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MINERALOGICAL CHARACTERISTICS AND CONTROL FACTORS OF SURFACE SEDIMENTS IN THE SEA AREA NORTHWEST OF THE ANTARCTIC PENINSULA

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Abstract Analysis and study of clastic and clay minerals of surface sediments and their chemical composition in the sea area northwest of the Antarctic Peninsula enable the authors to divide this area basically into four mineralogical provinces : (1) the mineral ogical province of coast and island shelf of the Southern Shetland Islands, (2) the mineral ogical province of the eastern Bransfield Strait, (3) the mineral ogical province of the western Bransfield Strait, and (4) the mineral ogical province of the western Antarctic Peninsula. Finally, the relationships between the mineral distribution and geologic, structure, material sources, glaciers, currents, and environments are briefly described.

Key words Antarctic Peninsula, Sea area, control factors, mineralogical characteristics.

From November, 1984 to April, 1985, Chinese first Southern Ocean comprehensive scientific investigation was carried out on R/V "Xiang Yang Hong-10". 34 surface sediment samples were obtained by using ocean-50 and big box samplers. 31 of them are mud-sand samples, 23 were analysed on clastic minerals, 29 were analysed on clay minerals. Analysed Grainsize of the former samples are 63—125 μm and the latter are less than 2μm.

1. Mineralogical characteristics

1.1. General characteristics of clastic minerals

According to their source and genesis, clastic minerals are divided into two types.

1.1.1 Volcanic clastic minerals

Among the volcanic clastic minerals, the dominant minerals are clinopyroxene, orthopyroxene, magnetite, ilmenite, pyrite, olivine, apatite, zircon, oxyhornblende (P.87~p.88 Plate I. 1—5. Plate II.3). and plagioclase, quartz, voclanic vitric fragments etc. The crystal forms of these minerals commonly are fine. M ostof them have no apparent trace of transportion. They have bubble-well texture, zonal structure and solution margin. Magnetite is covered with glass. The cleavage plane of the pyrite are clearly visual (p.87~p.88 Plate I. 1., Plate II. 5. 6.). The volcanic vitric fragments are brown and colourless. They are sheet, chicken-bone, stripe, arc-plane and multiangular in shape (Wang et al., 1983). Most of quartz surfaces are not clear, and have cracks on it, and β-quartz can be seen occasionally. The characteristics of main minerals can be seen in the table (Ma *et al.*, 1990, table 1). Chinopyrone is mainly augite. Orthopyroxene is mainly hypersthene. The refractive index of the brown volcanic vitric fragments is about 1.5980—1.6005. SiO_2 content in the fragments is less than 47%, so they are basaltic. The refractive index of the colourless vitric fragments is 1.5070 —1.5100, so they are dacitic. Brown vitric fragments are dominant over colourless.

The refractive index of plagioclase is 1.5605—1.5715 and corresponds to andesine-bytownite. The volcanic clastic minerals are mainly distributed in the surrounding sea areas of the Southern Shetland Islands, especially in Maxwell Bay, King George Bay and the sea area adjacent to Livingston Island (Fig. 1; Ma, 1990).

1.1.2 The terrigenous clastic minerals.

The minerals are mostly hornblende, epidote, magnetite ilmenite, limonite, hematite, muscovite, biotite, chlorite, garnet, zicon, and tourmaline, and less are quartz, plagioclase, tremolite, sphene, clinozoisite, oxyhornblende, and glaucophane. But rutile, piedmontite, andalusite, actinolite, xenotime, etc are occasionally appear. Part of these minerals have not apparent traces of transportation, their crystal forms are fine and remain ideomorphic, such as zircon and garnet (p.88 Plate II. 2.). some of these minerals have undergone transportation, and became rounded, subangular and subrounded, such as zircon, apatite etc (p.88 Plate II. 1,4.). Hornblende are mainly green,partially dark-brown. Hornblende is mainly magnesiohornblende, ferroedenite, pargasite, etc. Ma, *et al* (1990, Table 1). Garnet is mainly almandine. The terrigenous clastic minerals are mainly distributed in the sea areas of western Antarctic Peninsula, near Livingston Island and west of Biscoe Islands.

