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ISOTOPIC COMPOSITION OF SNOW SAMPLES FROM NORTHERN VICTORIA LAND (ANTARCTICA) AND CORRELATIONS WITH GEOGRAPHICAL FACTORS

ABSTRACT: DINI M., LONGINELLI A., OROMBELLI G. & SMIRAGLIA C., *Isotopic composition of snow samples from Northern Victoria Land (Antarctica) and correlations with the geographical factors.* (IT ISSN 0391-9838, 1997).

During the 1989-90 and 1994-95 Italian expeditions to Antarctica, two sets of fresh surface snow samples were collected in order to analyse their isotope composition and correlation with geographical factors, such as elevation and distance from the coast.

A linear relationship between $\delta^{18}O$ and δD was found yielding a high correlation coefficient. Mean vertical isotopic gradients of –0.6‰/100m and –0.5‰/100m were obtained for $\delta^{18}O$ from the two different sets, whereas the δD/elevation gradients were –4.7‰/100m and –3.5‰/100m, respectively. The correlation coefficients between isotopic composition of snowfall and elevation were higher (R^2 from 0.42 to 0.81) than those between isotopic composition and distance from the coast.

The correlation between deuterium excess and distance from the coast was very weak with higher values moving inland, probably owing to the rather complicated morphology of the area.

KEY WORDS: Snow isotopic composition, Altitude effect, Victoria Land, Antarctica.

RIASSUNTO: DINI M., LONGINELLI A., OROMBELLI G. & SMIRAGLIA C., *Composizione isotopica di campioni di neve nella Terra Vittoria Settentrionale (Antartide) e relazioni con i fattori geografici.* (IT ISSN 0391-9838, 1997).

Durante le spedizioni italiane in Antartide negli anni 1989-90 e 1994-95, sono state raccolte due serie di campioni di neve fresca superficiale per analizzare la loro composizione isotopica ed evidenziare le correlazioni con alcuni parametri geografici, quali altitudine e distanza dalla costa.

È stata trovata una relazione tra $\delta^{18}O$ e δD con un elevato coefficiente di correlazione. Inoltre, nei due differenti periodi di campionamento sono stati ottenuti dei gradienti isotopici verticali medi di –0.6‰/100m e –0.5‰/100m per l'ossigeno e di –4.7‰/100m e –3.5‰/100m per l'idrogeno.

I coefficienti di correlazione fra la composizione isotopica della neve e l'altezza sono risultati più alti (R^2 varia da 0,42 a 0,81) rispetto a quelli con la distanza dalla costa. La correlazione tra l'eccesso di deuterio e la distanza dalla costa è risultata piuttosto debole, forse a causa della complicata morfologia dell'area esaminata, con una progressione verso valori più elevati allontanandosi dalla linea di costa.

PAROLE CHIAVE: Composizione isotopica della neve, Effetto altitudine, Terra Vittoria, Antartide.

INTRODUCTION

The samples were collected in two periods: from January 15 to February 20, 1990 and from November 6 to November 26, 1994.

All the sampling sites are located in Northern Victoria Land (figs. 1 and 2). The first set consists of 16 samples from 12 sites roughly distributed along a South-North transect 140 km in length, extending from Tarn Flat (75°00'S, situated a few kilometers north of Larsen Glacier) to Mt. Pollock (74°15'S, close to the higher Campbell Glacier). The longitudinal extension was about 60 km, from Hogden Heights to Mt. Emison (excluding the Ricker Hills site, situated about 50 km west of Mount Joyce, as shown in fig. 2). Sampling site elevations ranged from 10 m at Tarn Flat (a flat, deglaciated area between Larsen Glacier and Reeves Glacier) to 3490 m on Shafer Peak (on the ice-divide between Reeves Glacier and Campbell Glacier). The distribution of sampling frequency according to altitude was: 3 samples in the 0-100 m altitude range, 6 samples in the 1000-2000 m altitude range, 6 samples in the 2000-3000 m range and 1 sample at an elevation of over 3000 m. The distance from the coast ranged from 5 km at Tarn Flat to about 100 km at Mt. Pollock.

