Journal of Glaciology, Vol. 27, No. 97, 1981

FIRST GLACIOLOGICAL STUDIES ON THE JAMES ROSS ISLAND ICE CAP, ANTARCTIC PENINSULA

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Abstract. A 10 m deep core and a 2 m pit were achieved in December 1977 on the ice cap of James Ross Island (Antarctic Peninsula) 3 km westward of the main dome at an altitude of 1 500 m. The 10 m temperature was −14.2°C. The core was cut into 106 samples which have been used for density, total β radioactivity, electroconductivity, and deuterium-content measurements. The age at the bottom of the bore hole has been estimated to be 1 965 ± 1 year and a mean annual snow accumulation rate 37.7 ± 3.0 g cm^{-2} a^{-1} is calculated over the last 13 years. By comparing our results with those obtained in other areas of the Peninsula, the climate of the upper part of James Ross Island seems to follow the climatic regime of the western coast. A preliminary chemical analysis of the pit samples leads us to conclude that the snow impurities are mainly sea-salt derived. The conductivity measurements show a clearly defined peak at the end of 1967 which could be linked with the volcanic eruption of the Deception Island volcano in December 1967. The interest of the studied location is discussed in view of further more extended glaciological investigations and particularly a possible coring to the bottom.

Résumé. *Premières études glaciologiques sur la calotte glaciaire de James Ross Island, Antarctic Peninsula.* En décembre 1977 un carottage à 10 m de profondeur et un puits de 2 m ont été réalisés sur la calotte polaire de James Ross Island (Antarctic Peninsula) à 3 km à l'ouest du dôme supérieur de l'île et à 1 500 m d'altitude, la température à 10 m de profondeur étant de −14,2°C. La carotte a été découpée en 106 échantillons sur lesquels, on a effectué des mesures de densité, de radioactivité β globale, de conductivité électrique et de teneur en deutérium. L'âge au fond du carottage a été estimé à 1 965 ± 1 a. On en a déduit une accumulation moyenne annuelle en ce lieu de 37,7 ± 3,0 g cm^{-2} a^{-1} sur 13 ans. Par comparaison avec des résultats portant sur d'autres régions de la péninsule, il semblerait que le climat sur la partie supérieure de James Ross Island s'apparente à celui de la côte ouest de la péninsule. Une analyse chimique succinte des échantillons prélevés dans le puits permet de mettre en évidence l'origine marine des impuretés présentes dans la neige. Les mesures conductimétriques montrent un pic défini fin 1967, en liaison vraisemblablement avec une éruption du volcan de Deception Island à cette date. On conclue sur l'intérêt du site étudié pour la réalisation de travaux glaciologiques plus importants en particulier pour un forage jusqu'au socle.

Zusammenfassung. *Erste glaziologische Studien auf der Eiskappe der James Ross Island, Antarctic Peninsula.* Im Dezember 1977 wurde auf der Eiskappe der James Ross Island (Antarctic Peninsula) 3 km westlich des Hauptdomes in einer Höhe von 1 500 m ein Bohrkern vom 10 m Länge gewonnen und ein Schacht von 2 m Tiefe gegraben. Die Temperatur in 10 m Tiefe betrug −14,2°C. Der Bohrkern wurde in 106 Proben zerschnitten, die zur Messung der Dichte, der Gesamt-β-Aktivität, der elektrischen Leitfähigkeit und des Deuteriumgehaltes herangezogen worden. Das Alter des Eises am Grunde des Bohrloches wurde auf das Jahr 1 965 ± 1 Jahr geschätzt; die mittlere jährliche Schneeakkumulation wurde für die letzten 13 Jahre zu 37,7 ± 3,0 g cm^{-2} a^{-1} berechnet. Im Vergleich zu Ergebnissen aus anderen Gebieten der Halbinsel scheint das Klima im oberen Teil der James Ross Island dem Klimaablauf der Westküste zu folgen. Eine vorläufige chemische Analyse der Schachtproben führte zu dem Schluss, dass die Verunreinigungen im Schnee hauptsächlich vom Salz des Meerwassers stammen. Die Messungen der Leitfähigkeit zeigen ein klar ausgeprägtes Maximum am Ende des Jahres 1967, das mit dem Ausbruch des Vulkans auf Deception Island im Dezember 1967 in Verbindung stehen könnte. Das Interesse an der untersuchten Stelle wird im Hinblick auf weitere, ausgedehnte glaziologische Studien, besonders auf eine mögliche Bohrung bis zum Felsuntergrund, diskutiert.

