Preliminary Report on the Morphology of the Inland Ice Sheet of the Mizuho Plateau, East Antarctica

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東南極みずほ高原の形態について

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要旨

第5次越冬隊は，1961年10月4日から12月19日わたって，大和山脈を経由し，南緯75度に達する内陸調査を行なった。その際に得た雪氷学・気象学上の成果は，目下別に整理されているが，ここでは大陸氷の形態的観察にもとづいて考察し，大陸氷の特徴としてつぎの諸点を得た。

1) 大陸氷の形態からみて，Mizuho plateau は inland plateau と marginal slope の区域に2分できる。その境界は大和山脈の南方，海抜2,300m付近にある。大和山脈の東側には，これと並行する2条の基盤の高まりがあり，大和山脈およびこれら基盤の高まりが，大陸氷の外方への流動を妨げているものと思われる。かかる大陸氷の dam up による特徴は，Queen Maud Land において海岸から 200～300km の内陸で共通的にみられる。

2) Marginal slope の大陸氷は一般に勾配が急で，また基盤の起伏を反映した表面形態を呈する。Inland plateau の大陸氷の表面はきわめて平坦であり，表面から基盤形態をまったく推定できない。調査隊の最終到達点（75°0′S, 38°27′E）の高度は 3,230 m である。これ以南の大陸氷もかかる緩勾配をなしながら，大体80度付近にあると思われる東南極大陸の分水界まで高まるものと考えられる。

3) Sastrugi の形態と発達方向には顕著な地域性が認められ，それによって各地域における卓越風の性格が判明した。Inland plateau では，風は一般に弱く，定常的な東風が卓越する。Marginal slope では，東風のほかに，blizzard の際の北東ないし北風が sastrugi形成に関与する。Blizard の影響する範囲は，大体昭和基地南方 400 km の内陸までと見なされる。大陸氷の急斜部では katabatic wind が強く，これが sastrugi 発達の地域性を非常に複雑にしている。

1. Introduction

The Mizuho Plateau, part of the Antarctic inland south of the Syowa Base, is the area explored by JARE (Japanese Antarctic Research Expedition) since 1957. The area was formally called Eastern Queen Maud Land (Photo. 1). The Japanese Expedition surveyed not only around the Syowa Base but also performed yearly

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survey trips to the Mizuho Plateau, and consequently gained geographical ifnormation of this absolutely unknown region in Antarctica.

During the period from October to December 1961, the Wintering Party of the 5 th JARE explored the Mizuho Plateau through the Yamato (Queen Fabiola) Mountains up to 75° south in latitude. In this survey trip, morphological investigations, ice thickness measurements by seismic soundings, gravimetry of the inland ice sheet, and meteorological observations were made along the traverse route. In the return trip, geomorphic surveys were actively carried out in the Yamato Mountains. Prior to this trip, a party was dispatched to the head area of the Shirase Glacier (Oku-shirase Daira) in late autumn to establish a depot for the spring traverse. The data of the spring and autumn survey trips are being analyzed by the members of each section. In this paper the writer gives a preliminary report on the morphology of the inland ice sheet based on the data obtained in these trips. The topography of the Yamato Mts. has been reported in another paper[1].

2. Inland ice sheet

The surface features of the inland ice sheet of the Mizuho Plateau are quite different between the inland plateau and the marginal slope, with the boundary situated near the Yamato Mts. The marginal slope on the outer edge of the inland ice sheet is comparatively steep and presents broadly undulated surface features. On the contrary, no such features are observed in the inland plateau south of the Yamato Mts., where the surface is extremely smooth. Therefore, the inland part of the Mizuho Plateau is believed to belong to the main plateau of East Antarctica. Fig. 1 shows the traverse profile of the inland ice sheet along the Spring trip route. Two barometric altimeters were used in the trip to measure the surface altitude of the inland ice sheet. The height values in Fig. 1 were corrected to eliminate errors owing to temperature changes, but barometric corrections were not made. Since all sledges of the trip party were operated simultaneously, it was difficult to correct errors caused by atmospheric pressure variations*.

