Chinese Journal of Polar Science, Vol. 14, No. 1, 73－80, June 2003

Comparative studies in method for stratigraphical structure measurement of ice cores: Identification of cloudy bands

Morimasa Takata[1,3], Hitoshi Shoji[2], Atsushi Miyamoto[2,3] and Kimiko Shimohara[2]
1 National Institute of Polar Research, Kaga 1－9－10, Itabashi-ku, Tokyo 173－8515, Japan
2 Kitami Institute of Technology, Koencho 165, Kitami, Hokkaido 090－8507, Japan
3 Institute of Low Temperature Science, Hokkaido University, N19W8, Kita－ku, Sapporo, Hokkaido 060－0819, Japan

Received April 26, 2002

Abstract Cloudy bands are typical stratigraphic structure in deep ice core. Detailed recording of cloudy bands is important for dating of ice core since pair of series cloudy band and clear layer is corresponds to annual layer and it sometimes corresponds to volcanic ash layer. We developed two type scanners, transmitted light method and laser tomograph method for the stratigraphic study. Measurements were carried out for NGRIP deep ice core, which containing many cloudy bands, using the two type scanners and digital camera. We discussed about the possibility of identification of cloudy bands by each method and about advantage and disadvantage of measurements and their results.
Key words Ice core, cloudy band, physical structure, laser tomograph, measurement technique

1 Introduction

Cloudy bands are typical stratigraphic structure in deep ice cores and they look white color when a florescent light was irradiated. In Wisconsin ice-age ice at the Greenland, many cloudy bands are located in cold periods ice and cloudy bands are used for dating of deep ice core since pair of series cloudy band and clear layer corresponds to annual layer (Alley *et al*. 1997; Meese *et al*. 1997). And cloudy band corresponds to volcanic layer for the Antarctic ice core (Gow and Williamson 1976). Therefore, identification of cloudy bands is important work for dating of ice cores.

We developed two type scanners, (1) transmittance light method and (2) laser tomograph method and carried out stratigraphical measurement using a digital camera and the two type scanners. Line scanner method is one of a transmittance light method. It was used for continuous measurement of Greenland and Antarctic ice cores at field and cold room as an initial core analysis. Cloudy bands were identified well for Greenland ice core (Dahl-Jensen *et al*. 2002). Laser tomograph measurement was carried out for Antarctic deep ice core by Fujii (1997) and for Greenland shallow ice core by Takata *et al*. (2002).

We compared results obtained by three type measurements and discussed about advantage and disadvantage of obtained image and measurement.

2 Methods

Measurement sample was obtained at NGRIP site, Greenland, in 2000 season. The sample depth is 1803.45 – 1804.00 m and the age is about 24 thousand yeas ago which corresponds to cold period between warm interstadials (IS) 2 and 3 in Wisconsin ice-age (Clausen, personal communication). Annual layer thickness was estimated to be 19 mm at the depth (Johnsen, personal communication). The ice core sample includes many cloudy bands. Sample shape is slab with 30 mm thick and 98 mm width, made by cutting two side of ice core. Pictures by digital camera of the ice core sample were obtained at the field. The sample was sent to Kitami Institute of Technology, Japan, and stored in – 20 ℃ cold room. Scanner type measurements, transmittance light method and laser tomograph method, were carried out five month later after the drilling of the ice core.

2.1 Digital camera

Pictures of the ice core sample were obtained by a digital camera, Olympus C2500L. Both surfaces of the slab ice sample were cleaned with microtome knife. The sample was put on a black cloth and fluorescent light was irradiated from side of the sample as light source. Pictures were taken for divided three parts of one ice core sample of 55 cm long in order to obtain a high spatial resolution image. After taken pictures, mosaic image of whole the core sample was obtained by connecting the three pictures using image edit software on PC.