1. Introduction

A widespread network of stations for the collection of glaciological information covering the entire Antarctic Peninsula and adjacent islands is necessary for the further progress of the glaciology of this region (GAP programme, see Swithinbank, 1974). The only existing published data (Peel and Clausen, in press; Martin and Peel, 1978) concern mainly the central southern regions where there is no permanent meteorological station. A major objective of these studies is to select the most favourable sites for deeper drills (>100 m) in order to establish climatic records covering at least the last century. It should also be noted that the northern part of the Peninsula is an important link in mountain range that joins the Northern Hemisphere to Antarctica through the Andes.

Logistics (the nearness of the Vicecomodoro Marambio base) as well as glaciological considerations (the presence of a small but relatively thick polar ice cap) led us to initiate glaciological studies on James Ross Island (*c.* lat. 64° 13′ S., long. 57° 38′ W.) (see Fig. 1). Snow and ice studies in this area could also lead to information (by conductivity measurements) concerning the regional extension of sea ice (as suggested by Swithinbank, 1974) and the impact of the Deception Island (lat. 63° S., long. 60° 40′ W.) volcanic activity on the chemistry of snow in this area (this volcano is about 200 km from James Ross Island, see Fig. 1). During summer 1975–76, a small Argentinian expedition collected firn samples and measured a 10 m temperature (−12.9°C) sufficiently low to encourage further glaciological investigations (unpublished work by R. E. Dalinger, P. Skvarca, and A. J. Aristarain).

This paper presents the first data of glaciological and climatological interest concerning this small Antarctic ice cap.

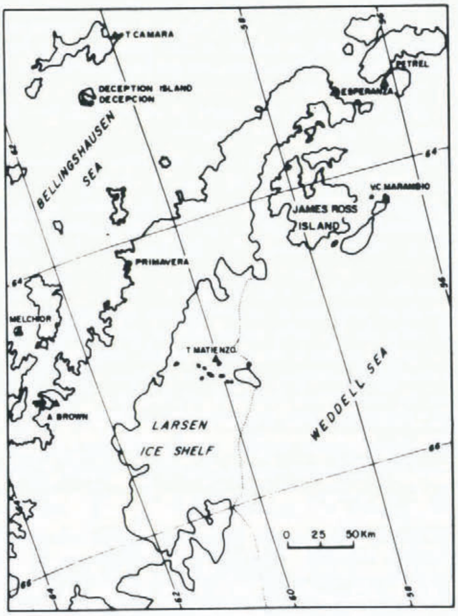

Fig. 1. The northern part of the Antarctic Peninsula with James Ross and Deception Islands and Vicecomodoro Marambio base. Also indicated are the Argentine research stations.

2. Field work and analytical methods

Field data and firn samples were collected during a short stay on James Ross Island at the beginning of December 1977. A 10 m firn core was taken and a pit 2 m deep dug 3 km west of the summit at an elevation of about 1 500 m. The site was situated on a gentle slope facing the Antarctic Peninsula. The snow surface was relatively hard and regular (small sastrugi). The air temperature during sampling was always well below zero.

Special care was taken during work in the pit in order to avoid contamination problems. Twenty-eight snow samples were collected representing a continuous sequence from the top to the bottom of the pit. Polyethylene boxes (150 ml) were driven into the snow wall with the aid of a plastic hammer. These samples were analysed in the laboratory in Grenoble.

The core (diameter: 7.6 cm) was kept frozen for cutting in the cold room of the base (Vicecomodoro Marambio). From an estimated annual snow accumulation rate of 80 cm (from the unpublished work of R. E. Dalinger and others already referred to), the core was cut into 6 to 10 cm thick slices and densities were determined by weighing these pieces. Each one was then melted in a plastic bag, 50 ml being separated for further deuterium determinations. Electrical conductivity measurements were made using La Motte Chemical pocket conductivimeter (with temperature correction) and then the melt water was filtered using an ion-exchanger filter (Delmas and Pourchet, 1977) for total β radioactivity determinations.

