Preliminary Report of Glaciological Study at Brunt Ice Shelf Near Halley Base, Antarctica in January 1982

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1982年1月英国ハレー基地付近のブラント棚氷における雪氷調査概報

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要旨: 1981年から1982年にかけての3カ月間，交換科学者として英国南極観測隊(British Antarctic Survey)に参加し，1月中旬にハレー基地のあるブラント棚氷で，1.75 m 深の積雪断面観測と 22 m コア掘削を行った．層位解析と試料の pH 測定による予察的な解析から，ハレー基地付近の積雪の堆積環境の特性として，次のことが明らかとなった．1)積雪の pH は，夏から秋に小さくなる傾向がある．2)コア底部の年代は 1952/1953 年の夏で，このため年平均涵養量は，41.6 $g\cdot cm^{-2}$ と推定される．3)しもざらめ層は，秋に発達する．今後，試料の解析（微小固体粒子濃度，総 β 線量，$\delta^{18}O$，化学成分）と気候学的解釈を行い，この地域への大気を通しての物質輸送過程を明らかにしていく．

Abstract: Glaciological work was done on the Brunt Ice Shelf near Halley Base in January 1982 by the author who participated in the British Antarctic Survey as an exchanging scientist. Preliminary results of 1.75 m pit work and the analysis of a 22 m long core obtained with a microdrill system indicate (1) the seasonal variation in acidity of snow, (2) the average annual balance of $41.6\, g\cdot cm^{-2}\cdot a^{-1}$ and (3) the depth hoar development in autumn. Further analysis of samples, such as microparticle concentration, gross β activity, $\delta^{18}O$ and chemical component, and the climatological interpretation will clarify the process of atmospheric transportation of materials to the Brunt Ice Shelf, the Antarctic coast in the Atlantic sector.

1. Introduction

This is a preliminary report of glaciological work done on the Brunt Ice Shelf near Halley Base (Fig. 1; 75°31′S, 25°56′W) in January 1982 by the author who participated in the British Antarctic Survey (BAS) under the Antarctic treaty provisions on the exchange of scientists.

Since the Antarctic ice sheet and ice shelves are completely remote from the arid regions in the middle and low latitudes of the Southern Hemisphere and civilized areas, the microparticles in the Antarctic snow and ice provide the information about global atmospheric turbidity. Sea salt from the Southern Ocean and sulfate aerosols seem to be the most probable chemical materials in the Antarctic snow and ice, which are transported through the atmosphere. It is, therefore, considered that the studies on microparticles and chemical components, which describe the acidity of snow and

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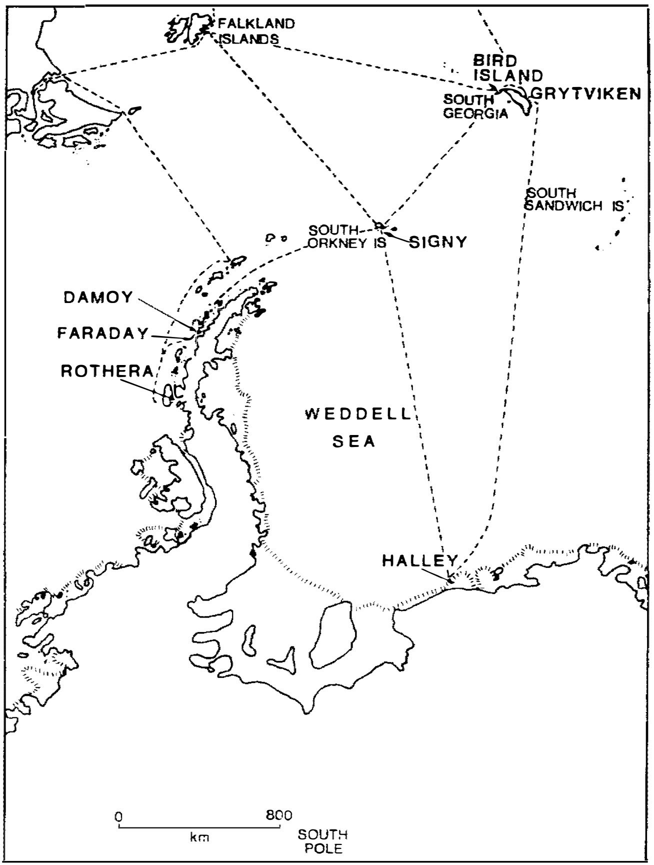

Fig. 1. Voyage route of R.R.S. BRANSFIELD during the period from November 1981 to February 1982 and location of Halley Base.

ice, provide the information about the local and global atmospheric circulation regimes over Antarctica. Furthermore, the relation to the present climate is important as a guide of deep ice cores to past climates.