1) *Marginal slope of inland ice sheet*

The morphology of the ice sheet in the marginal slope is largely controlled by

* Though small in scale, atmospheric pressure variations at the camping ground during stagnation are similar to those at the Syowa Base (see Fig.2). Consequently, through the meteorological data of the Syowa Base, it was possible to some extent to calculate the atmospheric variations at camping sites. But, since some assumptions are required in calculation, barometric corrections are not given in this report.

rock exposures on the coast, and to some degree by subglacial rock relief. Because of the existence of conspicuous mountain blocks of the Langhovde and Skarvsnes, the geomorphic features of the east coast (Prince Olav Coast) of Lützow-Holm Bay are quite different from those of the west coast (Prince Harald Coast) where rock exposures are small and sporadic.

The surface profile of the inland ice sheet on the opposite coast of the Ongul Islands shows a distinct break at an altitude about 800 m above sea level. The mean gradient of the terminal slope lower than 800 m above sea level is 1 in 31 which is much steeper than in the area above 800 m where the mean gradient is 1 in 125. The surface of the terminal slope shows broad undulations like terraces, rising step by step toward the inland. In the convex surface many hexagonal cracks develop. Blue ice is exposed on slopes up to the altitude of 650 m above sea level. In summer plate shaped hollows 10 cm to 20 cm in diameter are formed all around, which suggest active ablation of ice by melting. Melting is more noticeable near to the