2.2 Scanner type measurements

Figure 1 shows a schematic drawing of our scanner system. Equipment is shown in Fig 1a. Light source 1, high frequency fluorescent lights with slit plate, was used for transmittance light method. And light source 2, laser head, was used for laser tomograph method. Different in equipment between laser tomograph method and transmittance light method is only the light source and it will easy to change two light sources. The light source and CCD camera were mount on a moving stage and were moved simultaneously along the ice core sample at a constant speed of 5 mms^{-1}. CCD camera images were recorded in digital video during the moving stage was in motion. Data analysis procedure is shown in Fig 1b. After the measurement, obtained images on digital video were captured on the PC as movie file. Transmittance light image or laser tomograph image was obtained by analyzing movie files using our developed image analysis program for transmittance light measurement or laser tomograph measurement, individually.

Transmittance light method Concept of this equipment was same as used by Dahl-Jensen *et al*. (2002). We used simpler light source, high frequency fluorescent lights with slit plate, alternately their light source. Light comes from transmittance direction and fluorescent lights located below of CCD camera was masked with slit plate in order to avoid that fluorescent lights were taken in center part of image where we used for image analysis. Slit plate was painted frosting black. A part of the sample was irradiated by the light source from transmittance direction and another the surface was observed with CCD camera. Before the measurement, observation and light incident surfaces of the sample were treated with microtome knife.

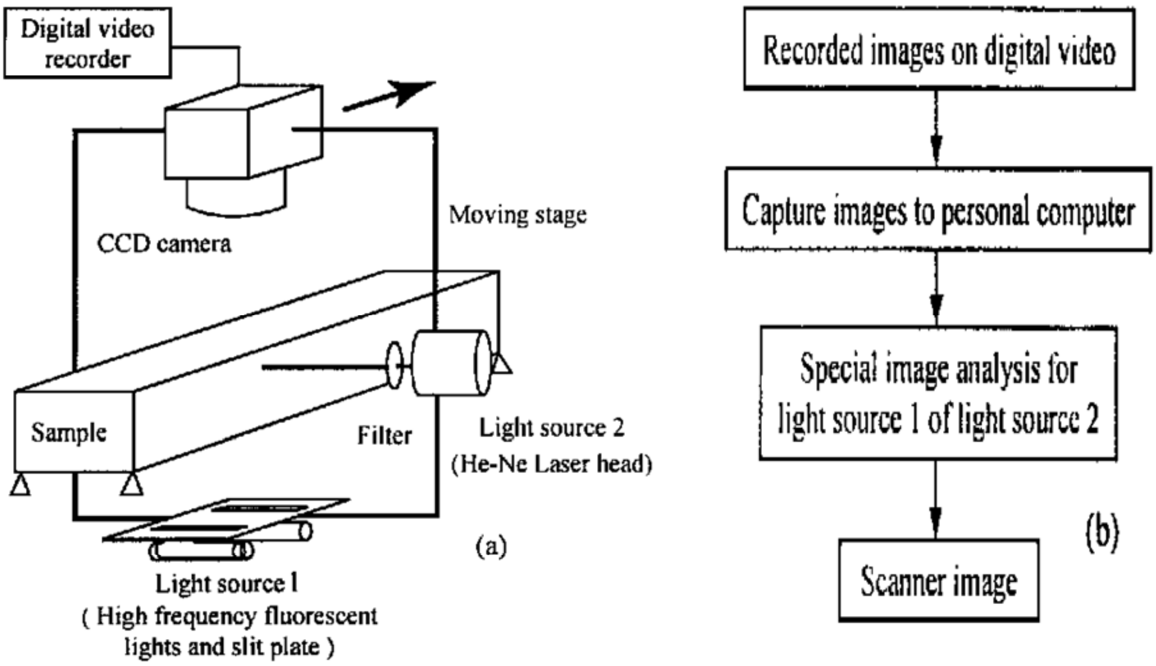

Fig. 1. Schematic drawing of scanners system. (a) Measurement equipment. A light source 1, fluorescent light with slit plate, was used for transmittance light method as light source. A light source 2, laser head, was used for laser tomograph method. (b) Data analysis procedure.