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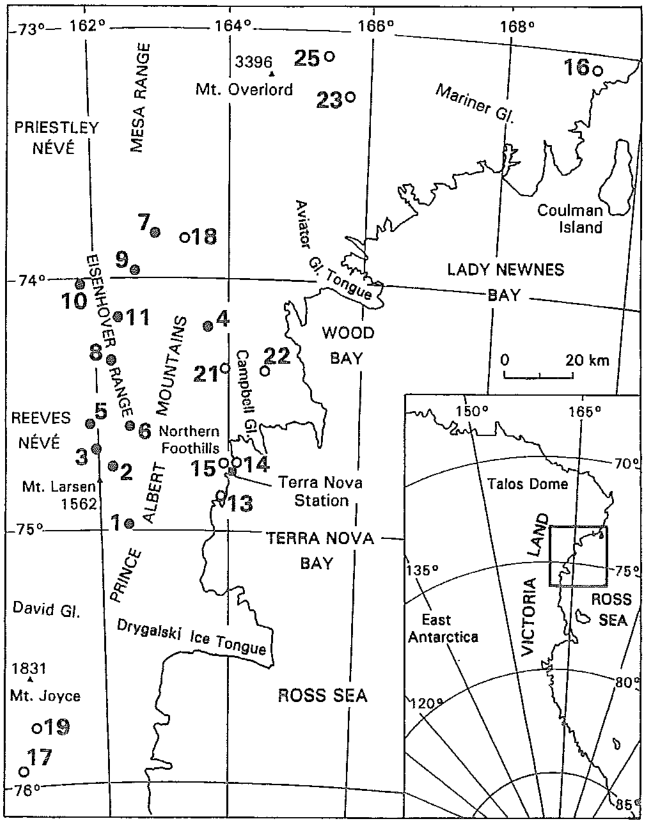

FIG. 1 - Location of the sampling sites (black points = 1989-90 set; white points = 1994-95 set): 1) Tarn Flat, 2) Andersson Ridge, 3) Mt. Matz Glacier, 4) Mt. Emison, 5) Thern Promontory, 6) Mt. Nansen, 7) Mt. Pollock, 8) Eisenhower Range, 9) Shafer Peak, 10) Hogden Heights, 11) Timber Peak, 13) Hell's Gate, 14) Oasis Campus, 15) Amorphous Glacier, 16) Mandibole Cirque, 17) The Mitten, 18) Campbell Glacier, 19) Mt. Bowen, 21) Mt. Dickason, 22) Mt. Melbourne, 23) Hercules Névé.

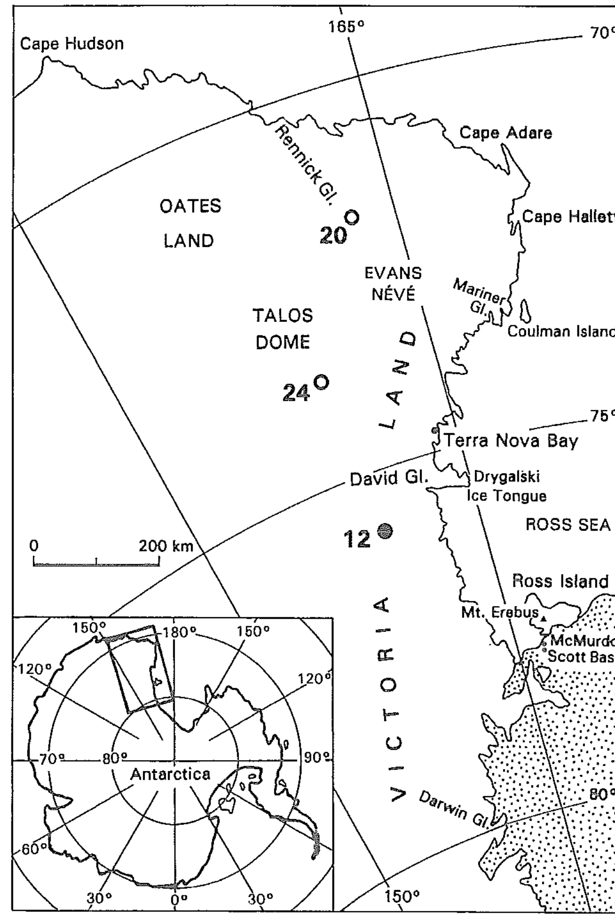

FIG. 2 - Location of the sampling sites (black points = 1989-90 set; white points = 1994-95 set): 12) Ricker Hills, 20) Lanterman Range, 24) Reeves Névé.

The second set consists of 13 samples from 13 sites distributed over an area with lower elevations, ranging from 10 m at Hell's Gate (a small ice shelf, several kilometers SSW of Terra Nova Station) to 2600 m at Hercules Névé (north of Aviator Glacier). Four samples were collected in the 0-1000 m elevation range, 5 samples from the 1000-2000 m range and 4 samples at elevations higher than 2000 m. The areal distribution was wider and the distribution of the distances from the coast was higher than for the first set: from 72°23'S at Lanterman Range (close to Rennick Glacier) to 76°00'S at The Mitten (south of Mt. Joyce) over a distance of about 530 km. The longitudinal extension ranged from 150°E (Reeves Névé) to 169° (Mandibole Cirque, located NNE of Coulman Island) over a distance of 400 km. Distances from the coast ranged from 0 km at Oasis Campus to 230 km at Reeves Névé.

