Vascular Plant Activity During the Pre- and Inter-Glacial Periods Based on Organic Components in the McMurdo Dry Valleys, Antarctica

GENKI I. MATSUMOTO*, YOSHIO YOSHIDA**,
KUNIHIKO WATANUKI*** and TETSUYA TORII****

Abstract

Distribution of organic components (acyclic and cyclic alkanes and alkenes, fatty acids, 2-, 3-, (ω-1)- and ω-hydroxy acids, and α, ω-dicarboxylic acids) and microscopic data of microorganisms and visual kerogen in soil samples from the McMurdo Dry Valleys of southern Victoria Land in Antarctica have been discussed in relation to the evidence of the distribution of vascular plants in the past. Organic components in the soils are probably derived from various source organisms ranging from bacteria to vascular plants, except for living organisms, in different periods from Devonian to Holocene. Long-chain n-alkanes and n-alkanoic acids are believed to be vascular plant origin, and strongly suggest that vascular plants are widely distributed in and the surroundings of the McMurdo Dry Valleys during the pre- and inter-glacial periods of Eocene-Pleistocene.

Introduction

Antarctica was once a part of Gondwanaland from late Precambrian to Jurassic ages, and would have provided a favorable habitat for vascular plants throughout the continent, except in the period of Paleozoic continental glaciation. After the breakup of Gondwanaland, relatively warm climatic conditions in the pre- and inter-glacial periods of Antarc-

* GENKI INOUE : School of Social Information Studies, Otsuma Women's University, Associate Professor
** National Institute of Polar Research, Professor
*** University of Tokyo, Professor
**** Japan Polar Research Association, Director
(Received June 10, 1992)

tica are believed to be suitable for biological activity, including vascular plants. Presently, Antarctica is extremely harsh for biological activity and no vascular plants grow in the continent, except in the northern part of the Antarctic Peninsula.

Although Antarctica is covered with ice sheets with an average thickness of 2450m, some areas are ice-free especially in coastal regions and inland mountains. The McMurdo Dry Valleys of southern Victoria Land are the largest ice-free areas in Antarctica, extending approximately 2500km^2. Moraines containing various glacially eroded materials are in the valley depressions, and are considered to be a key material to elucidate the paleoenvironment of Antarctica. Here we discuss organic components, and microscopic data of microorganisms and visual kerogen in soil samples obtained from moraines in the McMurdo Dry Valleys in relation to distribution of vascular plants during the pre- and inter-glacial periods in Antarctica.

Studied Sites

The McMurdo Dry Valleys mainly consist of Taylor, Wright and Victoria Valleys (Fig. 1). Floors and some parts of walls of these valleys are covered with morainic and fluvioglacial deposits of Pliocene to Holocene ages. Soil-like materials can be found in the deposits in many places. In December 1981 and 1983, surface soil samples (0-10cm) were collected from the east side of Don Juan Pond (Don Juan samples) in the Wright Valley (Fig. 2), and the surroundings of Lake Bonney (Bonney samples) in the Taylor Valley (Fig. 3).