Laser tomograph method Detail of this system was described in Takata and Fujii (2000). Laser beam was irradiated to ice sample from right angle to observation surface and scattering image were observed using a CCD camera. We first apply our developed equipment to deep ice core study. Measurement settings and analysis program to obtain a laser tomograph image were almost same that of shallow core analysis. Before the measurement, observation and laser irradiation surfaces were treated with microtome knife.

3 Results and discussion

3.1 Digital camera

Figure 2 shows the result of mosaic image. The method is easiest way in order to identify each cloudy band in a picture using the difference of brightness. Although we carefully connect the pictures, they did not fit well. Discontinuity, 0.5 mm in maximum, occurs at boundaries of picture frames. And even though same position in ice core sample was taken in pictures, brightness is different with each picture due to inhomogeneous light condition. Therefore continuous measurement of stratigraphy in ice core using this method is difficult since (1) complete connection of pictures is difficult and (2) getting brightness only accordance with difference of stratigraphical layers is unavailable.

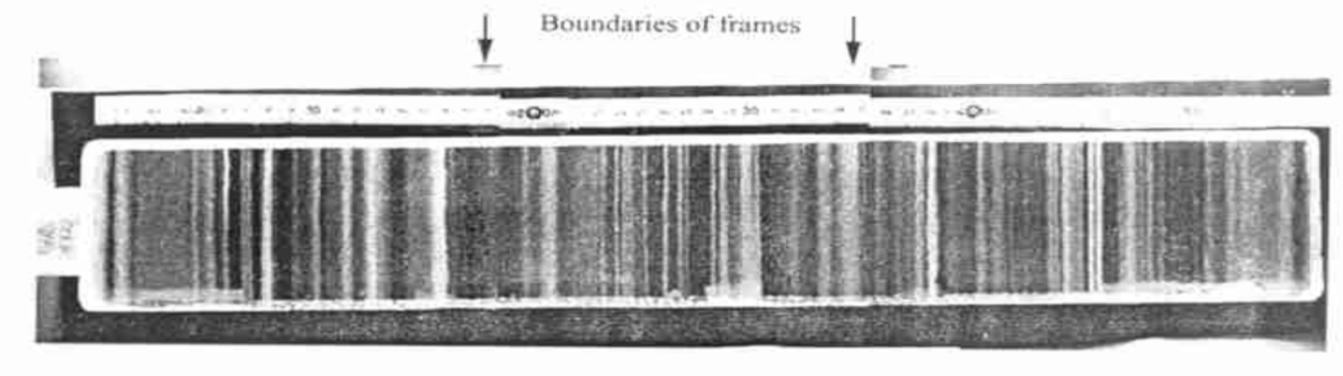

Fig. 2. Mosaic image of ice core obtained by digital camera.

3.2 Scanner type measurements

Scanner type methods solve the problems of discontinuity of image and inhomogeneouslight condition since light sources locate at completely same position from sample and CCD camera during the measurement and frame images are obtained with every 0.17 mm interval along the sample.

Transmittance light method Figure 3 shows that an example frame image obtained by transmittance light. Frame images such as Fig. 3 are obtained about 3000 during the measurement of ice core sample of 55 cm length. Layers are identified by difference of brightness in the figure. Both sides of frame image are brightest since light is coming from two bottom sides to observation area. Therefore around center parts, 10 pixels width (about 0.5 mm) in the all frame images were used for image analysis in order to obtain a transmittance light image by same light condition as possible. Figure 4a shows the transmittance light image. Cloudy bands are well identified as high brightness layers, white and gray color, and clear layer were also well identified as low brightness layers, black color, in Fig. 4a. Intensity profile of brightness is shown in Fig 4b. Each value of intensity is average of brightness of pixels at same depth. The intensity indicates large value at the cloudy bands and it indicates low value at clear layers. Therefore cloudy bands are identified well using by transmittance light method using transmittance light image and the intensity profile.

