

# The digital mapping of satellite images under no ground control and the distribution of landform, blue ice and meteorites in the Grove Mountains, Antarctica

Sun Jiabing (孙家柄), Huo Dongmin (霍东民), Zhou Junqi (周军其) and  
Sun Zhaohui (孙朝辉)

*School of Remote Sensing and Informatic Engineering, Wuhan University, Wuhan 430079, China*

Received June 1, 2001

**Abstract** The colorful satellite image maps with the scale of 1 : 100 000 were made by processing the parameters-on-satellite under the condition of no data of field surveying. The purpose is to ensure the smooth performance of the choice of expedition route, navigation and research task before the Chinese National Antarctic Research Expedition (CHINARE) first made researches on the Grove Mountains. Moreover, on the basis of the visual interpretation of the satellite image, we preliminarily analyze and discuss the relief and landform, blue ice and meteorite distribution characteristics in the Grove Mountains.

**Key words** Grove Mountains, parameters-on-satellite, satellite image, digital mapping, blue ice, meteorites distribution.

## 1 Introduction

The Grove Mountains are located in the Princess Elizabeth land on eastern Antarctica, the range includes  $73^{\circ} - 76^{\circ}\text{E}$ ,  $72^{\circ}15' - 73^{\circ}15'\text{S}$ , about 100 km vertically and 80 km horizontally. The distance to Zhongshan Station is 380 km or so. The Topography relief shows that it is higher southeastwards, while lower northwestwards, and the drop in level is around 1200 m. In the Grove Mountains, there are more than 50 exposed mountaintops, among which foreign countries have named 16 outcrop peak groups. The average temperature in January is  $-17^{\circ}\text{C}$  or so, and the average wind velocity is 10.2 m/s. So it has been one of our ideal midway station points in the route from Zhongshan Station to eastern Antarctic ice-cover and in the expedition of Antarctica Pole Point.

In 1998, the Chinese National Antarctic Research Expedition (No. 15th) first went to the Grove Mountains for research. In order to ensure the smooth performance of the choice of expedition route, navigation and research task, the China Surveying and Mapping Research Center of Antarctica processed the parameters-on-satellite and made the colorful satellite image map with the scale of 1 : 100 000 under the condition of no date of ground control points. By analysis and interpretation of the satellite image map, we have found that the Grove Mountains may be considered to be ideal areas of concentrated meteorites distribution where blue

ice is widely distributed on a great surface areas. The unique relief became the protective screen to stop ice-flow widespread.

## 2 Digital mapping of satellite images under no ground control points in the Grove Mountains

### 2.1 The data

Satellite images are the data of waveband 4, 3, 2 of two images, the two images 122/ 111 and 122/ 112 are acquired from TM in LandSat-4. The height of orbit is 705 km, the inclination is  $98^{\circ}22'$ , the period is 98.9 min, and the cycle of repetition is 16 d. The satellite passes through the region at about 7:00 in the morning of local time. The width of image is 185 km. The wavelengths of the three wavebands are separately TM4/ (0.76 – 0.90)  $\mu\text{m}$ , TM3/ (0.63 – 0.69)  $\mu\text{m}$ , and TM2/ (0.52 – 0.60)  $\mu\text{m}$ . The two images are not acquired at the same time because of weather. The one 122/ 112 near south was acquired on Jan. 6, 1990, in which a small part of it or in its northwest is covered by clouds, it may be because clouds covered a large area of north that day. So the image 122/ 111 was acquired by satellite after a repetition cycle on Jan. 22, 1990. And that caused the above two images to show differences in contrast and hue. GPS is equipped in LandSat-4 and the parameters such as the center coordinates of images can be read out in the head file of digital image tape. It is indicated as following Table 1.

The recording pattern in digital image tapes is the continuous BSQ pattern, per row per pixel according to waveband. The size of image is  $5963_L \times 6964_P$ . Moreover, the satellite provides part of posture parameters.