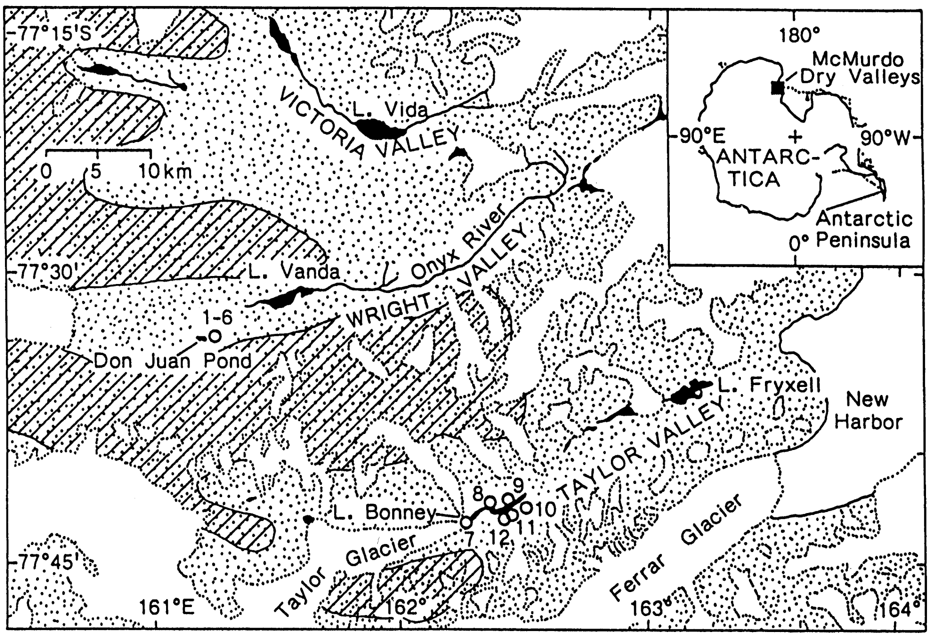

Fig.1. Sampling locations in the McMurdo Dry Valleys of southern Victoria Land, Antarctica. Dotted area : Ice-free region. Oblique lines area : Beacon Supergroup (modified from Barrett and Kyle, 1975). Sampling site: 1-6, Don Juan-1 to Don Juan-6; 7, Bonney-W1; 8, Bonney-C1; 9, Bonney-E2; 10, Bonney-E8; 11, Bonney-E9; 12, Bonney-E12.

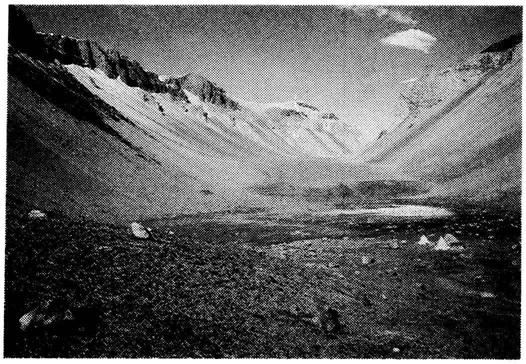

Fig.2. Don Juan Pond viewed from the east side in the Wright Valley of the McMurdo Dry Valleys.

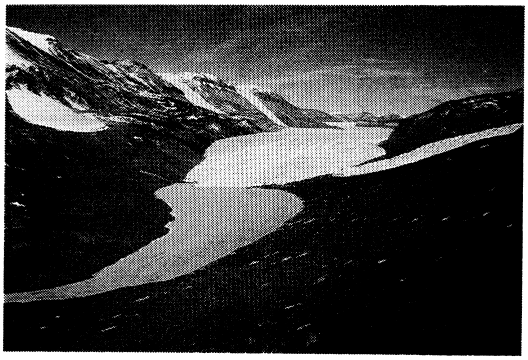

Fig.3. Lake Bonney west lobe with the terminus of the Taylor Glacier in the Taylor Valley of the McMurdo Dry Valleys.

Characteristics of Organic Components

Analytical results of organic components in soil samples are reported elsewhere (Matsumoto *et al.*, 1981, 1990a, b, c; Table 1). A series of *n*-alkanes (C_{13}-C_{35}) and *n*-alkenes (C_{15}-C_{35}) were detected with a predominance of odd-carbon numbers, as evidenced by high carbon preference index values (CPI, Table 1; Kvenvolden, 1966). Normal-alkanoic acids (C_8-C_{40}) with a predominance of even-carbon numbers were found, together with small amounts of *iso*- and *anteiso*-alkanoic, and *n*-alkenoic acids. Of special interest was a predominance of long-chain *n*-alkanoic acids ($>C_{19}$; Fig. 4). 3-Hydroxy (C_8-C_{30}) and (ω-1)-hydroxy (C_{22}-C_{30}) acids were detected with a predominance of even-carbon numbers, but 2-hydroxy (C_8-C_{30}) and ω-hydroxy (C_8-C_{30}) acids showed no even-carbon predominance. Small amounts of *iso*- and *anteiso*-2-hydroxy and 3-hydroxy acids were present in the soil samples. α, ω-Dicarboxylic acids (C_8-C_{31}) were detected with near unity CPI values; mainly the C_{13} dicarboxylic acid predominated.