The purposes of the present glaciological study on the Brunt Ice Shelf near Halley Base were as follows:

a) To clarify the periodicity of microparticle concentration, chemical composition and acidity of surface snow layers and their correlations to the atmospheric circulation.

b) To clarify the recent variation of microparticle concentration and acidity and the correlation to recent climatic variation.

c) To clarify the stratigraphic characteristics of surface snow layers.

2. Glaciological Field Work

The new site of Halley Base about 13 km away from the present base was selected as the site for my glaciological work by the kind cooperation of the BAS personnel on R.R.S. (Royal Research Ship) BRANSFIELD. The site is thought to be an ideal place being well away, in the direction of prevailing wind, from the source of pollution at Halley Base, while being close enough to the base from the viewpoint of the use of the recent climatological data.

Field work was carried out with the help of Messrs. D. D. W. FLETCHER, D. J. CARRIVICK and J. BEATY from January 14 to January 23.

The measurements of acidity (pH) of snow samples were done at Meteorological Office, Halley Base on January 14 with the kind cooperation of the base personnel.

The daily operation is summarized below.

January

14 From BRANSFIELD to Caboose B at 1040 with Mr. D. D. W. FLETCHER. Pit excavation (2.0 m in width and 1.75 m in depth) and the observation. Stay with Mr. FLETCHER till the 16th.

15 Pit observation, measurements of snow density and hardness, and sampling.

16 Setting of drill system and coring to 2.92 m. Recovery of frozen drill at 2.9 m depth. Shift of coring site. Stay with Mr. J. BEATY till the 18th.

17 Coring to 5.9 m depth in the morning and the observation and sampling in the afternoon.

18 Coring to 11.4 m depth. Stay with Mr. D. J. CARRIVICK till the 23rd.

19 Day off due to blizzard.

20 Day off due to blizzard.

21 Coring to 21.8 m depth. Considerable snow drift around the coring site.

22 Core observation and sampling. Fine weather since the evening.

23 Core observation and sampling. Fine weather and calm. From Caboose B to Halley Base at 1830 with Mr. CARRIVICK.

24 Measurement of pH of samples from pit and core at Meteorological Office. From Halley Base to BRANSFIELD at 2100.

3. Pit Work

Glaciological pit work was carried out to reveal the detailed stratigraphic characteristics and to obtain various kinds of samples from each snow layer to clarify the seasonal variation. The pit was excavated with the observation wall 2.0 m wide and 1.75 m deep at a right angle to the prevailing wind indicated by sastrugi.

Stratigraphic observations were as follows:

a) Observation of layer boundary which was classified into two types; with or without ice layer.

b) Observation of the structure of each snow layer by paying particular attention to the ice lenses or columnar ice which was formed by freezing of melt water, and to the type of development of depth hoar. The latter was graded from zero for snow grains without metamorphosis by condensation-sublimation process to ten for well-developed depth hoar such as that with many large cavities.

c) Measurements of density and hardness of snow in each snow layer using a snow sampler and a Canadian Gauge respectively.

The snow samples obtained were as follows:

a) 29 samples for pH measurement with a DKK HG3 pH meter at Halley Base.

b) 33 samples for home analysis of concentration and size distribution of microparticles.

c) 18 samples for home analysis of chemical composition.

d) 31 samples for home analysis of $\delta^{18}O$ (stable oxygen isotope composition).