Table 1. The center coordinate of 122/ 111 and 122/ 112 images, the sun altitude angles and the sun azimuths

No. of images	Longitude	Latitude	The sun attitude	The sun azimuths
122/ 111	$76^{\circ}52'31.2159''\text{E}$	$72^{\circ}13'04.9977''\text{S}$	$27^{\circ}$	$70^{\circ}$
122/ 112	$74^{\circ}25'24.6952''\text{E}$	$73^{\circ}29'04.0395''\text{S}$	$29^{\circ}$	$71^{\circ}$

### 2.2 Image correction

On the basis of imaging characteristics of TM, the relationship between image points on every scanning line and the ground coordinate can be indicated by co-line equation.

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix}_P = \begin{vmatrix} X \\ Y \\ Z \end{vmatrix}_S + \lambda A R_0 \begin{vmatrix} 0 \\ 0 \\ -f \end{vmatrix} \quad (1)$$

Final mapping is completed by applying Gause-Klarke Coordinate System. The Earth ellipsoid employs Krasovsky referential ellipsoid, the parameters are  $a = 6378.245$  km,  $e = 0.08181333$ . The geographic coordinates (longitude and latitude) is used to position in GPS, it should be transformed into Gause Coordinates by the following formula (2):

$$\begin{aligned}
X_m = & S + \frac{N}{2} t \cos^2 B \cdot l^2 + \frac{N}{24} t (5 - t^2 + 9\eta^2 + 4\eta^4) \cos^4 B \cdot l^4 + \\
& \frac{N}{720} t (61 - 58t^2 + t^4) \cos^6 B \cdot l^6 \\
Y_m = & N \cos B \cdot l + \frac{N}{6} (1 - t^2 + \eta^2) \cos^3 B \cdot l^3 + \frac{N}{120} t (5 - 18t^2 + t^4 + 14\eta^2 - 58\eta^2 t^2) \cos^5 B \cdot l^5
\end{aligned} \tag{2}$$

But WGS-84 System is adopted in GPS, which is different from Krasovsky ellipsoid in parameters and position of Earth's core. So the conversion between these two systems is necessary. The differences of the center coordinates in the two systems are shown in Table 2.

Table 2. Comparison of the center coordinates of 122/ 111 and 122/ 112 images between the WGS-84 and Krasovsky systems

No. of images	Ellipsoid used in coordinate calculation	X/m	Y/m
122/ 111	Krasovsky ellipsoid	529849	1983182
	WGS-84	529848	1983321
122/ 112	Krasovsky ellipsoid	449962	1841413
	WGS-84	449963	1841553

Gause projection is adopted in Table 2. The center meridian is laid on 76°E. The coordinate system moves 500 km westwards and 10000 km southwards. The order calculative formulae (Sun 1997) from equation (1) are:

$$\begin{aligned}
X_P = & X_S + (Z_P - Z_S) \frac{a_{12}f \sin\theta - a_{13}f \cos\theta}{a_{32}f \sin\theta - a_{33}f \cos\theta} \\
Y_P = & Y_S + (Z_P - Z_S) \frac{a_{22}f \sin\theta - a_{23}f \cos\theta}{a_{32}f \sin\theta - a_{33}f \cos\theta} \\
Z_P - Z_S = & -H \text{ when relief is ignored.}
\end{aligned} \tag{3}$$

Because the way of the order calculation cannot put corrected image pixels in good order, resampling of gray scale is adopted to rearrange image pixels. First the size of corrected image pixels is set to 20 m × 20 m, and then interpolation of gray weight is used:

$$I' = \frac{\sum_{i=1}^n K_i I_i}{\sum_{i=1}^n K_i} \tag{4}$$

After being corrected, the relative positioning accuracy of more than 20 match points of the upper and lower images is 460 m in X-direction, 660 m in Y-direction. The two images can be classified in unified coordinate by matching and adjusting between images.

### 2.3 Mosaic of images

As stated above, the upper and lower images acquired in different time have differences in hue and contrast. Image matched only can solve geometric continuity. If directly mosaic, images have distinct seam. So gray scale of the two images must be adjusted and the mosaic rim must be smoothed also.

