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PERIGLACIAL OF MC MURDO STRAIT (ANTARCTICA) **

Sommaire

(1) Dans les sables quaternaires et actuels, des grains de quartz ronds et mats frais indiquent une forte action du vent. Celui-ci est aussi responsable de la dissémination de gravillons d'environ 25 mm.

(2) Dans la vallée de Victoria, on observe non seulement des dunes de sable (signalées par les Néo-Zelandais), mais aussi des manteaux nivéo-éoliens, de pente 5 à 10 fois plus faible, et faits d'une interstratification de sable et de neige. Un tel type de dépôt n'avait été jusqu'ici décrit que du Groenland. Il rend compte d'un grand nombre de dépôts quaternaires d'Europe.

(3) L'usure par tous les glaciers étudiés, à en juger par l'indice d'émoussé des cailloux de 50 mm, est plus faible que dans aucun autre dépôt glaciaire connu. Par là elle est en violent contraste avec les moraines de fond de Nouvelle-Angleterre, à galets bien mieux usés, et où l'usure par l'eau courante ou tourbillonnante a dû être beaucoup plus forte. En Antarctique, cette l'usure a été extrêmement faible.

(4) Un type curieux de grains de quartz, parfaitement ronds, limpides et brillants, de 0,2 à 0,3 mm, toujours très peu abondants, connus de diverses parties du Monde (Guyane, Guinée), a été trouvé aussi à Mc Murdo NAF et là il s'est avéré provenir d'activité volcanique, comme le montre un échantillon de Castle Rock.

(5) La dimension des plus gros débris transportés, déterminée par la très rapide et pratique méthode du premier centile, est bien plus grande (20 à 100 mm) dans les dépôts d'eau de fonte de terrasses quaternaires, que dans l'actuel (2 à 3 mm, ce qui indique un sable). On peut en conclure qu'a certaines époques du Quaternaire, le volume des eaux de fonte, bien qu'insuffisant pour émousser beaucoup les cailloux, a dû être ici (vallée de Victoria) plus grand qu'aujourd'hui: nouvelle preuve de paléoclimats dans l'Antarctique.

Periglacial actions are numerous in Antarctica, but they are limited to emerged parts only, not covered by the ice, about 250000 to 300000 km². Some aspects of their manifestations have been mentioned in forty publications approximatively. The restatement of all the question, up to date in 1962, has been published in *Geology of Antarctica*, by A. Cailleux (1963, p. 95—114). More recent particular works are mentioned in the bibliography, at the end of the present work.

The Mc Murdo area is located through and through the Mc Murdo Strait, in latitude 77° and 78° south and longitude 161° and 167° east.

Seen from the air, the most significant feature in the landscape is tesselation or subdivision in contraction polygons (polygons due to cold weather) 10 to 15 m in size. They form the subject of the works of T. L. Pé-

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wé (1959), R. F. Black and his collaborators. Taffoni (cavernous weathering) have been studied by P. Calkin and A. Cailleux (1962, 1963). In order to avoid repetition, the present work will bear on the other aspects.

The Mc Murdo Strait is occupied by the ice-pack during 9 to 12 months, according to localities. In the south, towards 78°, it is obstructed by the Mc Murdo Ice-shelf, that links it to the Ross Ice-shelf towards the southeast. Mc Murdo Ice-shelf is very different, particularly its speed of displacement towards the northeast is slower and shows to the aerial observer melting moraines and many small round or oval ponds.

I have worked on the continent (in the west part of the Strait) at Victoria Valley and at Marble Point and around (Gneiss Point); on Ross Island, at Hut Point (Mc Murdo NAF) and around, at Cape Royds and Cape Evans (fig. 1).

Air temperature at screen has an annual mean of −17° C at Hut Point (20 m in height); mean in January, −3°; in August, −29°; absolute minimum −49.5°; absolute maximum +4.4°. Mean wind speed is 22 km/h at Hut Point, station exceptionally sheltered; it is stronger elsewhere. Mean nebulosity: 0.5. Precipitations, entirely in snow form, are very weak: from 50 to 150 mm according to localities.

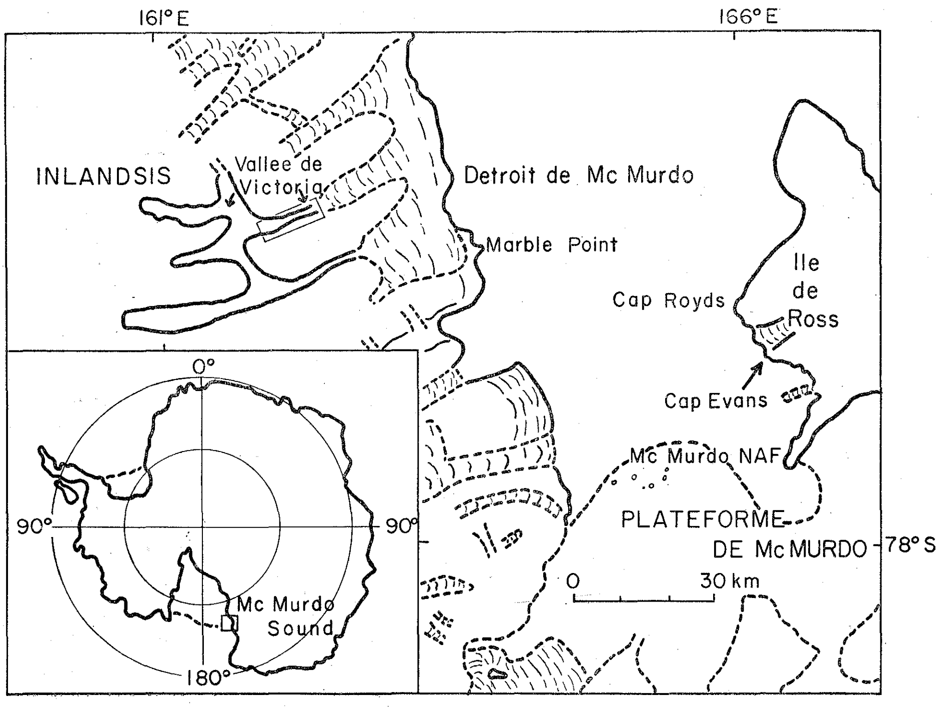

Fig. 1. Location of the area investigated

Some of the following observations have been published in French (Cailleux, 1962), in a report at the French National Board for Antarctic Research; this report is now out of print. I wish to thank Mr. Laclavère, President of this Board, who has authorized their translation, Mr. Dylik who assures the publication, Mr. Germain Tremblay, who made this translation, and all the colleagues and friends of the United States and other countries who assisted me during three months in Antarctica.

I adopt the following plan: (A) Sands, (B) Granules and small pebbles, (C) Pebbles and boulders, (D) Clays and silts.

SANDS

FORMS ON THE GROUND

On Victoria Valley, sand forms the recent filling of very small melt-water streams, niveo-eolian covers with interstratified layers of snow and also dunes.

North and east of Vida Lake, dunes are to be seen at the junction of Lower Victoria Stream (thus I shall name the outlet of Lower Victoria Glacier, which flows from east to west towards Vida Lake) and the outlet of Packard Glacier, coming from the north. They are like, at all points, the dunes of moderate or warm regions; in addition, when wind blows, a sandcloud arises; it is dense only near the ground, 10 to 20 cm and it gives large longitudinal trails; the wind moulds itself on the dune; in the hollows where the rubble substratum outcrops, a kind of feidjs, wind is moderate, without sand.