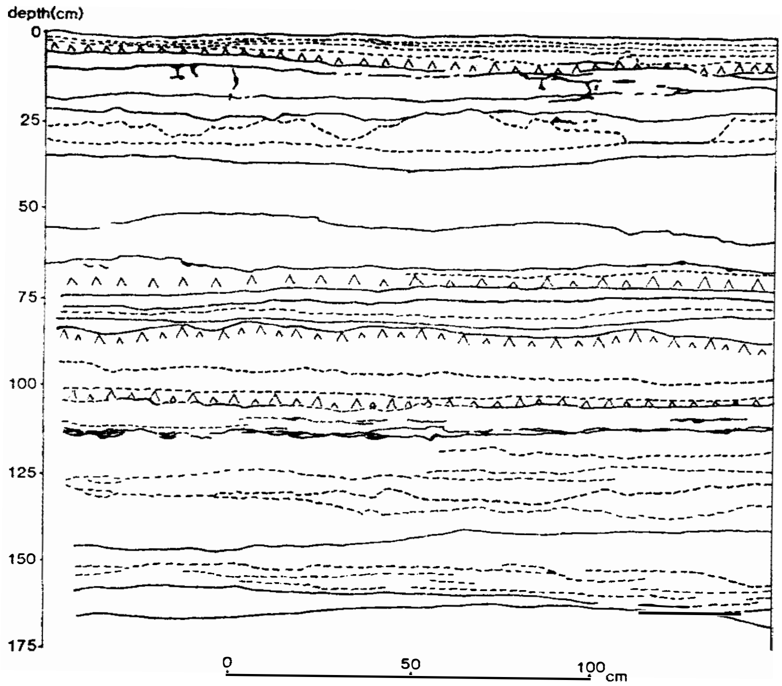

Fig. 2. Snow stratigraphy of the 1.75 m deep pit.

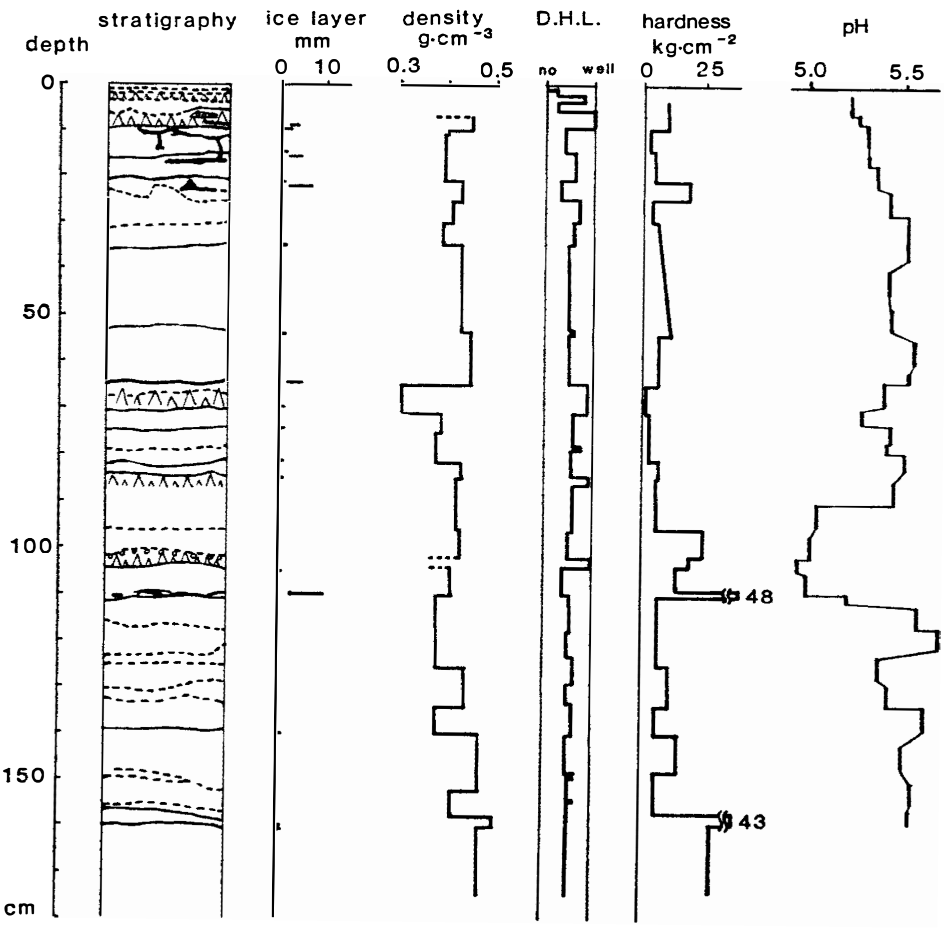

Fig. 3. Stratigraphic diagrams of the 1.75 m deep pit.