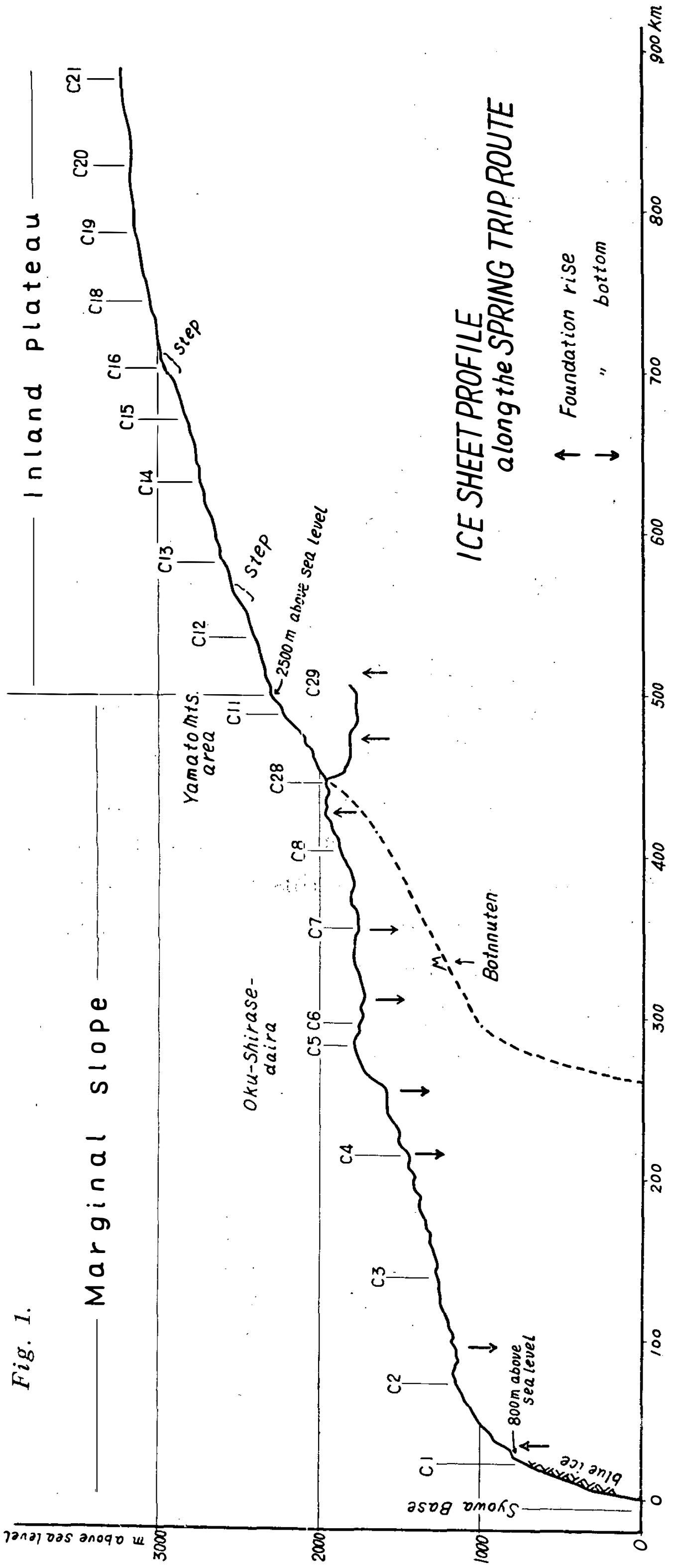

Fig. 1.

coast. Especially, in the steep slopes, melting water flows in channels 20 cm to 50 cm deep on the surface of the blue ice. Even in the blue ice zone, snow drifts are scattered in places where the surface is slightly dented. Immediately after a blizzard or after the winter season, snow is widely distributed, but is generally very thin on the blue ice.

Transverse crevasses are remarkably developed on the conspicuously convex surfaces of the ice sheet at an altitude of about 800 m above sea level. This crevasse zone appears to extend long in the SSE direction. The convex features of the ice sheet surface are believed to be the reflection of the subglacial ridge detected in this area by seismic soundings performed by the 3 rd Expedition party[2]. It is interesting that the above-mentioned direction is parallel to the structural trend of the Langhovde Mountains.

The surface of the inland ice sheet higher than 800 m has broad undulations 30 m to 80 m in relative height (Photo. 1). The mean gradient of the ice sheet in this area is small, especially in the area between Camp 2 and Camp 3. Because the 5 th Expedition party took a survey route parallel to the east coast of Lützow-Holm Bay, the real longitudinal section of the inland ice sheet is not shown in Fig. 1. But, even the 3 rd Expedition party, which advanced in the direction of the gradient of the ice sheet on the east coast of Lützow-Holm Bay, found the ice surface rather flat in this area. According to the result of the 3 rd Expedition, the subglacial rock surface in this area is known to make a broad valley 1,000 m deep below sea level. For this reason, it seems that the ice sheet in this area is very thick, filling the detected valley, and has a gentle surface, being dammed up by the subglacial rise west of the valley.

The small undulations of the ice sheet surface between Camp 2 and Camp 4 may be reflecting the subglacial rock relief, although any evidence to verify such relationship is not available. However, in the area between Camp 4 and Camp 7 at Oku-shirase Daira, four subglacial valleys extending upward from the Shirase Glacier coincide well with four troughs on the ice sheet surface. Some of these troughs are deeper by about 50 m to 100 m than the surrounding area; transverse crevasses on the slopes of the troughs were impassable for sledges. The 4 th party encountered this zone of crevasses at 70°30′S and 41°00′E and the 5 th party made a detour around it (70°50′S, 41°10′E). According to the result of the seismic soundings by the 4 th party, the subglacial valley under one of the troughs is 1,000 m to 1,400 m deeper than the surrouning area[3].

2) *Morphology of inland ice sheet in the vicinity of Yamato Mountains*

The Yamato Mountains consist of seven massifs and several nunataks extending over 50 km from north to south. The height of the massifs ranges from 2,000 m to 2,400 m above sea level. The ice sheet in the vicinity of the mountain area flows from SE to NW across the mountains, forming outlet glaciers and abruptly descending 200-300 m. Therefore, the ice sheet on the SE side is 1,800 m to 1,900 m high above sea level while on the NW side it is only 1,500 m to 1,600 m above sea level (Photo. 2)[4].

The ice sheet on the east side of the mountains is mostly covered with accumulated snow, but on the west side a wide blue ice zone of true glacier ice extends. Especially on the lee side of the main massifs sheltered from prevailing winds, drifted snow was not seen (Photo. 3). Ice ablation by melting is active in the blue ice zone on the coast in summer, but is not found in this area where sublimation and wind corrasion are dominant. Going father away from the mountains, blue ice disappeares and snow covers the surface again.