Niveo-eolian covers (Pls. 1 to 4) present much interest. Such a type of deposit has been seen for the first time by C. E. Wegmann in Greenland, but has not been described in details. Edelman and other writers have then interpreted, as niveo-eolian covers, many surficial Quaternary sands of the Netherlands, Belgium, and the north-european borderland from Landes of Gascony to Poland. The term *niveo-eolian* has been proposed on the ground by Van Straelen, during an excursion of Congress „Sedimentation et Quaternaire" in Campine (Belgium), in 1946, and has been immediately adopted.

In Victoria Valley, niveo-eolian covers are recent, functional. They occupy five times more space than dunes; they cover about 75 percent of the surface between the front of Lower Victoria Glacier on the east and the outlet of Packard Glacier. From this point, they run westwards almost to Vida Lake. We find niveo-eolian covers also on the North side of this lake. On aerial pictures, they appear in the form of white elongated veneers, bigger than dunes, less clearly limited, but easy to distinguish from thalwegs because they are not continuous. They occur on the valley bottoms and gently sloping valley sides. Their median slope reaches 2 degrees only. As well as dunes, they are without vegetation; in January their surface is composed of sand; when the wind is strong, the sand is transported; they show parallel ripples at intervals of 6 to 10 cm. But they may be distinguished from dunes by many features (Table I).

Table I

Niveo-eolian covers and dunes of Victoria Valley

	Niveo-eolian cover	Dunes
General slope	Weak, 0 to 10°	Strong, 5 to 31°
Median length	Big, 500 to 2000 m	Small, 200 to 600 m
Crests	Well rounded	Angular
Perceptible substratum	From place to place	Only in interdunes
Small pebbles 3 to 5 mm long	Present; rare nests	Nil
Volcanic particles 1 mm, black	Mixed with the rest	Sorted, by trails
Big ripples, wave-length 0.8 to 1 m	Frequent	Absent here. Exceptional elsewhere (Sahara)
Interstratified layers of snow	Present	Never seen
Contraction wedges	Frequent	Nil or very unusual
Crevasses at the foot and subsidence	Present	Nil

Tranversal sections of niveo-eolian covers show interstratified sand and snow. Such sections are difficult to observe; indeed only a sand-layer 20 to 30 cm thick thaws every summer; below, there is permafrost, impenetrable by the hammer and piolet. Few meltwater streams, here and there, cut niveo-eolian covers, but these sections cut by stream erosion show, in most cases, blankets of recent taluses consisting of alternating sand and snow layers, for example 1 km east of Vida Lake (Pl. 4).

Nevertheless a few good outcrops show the section of the niveo-eolian blanket itself. For instance two or three km east of Vida Lake, on the side of a blanket truncated by meltwater erosion, with a slope of 15°, we see, below 8 cm of sand, 12 cm of snow, well stratified, dense, having the aspects of firn with a probable density of 0.5 to 0.6. It crumbles between fingers, but only if we press. The piolet cuts it easily; we could expose a section 2 m in width; 3 or 4 lens of sand were interstratified with snow.

Near this section, erosion by a meltwater streamlet shows, below the sand, stratified snow with dark layers containing sand; in one place, this snow, in a distance of 30 cm, turns to firn and to granular ice. Somewhere, the grain of this interstratified ice can reach 3 mm; in some cases, it is like small peas. In many cases, this ice is bubbly; the bubbles are 0,2 to 0.6 mm in length.

On the surface, these niveo-eolian covers show common small ripples spaced 6 to 10 cm apart, and big ones spaced 80 to 100 cm, with a height of about 7 cm. These big ripples are grouped more or less in a parallel direction, evoking old ploughings; but they have a rather sinuous outline; in some places, ripples relieve one another, giving an elongated rhomb-shaped disposition. These ripples are not symmetrical; they have a gentle slope towards the east, where wind comes from in January; an abrupt slope towards the west. On the ice of Vida Lake, snow fallen on January 25th, 1961 is arranged in ripples of this kind, in trails or sigma, 80 to 100 cm apart, with only 2 cm in height because there has been little snow. Big ripples have been seen in other places on snow and also on Sahara sands, where Queney described them for the first time (1951—1953).

Contrary to dunes, the surface of niveo-eolian covers presents in many cases, for example towards the front of Lower Victoria Glacier, cracks of contraction, arranged in nets with a predominance of right angles or nearly. The intervals between cracks are 10 to 20 m, the cracks are 10 to 15 cm in width at the top; the visible filling consists of sand, similar to that of the cover itself; sometimes thinner cracks subdivide the big polygons. These cracks are a kind of the so-called *fentes en coin* (wedges) which are very well known in the Quaternary in Europe and in the Recent in Antarctica where they have been described and studied first by Péwé (1959).

Niveo-eolian covers again differ from dunes by extremely striking features. At long intervals, they show subsidence-troughs, 4 to 20 m in length, 2 to 5 m in width and 0.1 to 0.3 m in depth, may be due to the subsiding of underlying snow. And on their steep-sloped sides or near them, we can see kinds of cracks, parallel to the side, 10 to 40 m in length, 40 to 80 cm in width and 10 to 30 cm in depth; they remind of the cracks of clayey slopes; they mark a quarrying, due partly to sliding, may be to the sapping by the meltwater stream at the foot of the slope; as they are absent in dunes, interstratified snow in the covers is probably liable for their appearance, either in melting, or in helping the slide. Other distinctive characters of the niveo-eolian covers are indicated in table I.

Niveo-eolian covers may be much less thick than dunes; in some places they are so thin that morainic boulders from underneath outcrop: such is the case at 1 or 2 km W of the front of Victoria Glacier. Eolian sand in thin patches is still found scattered on the ground moraines or fields of gelifracted stony fragments; it forms the whole or a part of the filling in the contraction cracks; here and there it is found below the pebbles of the surface which have protected it against deflation. Niveo-eolian covers laterally pass to dunes by transition, for example around the big dune north of Vida Lake.

In January, in Victoria Valley, the prevailing wind comes from the east; this direction is well corroborated by the dissymetry of the dunes and ripples. In return, wind from the west or southwest is indicated by two kinds of facts: (1) The big accumulations of sand are all situated in the east and northeast parts of the valley system. (2) Parker Calkin has noted that basaltic or doleritic boulders scattered on the ground have on their east and northeast sides a brownish shade, due to a coating or exudation of iron hydroxyde, whereas the west and southwest sides are black, having been scoured by wind; the difference is very perceptible; when the sky is cloudy, we have only to look in one direction, and then in the opposite one, to realize it. Is this prevailing wind from the west and southwest the actual winter wind? Or does it date from an old period with a different climate? A wintering in this region could settle this question once and for all, and would allow to observe how snow and sand become interstratified in covers. In summer — in January — blowing of sand by wind is well marked on dunes, on niveo-eolian covers, and on the actual alluvial flats, which are plastered with sand and dry during most of the year and on the biggest part of their width. Near the thin streamlet or trickle of water, when wind blows, this sand is raised and big bands are blown off along the ground, probably by saltation (Pl. 5).

We can study this sand-lifting quantitatively. If we examine, facing the shining sun the sand of Victoria Valley, we see on dull bottom very bright particles, angular feldspars generally showing cleavage under favourable incidence, scattered at every 10 or 15 cm. We fix one of them, at a distance of 2 or 3 m, and we observe during how much time we can still see it. When sand-drift is strong, the particle remains only a fraction of second before it disappears; then we fix another particle and we note that it disappears as quickly, blown off by wind. When it is abating, some particles persist until two seconds. Dull or differently oriented particles evidently disappear approximatively at the same speed, but to the naked eye, we cannot realize it.

In examining bright particles, we remark that, by moderate wind, on recent, sandy beds of streams, each particle disappears after an average of one second. On terraces, a little bit gravelly, Quaternary, particles keep four to six times more; some do not move at all. On coarser old fluvioglacial covers, with boulders, there is still less lifting of sand.