The major pentacyclic compounds in the Don Juan samples were triterpenes, such as hop-17(21)-ene, neohop-13(18)-ene and hop-22(29)-ene as well as triterpanes i.e., 17β(H)-22,29,30-trisnorhopane, 17β(H),21β(H)-hopane and/or 17β(H),21β(H)-homohopane, while those in the Bonney samples were mainly 17β(H)-22,29,30-trisnorhopane, 17α(H),21β(H)-30-norhopane and 17α(H),21β(H)-hopane. The major steranes and diasteranes in the Don Juan samples were (20S)-5α(H),14α(H),17α(H)-cholestane, (20R)-5α(H),14α(H),17α(H)-cholestane, (20R)-24-methyl-5α(H),14β(H),17β(H)-cholestane/(20R)-24-methyl-5β(H),14α(H),17α(H)-cholestane, (20R)-24-ethyl-5α(H),14β(H),17β(H)-cholestane/(20R)-24-ethyl-5β(H),14α(H),17α(H)-cholestane, and/or (20R)-24-ethyl-5α(H),14α(H),17α(H)-cholestane. Generally, distributions of the pentacyclic compounds and sterane compositions of the Bonney samples are more complex than those of the Don Juan samples, and comprise many isomerized forms (Matsumoto *et al.*, 1990b).

(20S/20R)-24-Ethyl-5α(H),14α(H),17α(H)-cholestane ratios (0.03-0.66) and (22S/22R)-17α(H),21β(H)-homohopane ratios (0.01-1.1) revealed that organic components in the soil samples have experienced various thermal stresses (e.g. Seifert and Moldowan, 1981; Philp, 1986; Table 1).

Table 1. Geochemical markers for sources and thermal maturation of organic components found in soil samples from the McMurdo Dry Valleys of southern Victoria Land, Antarctica

Sample	*n*-Alkane		*n*-Alkene		*n*-Alkanoic acid		2-Hydroxy acid		3-Hydroxy acid		ω-Hydroxy acid		α, ω-Dicarboxylic acid		Sterane		Triterpane
	Long/* short	CPI#	Long/* short	CPI#	Long/* short	CPI#	Long/* short	CPI#	Long/* short	CPI#	Long/* short	CPI#	Long/* short	CPI#	C_{29}/$ C_{27}	(20S/20R)-¥ C_{29}	(22S/22R)-@ C_{31}
Wright Valley																	
Don Juan-1	3.4	2.3	49	6.5	0.85	1.5	ND	ND	ND	ND	ND	ND	ND	ND	1.3	0.16	0.18
Don Juan-2	5.5	2.3	330	5.2	3.0	1.8	3.5	0.77	1.3	2.9	0.45	0.97	0.66	0.98	0.89	0.18	0.30
Don Juan-3	2.0	2.7	99	4.1	0.91	1.8	0.92	0.89	0.61	2.7	0.25	1.0	0.23	0.99	0.89	0.10	0.29
Don Juan-4	9.1	2.8	16	3.4	2.7	2.8	1.9	1.3	0.63	5.6	1.7	1.3	0.66	1.0	3.5	0.03	0.10
Don Juan-5	6.5	2.3	16	4.9	1.7	2.0	1.9	1.2	0.53	2.8	0.94	1.1	0.55	0.91	3.6	0.04	0.01
Don Juan-6	13	1.9	Large	3.0	2.0	2.0	3.6	1.5	0.88	3.4	0.45	1.1	0.85	0.87	1.3	0.20	0.22
Taylor Valley																	
Bonney-W1	6.1	2.0	17	17	ND	ND	0.93	3.0	0.03	22	0.13	1.4	0.46	0.80	0.46	0.49	0.55
Bonney-C1	6.9	1.5	Large	7.8	0.95	2.0	1.6	1.8	0.35	1.3	0.22	0.91	0.05	0.85	1.2	0.65	1.0
Bonney-E2	16	1.9	Large	3.5	1.0	3.0	2.3	1.6	0.27	5.6	0.20	1.0	0.42	0.80	1.0	0.56	0.71
Bonney-E8	8.9	1.4	Large	1.6	1.2	1.9	1.8	1.7	ND	ND	0.14	1.0	0.20	0.82	0.93	0.66	1.1
Bonney-E9	15	1.8	Large	3.2	1.4	2.4	1.9	1.1	0.07	6.4	0.12	0.91	0.03	0.98	1.2	0.57	1.1
Bonney-E12	11	2.0	Large	3.2	0.80	3.0	0.86	1.5	0.23	4.9	0.16	0.91	0.14	0.83	1.1	0.47	0.62