Shape of ice core sample using this measurement was slab and two parallel surfaces were cleaned with microtome knife. Using this sample shape and surface treatments, we could obtain good results, however, poor quality images were obtained by a measurement of half circle section samples (Kipfstuhl, personal communication). Therefore, we should need to use a sample of slab section for the measurement. Two times cutting of ice core are required to obtain a sample of slab section shape and two surfaces treatment are also necessary before a measurement using the transmittance light method. Their sample preparation processes consume time and this is a disadvantage of this method.

Laser tomograph method When laser beam was irradiated to ice core samples, light scattering occurred at cloudy layers and it did not occurred at clear layers. Cloudy bands, therefore, can be identified using these differences of light scattering. In order to detect scattering sensitively from ice core sample, red color constituent in frame images was used for the image analysis since we used red color laser. Figure 4c shows a laser tomograph image and Fig. 4d shows an enhanced image of Fig. 4c. Intensity level of Fig. 4c and 4d

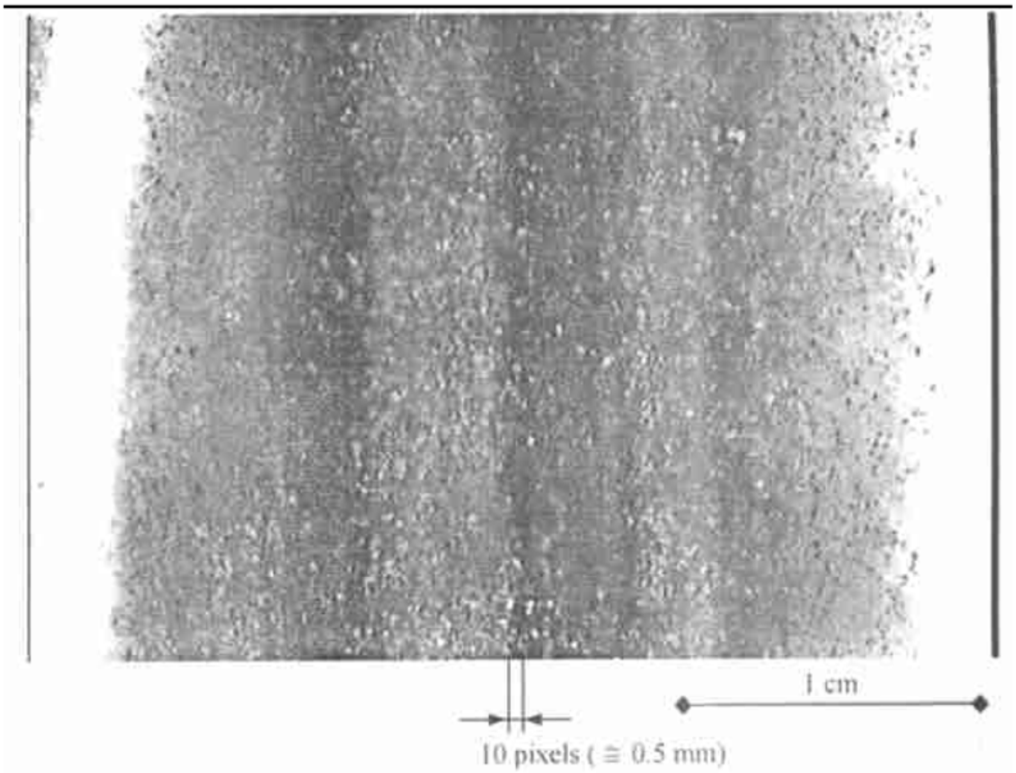

Fig. 3. An example of frame image obtained with transmittance light method.

are 30 since an area of 100 pixels width around laser beam axis was used for the analysis and integral the width area on the laser tomograph image after binarization process (Takata and Fujii 2000). Cloudy bands and clear layers were identified as high brightness layers and low brightness layers, individually, in Fig. 4c and Fig 4d. Figure 4e shows the SN, signal to noise, ratio profile of the laser tomograph image. For the deep core analysis, we judged a pixel in the laser tomograph image to be signal when scattering at the point occurs in more than two times, which was a different with shallow core measurement. And signal profile is obtained by total value of the signal at same depth. The noise level was calculated by standard deviation of the signal profile at most clear layer, around 87 mm from the top of the sample. Cloudy bands are also identified well using SN ratio profile since peaks are appears at cloudy bands. The location of all peaks is same with the profile of transmittance light method (Fig. 4b) and, therefore, cloudy bands were identified completely using laser tomograph method.