NATURE OF SAND GRAINS

Everywhere, next to quartz, there is a large proportion of feldspar (about 10 to 60 per cent) indicating that granito-gneissic bedrock has principally undergone mechanical disaggregation, and there has been no chemical actions (Cailleux and Tricart, 1959, t. 1, p. 34—36).

Volcanic particles prevail in a large proportion (90 to 100 per cent) in all the sands of volcanic Ross island; in many cases they are black, sometimes bubbly; many grains are feldspars; some, olivines or amphiboles. On the continent, in Victoria Valley, volcanic grains are more sparse; they seem to come from old basalts and dolerites principally; at Marble Point, there are about 10 per cent of volcanic grains.

The Marble Point sands show some biotites and muscovites and green lamellae, chlorites probably. At Wright Dry Valley, we have some micas.

Some sponge spicules can be seen at Cape Royds, in sandy sheds, 120 and 200 m in height. They come from sea; the two studied dredgings contain some sponges (Ice Hole near the Mc Murdo NAF, 580 m in depth; and off Cape Royds, 435 m in depth). A calcareous Foraminifere has been found at Cape Royds, 200 m in height; the two above-mentioned dredgings also contain Foraminiferes. A fragment of calcareous shell has been found in the same sand of Cape Royds, and two others, one fibrous and the other stratified, in superficial sand, 1.2 km north of Mc Murdo NAF, about 150 m in height. From sea until their actual height, these spicules, Foraminiferes and fragments of shells have been probably transported by wind, eventually by birds.

SHAPE OF SAND GRAINS

(*a*) *Angular fragments*

There are many angular particles in the recent volcanic, particularly at Cape Evans. They are more or less abundant in quartz and feldspars derived from granites and gneisses, for example at Cape Royds, where they come from the disaggregation of erratic boulders.

(*b*) *Rounded and dull grains, shaped by wind*

In most studied sands, among quartz from 0.5 to 1 mm, these grains are numerous and typical, and they show strong wind-wearing. But how old is this wearing? Beacon, or Quaternary?

Some quartz particles are certainly reworked from Beacon sandstone, they are easily recognizable by the presence of recrystallization little facets, 10 to 50 microns, very plane. They are very abundant, near Mount Gran, where the Beacon sandstones outcrop.

But other rounded and dull grains result from a more recent wind action, probably Quaternary and recent. Thus many quartz particles show no mark of recrystallization facets; in some places, they form the whole. All the transitions between angular and rounded and dull quartz are found: smoothed and dull, numerous in many cases; there are no such transitions in the Beacon. Feldspars are also rounded and dull, or smoothed and dull, approximatively in the same proportion that quartz; in the Beacon they are exceedingly rare. Finally, in the Recent, the compact volcanic grains are in many cases also rounded and dull or smoothed and dull; such a type of grains are absent in the Beacon, according to the present state of knowledge, and the volcanism in this region is subsequent to it.

Summing up, the recent moulding of sand grains by wind has been strong; it can be seen on dune, niveo-eolian, glacial, marine, or streamlet sand, because the same grains are unceasingly reworked from one formation into the other and the wearing by wind is the strongest one. At the front of Lower Victoria Glacier, sand grains of 1 mm are enclosed in the ice, which is well stratified; they are already very rich in rounded and dull wind-worn grains, probably because they have been transported over by wind, on the firn. Where this front forms a vertical cliff, 15 m in height, actual ablation is very important. About 15 to 16 hrs in the afternoon, every 30 seconds, a gust of wind pulls away sand from the cliff and blows it out. The sand whirls 2 or 3 seconds and falls at the foot, due to the melting of the front, but also to its sublimation and high evaporation, *in situ*, of meltwater. Some days, in summer, a little bit of meltwater flows and brings sand towards the outlet, further downstream. On the dry bed, wind blows out the sand again and incorporates it into covers or dunes.

Sometimes eolian grains fall into the sea; thus the Ice Hole dredging, near Mc Murdo NAF, 580 m in depth, shows typical eolian quartz; drift-ice could bring it here. The same rounded and dull or smoothed and dull quartz are seen on the adjoining Ross Island, however volcanic; there they have been probably brought by wind itself, as this is the case with the spicules; the highest sample, near Castle Rock, about 250 m in height contains such round-dull-quartz grains.

About 1 km northeast of Mc Murdo NAF, sand enclosed in the anfractuosities of a volcanic boulder, is very well sorted, without grain above 1 mm, which proves that it has been brought there by wind; it is very heterogeneous, being composed of volcanic grains of any colour and compactness, feldspars, olivine and quartz; there are many rounded and dull or smoothed and dull grains among the volcanics and quartz; we can attribute to wind not only wearing, but also good sorting of this sand.

(c) Lack of smoothed and shiny grains

Amongst the studied samples, there were no smoothed and shiny grains due to water-wearing, what is well explicable because running waters are very weak and the sea is frozen during 340 to 365 days every year.

(d) Shiny and clear quartz pearls

Many samples of Ross Island have little spheres or ellipsoides of quartz, 50 to 300 microns long, exceedingly rare (less 1 for thousand) but very typical by their clarity and shining vividness. A such type of pearl was known until to-day only in the soils and river-sands of Guiana and West Africa, and their origin was unexplained.

At the foot of Castle Rock Hill, made out of volcanic breccia, the same pearls were found in the volcanic talus; they are abundant, some still imbedded in red or green scoriae, where they seem to be a bubbles filling. They have 50 to 300 microns; some are isolated, in sphere or ellipsoide a little bit flat; others are coalescent, consisting of two or three pearls or more; others finally are spheres having lost their buds, of which the sear is like a circle; most pearls are shining, but some are lustreless, probably due to different conditions of solidification.

Thus in Antarctica, quartz pearls are associated with explosive volcanic eruptions.

GRANULES AND SMALL PEBBLES FROM 7 TO 30 mm

On the Hut Point volcanic peninsula, Sam Treves has mentioned a seed of pebbles of 7 to 30 mm, composed of granite, gneiss and other erratic rocks. I found these pebbles wherever I looked for them, until the hill south of Castle Rock; we find these pebbles even on the crater 2.8 km north of Mc Murdo NAF, 280 m high. Their frequency is variable; thus at the bottom of the crater, there are only some pebbles and on the sides much more: several samples in one square meter.

These exotic rocks are in most cases a little bit rounded. They have been brought, but not by a glacier, because in this case there would be also big boulders, 30 cm and even 1 m and above, as at Cape Royds. At Hut Point that is not the case. The same reason excludes transportation by sea or icebergs. Transportation by running water is left out due to their extreme scarcity, and the fact that small exotic rocks are even seen on ridges. Only transportation by wind is possible.

In West Antarctica, Wade (1945) has observed small fragments of rock transported by wind on the surface of snow, until 1500 m away from outcrops; according to his figure, these fragments have from 5 to 20 mm.

On the very fresh little volcano, 2.8 km north of Mc Murdo NAF, the red scoriae, completely angular, of which the boulders reach 2 m and more in length, are covered on the surface with a blackish granular layer, composed of granules of 2 to 15 mm approximatively, with 90 per cent of black volcanic grains and 10% of granites, gneisses and other exotic rocks. But the volcanic particles themselves are rounded and stand in contrast with the angular scoriae of substratum; they also have been brought, and on this abrupt slope, only wind was able to plaster them.