1.2. Chemical Characteristics of the Minerals

In order to understand distribution of chemical elements in clastic minerals, heavy minerals were analised by using neutron activation, analytical data of 22 elements are obtained (Wang and Zhao, 1989).

1.2.1. Characteristics of the trace elements in heavy minerals

Heavy minerals contain high Fe (7.97—22.5%) and Ni (0.31—1.81%). High values of Fe. Co. Ni and As were bound at the stations near Southern Shetland Islands. Apart from the island, Fe. Co. Ni and As decrease slowly in content (Ma, 1990, Fig.3) ,but distributons of U, Th, Hf and Ta are just contrary, Contents of U, Th, Hf, and Ta are low on Southern Shetland Islands and gradually increase with distance from the islands (Ma, 1990, Fig. 4) Distribution of Zr is similar to that of U, Th, Hf, and Ta. The distribution characteristics of the elements are coinsident with that of clastic minerals. In the surrounding area of the Southern Shetland Islands, pyroxenes are high in content as they are the characteristic minerals of basic rocks. Fe, Co, and Ni are main elements in basic and ultrabasic rocks. Thus, here is a certain area for high contents of Fe, Co, Ni. But U, Th, Hf and Ta are lithophile elements and are in close relation with intermediate-acidic rocks. Both these groups of elements are in reverse correlation. Fe, as a representative element in this area, is in a negative correlation to U, Th, Hf and Ta.

1.2.2. Characteristics of rare-earth elements (REE) in heavy minerals

Distribution pattern of chondrite-normalized REE (average value of 26 chondrites) (Zhao, 1982) is basically in two cases. One is similar to the distribution pattern in basic rocks (Ma, 1990, Fig. 5) though the curve slopes toward right, but smooth. Ce / Yb is 5.2—35.8, total value of rare-earths (8 rare-earth elements) is 111.0—175.0, Eu anomaly value is not evident. The distribution pattern is mainly found in the sea area adjacent to Southern Shetland Islands. The other distribution pattern is similar to that in intermediate-acidic rocks (Ma, 1990, Fig. 6) of which the negative anomaly of Eu is evidently characteristic, and shows a deep valley on the curve with an uprising slope ,Ce / Yb is 13.0—36.0. Total amount of rare earths increases (210.0—535.0). These

characteristics correspond to the rare-earth distribution pattern in intermediate-acidic rocks or in Si-Al-rich rocks. This distribution pattern is mainly found in the sea areas west and east of Southern Shetland Islands.

1.3. Clay minerals

X-ray diffraction, infrared spectrum and electro scanning microscope analyses, indicate that main clay minerals in the studied area are montmorillonite, illite, chlorite and kaolinite. Using Bradle 's (1966) weight cofficint, 18 Å: 10 Å = 4: 1; 7 Å : 10 Å = 2.5: 1, peak-high ratio algorithm semi -quantitative result was obtained (Gao, 1990). result of chemical analysis is given in Table 1. distribution of clay minerals in this area may be roughly centered in two sedimentary provinces.

1.3.1 The sedimentary province round Southern Shetland Islands

Here assemblage of clay minerals consists of montmorillonite (average 46%), illite (average 32%), chlorite (average 15%) and kaolinite (average 8%). This sedimentary province is mainly affected by the volcanic action in Southern Shetland Islands.