### 2.3.1 Search of the boundary of mosaic

Mosaic boundary line can be selected in the range of images' overlaps, and be made up of points whose brightness values are the nearest in the two images, upper and lower or left and right. The lines should be a curve. In Antarctica because the scenery is monotonous. they form approximately broken line as showed in Fig. 1. One-dimension module is used to find the mosaic points. It's supposed that the width of overlap is  $K$ , the length of one-dimension module is  $W$ , the pixel number of the center point of module in left and right images is  $T$ . Beginning with  $T$ , the module is moved from left to right and start to searching. The methods are:

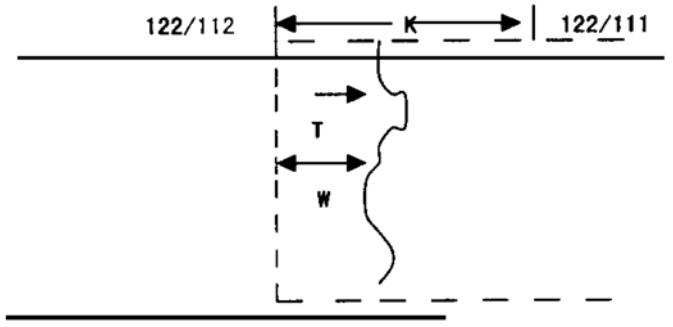


Fig. 1. The digital mosaic of images.

#### 2.3.1.1 Difference

$$D(i)_n = \sum_{j=-W/2}^{W/2} |L(i+j)_n - R(i+j)_n| \quad (5)$$

$D(i)_n$  in this formula is the absolute value of the sum of the left and right images' difference in module;  $i$  is the pixel number of the left and right image from  $T$  to  $(T+K-W)$ ;  $N$  is the row number;  $L(i+j)_n$  and  $R(i+j)_n$  are brightness values of the left and right images;  $j$  is the pixel number in module. There are  $(K-W)$   $D(i)$  in one row and among them the minimum  $D(i)_{\min}$  is the mosaic boundary point.

#### 2.3.1.2 Interrelated coefficient

$$r(i)_n = \frac{\sum_{j=-W/2}^{W/2} [L(i+j)_n \cdot R(i+j)_n]}{[\sum_{j=-W/2}^{W/2} L^2(i+j)_n \cdot \sum_{j=-W/2}^{W/2} R^2(i+j)_n]^{1/2}} \quad (6)$$

The symbols in this formula have the same meanings as Formula (5). And accordingly there're  $(K-W)$   $r(i)$  among which the maximum  $r(i)$  is selected to be the mosaic boundary point.

We have found that the way of Interrelated Coefficient took us much more time than Difference and its result is inferior to difference. So finally Difference is selected and used to search mosaic boundary line.

### 2.3.2 Enhancement

It's necessary to adjust the contrast of one of the two images after the boundary of mosaic is found. First the average brightness value, the max and the min brightness value of the boundary is calculated. The average brightness value, the max and the min brightness value of 122/111 and 122/112 are shown in Table 3.

$$R'^{111} = R^{112} + (R_{ave}^{112} - R_{ave}^{111}) \quad (7)$$

Table 3. The concerning brightness value of the two images

No. of images	$D_{\min}$	$D_{\max}$	$D_{ave}$
122/111	0	158	74.74
122/112	0	220	76.63

Add the whole image of 122/111 to the difference of the average brightness value of

the two images:

$$R'' = AR' + B \quad (8)$$

And then stretch the contrast of 122/111. In above formula:

$$A = \frac{R_{\max}^{112} - R_{\min}^{112}}{R_{\max}^{111} - R_{\min}^{111}}, \quad B = -A \cdot R_{\min}^{111} + R_{\min}^{112}$$

It is better to use sectional linear stretch according to the distribution characteristics of the ground object in images.

### 2.3.3 Smooth boundary

The boundary of the two images is still obvious. Smoothing with weight is used to eliminate the boundary of the mosaic images. 49 points with the length of 99 points are selected separately on the two sides of boundary points are shown in Fig. 2. So

$$D_i = \begin{cases} D_i^{111} & i < j - (s-1)/2 \\ D_i^{112} & i > j + (s-1)/2 \\ P_i^{111} D_i^{111} + P_i^{112} D_i^{112} & j - (s-1)/2 \leq i \leq j + (s-1)/2 \end{cases}$$

In the formula  $j$  is the pixel number of the boundary points in images;  $i$  is the pixel number;  $D_i^{111}$ ,  $D_i^{112}$  are respectively pixel brightness of the 122/111 and 122/112 at point  $i$ .