*Long (C_{20}-C_{34})/short (C_{12}-C_{19}) ratios for straight chain components.

#CPI values show odd/even-carbon ratios for *n*-hydrocarbons, and even/odd-carbon ratios for straight chain acid components.

$(20R)-24-Ethyl-5α(H), 14α(H), 17α(H)-cholestane/(20R)-5α(H), 14α(H), 17α(H)-cholestane ratio.

¥(20S/20R)-24-Ethyl-5α(H), 14α(H), 17α(H)-cholestane ratio.

@(22S/22R)-17α(H), 21β(H)-30-Homohopane ratio.

Large : No short-chain *n*-alkenes were found.

ND : No data.

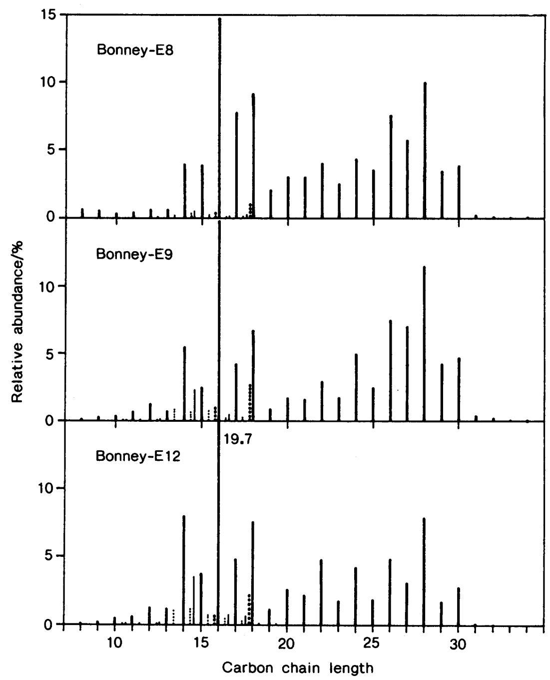

Fig.4. Relative abundances of fatty acids in selected soil samples from the McMurdo Dry Valleys. Bold solid line: Normal alkanoic acids. Bold dotted line: Normal alkenoic acids. Dotted line: *Iso*-alkanoic acids. Solid line: *Anteiso*-alkanoic acids.