Table 1. Major components of clay fraction(%).

st.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	NaO	K_2O	(a)	(b)	(c)	(d)
S_{28}	57.11	0.70	14.55	1.75	5.69	0.12	3.90	1.57	2.28	2.45	0.85	0.63	3.73	0.055
S_{21}	59.29	0.52	12.85	6.72	5.15	0.10	3.68	1.43	1.94	2.19	0.59	0.60	3.49	0.046
S_5	55.27	0.92	13.42	10.65	5.84	0.14	4.11	1.56	1.26	1.93	0.48	0.47	3.27	0.078
R_2	51.08	0.70	17.95	8.72	4.58	0.14	5.14	1.20	1.42	2.53	0.60	0.49	3.49	0.042
J	51.74	0.74	17.01	9.72	5.74	0.13	5.72	1.50	1.51	2.06	0.57	0.36	2.97	0.049
L_1	56.99	0.77	12.61	8.47	7.10	0.10	3.90	1.27	1.14	1.66	0.53	0.42	3.23	0.069
M_5	50.10	0.75	17.38	9.86	6.70	0.13	4.97	1.09	1.50	2.08	0.57	0.42	3.50	0.049
S_{20}	55.35	0.91	13.79	11.37	3.27	0.10	4.51	1.13	1.47	2.43	0.48	0.54	3.06	0.075

* (a), (b), (c), (d) represent $Al/Al+Fe+Mn$, K_2O/MgO, Al_2O_3/MgO, Ti/Al respectively.

1.3.2. The sedimentary province of northwestern side of Antarctic Peninsula

Here assemblage of clay minerals consists of illite(49%), montmorillonite (23%), chlorite (20%), and kaolinite (8%). This province may mainly be affected by the physical weathering in northwestern side of the Antarctic Peninsula. In this province, two origins of montmorillonite are possible, authigeneous and terrigenous clastic. The former is Na-montmorillonite, which was mainly formed from the volcanic effusive materials) altered by sea water. It is mainly characterized by strong and distinct diffraction peak of Na-montmorillonite. But Ca-montmorillonite is terrigeneous, and of weathering residual type.

2. Mineral assemblages and mineralogical provinces.

More than fourty kinds of minerals are regularly distributed in the study area, four mineral ogical province were distinguished according to the dominant mineral assemblages and the characteristic minerals (Edwards and Goodell, 1969) (Table 2, Fig. 1).

2.1. The mineral ogical province of the bay and shelf of the Southern Shetland Islands

It is located in the bay, and nearby sea area of the islands. The water depth is less than 500m. Since this area is close to the land, the mineral composition reflects the composition of mother rocks on the land. The dominant heavy minerals are pyroxene (57.8%), magnetite, ilmenite, and other ferrous metal minerals (14.4%). Secondary minerals are epidote and hornblende. This province is characterized by endogenic pyrite which is commonly well crystallized. Among light components, volcanic vitric fragments is 20.4% in average and 73% in maximum. Among clay minerals, montmorillonite is dominant, 46% in average. Chemical composition of heavy minerals is characterized by high contents of Fe, Ni, Co, and As. Chondrite -normalized pattern of REE corresponds to that in basalt. These characteristics are in agreement with those of the intermediate-basic rocks. The source materiats are mainly intermediate-basic volcanic rocks and recent volcanic effusive mass on the Southern Shetland Islands.

2.2. The mineral ogical province of East Bransfield Strait

It is located in a wide area southwest of Elephant Island and the eastern strait at a greater water depth, about 500–2000m. But the sediments is commonly coarser, from clayey silt to silty sand. The dominant assemblage of clastic minerals is similar to that in province 1. and mainly composed of pyroxene (44.5%), ferrous metal minerals (14%), and volcanic vitric fragments (22.5%). Garnet is characteristic mineral in this province, 4.8% in average, and 15% in maximum but the contents of hornblende and epidote are slightly higher than those in province 1. In clay minerals illite is dominant (44%), next montmorillonite (32%). Among trace elements in heavy minerals, contents of Zr, U, Th ,Hf and Ta are higher. Obviously, in this province minerals originate from both intermediatebasic volcanic rocks, on the Southern Shetland Island and the weathered metamorphic rocks on Elephant island and the materials carried by the Weddell sea currents from Southern Antarctic Peninsula. The source materials are very complex, basically derived from a mixed mineralogical-sedimentary province of intermediate-basic volcanic rocks and metamorphic rock.