The presence, on the gelifracted rock, of granules not belonging to this rock, seems to be general in the region. At Victoria Valley, on the south side of Vida Lake, free from glacial deposit, the slabs of gelifracted

Table II

Composition of small erratic pebbles above 10 mm on gelifracted rock, about 200 m south of the west end of Vida Lake (Victoria Valley)

	On gneiss	On basalt
Number of erratics	172	137
Length of the biggest, mm	68	46
Length of the smallest, mm	10	10
Composition in per cent:		
Basalt and dolerite	48	—
Microgranite and rhyolite	20	9
Granite	8	} 70
Gneiss	—	}
Yellow weathered gneiss	5	7
Gneissic quartz	7	7
Vein quartz	4	3
Quartzite	3	2
Sandstone	5	1
Graywacke	—	1
Total	100	100

granite are covered with pebbles of black basalt, from 10 to 30 mm generally, exceptionally 80 to 100 mm, that are very much worked by wind; there are 0 to 4 such pebbles by square metre. Inversely, on the basalt veins, there are fragments of granite from 2 to 8 mm approximatively. On the north side of the same lake, on the outcrop of gelifracted dolerite with a slope from 16 to 23°, one finds little quartz from 5 to 20 mm, yellow or white, rounded, coming from the disaggregation of Beacon conglomerate. This conglomerate outcrops only at several kilometers from Vida Lake. The lack of big erratic rock excludes glacial transportation, and only wind can explain the presence of these small ones.

At 200 m south of the west end of Vida Lake, on the gelifracted gneiss *in situ*, on 8 square decimeters, I collected 172 erratic small pebbles of 10 mm and more; the longest is a basalt that measures $68 \times 33 \times 14$ mm^3; the biggest is a sandstone having $44 \times 34 \times 19$ mm^3; the median is about 20 mm. 100 m farther, on the basalt (of the dolerite series), among 137 erratic small pebbles of 10 mm and more, the longest is a gneiss measuring $46 \times 37 \times 7$ mm^3, the biggest is a weathered gneiss having $45 \times 23 \times 12$ mm^3; the median is about 20 mm. The nature of these two samples is given in table II. Very likely their deposition is due to wind.

The small pebbles can show a little bit of wearing; this will be discussed in connection with the bigger pebbles that we will now consider.

PEBBLES AND COBBLES 50 TO 2000 mm AND MORE

PENGUINS' ACTION

Near the sea, it is questionable whether some small indications of wearing — a such type of wearing has been seen in Adelie Land — are attributable to the transportation and trampling by the penguins. In fact, Adelie penguins at Cape Royds collect for their nests small pebbles (median about 30 mm); but their surface is entirely covered with dry excrements, which protect it against wearing. So penguins do not wear stones; on the other hand they sort them according to their size.

WEATHER ACTIONS

(*a*) *Freezing and thawing actions*

Here are some measures with regard to the depth of thawing or soft ground, January first, 1961, at Victoria Valley, near the confluence of Lower Victoria Stream and the outlet of Packard glacier.

Measures made with a piolet. Depths in cm:

Niveo-eolian cover, slope 1°: 11—15—16—cm

Pebbles with morainic boulders, southside, 300 m above the valley, slope 20°: 11—14—15—16

Same side, wash channel with a sandy bottom: 11—17—20

Prominent border of the same channel: 15—18—20

Bottom of valley, moist lateral streamlet: 14—15

Nearby, subhorizontal moraine: 16—16—18

Bottom of valley, depressed center of a polygon: 9—10

Prominent border of the same: 42—43

Hillock of isolated pebbles: 28—29—30—32

Moist high-water bed of Lower Victoria Stream: 16—18—18—20

The same bed, 2 km below the front: 17—18—19—21—23—23—23—25—26—26

Side of dry dune: 25—25—27—27—31—44

Top of dry dune: >83—>85

Top of moist dune: >70

We see that the prominent parts thaw more deeply; mean air temperature being —3° or —4°C in January, conduction and convection must tend to cool them; the effect of the absorption of solar radiation is very strongly predominant. Here we rejoin the conclusion we have obtained by the study of deglaciated areas.

February, 5, 1961 after many days of frost, on the side of Vida Lake, west end, we find the soil under water not frozen, 28 to 30 cm in depth, and the soil in the open air 5 cm in depth only; these values occur, under water, until 5 cm from the shoreline, and in the open air, until 2 cm. Thus the lake water is liable for reheating, and the limit of its action is very sharply marked.

Everywhere, all the rocks *in situ* are strongly gelifracted; the works of foundation for atomic generator at Mc Murdo NAF (Pl. 6) showed, on more than 6 m in depth, in the volcanic rocks, veins and lenses of ice. On the surface, for the evaluation of the size of fragments, the most rapid and useful method, on the ground, is that of centile (Cailleux and Tricart, 1959); its results are expressed, in the following pages, by the side of square such as 1 per cent of the ground surface is occupied by pebbles or grains of equal or superior surface.

In each choosen area, we make 5 to 11 measures, and we take the median value. South of the west end of Vida Lake, the fragments of rock *in situ*, broken by freezing, have their first centile towards 135 mm in the gneisses; 150 mm in the basalts; 3 km to the east, granite gives bigger slags. The flattening indexes of fragments (length and width divided by twice the thickness) are strong, what is characteristic of freezing action; for those of 50 mm in length, south of Vida Lake, we have as median 4.0 for the gneisses; 2.65 for the basalt and 2.7 for the granite. In many cases, when we lift a boulder 20 to 30 cm long, the lower part gives scales, very fresh, not weathered, probably due to frost. An erratic granite boulder of Cape Royds gives fragments of median flattening 6.0. At Marble Point, a gelifracted granite boulder gives 2.1 for the upper fragments and 4.3 for the lower ones. Even the volcanic scoriae, material usually not very flat, give 2.8 for the fragments below a gelifracted boulder, 1.3 km northeast of Mc Murdo NAF (Table III).

Gelifracted fragments are usually very angular. Nevertheless, 2 km southwest of Vida Lake, the granular dolerite, *in situ*, disintegrates into spheres or balls 50 to 200 mm in diameter; but this rounding is not at all due to wearing. Further downstream, the same balls are mixed with other detrital deposits and hence difficult to distinguish from the possible actions of mecanical wearing by water.

By far the most spectacular cryoturbation action consists in the subdivision of the ground in more or less tetragonal polygons, bounded by fissures, 10 to 20 m in interval, of the type of ice-wedges. It affects all the ground, except the dunes, flat bottom of the functional actual thalwegs and exceptional outcrops of compact rock. Exceptionally, 4 cells of polygon occur at the same point; generally, a little side of 30 to 60 cm in length, is intercalated between two cells. The wedge is depressed, but its sides are raised, on both sides. They form two crests that have, sometimes, in gelifracted rocks, 60 or 80 cm in height and are 3 m apart; the cell center is depressed. The rise of the sides is probably due to the gradual widening of the wedges; in winter, the polygon would contract in the horizontal direction; then the whole of the wedge having been filled up in spring by ice or sand, according to the mechanisms described by Péwé, the estival dilatation would swell the sides so much easier that they are more deeply unfrozen, hence more easily deformed than the centre of the polygons. In a vertical section, near Vida Lake, I have seen in the side of a wedge, vertical layers of sand. On some valley-sides, for example at Victoria Valley, cells are aligned in files parallel to the slope. Thomas Berg studied those wedges and cells.

Smaller polygonal soils, with stone sorting, are exceptional and little typical. I have seen one example at Cape Royds, on the trail going from sea to inside, 100 m in height, 500 m from sea. Here, we can observe, on little trains of solifluction, in thalweg, with soft soil into which the foot penetrates, a beginning of stone sorting and polygons, about 70 cm in diameter.