Sources of Organic Components

A large variety of organic compounds suggest that organic matter in the soil samples is derived from various organisms ranging from bacteria to vascular plants, with various periods from Devonian (Beacon Supergroup) to Holocene. Especially, abundance of long-chain *n*-alkanes and *n*-alkanoic acids in the soil samples strongly suggests that organic matter was largely derived from vascular plants. However, no vascular plants are presently distributed in the McMurdo Dry Valleys and adjacent regions. Therefore, direct contribution of vascular plants is impossible. Aeolian transport of the waxes of vascular plants from the mid and lower latitudes is not important (Matsumoto *et al.*, 1981, 1990a). Detailed microscopic studies revealed that no living cyanobacteria and microalgae occurred, but small amounts of their debris were detected in some soil samples (Matsumoto *et al.*, 1990a). No *n*-alkenoic acids were dominant in all the soil samples. Hence, living organisms are not important sources of these organic components. Amorphous kerogen (68-98%) due to microbial debris was found as the major component, with small amounts of very fine coals (2-32%), but no woody and herbaceous kerogens were detected in any soil samples. This result implies that the main sources of organic matter were microorganisms and ancient vascular plants (Matsumoto *et al.*, 1990b).

Cyanobacterial mats containing various microorganisms are commonly distributed in and around the streams, lakes and ponds of the McMurdo Dry Valleys. Katabatic wind in the valleys is strong and, thus atmospheric transport of these microbial materials may be responsible for the sources of soil organic matter. Some organic matter may have been produced by *in situ* microbial activity, and accumulated for a geological time. Certain short-chain *n*-alkanes and *n*-alkanoic acids, *n*-alkenes, and hydroxy acids may have attributed to these cyanobacterial mats as well as microbial activity (Matsumoto *et al.*, 1990a, b). However, long-chain components and organic components having low CPI values are uncommon in these cyanobacterial mats (Matsumoto *et al.*, 1979; Matsumoto, 1989). Thus, wind-transported cyanobacterial mats are not important sources for these organic components in the soil samples, and long-chain compounds are probably attributed to the following two candidate sources: (1) Erosion of the Beacon Supergroup, and (2) vascular plant debris in the pre- and inter-glacial periods.

The Beacon Supergroup of Gondwanaland sediments is widely distributed in the high altitude areas (>1500m above sea level) of the McMurdo Dry Valleys and adjacent regions (e. g., Barrett and Kyle, 1975; Fig. 1). The Beacon Supergroup often contains fossils of vascular plants, such as *Glossopteris*. Matsumoto *et al.* (1986, 1987) reported hydrocarbons and fatty acids in these sedimentary rocks in the same area, although their compositions are much different from those in the soil samples. Especially, long-chain components having relatively high CPI values are not abundant in the Beacon Supergroup samples. Also, the Beacon Supergroup in this region contains triterpanes and steranes having a wide variety of maturation from near zero to equilibrium ratios (Matsumoto *et al.*, 1987). It is consistent with those of the soil samples (Table 1). α,ω-Dicarboxylic acid distributions in the soil samples are very different from recent sediments where even-carbon numbered dicarboxylic acids usually predominate, but similar to those in ancient sediments, e.g. Scottish Torbanite (Carboniferous), in which no even-carbon dicarboxylic acids predominate (Douglas *et al.*, 1970; Table 1).

It is probable, therefore, that these dicarboxylic acids, straight-chain compounds having low CPI values, and some cyclic compounds are derived from the Beacon Supergroup. The soil samples, however, contain considerable amounts of triterpenes and less matured triterpanes and steranes, indicating the presence of young organic matter due to biological activity other than that in the Beacon Supergroup. Thus it is unlikely that the Beacon Supergroup is important sources of long-chain components in the soil samples.

After isolation of Antarctica from Gondwanaland, relatively warm climatic conditions may have provided a favorable habitat for various organisms, including vascular plants in the McMurdo Sound region. Palynomorphs and a *Nothofagus* leaf impression in the CIROS-1 drillhole (702m long, 36-34.5 Ma and 30.5-22 Ma) suggested that cool temperature forest formed on the foothills of the Transantarctic Mountains and persisted through several glacial cycles (e.g., Barrett *et al.*, 1989; Harwood *et al.*, 1989; Hill, 1989). Furthermore, parenchymatous and woody tissues were found in the Sirius Formation (3.1-2.5 Ma) of the Beardmore Glacier region in Transantarctic Mountains (ca. 85° S; Askin and Markgraf, 1986). Relatively warm climatic conditions prevailed in this region when portions of the Sirius Formation were deposited (Webb *et al.*, 1987). These biological materials including vascular plant debris were probably buried beneath the ice-sheet during glacial periods under a favorable condition for preservation of organic matter.