2.3. The mineral ogical province of the western Bransfield Strait

It is located in the western Bransfield Strait (including Smith Island and sea area adjacent to the Loh island), its water depth is 500—1700m, and 4105m at station S11. The sediments are clayey silt dominantly, gravel-bearing silty sand locally. The dominant heavy minerals are epidote (25%), pyroxene (22%), and hornblende (18%). The sheet minerals obviously increase, 5.3% in average and volcanic vitric fragments are 20%. In clay minerals is illite dominant, (45%), montmorillonite next (29%). According to the distribution characteristics of minerals, the source materials in this area have derived from not only intermediate-basic volcanic rocks on Southern Shetland Islands, but also from intermediate-acidic igneous rocks on the Antarctic Peninsula. Thus the province is a mixed sedimentary province of both source materials.

2.4. The mineral ogical province of the western Antarctic Peninsula

It is located on the western continental shelf of the Peninsula. Its water depth is about 300 –340m and 3026 m at one station, the sediments are coarser, mainly gravel-bearing silty sand. The dominant clastic heavy minerals are hornblende (26.4%), epidote (19.6%), sheet minerals (7%) ,and a few volcanic vitirc fragments. Among clay minerals, the illite is the highest (48%), and montmorillonite next (26%). Lower content of ferric family of elements are characteristic of the chemical composition of the heavy minerals, contents of Zn, Rb, Sr elements increase sharp-

Table 2. Characteristics of mineralogical—sedimentary provinces.

Province	Assemblage of clastic minerals	Assemblage of clay minerals	Chemical characteristics of heavy minerals
1. mineralogical province of bay and island shelf of the South Shetland Islands	pyroxene (57. 8%), ferrous metal minerals(14. 4%), endogeneous pyrite (3. 7%), volcanic vitric fragments(20%)	montmorillonite (46%), illite(32%), chlorite(14%), kaolinite(8%)	high contents of Fe, Ni, Co, As. REE chondrite normalized pattern consistent with that in basalt
2. mineralogical province east of Bransfield strait	pyroxene (44. 5%), ferrous metal minerals(14%), garnet(4. 8%), volcanic vitric fragments(22. 5%),	illite (44%), montmorillonite (32%), chlorite(17%), kaolinite(7%)	high contents of Zr, U, Th, Hf, Ta
3. mineralogical province of the western Bransfield strait	epidote (25%), pyroxene (22%), hornblende (18%), sheet minerals (5. 3%), volcanic vitric fragments(20%)	illite (45%), montmorillonite (29%), chlorite(18%), kaolinite(8%)	
4. mineralogical province of the western Antarctic Peninsula	hornblende (26. 4%), epidote (19. 6%), sheet minerals (7%)	illite (48%), montmorillonite (26%), chlorite(17%), kaolinite(9%)	low content of ferric family of elements. high content of Zn, Rb, Sr. chondrite normalized distribution pattern is similar to that in intermediate acidic rocks

ly, and chondrite-normalized REE distribution pattern is similar to that in intermediate-acidicy rocks. Above characteristics indicate that its eroded source is mainly intermediate-acidic igneous rocks on the Antarctic Peninsula.

3. Control factors

It is can be seen from the above-mentioned mineral ogical provinces ,each province has its dominant and characteristic minerals. These clastic and clay minerals are related to their sources. In addition to volcanic activity, ice-rafting transportation and sea current movement, which formed recent mineral distribution fremework (Edwards and Goodell, 1969).

3.1. Basic rocks on the islands and peninsula as a main source for the minerals

The distribution features of the above-descrebed four sedimentary provinces of clastic minerals indicates that the mineral provinces are closely related to their source areas.