Weight:

$$\begin{cases} P_i^{111} = \frac{j - i + (s+1)/2}{s+1} \\ P_i^{112} = \frac{(s+1)/2 - j + i}{s+1} \end{cases}$$

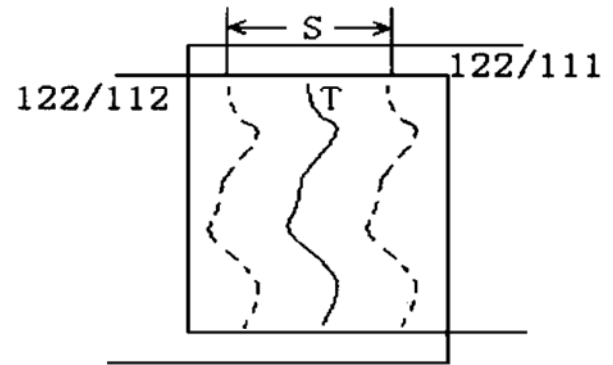


Fig. 2. The boundary of mosaic.

### 2.4 Mapping

The mapping range should include all outcrops and peaks, whose distribution area covers  $800 \text{ km}^2$ . The specific size of map designated is:  $Y_{\text{southmost}} = 1970000 \text{ m}$ ,  $X_{\text{westmost}} = 420000 \text{ m}$ ,  $Y_{\text{northmost}} = 1970000 \text{ m}$ ,  $X_{\text{eastmost}} = 500000 \text{ m}$ . Fig. 3 is the satellite image map of the Grove Mountains. The original coordinate point is selected  $10000 \text{ km}$  southwards far from equator. So it is convenient in application that the value of  $Y$  in the map can be regarded as approximate distance away from the Antarctica point. The kilo grids  $10 \text{ km} \times 10 \text{ km}$  are arranged in the map for the convenience in surveying distance and coordinate. Generally longitude and latitude are displayed when positioning with GPS. The grid whose latitude difference is  $15'$  and longitude difference is  $1^\circ$  is also marked in the map in order that the positioning data by GPS can be marked sooner in the map. The grid node should be marked after its coordinates in map are calculated with longitude and latitude values through formula (2). The meridian converges in the polar region that makes the intervals between longitudes smaller. So the projection of latitude shows the curvature with bigger curving line. The positioning precision varies from  $-200 \text{ m}$  to  $+200 \text{ m}$ , which has been testified by the 15th Chinese National Antarctic Research Expedition who first marched into this region and navigated with this image map.