Table III

Flatness and roundness indexes of pebbles of the Mc Murdo Strait

L — Length, l — width, E — thickness, r_1 — the smallest radius of curvature of the apparent contour in L and l plane

Length in mm	N	Flatness index (L+l) : 2E				Roundness index	
						$2000 r_1 : l$	$2000 r_2 : L$
		20	50	100	200	50	50
Gneiss							
In situ, gelifracted, Vida Lake SW	58		4.0	3.6	4.7		
Actual moraine, Lower Victoria Valley	19		1.9	—	—	48	73
Fluvio-glacial, Vida Lake, NW	23		2.1	—	—	51	77
Granite							
Gelifracted boulder } Marble	72	2.5	2.1	2.3			
Below this boulder } Point	36	4.0	4.3				
Below two gelifracted boulders	29	4.0					
at Cape Royds	18		6.0	10.0			
In situ, gelifracted, Vida Lake	56		2.7	2.5	3.3		
Actual moraine, Lower Victoria Valley	34		1.8	—	—	39	59
Actual moraine } Marble	35		2.4	—	—	27	43
Quaternary marine beach } Point	40		2.6	—	—	58	86
Superficial erratic boulders, Cape Royds	41		2.3	—	—	170	290
Basalt and dolerite							
In situ, gelifracted, Vida Lake, SW	52		2.65	3.1	4.8		
Actual moraine, Lower Victoria Valley	24		1.85	—	—	45	68
Actual moraine, Mc Murdo NAF	16		1.6				
Fluvio-glacial Vida Lake } NW, Quaternary	31		2.4	—	—	55	79
Fluvio-glacial Vida Lake } SW, Quaternary	29		1.8	—	—	125	125
Volcanic scoriae							
Below gelifracted boulder, Mc Murdo NAF	33		2.8	3.0			

Solifluction and gravity screes are mediocre. Thus the mountain side, south of Vida Lake (Pl. 11), in its part sloping 10 to 35°, shows, with unusual sharpness, the boundaries of the veins and sills of basalt (or dolerite) in gneiss, in several steps. If there had been recent solifluction, the blocks of one of these rocks would have been carried on the other and the limits would not be so sharp.

Is this absence or scarcity of solifluction due to lack or scarcity of liquid water? The only exceptions on this slope are towards its middle a grey trail problably coming from a vertical abrupt, possibly in consequence of a landfall: and, near the west end, a shallow channel with levees; this channel begins in the gneiss, then forks and matches the dolerite. At the foot of the same slope, on the piedmont sloping 4 to 5° ending at the lake, boulders are, in many cases, rocked, set upright with an angle of 70 to 80°, which is a proof of cryoturbation. A boulder of granite 4 m in width is cut into two parts by a vertical crack, and its downhill parts has slid on a distance of 80 cm; there has been, in this case, a little bit of solifluction. But it is weak and strictly localized.

(*b*) *Actions of wind on pebbles and boulders*

Pebbles with polished facets and sharp edges have been described by some authors in the beginning of the century; I found such pebbles at Hut Point, particularly near Arrival Heights, and in Victoria Valley. Their geographical distribution would deserve a fuller study. We have seen that, on big boulders of 30 cm and above, the orientation of their mostly worn side indicates where the effective wind came from; in Victoria Valley, from WSW.

Recent authors have assigned to wind, under the name of wind-weathering, aspects identical with taffonis: they will be described further.

(*c*) *Granular disintegration*

Its importance has been mentioned by all observers. It exerts its action particularly on granular rocks, as granites, gneisses, dolerites and marbles. The morainic gelifracted marble boulders of Marble Point weather and give fragments 1 to 5 mm long. The same happens to some granites. In the Lower Victoria Valley, disintegration has been moderate in the bottom, more active on the higher and older morainic sediments of south valley-side. Originally angular boulders can, under its action, take a deceptive rounded form, on their exposed part; but when one unburies them, the bottom part appears perfectly angular, as we have observed it with Sam Treves at Marble Point and Cape Royds (Pl. 8). Finally, granular disintegration contributes to the erosion of taffonis.

It affects the boulders of pink and red granite still half-hidden in the ice of Lower Victoria Glacier; so that at the foot of this glacier we see boulders 20 to 100 cm long and more, embedded in the ice, and angular fragments 2 to 5 mm long, coming from the crumbling of these or similar boulders and giving little taluses at the foot of the edge or even taken again in re-freezing ice.

Freezing seems to be the principal agent liable for this disintegration, at least in this case. But the intervention of the crystallization of the mirabilite, or hydrated sodium sulphate, Na_2SO_4, $10H_2O$, abundant in the area, is not excluded.

With the binocular microscope, we can make useful observations. So a marble pebble collected at Marble Point, on ground moraine, 300 m south of the camp, shows on its lower part a budding calcareous crust which will be described later, and is disintegrating by the action of fissures 0.2 mm wide, that affect the crust also. The retreat of the glacier seems recent, but the crust is still more recent and disintegration is actually active.

At the same place, a granite pebble shows a compact calcareous coating. When HCl has dissolved this superficial coating, we see, always under the binocular, bubbles of deeper origin coming out along little fissures of the granite, principally at the limit between two crystals and near biotites; we see also, by transparency across the quartz and feldspar of granite, bubbles taking form inside, increasing, then sliding up and bursting outside. The calcite which is thus attacked is not an original magmatic calcite; indeed, if we deposit a drop of HCl more deeply, it does not react. Briefly, this test allows us to distinguish in the pebble of examined granite, from inside to outside, three concentric zones: (1°) the intact rock, (2°) the fissured granite, 2 or 3 mm in thickness, (3°) the calcareous crust, here 0.3 to 0.5 mm in thickness. The calcite forms the crust and fills up the fissures of disintegration, either its crystallization creates these fissures, or it takes advantages of the pre-existent fissures, due to freezing or crystallization of mirabilite.

At the same place, an erratic marble boulder shows from inside to outside, the intact rock, a zone with little fissures plastered with green algae and finally a zone with fissures containing mineral dust.

At Marble Point, 600 m east of the camp, an erratic boulder of pink granite is partly disaggregated. On the fragments that seem intact, a hammer-stoke shows easy fracturing. On the fracture faces, some crystals are disturbed, lain on slab; a mica is broken into two parts, mineral dust adheres to it. On an erratic boulder of marble taken at 300 m east from the camp, fissures are beginning: I realize them with a hammer; under the binocular, the fissure appears plastered with a membrane of blue alga where miscellaneous particles adhere, particularly of quartz, mica and volcanic substance. With regard to the boulder of marble, these particles are extraneous, they have been brought in these fissures by water or wind. They are imprisoned. Some of them can act as a wedge; if any cause (freezing, crystallization or other) enlarges ever so little the fissure, the mineral particles which are well disposed oppose its closing. This processus, repeated, has one way only: the fissure enlarges more and more. This process probably has great importance in disintegration.

(*d*) *Exfoliation* (*Pl. 9*)

Some boulders of granites and gneisses, principally, exfoliate into slabs or lamellae, more or less concentric, both in their upper and lower parts. At Cape Royds, a lamella 25 cm long has broken off from the top of a granite boulder 39 cm long. It lies now 80 cm further, 12 cm downhill. At the foot of the south valley-side of Lower Victoria Stream, exfoliation is particularly distinct below the boulders. The more we go up, the greater is the exfoliation on the upper part of the boulders. It gives lamellae with a flatness index of 10. Some are separating; I detached a lamella of 18 cm in length and 12 cm in width. On the north slope, at the foot of a pink granite, the flattest exfoliated fragment has $210 \times 58 \times 13.2$ mm^3 and has 10 as flatness index; here the median flatness index seem to be 2.5 for a length of 50 mm.