The result of stratigraphic observation is shown in Fig. 2. Ice lenses and columnar ice with the thickness more than 3 to 5 mm were found at the depths of 10 to 25 cm and 105 to 115 cm below the surface. These ice-rich layers seem to have been formed in the warmest periods of 1981/1982 and 1980/1981 summers. Well-developed depth hoar was observed at around 10, 70 and 100 cm depths near ice-rich layers. The direction of crystal growth was downward, so the depth hoar seems to have developed from summer to autumn in a year at Halley Base. Discontinuous snow layers were seen at around 25 cm depth and between 120 and 160 cm depths. These discontinuities indicate surfaces which were formed by strong wind erosion of snow previously deposited in the seasons excluding summer.

Figure 3 shows preliminary results of the analysis such as acidity and physical properties of snow. The profile of pH shown in Fig. 3 indicates two features; one is the seasonal cycle in the upper 120 cm with higher acidity in the snow layers formed in the middle to late summer. The other is the tendency that the variation lessens with depth.

4. Core Drilling and the Preliminary Core Analysis

4.1. Core drilling

The core drilling system used was composed of the following equipments. A photograph of the system is shown in Fig. 4.

a) ILTS (Institute of Low Temperature Science, Hokkaido University) type microdrill MK III which was specially designed for the present glaciological work by Prof. Y. SUZUKI. The specifications are as follows:

Total length	1 450 mm	Reduction gear	125:1
Total weight	24 kg	Anti-torque system	Side cutter type with fin
Core barrel length	1 000 mm	Number of blade	4
Diameter of core	102 mm	Number of core cutter	4
Motor (National SSC-812E)	100 V, 220 W, 15 000 rpm		

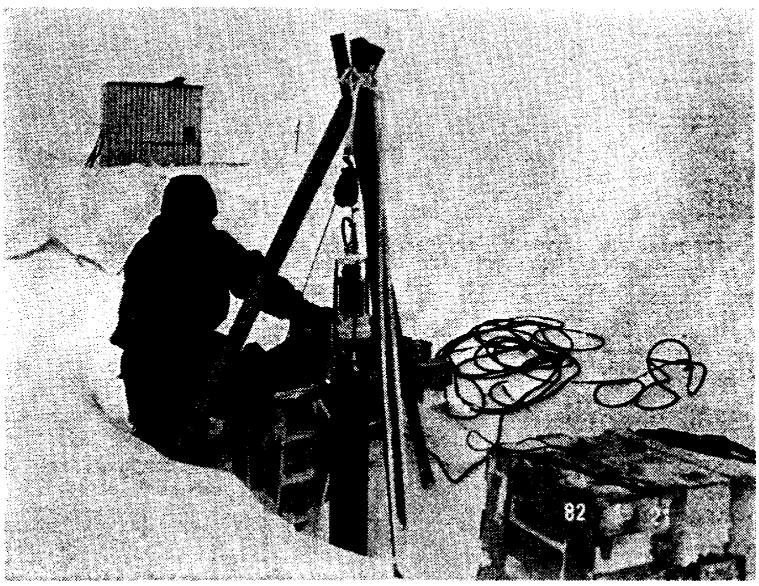

Fig. 4. A photograph of 22 m deep core drilling with a newly designed micro-drilling system.

b) A manual winch with 30 m long wire. Total weight is about 15 kg. The winch was anchored on a wooden box by the deadman method.

c) A control box with a variable voltage regulator, an ammeter and a voltmeter. Input and output are 220 V and 0–150 V respectively. Weight is about 4 kg.

d) A three-pronged fork using rectangular timbers with a small pulley. About 15 kg.

Coring was carried out smoothly with the average speed of 50 to 60 $cm \cdot min^{-1}$ at 50 V and 2 to 2.5 A. There were occasional failures in core cutting, even though core cutters worked quite well against ice when tested in the home cold temperature laboratory.

