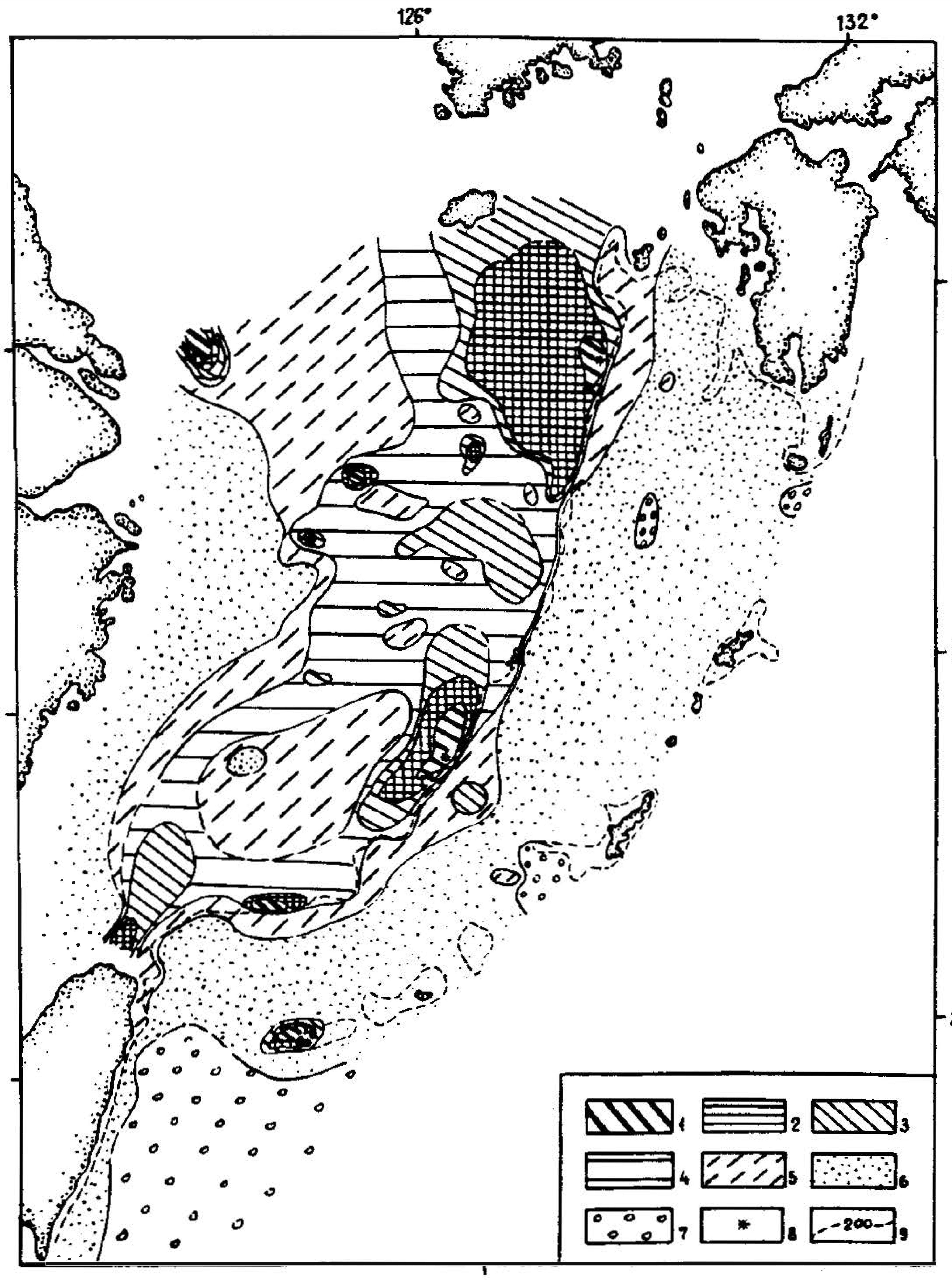

Fig. 4. Distribution of the contrast coefficient (Kc)* for the stable mineral group (zircon, garnet, sphene, anatase, ilmenite). 1. more than 2.0; 2. 1.0~2.0; 3. 0.5~1.0; 4. 0.5~0; 5. -0.5~0; 6. -1.0~-0.5; 7. less than -1.0; 8. stations with Kc maximum values; 9. 200 m isobath.
Note: Kc* = (Xi-X)/S, where Xi - the total content of the stable mineral group for each station, X - the mean content of the stable mineral group for the whole basin, S - the standard deviation.