3.1.1. The volcanic clastic minerals originated from the volcanic eruption

The sedimentary province of the volcanic clastic minerals is distributed around the Southern

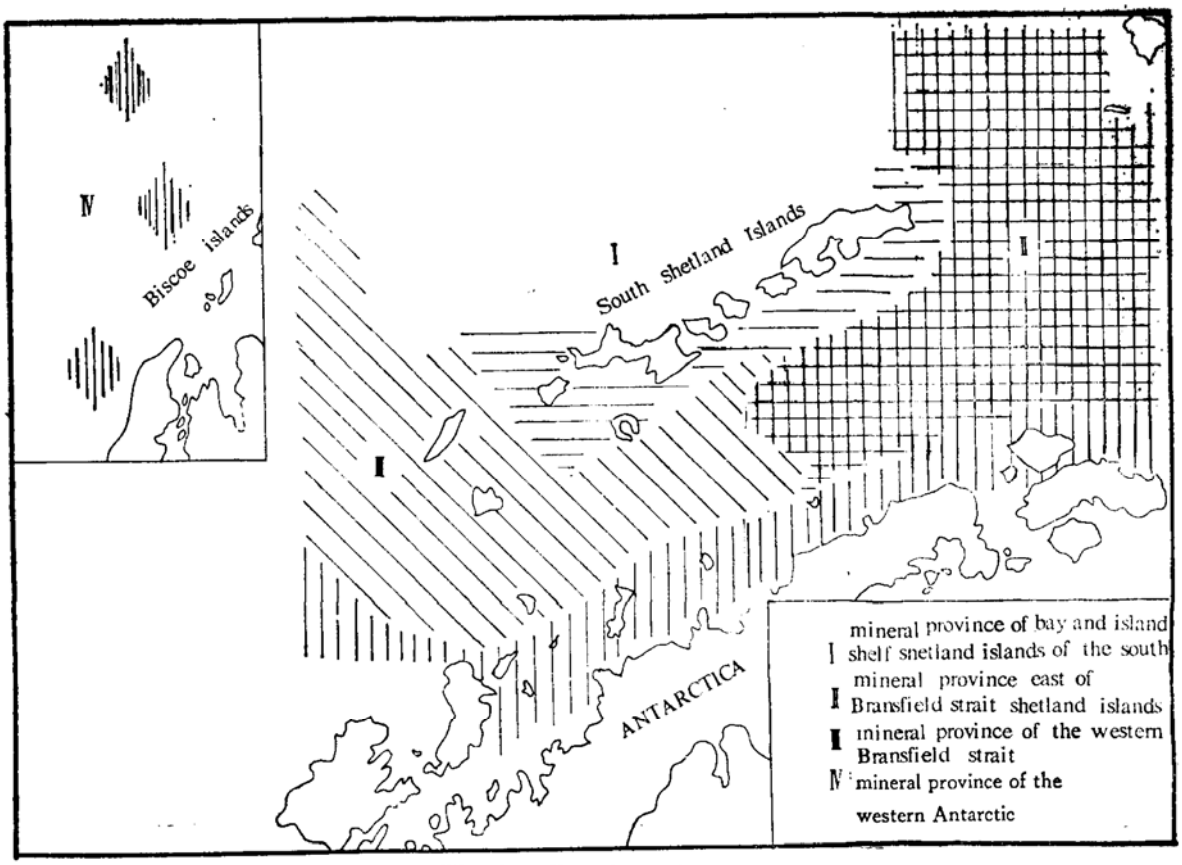

Fig. 1. Mineral provinces.

Shetland Islands. It is known that Southern Shetland Islands was built up of intermediate-basic volcanic rocks which are mainly the Jurassic-Cretaceous pyroxene—andesite, volcanic clastic rocks and recent olivine basalt. These clastic minerals from the weathered volcanic rocks are transported to the sea by glacier and floe ices and volcanic ash falling directly from the islands, or the volcanic eruptions on the sea bottom provided enormous volcanic materials, which represent pyroxene-volcanic clastic mineral assemblage and the clay mineral assemblage in which montmorillonite is dominant. The characteristics of the mineral assemblages reflect that volcanic eruption is a main control factor for formation of these mineralogical provinces.