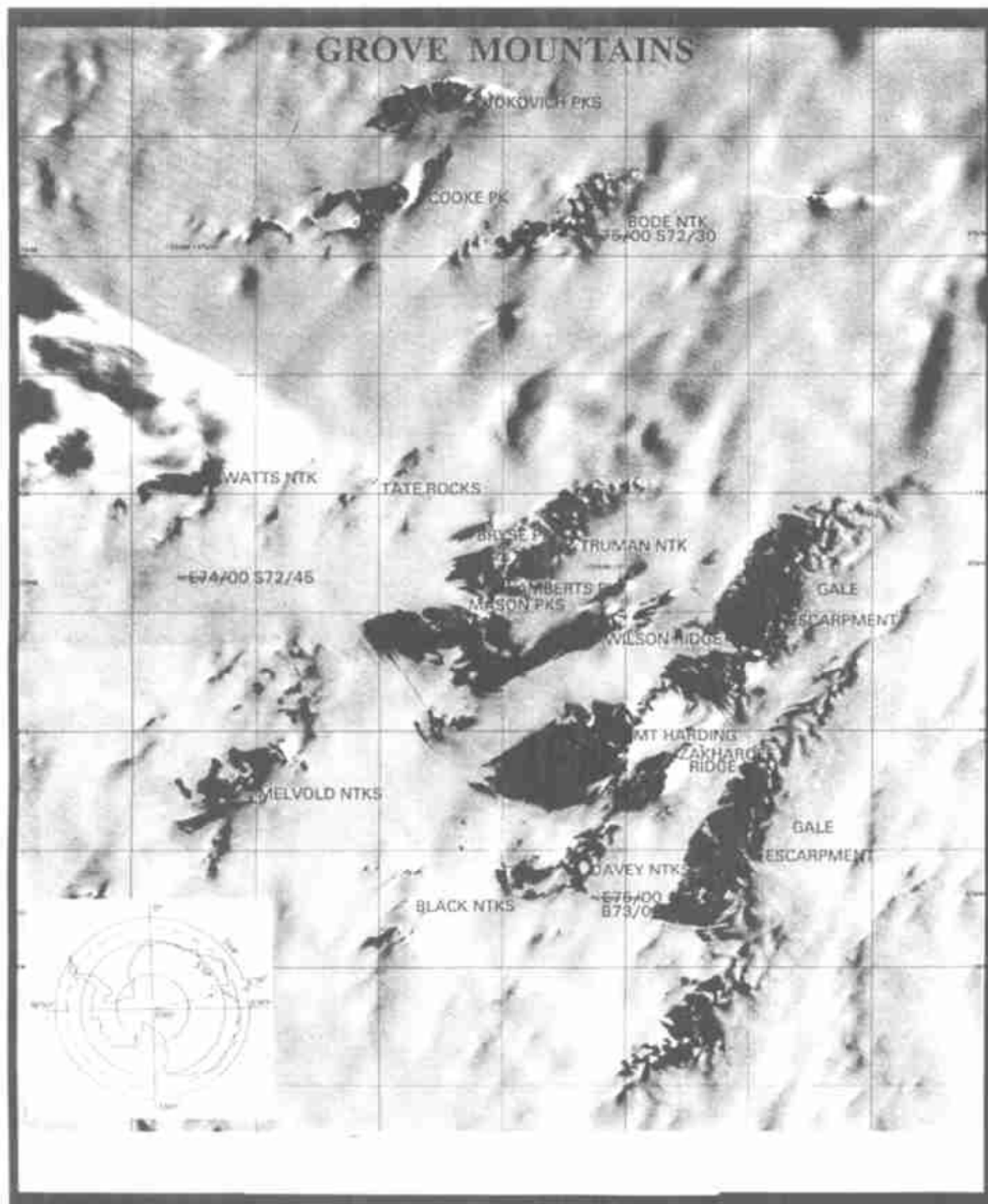


Fig.3. The satellite image map of the Grove Mountains (an originally colorful satellite image map with the scale 1 : 100 000).

### 3 Analysis of relief, blue ice and meteorites distribution in the Grove Mountains

#### 3.1 The characteristics of relief

The elevation is more than 2600 m in the southeast and beneath 1400 m in the northwest in this region through interpretation and analysis according to the colorful satellite image map of the Grove Mountains and other interrelated collected data. The glacier flows generally from southeast to northwest. Northeastward mountains

and many groups of peaks under ice form the protective screen to stop ice-flow. It makes the surface of ice to be distributed step by step. Among them there are three sections of large-size snow cliff whose length ranges from over 10 km to over 30 km. Some of them have over 300 m' drop in level. It's relatively flat before the cliff, but the form of ice is complex after cliff and peak. Some areas can be observed, from the satellite image, their distribution just like the bird's wings. The top of peak stands tall, erect and steep, and it is seldom covered by snow under the force of strong wind. It forms group of peaks with outcrop. Snow cliffs and peaks are distributed concentratedly in an area of over 1600 km<sup>2</sup> on 74°30'E - 75°45'E and 72°40'S - 73°05' S. They are also fragmentarily distributed in some other regions of the image map.

### 3.2 Blue ice and meteorites distribution

The protective screen of relief makes blue ice with hard bottom flow upwards to the ground. Strong wind's blowing clears away the surface covered with snow (Wang *et al.* 1999), which makes blue ice of large areas to be developed and formed. After survey of the spectrum brightness values of multi-spectrum images, it has great difference among the outcrop, the blue ice and the snow on the spectrum characteristics. Fig 4. shows the characteristic curves of spectrum from the above three representative ground objects. And the surveying values are listed in Table 4.