The R-mode factor and correlation analyses of the sediments collected in the areas under study revealed the most significant paragenetic mineral associations of the region. The distinct contrast in mineral paragenesis conditioned by the destruction of rocks with different petrographic compositions (island-arc volcanoclastic and granitic-metamorphic complexes) was observed. Actually, the first three factors reflect this contrast (Figure 6A). The factor model shows that the most significant are the following mineral associations: clino-, orthopyroxene is a typical island-arc association of the Ryukyu Arc; the clinopyroxene-olivine-brown and basaltic hornblende-biotite association originated mainly as a result of the pyroclastics of the volcanoes of the Luzon Strait. In the formation of this association, besides

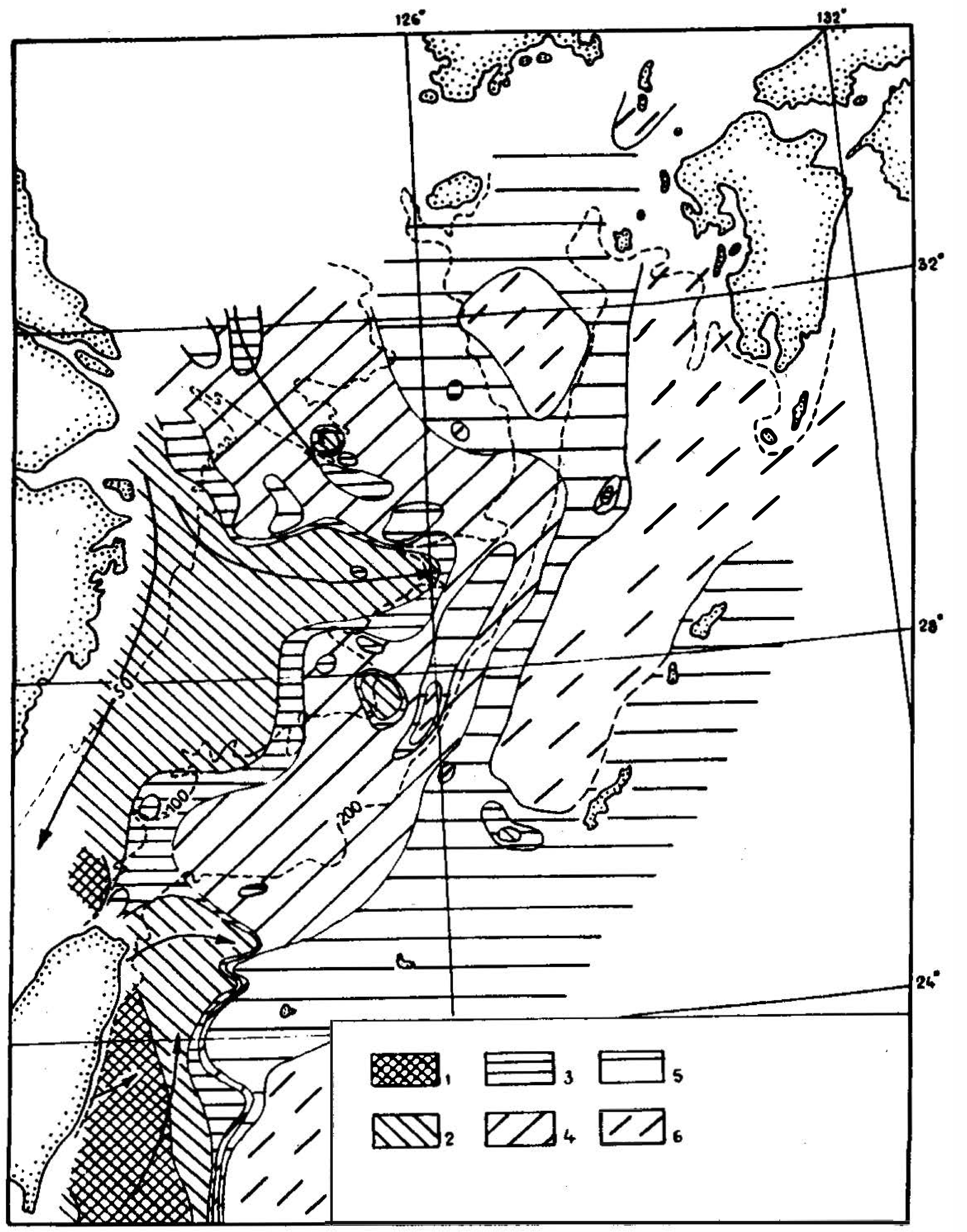

Fig. 5. Distribution of contrast coefficient (Kc) for tabular minerals (mica, chlorite, actinolite). 1. more than 2.0; 2. 1.0~2.0; 3. 0.5~1.0; 4. 0.5~0; 5. -1.0~0; 6. less than -1.0. The pointer shows the main directions of mineral migration.

volcanoclastics, the edaphogenic clastic material - a product of bottom rock destruction (olivine and partially clinopyroxene) also participates. Geographically, it is found in the areas adjacent to the Gagua Ridge.