METHODS

The snow samples were collected from very different morphological sites (glacial surfaces, mountain sides, deglaciated areas, etc.) by various samplings of 0.5 l polyethylene bottles.

All the samples were measured twice for $^{18}O/^{16}O$ ratios according to the CO_2-water equilibration technique proposed by Epstein & Mayeda (1953). H/D ratios were determined by using the zinc-reduction method as illustrated by Friedman (1953). Measurements were carried out by means of a Finnigan Delta-S mass spectrometer . The values are reported in the δ-notation, referring to the V-Smow isotopic standard (Gonfiantini, 1978). The standard deviations of the measurements were ± 0.10% (1σ) for oxygen and ± 1.5% (1σ) for hydrogen.

RESULTS

The location and the elevation of the sampling sites, oxygen and hydrogen isotopic compositions, as well as deuterium excess are reported in tabs. 1 and 2. The 1989-90 $\delta^{18}O$ values ranged from –20.49‰ to –38.64‰, while δD values ranged from –149‰ to –293%. The 1994-95 $\delta^{18}O$ values ranged from –26.16‰ to –43.84‰ and the δD

TABLE 1 - Results obtained for the 1989-90 samples

SAMPLE	ELEVATION (m)	$\delta^{18}O$	δD	DEUTERIUM EXCESS
1) Tarn Flat	10	-20,78	-158	8,24
2) Andersson Ridge	810	-20,49	-149	14.92
3) Mt. Matz Glacier	960	-21,17	-151	18,36
4) Mt. Emison	1360	-23,38	-175	12,04
5) Thern Promontory	1360	-30,54	-232	12,32
"	1640	-27,99	-210	13,92
"	1700	-27,21	-203	14,68
6) Mt. Nansen	2250	-31,79	-236	18,32
7) Mt. Pollock	1970	-30,63	-234	11,04
8) Eisenhower Range	2250	-25,38	-193	10,04
9) Shafer Peak	3000	-34,93	-266	13,44
"	3490	-38,64	-293	16,12
10) Hogden Heights	2660	-34,92	-264	15,36
"	2680	-34,12	-258	14.96
11) Timber Peak	2680	-38,08	-285	19.64
12) Ricker Hills	1480	-24,90	-181	18,02

TABLE 2 - Results obtained for the 1994-95 samples

SAMPLE	ELEVATION (m)	$\delta^{18}O$	δD	DEUTERIUM EXCESS
13) Hell's gate	10	-28,25	-222	3,70
14) Oasis Campus	55	-28,93	-230	1,44
15) Amorphous Glacier	290	-26,63	-207	6,44
16) Mandibole Cirque	500	-26,62	-201	12,46
17) The Mitten	1400	-36,63	-289	4,54
18) Campbell Glacier	1600	-36,70	-285	9,10
19) Mt. Bowen	1830	-41,30	-328	2,80
20) Lanterman range	1900	-26,16	-200	9,08
21) Mount Dickason	1960	-32,56	-254	6,78
22) Mount Melbourne	2040	-31,89	-246	9,22
23) Hercules Névé	2200	-37,65	-288	13,40
"	2600	-39,64	-301	16,02
24) Reeves Névé	2250	-43,84	-345	5,92

values, from −200‰ to −345‰. The least negative values were obtained from Andersson Ridge (810 m) and Lanternan Range (1900 m) and the most negative, from Shafer Peak (3490 m) and Reeves Névé (2200 m) for the 1990 and 1994 sampling periods, respectively.

As shown in fig. 3, a linear relation exists between the $\delta^{18}O$ and the δD levels in snowfall. In the specific case, it is expressed by the regression equation:

$$\delta D\ (\%) = 8.0826\ \delta^{18}O\ (\%) + 14.034 \qquad (R^2 = 0.997)$$

This is very similar to the so-called «meteoric water line» (Mwl), as defined by Craig (1961). The slope of 8.0826

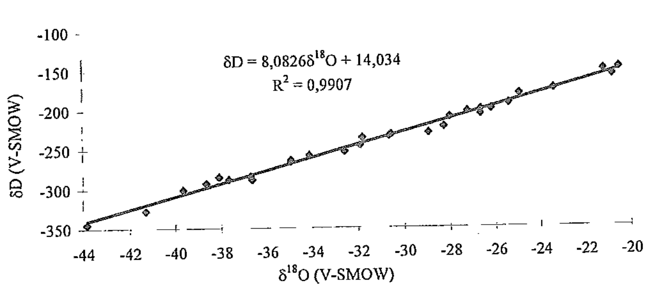

FIG. 3 - Correlation between $\delta^{18}O$ and δD for all samples (both data sets).

is very much in keeping with the values calculated for Antarctica by Jouzel & *alii* (1991).