Table 4 The spectrum brightness values of the outcrop, the blue ice and snow

Name of ground object	Brightness value			Remark
	TM4	TM3	TM2	
Outcrop	8	19	20	
	12	25	34	
	34	39	31	Face sun
	65	72	50	Face sun
Blue ice	83	166	162	
	79	159	157	
	70	145	146	
Snow surface	147	204	179	
	184	241	208	Face sun

TM4, 3, 2 are separately indicated with the colors of red, green and blue, when pseudo-color image is synthesized, the snow displays green in color, the blue ice blue-green and the outcrop brown-red (because the outcrop is enhanced solely and made bright red), the distribution of blue ice is so clear in the map. Most of the blue ice is distributed behind cliff and peak from the image. The reason is that glacier is heaped before cliff and peak, while the glacier passing through cliff and peak drops down, its cover of surface is scraped away by strong wind. Through surveying the area of the blue ice and outcrop in the image, the total area of the above two ground objects in the Grove Mountains is showed in Table 5.

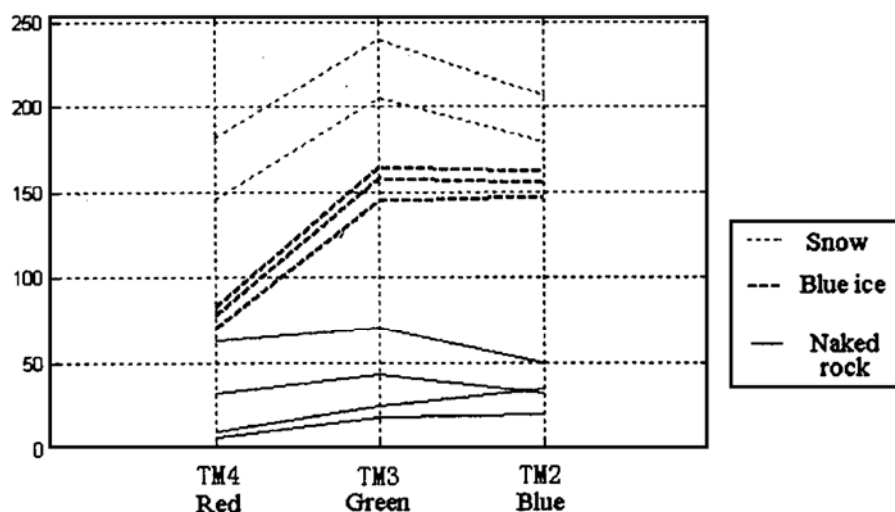


Fig. 4. The characteristic curves of spectrum reflection from the three representative ground objects — the outcrop, the blue and the snow.

Table 5 The total area of the blue ice and outcrop in the Grove Mountains

Name	Area / km <sup>2</sup>
Blue ice	559.351
Outcrop	7.320

The blue ice is distributed in a great area and breeds stranding surface of meteorites enrichment (Wang *et al.* 1999). When meteorites start to drop down, they are scattered in ice and snow of surface and mid-layer in Antarctica. They are moved with flowing glacier, gathered and piled up at the valley gateway of ice flow. When meeting the protective screen, such as bulging relief or especially cliffs, the blue ice is exposed, the cover of surface is swept off by strong wind. The meteorites still remain on the surface of the blue ice for their great quality (Wang *et al.* 1999). It has been reported that meteorites are found in the blue ice area overseas. In the Yamato Mountains named by the Japanese Antarctic Expedition, the blue ice is seen in an area of about 4000 km<sup>2</sup>, unexpectedly, more than 6000 pieces of meteorites fragments are also found. Although the area of the blue ice in the Grove Mountains has only 560 km<sup>2</sup> or so, its unique relief and climate become the extremely good condition for meteorites enrichment, especially the relief of the Gale Escarpment advances over 50 km continuously from southern section, middle section to northern section, and is approximately vertical to the moving direction of glacier. Three sections of the Escarpment forms three terraces in the southern and middle sections the terraces are parallelly distributed for about 8 km, and in the middle to northern sections they are recovered for over 15 km. Meteorites were first gathered over the Escarpment. The 15th Chinese National Antarctic Research Expedition recovered three meteorites over the northern section of the Gale Escarpment. But the glacier rushes down continuously over the Escarpment with too much covering snow, many meteorites moved down and were heaped on the blue ice under the Escarpment. The blue ice covers a great area and the wind performs a good function in blowing and melting, so it's easy to find meteorites here. The 16th Chinese National Antarctic Research Expedition just recovered 28 meteorites under the southern section of the Escarpment (Ju and Liu 2000) and the 15th CHINARE picked up one meteorite