The absolute values of the conductivity data may have to be shifted $\pm 30\%$ due to apparatus calibration problems, but variation in their relative values are reliable. It should be noted that these measurements were carried out under rough conditions (without using a glove box to cut the samples). We checked, however, that the readings were stable and that the conductivities of two aliquots of the sample were equal.

The above set of measurements led to the determination of four different physico-chemical parameters (density, deuterium content, β radioactivity, and conductivity) for the same firn layer. In addition the 10 m temperature was measured with the aid of an ASTM precision thermometer (± 0.1 deg).

In the laboratory, conductivities of the pit were measured (precision ± 0.03 $\mu S\ cm^{-1}$) using a Tacussel CD 7 A conductimeter (Legrand, unpublished) and Na, K, Ca, and Al were determined by graphite-furnace atomic absorption (Perkin Elmer 303, precision 10 to 20%). β radioactivity was counted using a low-level β counting device (background ≈ 10 dph, efficiency $\approx 60\%$; Pinglot and Pourchet, 1979). Deuterium measurements (precision 0.03‰ in the δ scale) have been made in C.E.N., Saclay (DRA/SRIRMA).

3. Results and discussion

3.1. *Density measurements*

Our experimental density data are represented in Figure 2d and the load d increases with depth z according to the approximation (personal communication from M. Pourchet) $d = az^2+bz+c$, where the constants a, b, and c are respectively equal to -2.33×10^{-4} kg/m², 11.55×10^{-3} kg/m, and 0.406 kg. It is generally accepted that summer snow, formed from coarser grains and with a lesser degree of wind compaction than winter snow, tends to have a lower density. This can be observed for the first three years where the density peaks correspond well to the isotopic maxima. The regular density oscillations can even be used to date the snow layers. At greater depths, the density profile (as well as the stable-isotopes profile) becomes more difficult to interpret due to the smoothing of short-term variations. This could be a result of the slow metamorphosis of snow which significantly modifies the initial grain-size and density of snow deposits. Moreover, thin ice strata present in summer layers sometimes result in higher densities in summer than in winter snow.

3.2. *Dating the firn core*

Datable reference horizons are now well established in Antarctic precipitation (Crozaz, 1969; Lambert and others, 1977). Two dramatic β radioactivity increases (mainly ^{90}Sr and ^{137}Cs), corresponding to two series of atmospheric nuclear weapon tests, have been detected at various locations on the Antarctic continent in the snow layers corresponding to the summers of 1954–55 and 1964–65. From this last date to 1969, a decrease of the radioactivity levels resulted because of the absence of high-energy atmospheric nuclear tests (1962–66) (Pourchet and Pinglot, 1979) and a new increase is marked in 1969 by the addition of radioactive fall-out from the more recent French and Chinese tests (Jouzel and others, 1979;