The deuterium excess ranged from 8.24 to 19.64 (for the 1989-90 samples) and from 2.80 to 16.02 (for the 1994-95 samples).

DISCUSSION

As in the case of rain, the isotopic composition of snowfall is essentially related to the origin of moisture, the meteorological processes to which it has been subjected and the condensation temperature (Dansgaard, 1964). Apart from temperature, several other related variables may be of importance such as elevation, amount of precipitation, distance from the source of vapour and seasonal and short-term variations (Dansgaard, 1964).

The relationship existing between the isotopic composition of snowfall and elevation is the so-called «altitude effect», which is dependent upon local climate and topography. This is clearly seen in figs. 4 and 5, both for oxygen and hydrogen, comparing the two sampling periods. The relationships between elevation and isotope compositions are expressed by the following equations, for the 1989-1990 samples:

$$\delta^{18}O\ (\%) = -0.006\ h\ (m) - 17.64 \qquad R^2 = 0.807$$
$$\delta D\ (\%) = -0.047\ h\ (m) - 129.11 \qquad R^2 = 0.799$$

for the 1994-1995 samples:

$$\delta^{18}O\ (\%) = -0.005\ h\ (m) - 26.93 \qquad R^2 = 0.477$$
$$\delta D\ (\%) = -0.035\ h\ (m) - 211.11 \qquad R^2 = 0.421$$

where h is the elevation.

The mean vertical isotopic gradients proved to be −0.6%/100m and −0.5%/100m for $\delta^{18}O$, and −4.7%/100m and −3.5%/100m for δD for the two different sampling periods. The most striking feature is the strong contrast in R^2 between the two data sets. This could be explained by the different sampling period of the two sets, in particular by different meteorological and climatic conditions during those periods. Unfortunately, there are not enough data to conduct deeper statistical analysis and to provide a satisfactory explanation for this difference: it is only possible to make a general comment on the values obtained.

The 1989-90 samples collected below 1000 m (Tarn Flat, Andersson Ridge and Mt. Matz Glacier) show constant isotopic values for both oxygen (around −21%) and hydrogen (around −50%) (fig. 4).This is probably due to the redistribution of snow caused by drift, as pointed out by Dansgaard & *alii* (1973): this process is likely to be responsible for the complete absence of an altitude gradient in areas below 1000 m.

The deviations from the straight lines in figs. 4 and 5, could have different explanations. First, we should consider that the isotopic elevation effect could often include an inland continentality effect (with lighter isotopic values moving inland). Second, the effect of snow drift should be considered again: in Antarctica, this mechanism is particularly effective due to low accumulation rates and the exposure of large areas to the wind effect. Loewe (1954) found that almost $25 \cdot 10^6$ tons/y^{-1} km^{-2} of snow drifted from East

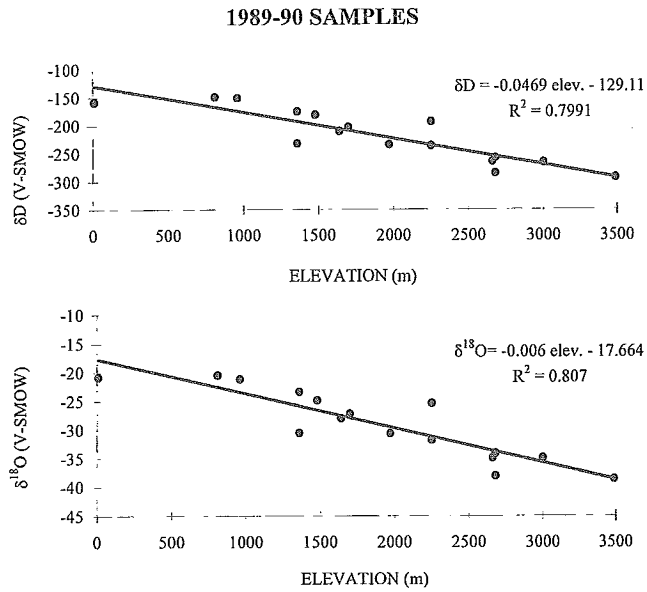

FIG. 4 - Correlation between δD,^{18}O and elevation for 1989-90 samples.