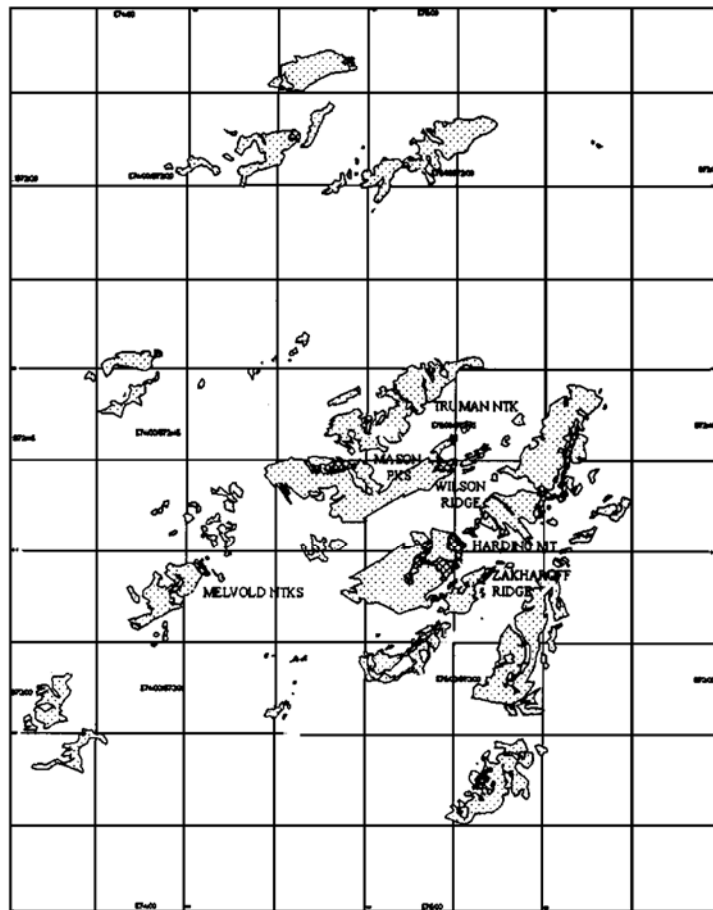


Fig. 5a. The panorama of the Grove Mountains.

under the middle section of the Gale Escarpment. Hereafter it is still necessary to search meteorites over and under the northern and middle sections of Escarpment. As to Harding Mountain, Zakharoff ridge and Wilson ridge etc. , these peaks also have a great number of the blue ice and, theoretically, the meteorites are likely to be heaped in these regions. But the distribution will be much less than that of the Gale

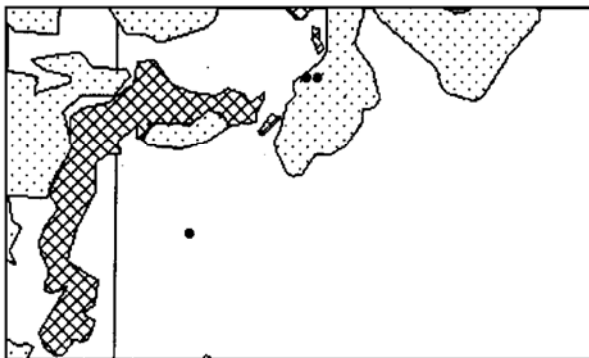


Fig. 5b. The meteorites enrichment area in the north of the Gale Escarpment (in the figure, the IDs of the three meteorites are respectively GRV9802, GRV9803 and GRV9804. The another one is located in the middle part of the Gale Escarpment. The figure 5a can be referenced).



Fig. 5c. The meteorites enrichment area in the south of the Gale Escarpment (in the figure, the IDs of the 28 meteorites are respectively GRV9802–GRV0028).