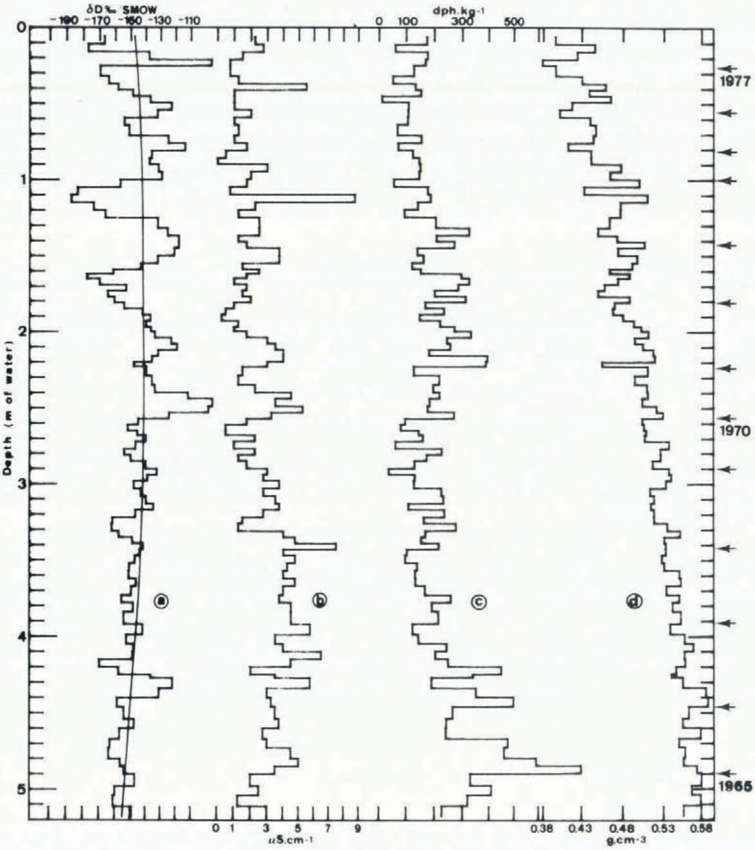

Fig. 2. Deuterium (a), deuterium smoothing (a, continuous line), conductivity at 25°C (b), β radioactivity (c), and density (d) versus depth of the James Ross Island 10 m core. Dating (see text) indicates the month of January.

Pourchet and others, unpublished). Moreover, seasonal patterns permit a more refined chronology of the cores. First, β radioactive maxima in summer linked to the annual subsidence of stratospheric products into the troposphere. Second, the stable isotope (δD and $\delta^{18}O$) oscillations (maxima in summer and minima in winter) that take place due to fractionation of water vapour during the condensation process (Dansgaard and others, 1973).

The δD values and the total β radioactivity profiles at James Ross Island are represented in Figure 2 as a function of depth (in metres of water). It appears that the annual δD cycles have been preserved only in the first part of the core. The highest β value ($\approx$750 dph kg^{-1}) is observed near the bottom at 4.90 m and is followed by a decrease until 2.90 m where a new increase is noted. This fact and the clearly registered annual oscillations of δD (at least seven peaks between 2.57 m and the surface, which give the order of magnitude of the accumulation), indicate that the radioactivity peak at 2.90 m is probably the 1969 horizon. Dating backwards from this secondary reference, the high β level at 4.90 m most likely corresponds to 1964–65 $\pm$ 1 year.* This conclusion is further supported by the satisfactory agreement between the β flux values calculated for the 1964–65 maximum at James Ross Island and at other Antarctic

* Unfortunately, the absence of the preceding yearly β peak in our profile results in a dating uncertainty of one year. An alternative possibility being 1965–66 summer peak at 4.90 m.

locations (Pourchet and others, unpublished) and by the specific β activity of this summer horizon ($\approx$400 dph kg^{-1}) given by Peel and Clausen (in press) for the Antarctic Peninsula.

The 1964–65 reference of 4.90 m, leads to the relatively low accumulation rate of 37.7 ± 3.0 g cm^{-2} a^{-1} over the last 13 years. With January 1970 at 2.57 m, the accumulation rates before (1965–70) and after (1970–77) this date are respectively 47.0 and 32.5 g cm^{-2} a^{-1}.

3.3. *10 m temperature and deuterium measurements*

At the sampling station, which is situated below the summit (mean annual temperature -12.9°C), we measured a surprisingly lower temperature -14.2 ± 0.1°C. This value is in agreement with stable isotope measurements and with visual observations (Table I).

TABLE I. 10 m TEMPERATURE AND MEAN STABLE ISOTOPIC VALUES IN THE JAMES ROSS ISLAND ICE CAP
1976 isotopic value was communicated by H. B. Clausen (Geophysical Isotope Laboratory, København) in $\delta^{18}O$ and converted to δD using the relation: $\delta D = 8\delta O + 10‰$.

Date	*Approximate elevation* m	*10 m temperature* °C	δD ‰	*Melt layers*	*Reference*
January 1976	1 620	−12.9	−126.9	Yes	Unpublished work by R. E. Dalinger and others
December 1977	1 500	−14.2	−146.7	No	This work

These δD and temperature values, plotted in the diagram of Peel and Clausen (in press, fig. 2) correspond well to those of the Antarctic Peninsula network. Moreover, the 10 m temperatures of the two sites clearly show that even though James Ross Island is situated on the east coast, its climate (at least for the upper part of the island) is similar to the central and western regions (Martin and Peel, 1978, fig. 2).

Sea-level stations in this area (Snow Hill Island, Marambio, and Matienzo bases) are subject to a temperature regime dominated by advection of cold air with a pronounced surface inversion from the Weddell Sea (Schwerdtfeger, 1975). This inversion, in addition to the difference in exposure to the sun of the sites, could explain why the summit of the ice cap is warmer than the 1977 station.