Surface treatments of laser tomograph method was only observation surface and around incident line of laser beam. The surface treatment for laser incident line is just a little area since incident depth of laser beam is close to observation surface and diameter of laser beam is 0.48 mm. Sample preparation, therefore, is much easier than transmittance light methods.

Figure 5 shows that detail of laser tomograph image and we considered here about this. The boundaries between cloudy band and clear layer were not straight line. Layers will be parallel to horizontal direction from radio echo measurement around NGRIP site (Dahl-Jensen *et al*. 1997). Layer boundaries were straight by transmittance light method. On the other hand a picture of thin section sample including cloudy band shows that cloudy band consist of small grains and boundary between cloudy band and clear layer inclines along the grain arrangement (*e. g*. Miyamoto *et al*. 1999). And laser tomograph image of shallow core measurement shows pore and/or bubble, main scattering source of shallow depth, distribution only around laser beam irradiation depth (Takata and Fujii 2000). Therefore its image obtained with deep core measurement also shows scattering information only around laser beam as thin section measurement. This is an advantage of this method for the detailed study of stratigraphical structure.

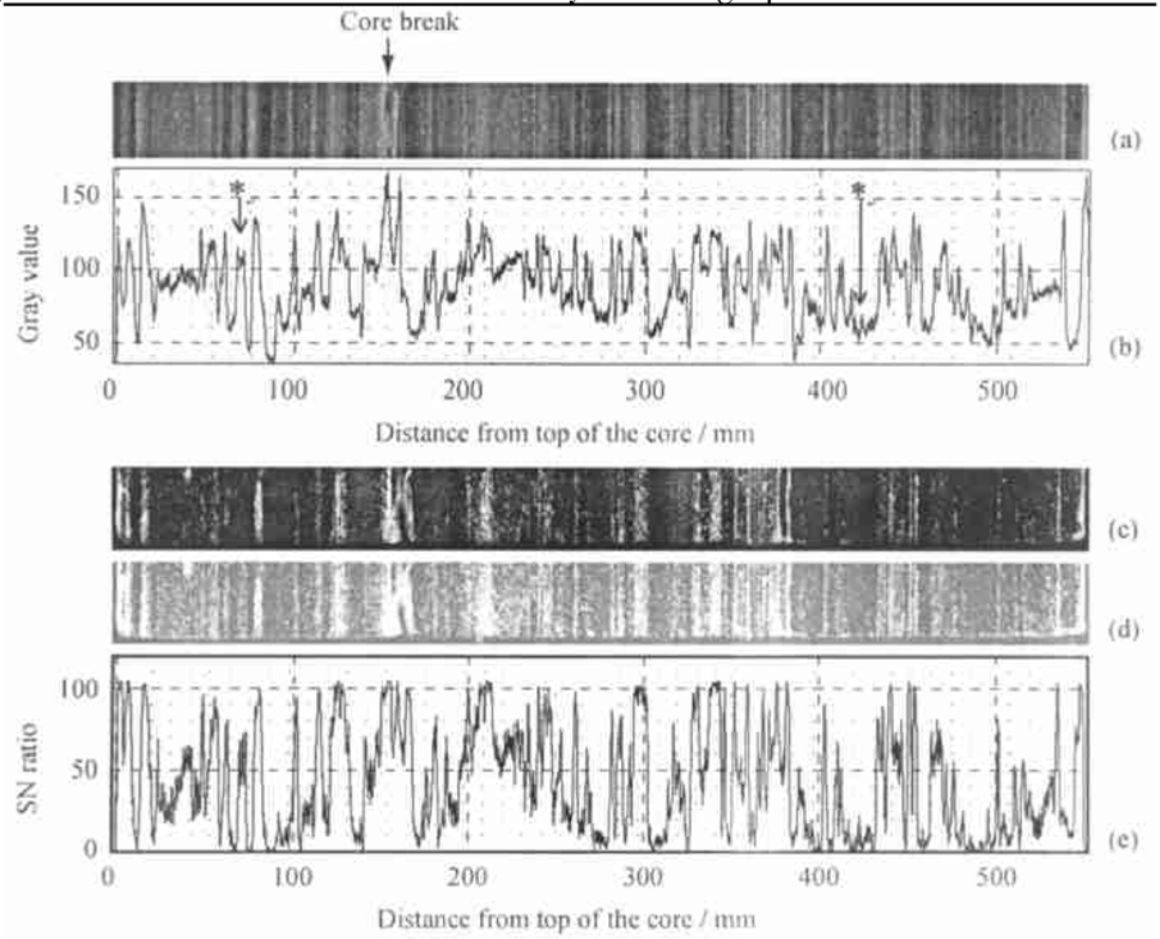

Fig. 4. Results obtained with scanner methods. (a) Transmittance light image. (b) Intensity profile of the transmittance light image (a). (c) Laser tomograph image. (d) Enhanced image of the laser tomograph image (c). (e) SN ratio of laser tomograph image (c, d).

But brightness level of laser tomograph image was often large close to laser incident line and it degrease with distance from laser incident points. Our developed program for analysis laser tomograph measurement was solved this problem for shallow core analysis but it is not enough for deep part analysis. Further improvement for the program is necessary to obtain a good laser tomograph image.

4 Summary

We carried out stratigraphical structure measurement using digital camera and two type scanners, transmittance light method and laser tomograph method. The summary of advantages and disadvantages using three methods is shown in Table 1. Measurement by digital camera was easiest method and acceptable to use identification of cloudy bands. It, however, has problems of discontinuously of frame image (maximum spatial error of 0.5 mm) at boundaries of picture frames and brightness error according to inhomogeneous light condition. Scanner type measurement solved these problems and, however, large