3.1.2. The clastic minerals originated from the intermediate-acidic igneous rocks on the Antarctic Peninsula

The sedimentary province of the clastic minerals from intermediate-acidic igneous rocks is located in the continental shelf area north-west of the Antarctic Peninsula. The minerals in the province is basically similar to that on the western coast of the Antartic Peninsula, where the rocks mainly are granite and granodiorite. The source for the clastic minerals in this sedimentary province must be the rocks on the western Antartic Peninsula. The fact that the clastic minerals and the assemblage of clay minerals in which illite is dominant are of intermediate-acidic igneous rocks is consistent with the characteristics of rocks on the western Antarctic Peninsula, indicating that the distribntion of minerals is controlled by the petrological features on Antarctic Peninsula.

3.1.3. The metamorphic minerals originated from the metamorphic rocks on Elephant Island

In the eastern study sea area, high contents of metamorphic minerals were determined. it is clear that the minerals are the products of weathering of the metamorphic rocks on the Elephant Island. The garnet and sheet minerals are closely related to the metamorphic rocks, such as garnet-albite schist, on Elephant Island and in adjacent area

3.2 The volcanic activity as a main control factor for the volcanogenic minerals

In the surface sediments of sea area around the Southern Shetland Islands, clinopyroxene, orthopyroxene, volcanic glass, and montmorsllonite are dominate. The pyroxene and magnetite are enclosed with brown vitric fragments in the form of glass casts of bubble-well texture and zonal structure. It indicates that these minerals resulted from the volcanic eruption on this island and sea bottom, and were not transported a long distance. Contents of pyroxene and volcanic vitric fragments decrease with the distance from this island, and then show their strip distribution. According to carbon-14 dating, the age of most of the sediments in this area is less than 7200 years. Thus the volcanic activity is recent. Statistic data indicate that there are 12 volcanic eruption centers on King George Island and a large number of volcanic scoria, breccia and ash can be found, indicating an important effect of volcanic activity on the distribution of the volcanogenic minerals.

3.3. The ice rafting as a main agent for transportation

In the continental shelf area colse to the peninsula or islands, the sediments belong to residual secondary ice-borne sediments of coarser grain sizes, and represent gravel-bearing fine sands, coarse sands and gravel-bearing sandy silts. Their sorting is bad. They were carred by the moving ice rafts, to the sea and then deposited. Most of the sediments were derived from nearby land and island. In the sea area far from the land or islands, for example, in Bransfield Strait, the grain size of sediments decreases with increasing water depth. Clayey silt is dominant, and belongs to mixed secondary ice-borne sediments. The sediments were also influenced by the source materials on the Antarctic Peninsula and the Southern Shetland Islands. In the conjunction area between these two sources, the mineral assemblage of mixed type were formed. According to field survey, along the coast, rock fragments often togather with ice mass collapse into the sea, and different iceberg and floe ice float along with the sea currents. Thus the ice rafting is a main agent for transportation of sediments.

3.4. The sea currents

In this area the mineral assemblages were obviously affected by the sea currents inainly from Bellingshausen sea. They flow from Southwest to northeast, and lead the ice-rafted sediments from the Southern Shetland Islands to spread toward northeast. For example, the volcanic clastic minerals from eastern King George Island spread to ward the Elephant Island. In summary, mineral assemblages in this area were strikingly influenced by the basic rocks on the Antarctic continent, Southern Shetland Islands and nearby islands. In this area the types of sediments were also obviously affected by the circulating currents.