By analysing the temperature records in the area of the Antarctic Peninsula, Schwerdtfeger (1976) found that a change in the temperature field took place on the west coast after 1970. Assuming, as discussed earlier, that the climatic regime of James Ross Island is similar to the western and central regions, it is of interest to see if our isotopic profile also illustrates this trend. A mathematical smoothing (by computer using a spline function) shows (see Fig. 2a) that a temperature maximum is observed during summer 1970–71 (depth: 2.30 m), which is basically in agreement with the work of Schwerdtfeger. A similar trend also seems to appear in some ^{18}O profiles given by Peel and Clausen (in press). Moreover, considering all the isotopic profiles available for the Antarctic Peninsula and the temperature record given by Schwerdtfeger, the year 1973 appears to be particularly cold in most of the locations studied.

3.4. *Conductivities*

The mean value of the conductivity of the core is 2.7 μS cm^{-1} corrected to 25°C. It is basically in agreement with the values obtained by Peel (1976, range: 1–3 μS cm^{-1}) and Gow (1968) and those measured in our laboratory for the samples taken from the pit (mean value: 2.0 μS cm^{-1}) (see Figs 2b and 3). The conductivity values determined by Peel and those measured in our laboratory are free from the influence of dissolved CO_2 ($\approx$0.8 μS cm^{-1}).

https://doi.org/10.3189/S0022143000011412 Published online by Cambridge University Press

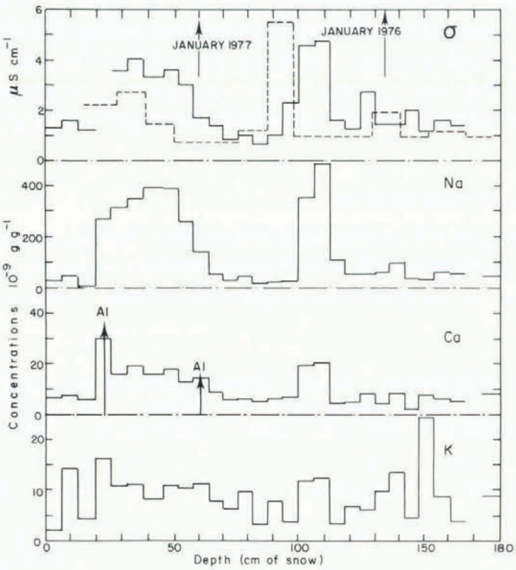

Fig. 3. Conductivity (σ) at 25°C and impurity (Na, Ca, K) concentrations of the pit samples. In dashed line: conductivity of the upper part (180 cm) of the core. Dating has been obtained by deuterium measurements. The arrows marked on the Ca profile indicate the only two Al (34 and 14 × 10⁻⁹ g g⁻¹) concentrations higher than the experimental detection limit (4 × 10⁻⁹ g g⁻¹).

The purpose of the conductivity measurements was to study two different questions:

Does the local atmosphere have a higher aerosol content in summer, when the sea surface is free of ice?

Are the three recent eruptions (1967–1969–1970, Govorukha, 1973; Orheim, [1975]) of the Deception Island volcano, recorded in our core?

In the upper part of the core (see Fig. 3), two high-conductivity levels are observed at depths of 0.35 and 0.95 m, in good agreement with the conductivity peaks observed in the pit at 0.35 and 1.10 m respectively. It appears that the highest conductivities are observed between summer and winter. This phenomenon has been previously described by Peel (1976) and was attributed to the storms that generally occur in the area at the end of summer, when the sea surface is still free of ice. This will be confirmed in our work by a study of the marine origin of the snow impurities.

The comparison of the mean values before (4.0 $\mu S\ cm^{-1}$) and after (2.1 $\mu S\ cm^{-1}$) the 1968 level (3.42 m) reveals a significant change in the conductivity of snow after the 1967–68 summer peak. The relatively high conductivities from 1965 to 1968 could be ascribed to the sulphuric acid fall-outs measured in central Antarctic snow and attributed to several volcanic eruptions of global significance (particularly Mount Agung) (Delmas and Boutron, 1980). Moreover the high conductivity peak at the end of 1967 (3.42 m) appears to be most probably evidence of the December 1967 eruption of the Deception Island volcano (Baker and others, 1969). The other two volcanic eruptions on Deception Island (February 1969 and August 1970) are less clearly recorded in the snow. This could be because of the unfavourable direction taken by the ejected volcanic ashes: southward in 1969 and north-eastward in 1970, in comparison with south-eastward (in the direction of James Ross Island) for 1967 (Govorukha, 1973). Further investigations are still needed to confirm whether or not the

1967 Deception Island eruption is a reliable reference horizon for dating the firn over the entire northern part of the Antarctic Peninsula. No conclusive evidence can be found in the conductivity profiles given by Peel (1976) for more southern locations on the Peninsula.