East of the Yamato Mountains, several nunataks and conspicuous mounds of ice sheet surface suggest the existence of a N-S trending subglacial rise. The inland ice sheet at about 37°30′E in long. has a broad ridge-like rise stretching N-S, as shown clearly in the surface profile of the ice sheet between Camps 8 and 28 in Fig. 1. On the way ascending south from Camp 9 to Camp 11 the 5 th sledge party discovered on the left hand side several round ice mounds where crevasses were highly developed. This suggests that the foundations of the ice mounds are comparatively shallow. Consequently, it is presumed that a subglacial rise exsists stretching N-S along the 37°30′E meridian. The reflection on the ice surface of the rise becomes fainter as going farther north and could not be clearly seen in the area passed by the 4 th party (30 km north of the route taken by the 5 th party). But, even in this area, seismic soundings detected a subglacial rise, 500 m in relative height, beneath the ice sheet[5].

As mentioned above, three N-S trending mountains and subglacial rises exist in the area around the Yamato Mountains. And these mountain groups hinder the flow of the ice sheet from the inland plateau and transform the surface features. This is believed to be the cause of the break in the surface profile at the altitude about 2,300 m above sea level as shown in Fig. 1, and the break of the surface gradient forming rather steep slopes extends through several nunataks southwest of the Yamato Mountains onto the Belgica Mountains*.

In the Queen Maud Land many mountains 2,000-3,000 m high above sea level, such as Kottas Mts., Muhlig-Hofmann Mts., Wohlthat Mts., Sør Rondane Mts. and the like, extend in a row at about 200-300 km inland from the coast. The Belgica Mts. and the Yamato Mts. are situated at the east end of this mountain

* According to the map of the Belgian Antarctic Expedition 1957-58.

chain. It has not been clarified how these mountains are connected in their geological structure, but they obstruct the outward flows of the ice sheet, serving as the boundary between the inland plateau and the marginal slopes in each meridian sector area. The outer edge of the inland plateau has an elevation about 2,800 m above sea level south of the Wohlthat Mts. consisting of several massifs over 3,000 m in height. Also the conspicuous outer edge of the inland plateau in Western Queen Maud Land makes a great escarpment that abruptly descends from 2,400 m to 2,200 m[6].

3) *Ice sheet in the inland plateau*

The ice sheet surface in the inland plateau is generally very smooth and unbroken. The monotonous surface of the inland ice is disturbed only by some transverse steps about 100 m high along the contour lines of 2,000 m and 2,950 m above sea level. On these steep slopes snow is blown away by wind and the solid surface is exposed showing small hexagonal cracks (Photo. 4).

The mean gradient of the inland plateau is 1 in 600 up to 3,000 m high above sea level and 1 in 800 m over 3,000 m high, and no undulation conld be discerned. The surface of the ice sheet is even and smooth as far as could be seen. The final destination of the traverse by the 5 th party (75°S, 38°27′E) was a plateau 3,230 m high above sea level and 660 km south of the Syowa Base, but the smooth featureless surface is believed to extend farther inland.

According to the data obtained by the USSR Expedition, the highest part of the ice sheet in East Antarctica is in the neighborhood of 81°-82°S and 70°-80°E and is higher than 4,000 m above sea level[7]. It seems that the vast divide of the Antarctic ice sheet stretches NW-NE and that the NW continuation of the divide presumably extends to the inland plateau south of the Wohlthat Mts. If so, it can be considered that the ice divide is in the neighborhood of 80°S south of the Mizuho Plateau, and that its height may be 3,600 m to 3,800 m above sea level, referring to the height of the "Pole of inaccessibility", 3,720 m high above sea level.

The results of seismic soundings by the 5 th party are being analyzed, but on the basis of preliminary information it is believed that the ice sheet south of the subglacial rises around the Yamato Mts. is fairly thick[8]. Also in Western Queen Maud Land it is known that the ice sheet is extremely thick south of the subglacial mountains, where the inland ice is dammed up. Hence, it should be concluded that the inland ice sheet is not an ice plateau covering a rock plateau but is the ice filling a rock basin. However, some exceptional cases have been found in East Antartica. For example, on the way from Komsomolskaya and Sovetskaya