As well as disintegration, exfoliation can be seen, very good, on the boulders still half-hidden in the ice at the front of Lower Victoria Glacier, and it suggests two hypothesis: freezing probably; may-be mirabilite.

(*e*) *Alveolar erosion and taffonisation*

They have been figured and mentioned by some recent American authors by the name of weathering or even wind-weathering. Their origin is debatable.

Alveoles and taffoni are cavities excavated on the side of boulders principally. They are rounded, in some cases hemi-spherical, with a rough surface. Alveoles have 20 to 100 mm in diameter, sometimes 500 mm; they are usually in groups. Taffoni have 500 to 1000 mm in opening or more, and 100 to 1000 in depth, or more. Between them and alveoles, there are transitions.

Alveolar erosion can be seen on Kenyite at Cape Royds, and it is, as taffonisation, more frequent at low altitudes (0 to 80 m) than higher (100 to

200 m). At Cape Evans, it is very well developed in the volcanic tuff; as taffonisation, it is more abundant on the higher parts of the ground than in the depressions; and a little more abundant in the southern part of the Cape than in the northern one: that proves it is a shade phenomenon, as noted by P. Birot elsewhere.

At Cape Evans, in alveoles, there are crumbled fragments; the top of boulders crumbles also; there are some cavities of which the axis slopes at 45° upwards. On the edges of alveoles, the anorthose feldspar of kenyite has bright cleavage; consequently it is not altered; some white patches are mirabilite.

Taffoni are still more frequent than alveoles, and they have size and extension at least as important as in Corsica where they have been described at first. We can see them on coarse-grained rocks: granite, gneiss, dolerite, kenyite, volcanic tuff; they are absent on fine-grained basalt. On the north side of Lower Victoria Valley they are more abundant and more beautiful on coarse-grained pink granites than on smaller ones (below 70 cm) or lower ones (below 30 cm). A boulder measuring 10 × 14 m^2 and 8 m in height shows alveoles at all heights, which proves that they are not attributable to sand erosion blown by wind, this sand being blown principally near the ground. On the top of the same boulder, there are a kind of vertical pot-holes, 30 cm in width and 80 cm in depth. Sand and snow can accumulate in taffoni at the foot of boulders, as well as at the foot of boulders without taffoni.

On the south side of the same valley, the more we go up towards the old moraines, the stronger is taffonisation; taffonis are met either near the ground or at leg level; their bottom is empty, or plastered with fragments, in many cases flat enough, due to a kind of disintegration; lamellae can be disjointed from the ceiling by the hand.

A study in collaboration with Parker Calkin (1961) shows that, on the lower part of Lower Victoria Valley, among the boulders that are more than 70 cm in length and 30 cm in height, the percentage with taffoni (defined as concavities of at least 10 cm in depth) varies from 86 per cent in the oldest moraine, to 56, 28 and 12 per cent in the more and more recent moraines; the number of hollows in each boulder varies from 2.5 in the oldest moraine to 2.3, 1.9 and 1.0. The percentage of boulders with taffonis is greater among big boulders, longer than 150 cm (general mean: 73 per cent) than among those 70 to 149 cm long (41 per cent). It is also greater among projecting boulders, higher than 40 cm (general mean: 56%) than among those 30 to 40 cm high (27%). Measures in the field show also that, there is no preferential orientation: consequently wind does not play a prevailing role.

The most spectacular taffoni are found in Mc Kelvey Valley, 2 km south of the west end of Vida Lake, in the abrupt rocks of dolerite; several of these rocks are *in situ*. Cavities have in some cases, 2 m in depth and 3.5 m in height. Taffonis can be seen in nooks screened against the wind, for example at the foot of a vertical cliff of rock separated from another parallel cliff by a passage of 50 cm in width. The absence of wearing by the wind is attested by the persistence of iron oxide film even on the side facing west, while in open places such films have been worn out by the wind blowing from the west.

The boulders with taffonis are always rough inside and outside, and the clivages of feldspars are always sparkling, while on the same rocks, wearing by the wind gives polished surfaces, finely pitted, where the clivages do not sparkle. On the moraines of the bottom of Lower Victoria Valley, where there is less taffonis, the working by wind is clear (polished faces, ridges, cupules); these two phenomena have distinct repartition. They can go together: then the big boulders have taffonis whereas the lower pebbles, with a projecting part of 1 to 5 or 10 cm above the ground are worn by wind; in fact the abrasive sand is transported at those small heights principally.

Summing up, wind cooperates to clean taffonis; but disintegration that generate them has another origin. An observation shows that these two phenomena are distinct: near the front of Packard Glacier and dunes, a gneiss of 70 cm in length and 45 cm in height is very well eolised (polished faces, ridges, cupules). But it has been broken by frost into three parts, and it disintegrates into one slab of 13 cm and many smaller fragments, the fractures of which are very fresh.

With regard to the cause of the disintegration in taffonis we can hesitate between freezing and the crystallization of salts, principally mirabilite.

GLACIAL PEBBLES AND BOULDERS

(a) Small volume of the moraines

As mentioned by the authors, the volume of the moraines is very small, in comparison with that of the moraines of temperate or arctic-glaciers, however more modest. We can explain this if we admit, with Marc Boyé, that the glacial erosion acts in two phases: (1°) before the coming of the glacier near its front, frost-splitting of rocks: periglacial staving; (2°) the glacier comes and removes, as a bull-dozer, the liberated fragments. Below the cold glaciers, as those of Antarctica, with temperatures of —15°

to —20°, the bottom remains frozen, few fragments are set free, so that the glacier removes few fragments only.

Some areas are devoid of morainic boulders. Such is the case for the valley-side south of Vida Lake; there we see, in its mean part, gelifracted bedrock and ubiquitous granules scattered by the wind. If it is true that an outlet from the inland-ice once came down there, it will be necessary to explain why, curiously enough, it left no erratic boulders.

(b) Sizes

On the ground moraine, 300 m south of the Camp at Marble Point, the first millile is 1050 mm; the first centile, 400 mm. In Victoria Valley, north of Vida Lake, on the Quaternary lateral moraine east of the dunes, the first centile is 600 to 800 mm; 530 mm on the Quaternary moraine 1 km west of the lake; and 650 mm on the moraine of the glacier WNW of the lake. All these values are very coherent, clearly higher than those of all other kinds of formations of the region, even of gelifracted rocks (135 to 150 mm). They show that antarctic glaciers are able to transport and indirectly they confirm that the small amount of moraines must be attributed to another cause: the lesser liberation of transportable fragments.

(c) Diversity of natures (Tabl. IV)

The composition of boulders and morainic pebbles changes with their size. For example in Lower Victoria Valley, opposite the end of Packard Glacier, in ground moraine, pink granite prevails in the big sizes (85% near 1000 mm) and gray granite in the small sizes (55% about 20 mm); gneiss has a maximum (27%) in the biggest boulders (2000 mm) and metamorphic quartzite is nearly absent, attaining its maximum of 1 per cent in the pebbles of 50 mm. At Marble Point, gneiss prevails (51%) among the boulders of 2000 mm; from 1000 to 20 mm gray granites are more important (51 to 71%); marble presents its maximum (7%) about 200 mm and quartz (6%) about 20 mm. At Cape Royds, scattered erratic boulders are principally granitic (68 to 85%); with regard to other pebbles and boulders, gneisses have their maximum (21%) about 1000 to 2000 mm, dolerite (15 to 16%) about 200 to 500 mm; quartzite (1%) about 50 mm and vein quartz (2 to 3%) about 20 mm. In Antarctica, as in other areas, the comparison of the compositions of detritals of different origins must be done only on pebbles or boulders having the same size.