Mineral paragenesis derivatives of granitic-metamorphic rocks include the following mineral associations: brown-green hornblende-epidote-actinolite-metamorphic mineral group (factor II); anatase-zircon-apatite-tourmaline-sphene-garnet (factor I); actinolite-epidote-green hornblende (factor III); green hornblende-garnet and calcite-mica (factor IV); chlorite (factor V). As is obvious in Figure 6 A, well distinguished are the associations of minerals different in stability and density: the group of stable minerals (zircon, sphene, tourmaline, anatase, garnet) is opposed to the ones characterized by great migrating ability (mica, hornblende, actinolite, etc.).

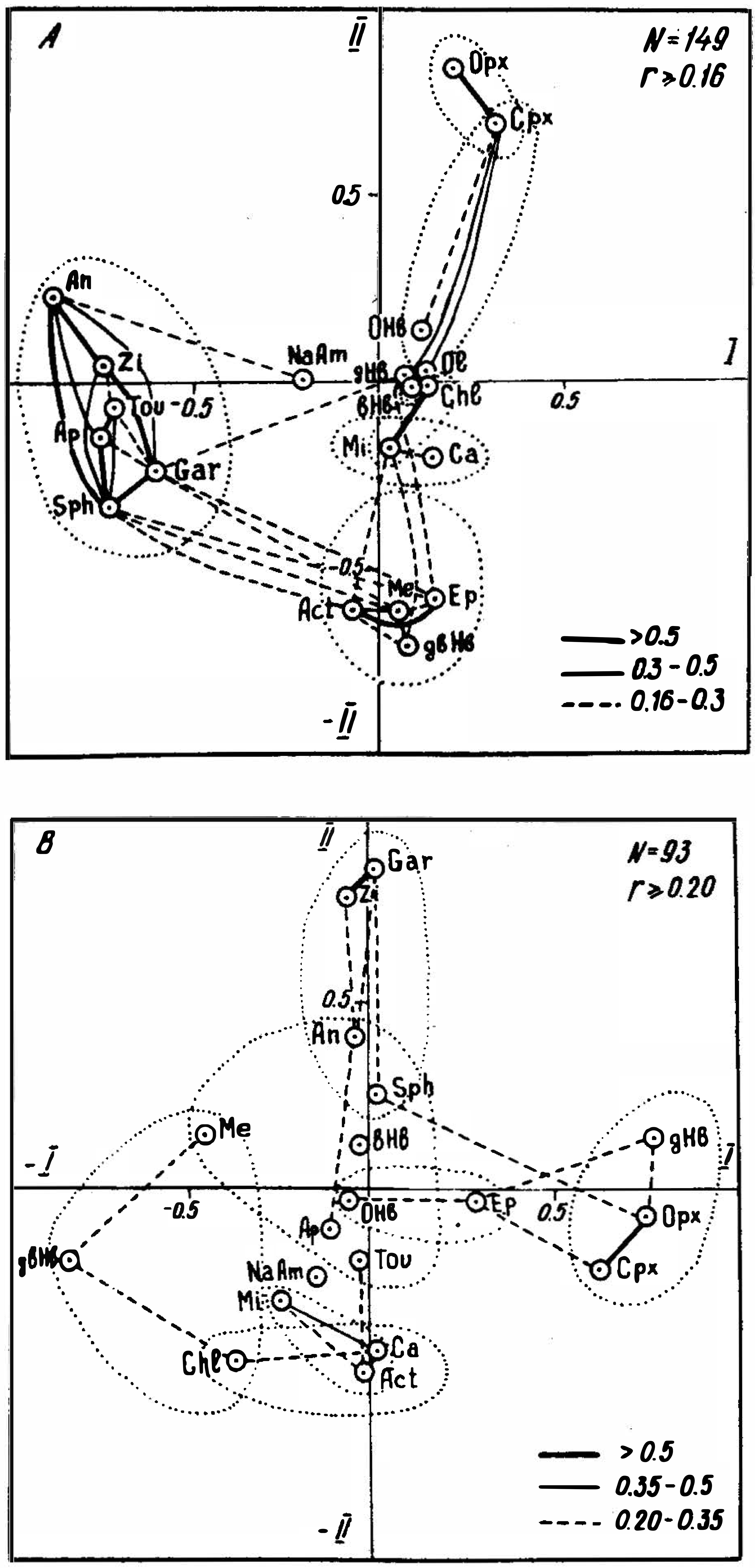

Fig. 6. Varimax rotated the R-mode factor loadings and positive correlation connections of heavy minerals in sediments of the East China Sea and areas near Ryukyu, Taiwan (A) and the East- China province (B) in the plane of leading factors. N - quantity of analyses; r - significant correlation coefficients.