These materials were eroded by glaciers and transported to the valley depressions as moraines. Long-chain *n*-alkanes and *n*-alkanoic acids in the soil samples are probably attributed to these vascular plant debris. Also, (20R)-5α(H),14α(H),17α(H)-C_{29}/C_{27} sterane ratios in 7 of 12 soil samples were found to be greater than unity, supporting that organic components in the soil samples are originated from certain vascular plants, although some cyanobacteria/green algae are possible sources (Matsumoto *et al.*, 1990b; Table 1).

Conclusions

Distributions of organic components in the soil samples from the McMurdo Dry Valleys of southern Victoria Land, Antarctica were discussed focused on vascular plant activity in the past. Complex distributions of organic components in the soil samples are attributed to the mixing of various source organisms ranging from bacteria to vascular plants with different ages from Devonian to Holocene, rather than from present day living organisms. Especially, the predominance of long-chain compounds strongly suggests that vascular plants were distributed in the McMurdo Dry Valleys and surroundings during the pre- and inter-glacial periods of Eocene-Pleistocene.

Acknowledgments - We are greatly indebted to the Antarctic Division, DSIR, New Zealand, US National Science Foundation, US Navy, Japan Polar Research Association and National Institute of Polar Research, Japan for their support in Antarctic research.

References

Askin, R. A. and Markgraf, V. (1986): Palynomorphs from the Sirius Formation, Dominion Range, Antarctica. Antarct. J. U. S., 21(5), 34-35.

Barrett, P. J. and Kyle, R. A. (1975): The early Permian glacial beds of south Victoria Land and the Darwin Mountains, Antarctica. Gondwana Geology, ed. by K. S. W. Campbell. Canberra, Aust. Natl Univ. Press, 333-346.

Barrett, P. J., Hambrey, M. J., Harwood, D. M., Pyne, A. R. and Webb, P. -N. (1989): Synthesis. Antarctic Cenozoic History from the CIROS-1 Drillhole, McMurdo Sound, ed. by P. J. Barrett, Wellington, DSIR Bull., 245, 241-251.

Douglas, A. G., Douraghi-Zadeh, K., Eglinton, G., Maxwell, J. R. and Ramsay, J. N. (1970): Fatty acids in sediments including the Green River Shale (Eocene) and Scottish Torbanite (Carboniferous). Advances in Organic Geochemistry 1966, ed. by G. D. Hobson and G. C. Speers. Oxford, Pergamon Press, 315-334.

Harwood, D. M., Barrett, P. J., Edwards, A. R., Rieck, H. J. and Webb, P. -N. (1989): Biostratigraphy and chronology. Antarctic Cenozoic History from the CIROS-1 Drillhole, McMurdo Sound, ed. by P. J. Barrett. Wellington, DSIR Bull., 245, 231-239.

Hill, R. S. (1989): Fossil leaf. Antarctic Cenozoic History from the CIROS-1 Drillhole, McMurdo Sound, ed. by P. J. Barrett. Wellington, DSIR Bull., 245, 143-144.

Kvenvolden, K. A. (1966): Molecular distributions of normal fatty acids and paraffins in some Lower Cretaceous sediments. Nature, 209, 573-577.

Matsumoto, G. I. (1989): Biogeochemical study of organic substances in Antarctic lakes. Hydrobiologia, 172, 265-289.

Matsumoto, G., Torii, T. and Hanya, T. (1979): Distribution of organic constituents in lake waters and sediments of the McMurdo Sound region in the Antarctic. Mem. Natl Inst. Polar Res., Spec. Issue, 13, 103-120.

Matsumoto, G., Torii, T. and Hanya, T. (1981): High abundances of long-chain *n*-alkanoic acids in Antarctic soil. Nature, 290, 688-690.