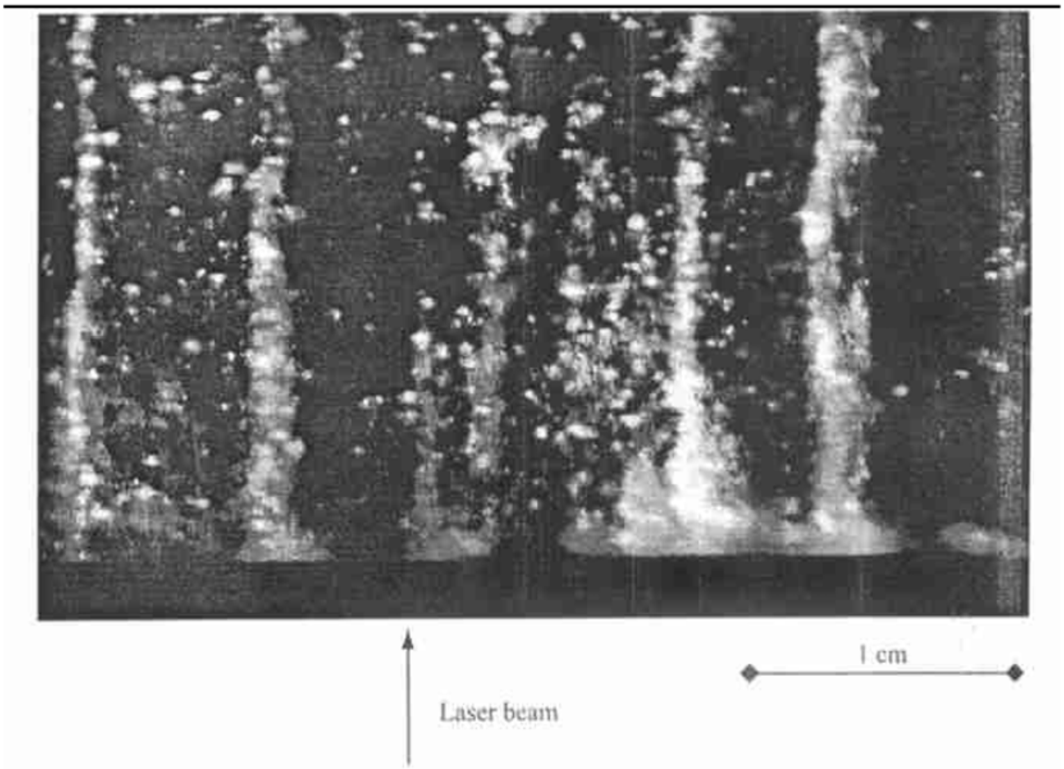

Fig. 5. An example for detail view of the laser tomograph image.

cost for equipments is required. Transmittance light method is a good method for cloudy band identification. Sample preparation, however, is not easy since sample shape should be slab and two parallel surfaces should be treated with microtome knife. Laser tomograph method is also a good method for cloudy band identification. Surface treatment is required only observation surface and around laser beam incident line. But the strong scattering occurred close to the laser incidence surface and improvement of image analysis program will be required.

The two profiles obtained by the two types scanner measurements show similar fluctuations and location of peaks is same even though small peaks. Although small peaks and internal peaks in a cloudy band (asterisk in Fig 4) look doubtful by one type measurement, they are sure signal because peak appeared at a same location by the two type scanner methods. Therefore, two types scanner measurement is better to identify all cloudy bands and detailed studies.

Table 1. Comparison of three methods for stratigraphical study

	Digital camera	Transmittance light	Laser tomograph
Equipment cost (US$)	< 1000	> 10000	> 10000
Identification of cloudy bands	Available*	Available	Available
Sample preparation time**	2	2	1
Maximum spatial error in obtaied images (mm)	0.5	0.05	0.05

(dotted shading) indicate predominant method over three.
*Excluding close to picture frame boundaries.