4.2. Preliminary core analysis

Total core length is 21.44 m from 0.39 m to 21.83 m depth below the surface of January 17. Samples for microparticle analysis and pH were obtained from each layer with the thickness more than about 5 cm, for $\delta^{18}O$ from every two layers and for gross β activity from every probable annual layer below 8 m depth. Numbers of samples are 125, 117, 83 and 12 respectively.

4.2.1. Stratigraphy

As is seen in the pit wall stratigraphy in Fig. 2, thick ice and coarse-grained layer are the most probable summer layer and the easily distinguished annual layer boundary. Table 1 shows the list of depths of probable annual layer boundary judged from the above criteria. When some cold summers make the judgement difficult because of the lack of evidence for snow melting, other criteria such as thin but dense ice layers were used and an uncertain depth of annual layer boundary is shown in parentheses in the table. Analysis of $\delta^{18}O$ and gross β activity will help the core chronology. The present stratigraphical chronology shows the age of core bottom as 1952/1953 summer which gives 41.6 $g \cdot cm^{-2} \cdot a^{-1}$ of mean annual accumulation

Table 1. Depth of probable annual layer boundary.

Depth (m)	Probable summer	Depth (m)	Probable summer
0.1	1981–1982	12.4	1966–1967
1.2	1980–1981	12.8	1965–1966
2.3	1979–1980	(13.6)	1964–1965
3.3	1978–1979	14.1	1963–1964
(4.2)	1977–1978	14.7	1962–1963
5.4	1976–1977	15.4	1961–1962
(6.4)	1975–1976	(15.9)	1960–1961
7.4	1974–1975	16.8	1959–1960
8.0	1973–1974	17.2	1958–1959
(8.6)	1972–1973	18.3	1957–1958
9.3	1971–1972	18.9	1956–1957
10.0	1970–1971	19.6	1955–1956
10.6	1969–1970	20.4	1954–1955
(11.1)	1968–1969	21.0	1953–1954
11.9	1967–1968	21.8	1952–1953

rate. The 5 or 6 annual layer boundaries are indistinguished.

After determining the age of each annual layer on the basis of stratigraphy, $\delta^{18}O$ and gross β activity, the climatological interpretation of the core will be made.

4.2.2. Density profile

Figure 5 shows the density-depth profile of the core. The density of upper 4 m fluctuates considerably reflecting the different original snow textures. The relation between density and depth seems to change at the density of 0.55 $g\cdot cm^{-3}$ at about

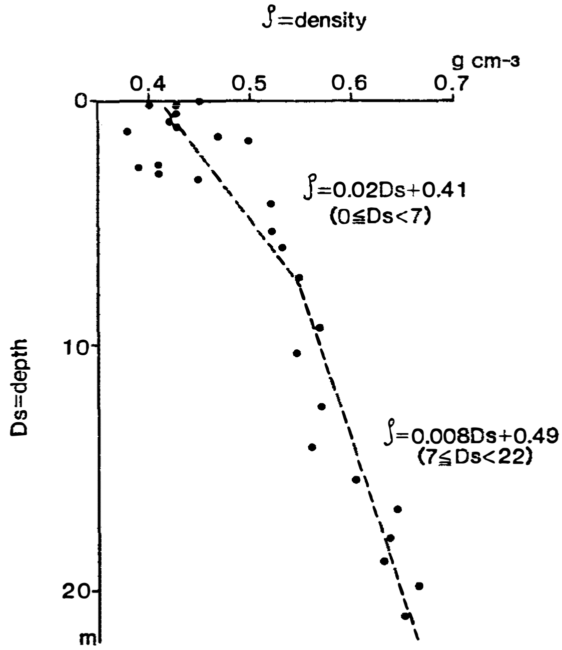

Fig. 5. Density-depth profile of a 22 m long core.