3.5. *Geochemical studies in the pit*

The conductivity, the chemical data (Na, K, Ca, and Al), and the seasonal temperature maxima (as determined from the neighbouring core by stable isotope measurement) are shown in Figure 3. The variations in conductivity follow the cation concentrations. Assuming that there is no fractionation in the marine aerosol and that Na is essentially of marine origin, it is calculated that sea salt is responsible for about 50% of the conductivity. The dominant contribution of marine aerosol to the snow chemistry on James Ross Island is clearly demonstrated by comparing the K/Na and Ca/Na ratios in snow with the composition of various local aerosol sources (Table II). Moreover, the low Al content ($<4\times10^{-9}$ g g^{-1}) indicates a low crustal contribution. This was not obvious before the study because the island is surrounded by snow-free soil surfaces (James Ross Island itself, Vicecomodoro Marambio base, and Cockburn Island) which are the source of large quantities of dust. Even small rock particles had been observed on the snow surface; however, this was always at lower altitudes.

TABLE II. CHEMICAL RATIOS IN SNOW AND IN POTENTIAL AEROSOL SOURCES

	Bulk sea-water (Pytkowicz and Kester, 1971)	*Crustal mean* (Taylor, 1964)	*Deception Island volcanic material* (Fourcade, 1972)	*James Ross Island rock* (Nelson, 1966)	*Snow* (this work)
K/Na	0.037	0.9	0.2	0.49	0.064
Ca/Na	0.038	1.8	1.0	1.92	0.076

4. VELOCITY OF THE ICE FLOW

The horizontal velocity of the ice flow at an elevation of 1 500 m (B.A.S. topographic map, British Antarctic Territory, James Ross Island, 1 : 250 000. BAS 250 series, sheet SQ21–22/1. London, Directorate of Overseas Surveys, 1974) can be estimated (assuming the ice cap to be in a steady state) by using a thickness of 200 m for the James Ross ice cap (from the radio echo-soundings of the British Antarctic Survey, personal communication from C. W. M. Swithinbank) and a mean snow accumulation rate of 40 g cm^{-2} a^{-1} (this work). The resulting low value ($\approx$2 m a^{-1}) indicates that deformations of the ice mantle are most likely slight.

5. CONCLUSION

These preliminary results show that valuable information of glaciological and climatological interest is most likely to be present in the small ice cap covering James Ross Island. Further studies are required to obtain a broader understanding of characteristics which could vary greatly from one point to another with elevation and geographic orientation. In the search for a deep-drilling site on the Antarctic Peninsula, our work has pointed out certain favourable conditions offered by this ice cap: extreme northern location, easy access, little or no summer snow melt, a reasonable accumulation rate, a climate representative of the northern part of the Peninsula, potential dating of the ice layers from known volcanic events, and low deformation of the ice mantle.

ACKNOWLEDGEMENTS

This work has been carried out through a programme of scientific co-operation between the Laboratoire de Glaciologie (Grenoble) and the Instituto Antártico Argentino (Buenos Aires).

The authors would like to thank Dr R. E. Dalinger who initiated the Antarctic glaciological investigations in Argentina.

We are very grateful to several members of the Laboratoire de Glaciologie and of the Instituto Antártico Argentino, particularly, M. Briat (atomic absorption determinations), M. Pourchet (β radioactivity dating), J. R. Petit (computational assistance), L. Merlivat and J. Jouzel (DRA/SRIRMA, CEN/Saclay, deuterium determination), and H. Smit (technical assistance).

This work was supported in the field by the División Antártida de la Fuerza Aerea Argentina.

We should also like to express our gratitude to Dr Claude Lorius for many helpful discussions and for his support in the development of this programme.

MS. received 23 January 1980 and in revised form 25 July 1980

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