The most feasible sizes for statistics are 1000 mm (700 to 1400 mm)

Table IV

Composition in per cent of Quaternary or actual pebbles 45 to 55 mm long of Mc Murdo Strait

	Quartz	Granite pink	Granite gray	Gneiss	Dolerite	Other Volc.	Marble	Sandstone
Cape Royds, scattered erratic pebbles	0	77		4	1	14	0	tr
Marble Point, front of the glacier	2	0	65	7	0	12	0	0
Marble Point, actual marine beach	0	0	76	8	0	13	0	0
Lower Victoria Valley, moraine	0.5	19	34	6	11	23		
Mc Kelvey Valley, South of Vida Lake, Moraine (?) — West				4	66	20		3
Mc Kelvey Valley, South of Vida Lake, Moraine (?) — South				14	69	13		1
Mc Kelvey Valley, South of Vida Lake, Moraine (?) — East				5	87	4		1

and 50 mm (45 to 55); the boulders of 1000 mm are counted on the ground; bigger boulders are very exceptional; small pebbles from 45 to 55 mm are collected in a restricted area; pebbles below 45 mm are not suitable for our aim, in this area, because they have been brought by wind.

There are many variations from one place to another. In other words even if we admit that the inland-ice should have tended to deposit more uniform sediments of distant origin, in fact the sediments of local origin, whether they are due to effluents or local glaciers, have prevailed.

(d) *Flatness and roundness*

Usually in the till deposited by an inland-ice the pebbles have small flatness indexes and mediocre roundness indexes (Cailleux and Tricart, 1959, t. I, p. 269—272, and t. 3, p. 54—124).

In the Mc Murdo area, flatnesses are according to the rule. For the pebbles from 45 to 55 mm, in the ground moraines, we find, opposite the outlet of Packard Glacier, a median of 1.8 for granites, 1.9 for gneisses, 1.85 for basalts and diabases; 1.6 for compact lava 1.5 km northeast of Mc Murdo NAF. At Marble Point, 100 m before the front of the glacier, granites and gneisses give 2.4 and at Cape Royds, near the Blue Lake, 2.3; these higher numbers are probably due to a more intense gelifraction.

But the most important characteristic is the very small value of roundness; instead of the usual medians of 0.100 for the roundness indexes of first order, we have, near the end of Packard Glacier, 0.040 for granites; 0.050 for gneisses; 0.045 for basalts and diabases; less than 0.020 for the lava of Mc Murdo NAF; 0.030 for granites and gneisses at Marble Point. In all three cases, glaciers are important; they are several kilometres long. In the similar alpine glaciers, one finds pebbles that are well rounded, in some cases like cannon-balls; and medians are higher. The difference is due to the fact that, in the alpine glaciers, there are meltwaters, and pot-holes where the pebbles wear each other in whirling. In Antarctica, meltwater is absent or restricted to thin trickles of water, without pot-holes and whirls; the weak roundness of pebbles reflects these conditions. These observations confirm the fact that the wearing of pebbles by the glacier itself is weak, and the very rounded pebbles observed in alpine or other glacial sediments are not due to the glacier itself but to meltwaters.

Nevertheless, in Antarctica, there are some exceptions. For erratic granites and gneisses of Cape Royds, near the Blue Lake, we find 0.170. It is difficult to say if this is to wearing by water or to granular disintegration.

MECHANICAL ACTION OF FRESH WATER

(a) General device

As noted by all authors, the discharges of fresh water are very scattered, very weak and very intermittent. In most cases, they come from glaciers, sometimes from névé (patches of snow). Ice plays a great part. All or part of their water freezes again every night. In Victoria Valley, where the following observations have been made, we distinguish: high-water beds or flood-plains, largely sandy and generally dry; terraces or dissipating areas, 1 to 5 or 10 m higher, gravelly, older, Quaternary probably.

(b) Flatness and roundness indexes of pebbles

On the Quaternary dissipating area north of the west end of Vida Lake, median flatness are rather high: 2.1 for gneiss and granite, 2.4 for diabase; they show a probable intervention of freezing. The first order roundness indexes are a little higher than in the neighbouring moraines: 0.050 for gneisses and granites, 0.055 for diabases. This example is very significant for Victoria Valley; wearing by running water is very weak, even if we take into account the short distances (2 to 12 km).

There is one exception: a fluvio-glacial or morainic deposit, at the end of Mc Kelvey Valley in Vida Lake; the flatness of dolerite is 1.8; the roundness 0.125. But 1 or 2 km upstream we have seen that *in situ* dolerites disintegrate into woolsacks. What is, in this roundness of 0.125, the part of this previous disintegration, and that of a possible wearing by running water? It is difficult to say.

(c) First percentiles (or centiles)

They show a clear opposition between actual beds, and terraces or old dissipating areas, which are coarser. Thus in Lower Victoria Stream, the actual first percentile is 2 mm; in the older dissipating area, south-east of Vida Lake, about 100 mm. North of Vida Lake, at the foot of the beautiful frontal moraine, downstream, 100 m from the lake, first percentile is 3 mm in actual sediments; 25 mm in the low terrace; 70 mm in the fluvio-glacial fan coming from the moraine; further upstream, at the origin of this dissipating area, 120 mm. At the end of the outlet of north-west glacier, 50 and 100 m from Vida Lake, first percentile is 2.5 mm in actual sediments; 42 to 45 in the terrace; 120 mm 1 km further upstream, in an older dissipating area. We find for the first percentile of the actual bed and terrace or nearest old dissipating area, in the outlet of the glacier of WNW of Vida Lake, respectively 3 and 55 mm in the middle of the stream, 3 and 24 mm further downstream; in upper Victoria Stream, 2 km upstream of Vida Lake, 2 and 20 mm; near its mouth, 3 and 15 mm.

Such differences are systematic. Actual discharges have a weak power of transport and low speed; older have had greater ones. Nevertheless, actual streams sometimes erode and rework old sediments a little bit· then there are in actual beds some pebbles 20 to 30 mm long, which have been transported for a short distance. Bigger boulders, 200 mm long or more, can be also observed, scattered from place to place in actual beds; presently, they are washed, but not displaced.

(d) Actual discharges and their geomorphological actions

They refer to sands principally, but we describe them here, because they help us to understand the dynamics of old gravelly sediments.

In Lower Victoria Valley, half-way between the glacier and Vida Lake, near Packard Glacier, the stream coming from Lower Victoria Glacier, in January, flows during some days, but not every day; in 1961, it becomes frozen every night, entirely or partly; during several days it was dry. Other days, in the morning it begins to flow upstream and it ends downstream by a front of infiltration. The snout advances further downstream; on January 23, it reaches our camp facing Packard Glacier at 13^{30} hours; then it moves forward at 20 or 30 cm/s; it has 1 or 2 m in width; 2 or 5 cm in depth. It progresses having 1 or 2 arms; in most cases it has 2 arms; they do not advance with the same speed. Progression is very curious. At some moments, the snout stops; all the water is engulfed in an empty space, under a crust of clean or dirty ice. Further behind, water carries floes that come from the bed-ice and date from the night before; they have 1 to 2 cm in thickness, from 3 to 15 cm in length. Most of the floes are dirty, truffled with particles of sand. Some are so heavy that they float under the water level. We see, in some cases, floating in water, a sludge made out of tangled crystals of ice and that is fulvous due to enclosed fine sand grains.

Other carried floes come from the banks probably. In any case, stream erodes in some places, either old dissipating areas or moraines or niveo-eolian covers and dunes. It can expose interstratified snow and ice in niveo-eolian covers, or in sediments at the foot of the slope, or older bed-ice, coming from the mean-water-channel, that has been capped later on by sand.