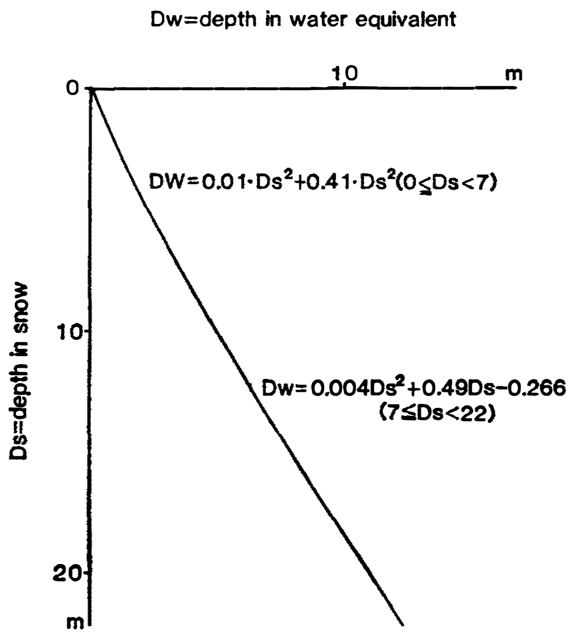

Fig. 6. Relation between depths in snow and in water equivalent of the core.

7 m depth. The density is known as that of the most closely packed snow. Below 7 m, the densification rate with depth decreases to about one third of that in the upper layer. The density of core bottom at 21.8 m depth is 0.65 g•cm^{-3}. Figure 6 shows the relation between depths in snow and in water equivalent of the core.

4.2.3. pH profile

The pH profile of the 22 m long core shows higher acidity in summer or autumn (or late summer) layers as well as the pit wall snow as shown in Fig. 3.

Figure 7 shows the pH profile of the core against linear depth scale of water

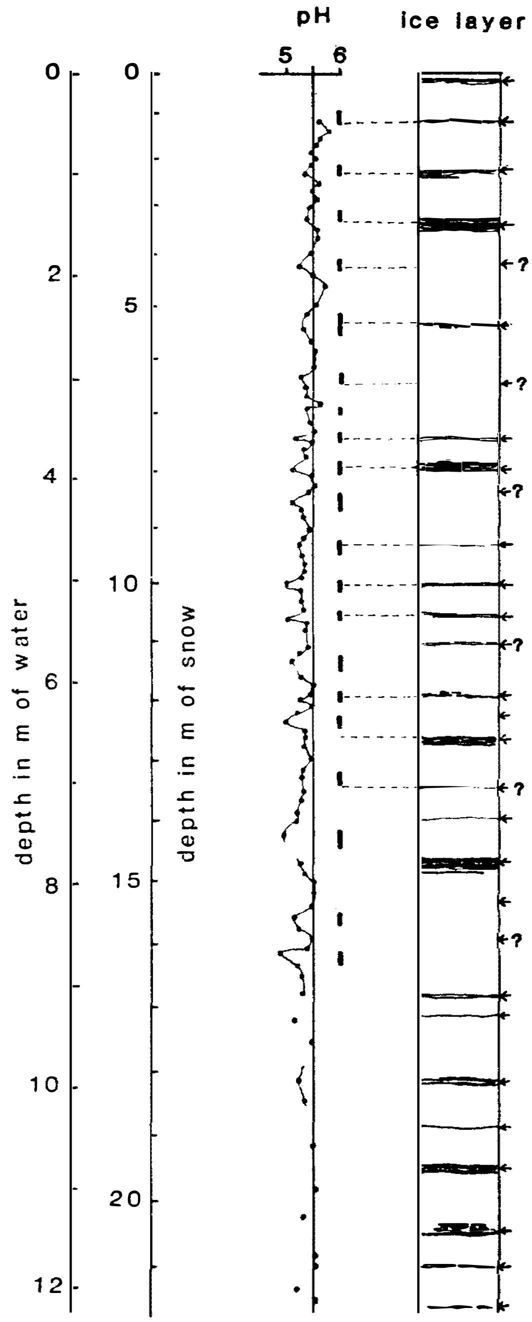

Fig. 7. A pH profile of the core showing the close relation of higher acidity period to summer/autumn season. An arrow indicates an annual layer boundary (summer surface).

equivalent using the relation given in Fig. 6. The short thick lines on the right of the pH profile indicate the period of higher acidity. These correspond to summer or autumn (or late summer) as shown by the existence of thick ice given in the right column. The possible causes of higher acidity of snow in summer and autumn will be carefully examined with reference to the profiles of chemical composition, $\delta^{18}O$ and microparticle concentrations, as well as the climatological data at Halley Base.

The long-term tendency of the last 30 years or so is that the higher acidity lasted for about 10 years from around 1963 to 1973 between the depths of 8 m and 14.5 m.

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