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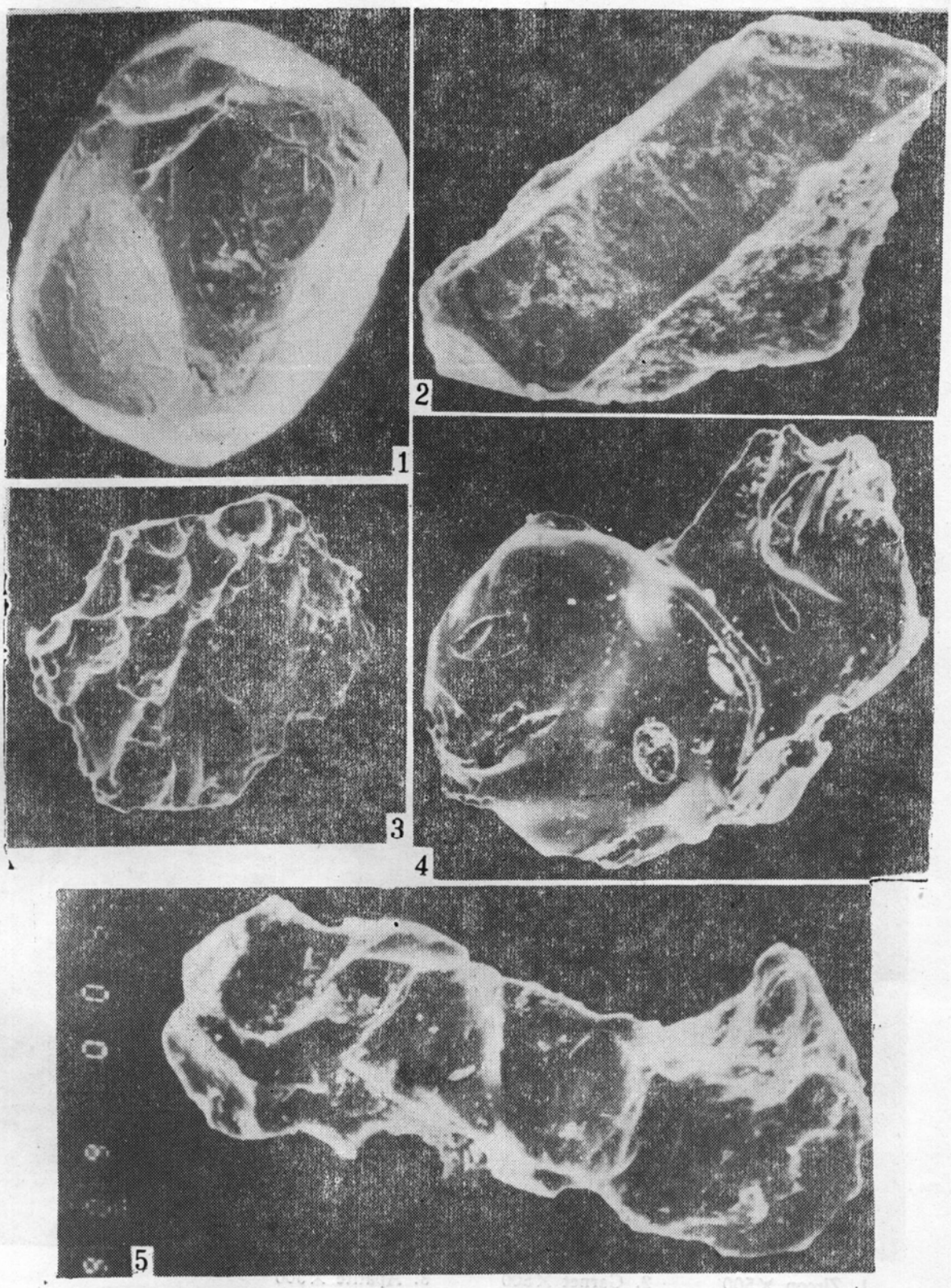
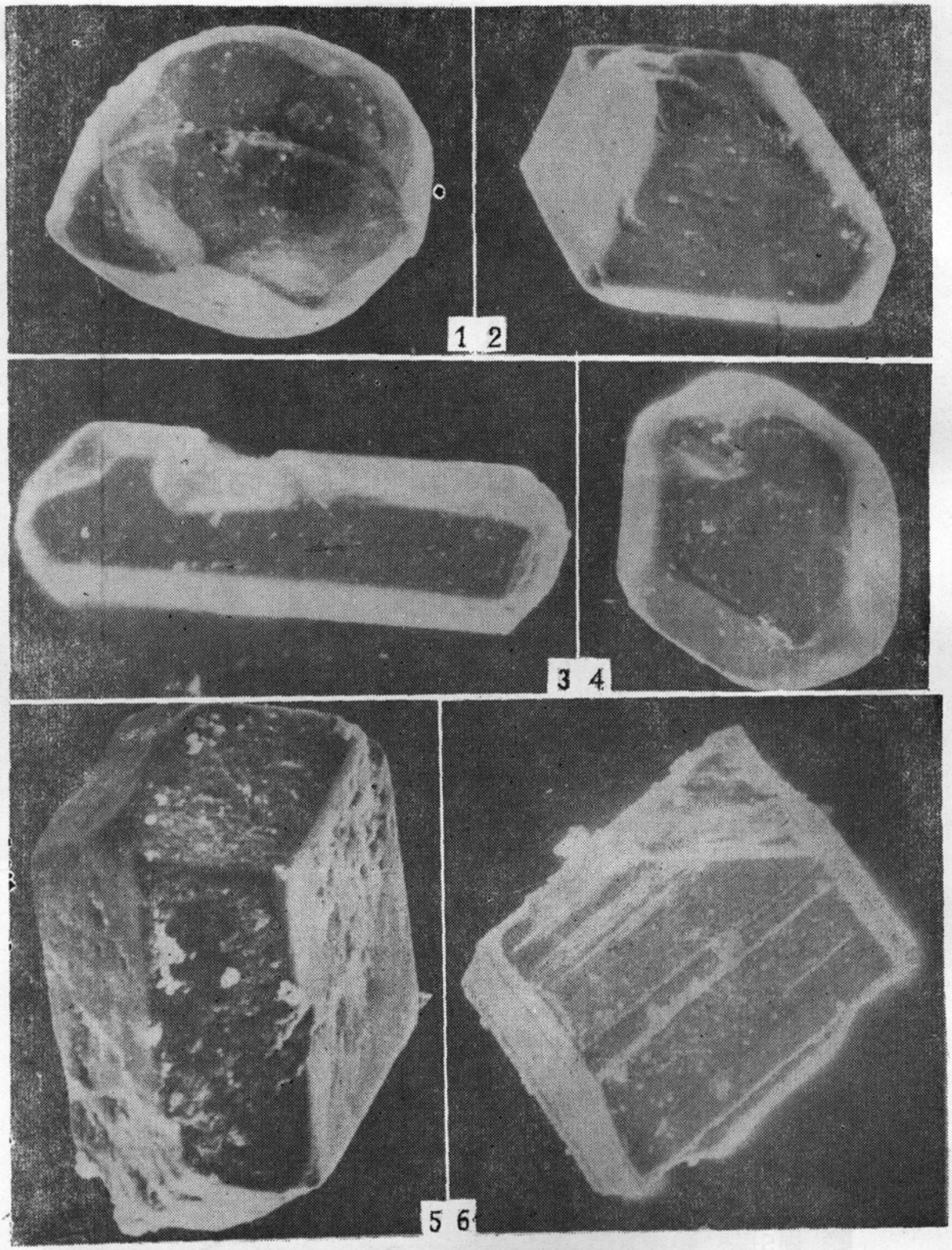


1. Magnetite ×500
2. Zircon ×200
3. Pyroxene ×200
4,5. Pyroxene ×500



1. Zircon ×500 2. Garnet ×500 3. Apatite ×500
4. Ilmenite ×500 5,6. Pyrite ×500