Matsumoto, G. I., Funaki, M., Machihara, T. and Watanuki, K. (1986): Alkanes and alkanoic acids in the Beacon Supergroup samples from the Allan Hills and the Carapace Nunatak in Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, 43, 149-158.

Matsumoto, G. I., Machihara, T., Suzuki, N., Funaki, M. and Watanuki, K. (1987): Steranes and triterpanes in the Beacon Supergroup samples from southern Victoria Land in Antarctica. Geochim. Cosmochim. Acta, 51, 2663-2671.

Matsumoto, G. I., Akiyama, M., Watanuki, K. and Torii, T. (1990a): Unusual distributions of long-chain *n*-alkanes and *n*-alkenes in Antarctic soil. Org. Geochem., 15, 403-412.

Matsumoto, G. I., Hirai, A., Hirota, K. and Watanuki, K. (1990b): Organic geochemistry of the McMurdo Dry Valleys soil, Antarctica. Org. Geochem., 16, 781-791.

Matsumoto, G. I., Watanuki, K. and Torii, T. (1990c): Geochemical features of hydroxy acids in soil samples from the McMurdo Dry Valleys, Antarctica. Proc. NIPR Symp. Antarct. Geosci., 4, 165-171.

Philp, R. P. (Ed., 1986): Fossil Fuel Biomarkers. Applications and Spectra. Methods in Geochemistry and Geophysics No. 23, Amsterdam, Elsevier, 294p.

Seifert, W. K. and Moldowan, J. M. (1981): Paleoreconstruction by biological markers. Geochim. Cosmochim. Acta, 45, 783-794.

Webb, P. -N., McKelvey, B. C., Harwood, D. M., Mabin, M. C. G. and Mercer, J. H. (1987): Sirius Formation of the Beardmore Glacier region. Antrct. J. U. S.,

XXII(1), 8-13.

有機成分からみた南極マクマードドライバレーの氷期前および間氷期における維管束植物の活動

松本(井上)源喜*・吉田榮夫**・綿秡邦彦***・鳥居鉄也****

*大妻女子大学社会情報学部 **国立極地研究所
***東京大学教養学部 ****日本極地研究振興会

要約

南極南ビクトリアランドのマクマードドライバレーにおける，過去の維管束植物の生息と関連し，土壌中の有機成分「環式および非環式炭化水素，脂肪酸，2-，3-，ω-，(ω-1) -ヒドロキシ酸，α，ω-ジカルボン酸」の特徴，ビジュアルケロジェンおよび微生物の顕微鏡観察結果を討論した。土壌中には多種類の有機成分が存在するが，長鎖($>C_{19}$)の *n*-アルカンや *n*-アルカノイック酸がかなり多くみられ，維管束植物由来の有機成分が寄与していることが確認された。それに対し，不飽和脂肪酸は非常に少なく，土壌中の有機成分には，現生の生物がほとんど関与していないと判断される。このことは顕微鏡観察でも生細胞がみられないことと一致する。ビジュアルケロジェンは，大部分が微生物由来の無定形成分（68—98%）であるが，その他には維管束植物由来の石炭質成分（2—32%）から構成されている。これらの有機成分は，古生代デボン紀（Devonian，3.95億年前）から現生に至る，バクテリア，藻類，維管束植物を含む多種類の生物に由来すると推定される。特に長鎖の有機成分の特徴より，始新世（Eocene，5800—3700万年）から更新世（Pleistocene，200—1.1万年）にかけて，マクマードドライバレーやこの周辺には，かなり温暖な時期（氷河期前および間氷期）があり，維管束植物が繁茂していたと考えられる。

Key Words(キーワード)

Antarctica(南極), McMurdo Dry Valleys(マクマードドライバレー), Soil(土壌), Vascular Plants（維管束植物），Chemical Fossils（化学化石），Organic Components（有機成分），Biomarker（バイオマーカー），Visual Kerogen（ビジュアルケロージェン）