**Compared with laser tomograph method.

Acknowledgments This work is supported in part by a Grant-in-Aid from Ministry of Education, Culture, Sports, Science and Technology, Japan.

References

Alley RB, Shuman CA, Messe DA *et al*. (1997): Visual-stratigraphic dating of the GISP2 ice core: Basis, reproducibility, and application. J. Geophy. Res., 102(C12): 26367–26381.

Dahl-Jensen D, Gundestrup NS, Keller K *et al*. (1997): A search in north Greenland for a new ice-core drill site. J. Glaciol., 43(144): 300–306.

Dahl-Jensen D, Gundestrup NS, Miller H *et al*. (2002): The North GRIP deep drilling programme. Annal Glaciol., 35: 1–4.

Fujii M (1997): Analysis of Dome F deep ice cores using laser tomography. Master's thesis, Hokkaido University (in Japanese).

Gow AJ, Williamson T (1976): Rheological implications of the internal structure and crystal fabrics of West Antarctic ice sheet as revealed by deep core dating at Byrd Station. CRREL Report, 76–35, 25.

Messe DA, Gow AJ, Alley RB *et al*. (1997): The Greenland Ice Sheet Projects depth age scale: Method and results. J. Geophy. Res., 102(C12): 26411–26423.

Miyamoto A, Narita H, Hondo T *et al*. (1999): Ice sheet flow conditions deduced from mechanical tests of ice core. Annal. Glaciol., 29: 179–183.

Takata M, Fujii Y (2000): A laser tomograph technique for ice core stratigraphy analysis. Polar Meteorol. Glaciol., 14: 16–26.

Takata M, Fujii Y, Watanabe O *et al*. (2002): Stratigraphical structure analysis of NGRIP shallow ice core using laser tomograph. Bull. Glaciol. Res., 19: 19–24.