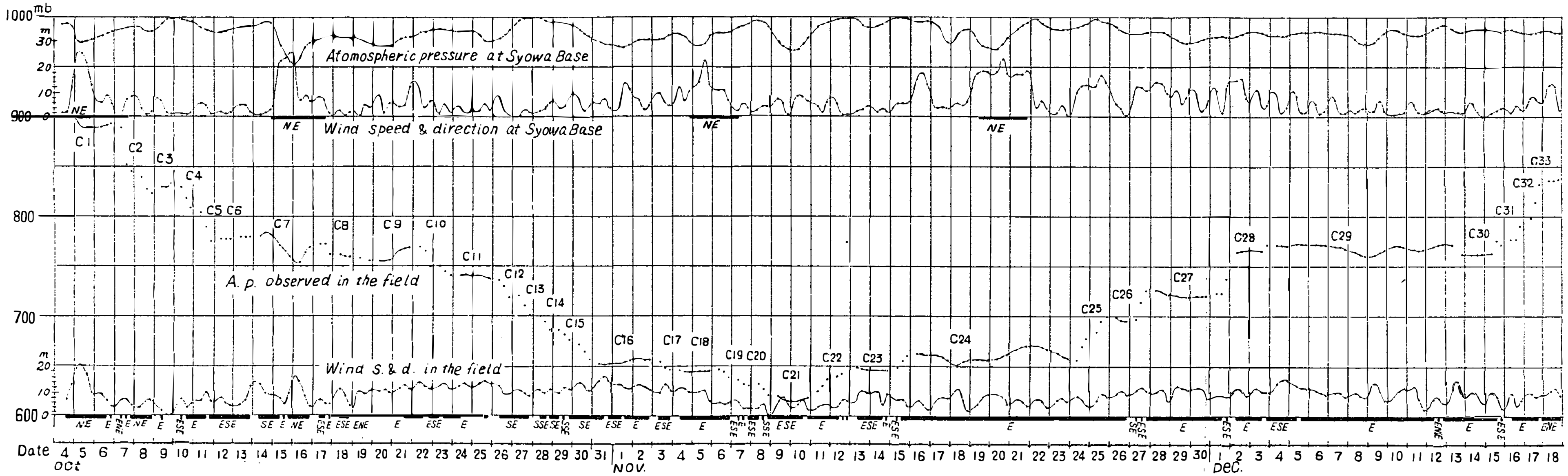

Fig. 2. Changes of atmospheric pressure and wind during the Spring trip.

to the "Pole of inaccessibility", a great subglacial rock plateau were discovered by seismic soundings, despite the fact that the surface feature showed no variations. Therefore, it may be concluded that the surface features in the inland plateau hardly reflect subglacial topography.

3. Minor features on the surface of ice sheet

Except in blue ice areas on coastal slopes and in the places sheltered from winds in the vicinity of the Yamato Mountains, the surface of inland ice is mostly covered with layers of snow. And the surfaces of snow layers are generally moulded into sastrugis of various types shaped by winds[9, 10]. In the Mizuho Plateau the writer observed sastrugis of so many different types that it was difficult to classify them into groups. Some characteristic sastrugis are shown in photographs.

The most important factors in formation of sastrugis are the wind and the properties of snow against wind erosion. Because the strength and direction of winds and the amount of snowfall vary with seasons, forms of sastrugis show remarkable seasonal variations. As sastrugis become less distinct inlandward and become largely influenced by the morphology of the ice sheet, the forms of sastrugis also show conspicuous regional differences.

In the Mizuho Plateau, easterly winds constantly blow from the Antarctic Anti-cyclone. On the other hand, strong winds of NE accompanying passage of cyclones far off the Antarctic coast disturb the monotonous sequence of weather in this area[11]. Fig. 2 illustrates variations of atmospheric pressure and wind as observed on the route of the Spring trip and at the Syowa Base. As shown in Fig. 2, easterlies with velocity of 5 to 15 m/sec prevail in the Mizuho Plateau with few windless day. The farther inland, the lower is wind velocity in general. In the inland area, 400 to 500 km distant from the coast, winds of 5 to 10 m/sec blow from SE every day. Hence, even in fair weather surface of snow is moulded by easterly wind and is transformed into sastrugis.