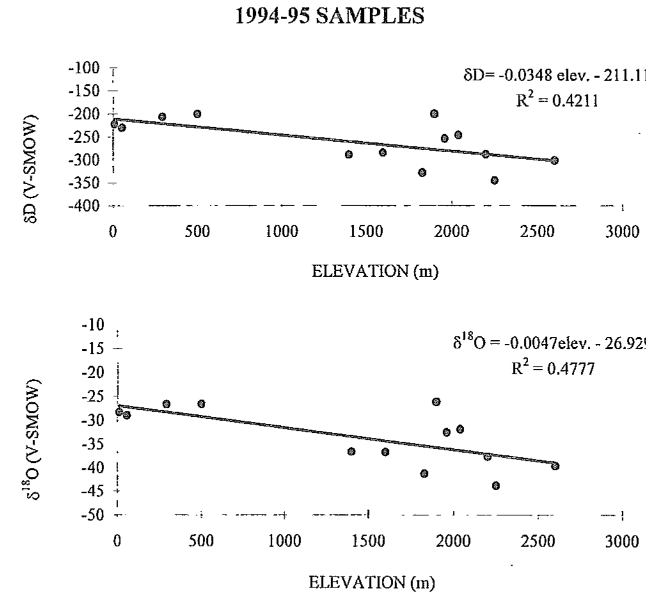

FIG. 5 - Correlation between δD, δ^{18}O and elevation for 1994-95 samples.

Antarctica at Port Martin. The values found at points lying below the straight line (i.e. Thern Promontory, Tarn Flat, Mt. Bowen, Reeves Névé...) are probably the result of drifting from higher to lower elevations. Consequently, the interpretation of the isotope contents of snow profiles may sometimes be difficult because of the effect of snow drift (Moser & Stichler, 1980). By contrast, the samples plotted above the line (i.e. Eisenhower Range) and showing a ^{18}O enrichment, could result from a partial evaporation of outer layers of snow crystals falling through drier air below the cloud level (Gat, 1980; Lorius, 1984). Indeed, evaporation could take place only if the cloud base does not reach the ground. This process is probably responsible for the inverse isotopic altitude effect reported for the coast of Terre Adelie by Lorius & *alii* (1969), and, in the same way, also for the slight decrease in the isotopic values from Oasis Campus (55 m) towards Amorphous Glacier (290 m) in the Northern Foothills (fig. 5).

The relationship with the distance from the coast is less evident than the relation existing with elevation, probably because it is a parameter that is not easily defined, given the influence of the morphology.

Correlations between the distance from the coast and the «deuterium-excess parameter» introduced by Dansgaard (1964), should also exist, in order to relate the composition of any water sample to the Mwl. This parameter is expressed by the equation: $d = \delta D - 8\ \delta^{18}O$. In general, the d-parameter may have a geophysical meaning in terms of the composition of the air mass from which the precipitations derive (Jouzel & *alii*, 1982) reflecting different conditions at vapour source regions (such as relative humidity, wind speed, sea surface temperature) (Petit & *alii*, 1991) and it increases with increasing distance from the coast.

The deuterium excess levels in the 1989-90 samples ranged from 8.24 to 19.64. In this case, there seems to be no clear-cut relationship between the deuterium excess values and the distance from the coast. However, an increase in the d-values (from 8.24 to 18.36) in the first 50 km inland can be identified, followed by a second increase (from 10.04 to 19.64) from 50 to 100 km from the coast. In this situation, the Prince Albert Mountains could represent the limit between the two areas.

The 1994-95 d-values range from 1.44 (a very low value) to 16.02 and did not reveal a clear-cut trend of lower to higher values moving inland. The high level found at Mandibole Cirque, situated along the coast (d=12.46), could be due to the extended presence of pack ice along this sector of the Northern Victoria Land coast that would keep Mandibole Cirque distant from open sea.

In any case, all the deuterium excess levels are comparable with those found in Antarctica by Petit & *alii* (1991) and Dahe & *alii* (1994).

CONCLUSIONS

The determination of the isotope composition of these snow samples confirmed the existence of a close relationship between δ^{18}O and δD. Furthermore, the isotopic/elevation gradient was calculated for both δ^{18}O and δD from the two different sampling sets, revealing values respectively of –0.6‰/100 m and –0.5‰/100 m (for ^{18}O) and –4.7 ‰/100 m and –3.5‰/100 m (for D).

The deviations from the straight lines are assumed to be due to snow drift processes.

The relationship with the distance from the coast is less clear because it may be influenced not only by the quite complicated morphology of northern Victoria Land, but also by the persistent presence of pack ice in Terra Nova Bay.

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