Note: The fields contoured by points include mineral paragenesis, which are joined by the first leading factors. Mineral indexes are given in Table 1.

The comparative analysis of the factor models of the provincial associations showed that such division of mineral paragenesis is mainly observed in the shelf sediments of the East China Sea. Some areas of the Japan Sea and Bering Sea were used as examples to demonstrate that a similar structure of correlations in minerals is mainly conditioned by the differentiation of clastic materials over hydraulic equivalence (Derkachev, 1989). Not only mechanical sorting (the differentiation of particles over their size) but also mineralogical separation indicating the depth of clastic material transformation were observed here. However, despite the visible isolation of shelf mineral associations of the East China Sea, no deep differentiation of clastic material took place there. This is proven by the weak structure of correlations between minerals within paragenesis and by the absence of a complete break in positive correlations between minerals with different densities (Figure 6B). Additional confirmation of this is noted in the analytical results of correlations and regressions obtained for the minerals with structural sedimentary parameters. Thus, the alteration of the mineral composition only by 12-18% depends on median diameter, sorting, kurtosis, and skewness, which perfectly agrees with the data obtained by Wang and Liang (1982). No notable correlation was revealed for the content of minerals in sediments and the median diameter and sorting. Only garnet, zircon, ilmenite, and mica were found to increase their content with better sorting. Stable minerals (zircon, garnet, ilmenite, anatase) are concentrated mainly in the sediments enriched in coarse-grained fractions (more than 0.25 mm); for fine-sandy fractions, this correlation is less prominent. The behavior of coarse-aleuritic particles (0.1-0.05 mm) agrees well with the distribution of hornblende, apatite, mica, and, to a less degree, metamorphic minerals and tourmaline in sediments. The stable correlation with fine particles (fine-aleuritic-pelitic) is mainly characteristic of volcanoclastic components contributed by island arcs and distributed in the adjacent deep-sea areas of the Okinawa Trough.

4. CONCLUSIONS

(1) Most of all mineral compositions of sediments of the investigated transitional areas are affected by the rocks of source lands and volcanism. The volcanoclastic material of the studied sediments is contributed by two main sources: volcanoes of the northern Ryukyu Island Arc (ilmenite-bipyroxene association) and the Luzon Strait (clinopyroxene-hornblende association including basaltic hornblende). Specific mineral association with dominating mica and chlorite is characteristic of the collision zone around Taiwan Island.

(2) The influence of the fundamental rocks of the Ryukyu Arc is insignificant. However, in the southern part of the arc (the Okinawa, Sakishima Archipelago), characterized by actinolite-epidote-chlorite paragenesis and the association with glaucophane, it is greater.

(3) Shelf sediments of the East China Sea are mainly composed of the material contributed by the Changjiang and Huanghe Rivers and are characterized by a similar mineral composition depending slightly upon the structural properties of sediments and greatly upon matter differentiation over grain shape, density, stability to weathering and distance from the source. However, judging from the analysis of the structure of correlations in minerals, no deep transformation of clastic material took place.

(4) The results obtained confirm the conclusions made by Chinese geologists (Wang and Liang, 1982; Wang *et al.*, 1984; Zhu and Wang, 1988) who distinguished three sedimentary zones within the shelf of the East China Sea: a) the coastal (estuarine) zone

of modern sedimentation with a high content of tabular minerals (mica in particular); b) the outer shelf zone with a distinct differentiation of minerals over hydraulic equivalence; c) the erosion zone in some outer shelf sites occupying the relict sediments of underwater-coastal-slope facies with a visible increase in the content of stable minerals. The absence of linearly oriented coarse-grained sedimentary zones with great concentrations of stable minerals (which indicate the position of ancient coastal lines) on the shelf of the East China Sea, which is peculiar to the shelves of the Japan Sea (Derkachev, 1992), is explained by the influence of the Changjiang and Huanghe River systems upon the sedimentation process. Perhaps, Pleistocene migration of river channels and deltas characterized by an unstable sedimentation regime did not support the differentiation of the matter supplied in great quantities.

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