On the smooth surface of the inland plateau such sastrugis as shown in Photo. 5 are common. The windward slopes of these sastrugis are corraded and indented by wind, and on the leeward slopes wind-blown snow accumulates slenderly and thinly. They are the most conspicuous ones in all seasons regardless of snow properties. The snow forming sastrugis of this type is compact due to wind pressure but is much softer than the older snow beneath. Therefore, sastrugis are composed of new snow discontinuously overlying old snow. They are not so large and normally rise 20-50 cm above old hard surface. From these facts it is believed that wind velocity is not so strong in the inland plateau all the year round. Ripple marks similar to those on sandy shore are found on old and hard snow surface in this area (Photo. 6).

Not only are the snow drifts stretch long but also they occasionally form crescent-shaped snow barchans facing their convex slopes windward (Photo. 7). They are 20-30 cm high and are generally found in the smooth flat snow field. Windward slopes of snow barchans are gentle but leeward ones are steep, so their profiles are extremely asymmetrical. There are clear signs of leeward shifting of snow barchans, as indicated by the banded structures exposed on windward slopes where former leeward slopes left their marks as they moved.

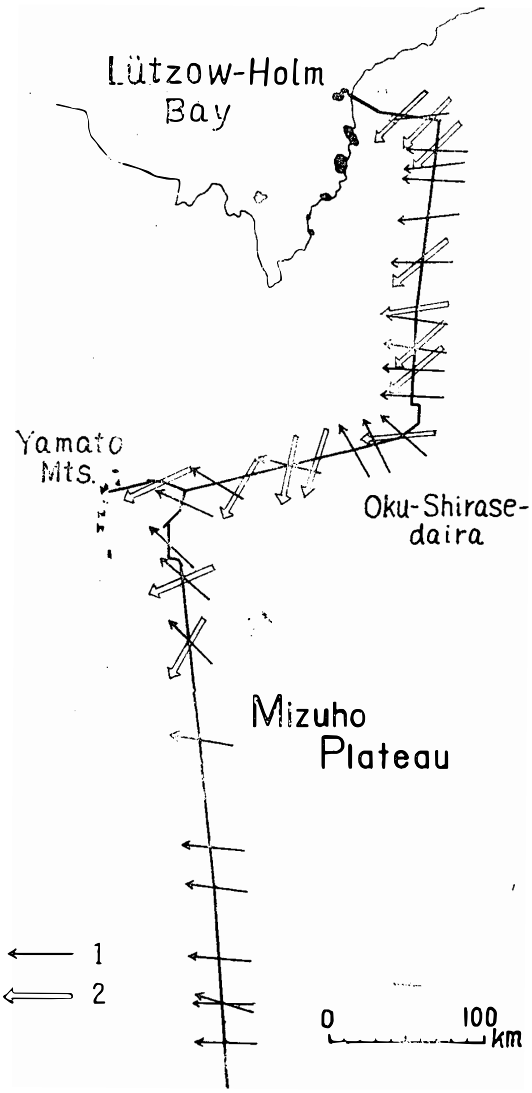

Fig. 3. Directions of the development of sastrugi along the Spring trip route.
1. Direction of sastrugi fomed mainly by wind erosion.
2. Direction of sastrugi distinguished a snow drift.

On the inland plateau sastrugis are conspicuously developed on steep slopes of transverse steps (Photo. 8). In places, very hard snow surfaces are deeply excavated by katabatic winds, forming sastrugis of large size. They are usually 0.5 to 1 m high, sometimes exceeding 1 m. Because of strong winds, snow or snow drifts are absent. These sastrugis are so large and hard that it was very difficult for the sledge party to travel across. It is known that the sastrugis which the British Trans-Antarctic Expedition encountered with had developed transverse slopes facing north[12]. These may be of the same nature as those encountered by the Japanese sledge party. Photo. 9 shows sastrugis of this type, extremely modified by wind corrasion. They are deeply carved at their windward bases, suggesting how severe is wind corrasion near the snow surface. They look like toads in every way from the windward and on back surfaces have pustules as on toad's back so that the Japanese party named them " snow toad ".