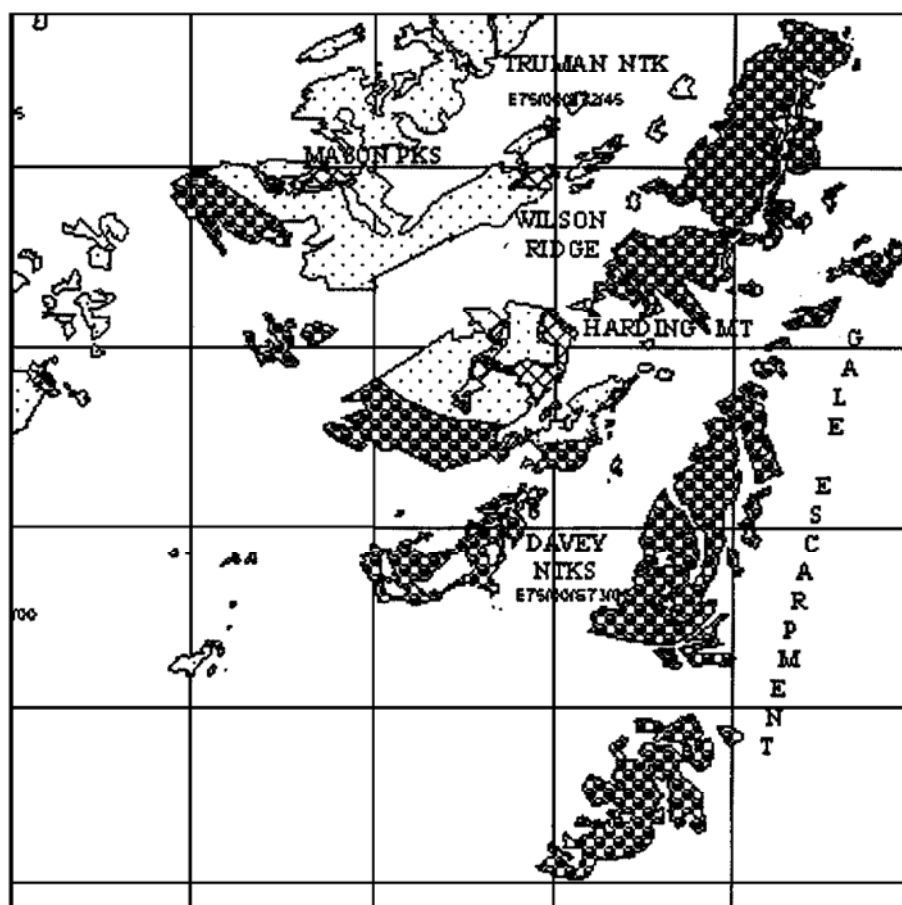


Fig. 6. The meteorites are probably distributed in these areas of the Grove Mountains.

Escarpment and mainly be at the valley gateway of ice-flow (Wang *et al.* 1999). Another phenomenon is that in these regions weathering stones from peaks are scattered on the blue ice and be mixed up with meteorites, which makes it difficult to search few meteorites. Fig. 5 (a, b, c) shows the blue ice distribution and the sites of recovered meteorites in the Grove Mountains. They maybe new gathering sites of meteorites on the sides of the Gale Escarpment. On the basis of interpretation and analysis, the areas where the meteorites were probably distributed were drawn out in 1998 in Fig. 6.

**Acknowledgments** Thanks to Mr. Li Guo from National Bureau of Oceanography and Liu Xiaohan from Institute of Geology and Geophysics of Chinese Academy of Sciences for their supports.

## References

- Sun JB (1997): Principles and methods and application of remote sensing. Beijing: House of Surveying and Mapping, 162 - 164, 171 - 172.
- Wang DD, Lin YT, Dai CD, Chen YH (1999): Comparisons of Antarctic meteorites and desert meteorites. Chinese Journal of Polar Research, 11(2): 125 - 127.
- Ju YT, Liu XH (2000): Meteorites collection in the Grove Mountains. Chinese Journal of Polar Research, 12(2), 137 - 141.