Katabatic wind is more predominant on the marginal slopes. Winds of 10 to 15 m/sec blew every day during the Spring trip in this area, drifting snow about 2-3 m thick on the snow surface, and actively modifying sastrugis. As shown in Fig. 3, directions of arrangement of sastrugis in this area are regionally very different according to the features of the ice sheet. In the Prince Olav Land sastrugis are arranged in the ENE direction in the area between the coast and Oku-shirase Daira, but in the area between Oku-shirase Daira and the Yamato Mountains sastrugis of the direction of ESE or SE prevail[13]. Sastrugis in the troughs on the Oku-shirase Daira develop in parallel with the troughs. Directions of sastrugis in the neighborhood of the Yamato Mountains are ESE or SE, but it has been reported that around the Botnnuten Mts. sastrugis develop at right angles with the coastline, that is, north-south[11].

On the marginal slopes there are sastrugis with the direction of NE or NNE diagonal to the E- or SE-trending sastrugis mentioned above. These are formed when a snowfall during a blizzard is accompanied with a powerful NE wind. Most of them are 1 m in height, 15 to 20 m in length and 3 to 5 m in width. In the Spring trip, at Camp 1 and Camp 7 where the party suffered from blizzards, sastrugis of the direction of NE were formed during blizzards. According to the records at the Syowa Base, two violent blizzards invaded the coastal area on November 5 and 19-21. During each blizzard the traverse party at Camps 18 and 19 in the inland plateau had only a slight snowfall, and no variation in wind velocity nor of wind direction was observed (Fig. 2). Moreover, sastrugis with the direction of NE were not found in that area. For these reasons it is deemed that the two blizzards in November did not invade inland as far as Camp 18. Judging from the features of sastrugis and meteorological observations, blizzards are considered to have invaded inland up to Camp 13 (about 400 km inland from the coast).

These sastrugis of the direction of NE formed by violent winds in blizzards are modified by easterly winds or katabatic winds blowing from the Antarctic Anti-cyclone, as shown in Photo. 10. The windward slopes of the sastrugis are corraded and transformed into steep scarps facing windward and small sharp ridges trending in the wind direction. On the other hand, on leeward slopes snow drift extends in the direction of wind. Many sastrugis having the features formed by winds of these two directions developed in the area between Oku-shirase Daira and the Yamato Mountains.

4. Conclusion

The matters mentioned in this paper can be summarized as follows:

1. From the morphology of the inland ice sheet, the Mizuho Plateau can be divided into two parts: the inland plateau and marginal slope, with the boundary located at about 2,300 m high above sea level south of the Yamato Mountains. East of the Yamato Mountains the existence of two subglacial mountain ranges running parallel to the Yamato Mountains is known. It is believed that the Yamato Mountains and the subglacial mountain ranges disturb the outward flow of the ice sheet from the inland plateau. Distinguished features of the ice sheet due to damming up by the mountains are commonly seen at 200 to 300 km inland from the coast of the Queen Maud Land.

2. The marginal slopes of the ice sheet are generally steep, and their surface features are influenced by subglacial rock morphology. On the other hand, surface of the inland plateau are perfectly smooth and scarcely reflect the subglacial rock morphology. The final destination of the inland traverse by the 5th Party was 3,230 m high above sea level. The ice sheet farther south has a featureless even surface and is believed to rise up to the divide of the Antarctic ice shield which may be located in the neighborhood of 80°S in latitude.

3. Conspicuous regional characteristics were recognized in the forms and directions of sastrugis. These are controlled by intensity and directions of prevailing winds in each area. Winds in the inland plateau are generally regular and weak. Winds originated from the Antarctic Anti-cyclone blow from east by south. Strong winds of NE accompanying cyclones passing off the coast are the main agency in the formation of sastrugis of large scale. It is presumed that the influence of the NE wind is distinct far inland from about 400 km south of the Syowa Base. Katabatic winds violently blows down on the steep slopes of the ice sheet, resulting in the regional characteristics of sastrugis. Sastrugis in Okushirase Daira and east of the Yamato Mountains are greatly influenced by such katabatic winds.

Upon concluding this report the writer is greatly indebted to the leader M. MURAYAMA and the members of the 5th Wintering Party of JARE.

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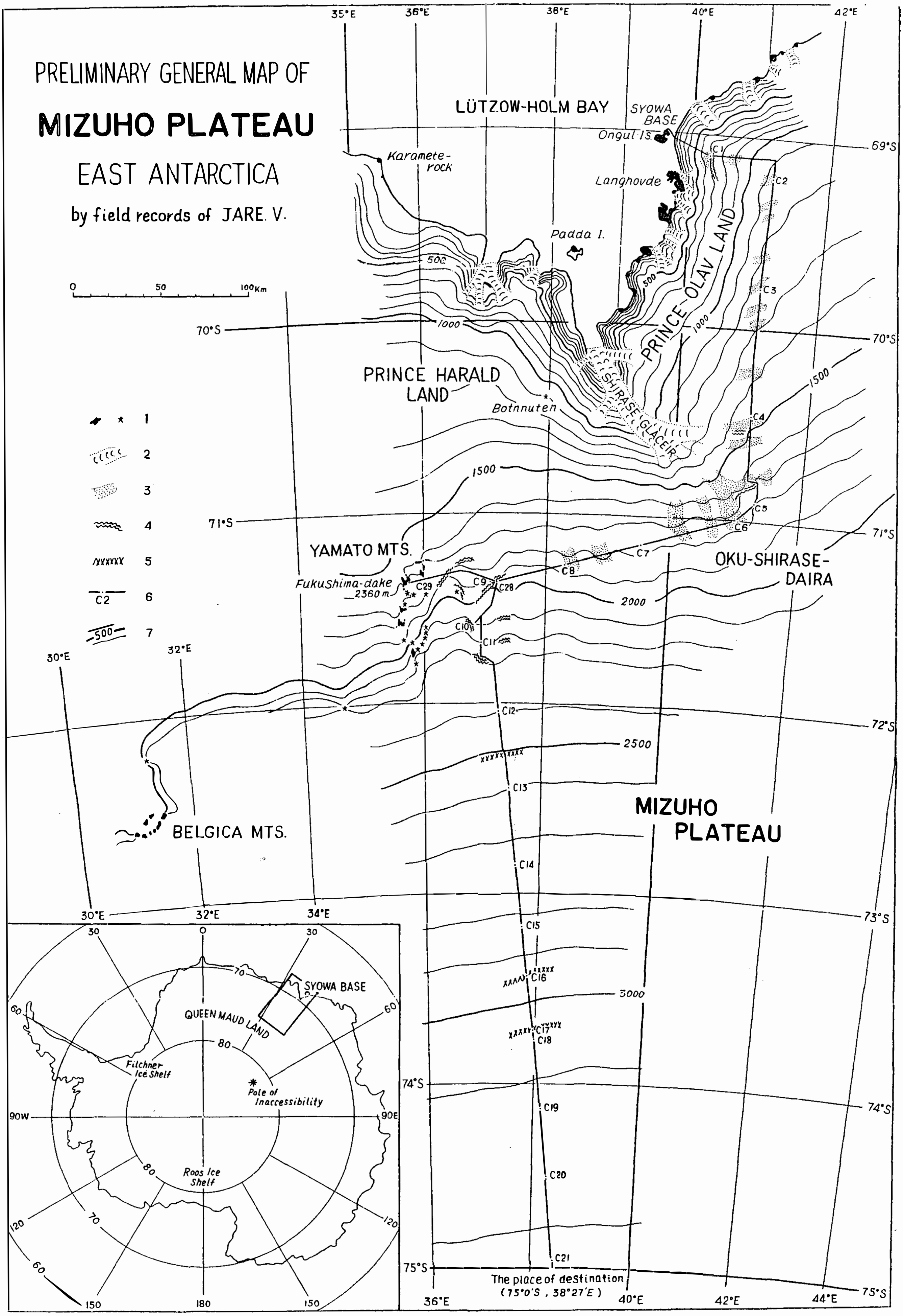

1. Massifs and nunataks.
2. Glacier and ice stream.
3. Trough on the ice sheet surface.
4. Crevasse zone.
5. Transverse step in the inland plateau.
6. Trip route and camp number.
7. Form lines at approximately 100 m intervals.

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