There are very curious sinks, underground streams and resurgences (Pl. 12). Near the front of Lower Victoria Glacier, the outlet, 2 m in width and 2 to 10 cm in depth, disappears under a niveo-eolian cover, 1 to 2 m; 10 m further downstream, it comes out again; where it disappears, there is in the niveo-eolian cover a layer of ice, interstratified. The ceiling of the underground stream, though it is composed of sand and snow entirely, resisted, because below 15 or 20 cm in depth it is entirely frozen and hard as concrete. Another sink of the same kind can be seen some kilometres further downstream. Another is located on the small temporary outlet of glacier north of Vida Lake, in the middle of the slope, some meters upstream from the beautiful old lateral moraine; here its bed, entrenched, disappears under the foot of a dune, and comes out again some metres further downstream. Sand resists for the same reason. Here, we can explain this phenomenon in this way: a given year, stream flows; then its surface freezes; the dune, while advancing, covers the ice; its sand freezes; later on, another year, when the stream flows again, it opens up a path across cavities under the top of frozen ice and sand. But other mechanisms are possible; to be able to observe them, one has to be in these areas in the nick of time...

Small streams of meltwater flow in contraction wedges, where they follow the slope. On south valley-side of Vida Lake, on the piedmont sloping at 4°, meltwater, coming from the median saddle, flew out by the two fissures, limiting a row of polygons. The beds, that are now dry, have from 80 to 100 cm in width and from 30 to 60 cm in depth. On the sunny slope, sand is hot (15 to 25 °C, by the touch).

The most sure criteria in the middle latitudes, to determine if a dry bed is functional or not, miss here: there is no vegetation and no lichen on stones or below; no trails of animals. But on sand, the pattern of a recent run-wash is a good indication, for the wind rubs it away very quickly. Another very good sign is given by the contraction cracks. Where we can see them, in the stream-beds, their spacing is the same as in other places, 10 to 20 m; but their width is smaller 5 to 12 cm, while it attains 10 to 20 cm in terraces or in neighbouring older gravelly dissipating areas. In the places where water flew recently, sand transported by run-wash has obliterated the cracks, substituting for their pattern that of its trickles, which is very different.

In this way, we see that, generally, in the stream-beds, water has not travelled through a large part of the bed width since some time; only a part was overflown. Let us examine the dry bed of the outlet of North Glacier, near its mouth in Vida Lake, 300 m upstream; there fluvial sand, probably deposited this year obliterates a tranversal fissure 2 m in width; it obliterates the following fissure 1 m in width only; it reached the third, poured sand in it but did not flow over; downstream, beyond, there are no traces of it. But at the foot of the west bank lies a névé. Trickles of water, as indicated by their trails, came out of it 5 to 10 m further downhill; they have converged and have given a new streamlet that effaced the two next transversal fissures, then disappeared. On the west bank, névés continue; further downstream, other traces of trickles of water appear, join each other and have the same destiny that the previous streamlet. Finally further downstream, a last streamlet coming from the névé has succeeded in flowing into the lake: this year, it has been the only one to do so, in that stream-bed.

The discharge, probably of 1961, of which we see the traces here, has been a discharge by stages. Water has flown on almost all the length of the bed; but the water that flew was not the same in the different, successive places. When we follow the dry stream of the upper Victoria Stream, until its mouth in Vida Lake, discharge seems to be of the same kind. More generally, what seems to be the thalweg of a glacial outlet — what has been such an outlet in the past, or during given years — is often, or during other years, a series of seepages coming from a patch of névé, and dried up before reaching the following one.

Some outlets never reach Vida Lake; thus the two outlets of the NW Glacier, that show upstream river-ice, disappear downstream in gravelly old dissipating areas. The outlet of the WNW Glacier shows two gravelly abandonned flows that previously rejoined the Upper Victoria Stream west of the actual mouth. Its bed is functional upstream where I could touch the river-ice. But before the mouth, it has been crossed by fissures; during this year, it was inoperative at this place. At the end of Mc Kelvey Valley in the main valley, about 2 km SW of Vida Lake, there are hollows, 10 to 15 m and more in depth; some of them are closed, some have diffluences due to a glacial overdeepening probably; actually, some have no traces of stream; in others, there are little trails of sand and, downstream, patches of frozen water. All this confirms the extreme weakness of discharge.

At their mouth in Vida Lake, most of the outlets have a curious pattern; it is not a delta, as in many Alpine lakes, but a wide opening as a bight or a bay. This is the case for the Lower Victoria Stream, for the South East Stream, and for one or two streamlets on the south coast and on the north coast also. This shows how few sediments these streams brought down there. But how can we explain the deepening of the bight? Mouths freeze and refreeze more often than the other parts of the lake, in summer, we have noted it with Parker Calkin. Perhaps this contributes to the comminution of fragments? Or are the latter incorporated in shore-ice or anchor-ice, and then transported by floating floes, towards the offing?

If so small an amount of meltwater, coming from snow and glaciers, flows in the open air, one may ask himself the question: what does happen with it? Most part of it disappears, infiltrating into the unfrozen ground, about 10 or 20 cm thick: below this level, it can refreeze; above, it evaporates; high wind and good insolation favour this evaporation.

The alimentation of Vida Lake is not clear. The glacial outlets bring few water. The most important in 1961, the Lower Victoria Stream, had at its mouth, in January, 3 m in width only and 5 to 10 cm in depth, and it probably reached the lake during 10 or 20 summer days only. The lake itself is almost covered with ice, but subject to sublimation. A large part of its alimentation must come directly from fallen snow, or from wind-driven one.

(e) Old discharges. Paleoclimates

Old fluvio-glacial sediments are gravelly with first percentiles of 20 to 120 mm and they stand in high contrast with the sediments of actual streams, which are sandy. They form raised terraces with regard to actual beds, from 1 to 6 m in most cases, or they plaster abandonned streams, as the two WNW of Vide Lake, already described. Another one, very beautiful, is an old outlet of Packard Glacier, 1 km below the actual outlet.

Upstream, it is obstructed by a recent dune; it is made out of small pebbles of 10 to 50 mm, against 1 to 2 mm in the actual outlet and it is more affected by the fissures of polygons, more embossed, with differences in level of 1 m or more.

These old sediments are very interesting and, owing to their coarser grain-size, they testify of flood discharges higher than nowadays. An identical opposition can be seen in the French Atlantic plains and there, in contrast with fine actual sediments, of temperate climate, Quaternary gravelly alluviums are explainable by colder conditions, periglacial ones, with permanently frozen ground and sudden floods resulting from the melting of snow. But transposed to Antarctica, this explanation cannot fit at all.

Melting, to-day, is already weak; let us assume that climate is colder, melting should be still weaker, and transportation should be annuled. In order to explain old gravelly sediments in Antarctica, we must take the opposite hypothesis, that of warmer climate. Interglacial climate? Or cataglacial? To-day, the annual mean of temperature is about $-17°$ centigrades; if we add an elevation of $12°$, in the hypothesis of an interglacial, we obtain $-5°$; that involves a permafrost and relatively important floods. So the interglacials of Mc Murdo have been probably colder than the glacials of France. Many other facts point to the same conclusion.

We see that the indications of Antarctic paleoclimates, such as mentioned here, constrain us, if we want to interprate them, to change our ways of thinking.

MARINE BEACHES

At Marble Point, the granitic pebbles of the actual beach, near sea-level, have very weak roundness indexes: 0.058 and 0.086 respectively for the first and second order indices; nevertheless, those indexes are twice larger than 5 km from this place, at the front of the glacier (0.027 and 0.043).

Flatness index is rather high, 2.6, due to freezing probably. In 1960—61, beach has been obstructed by ice, except for a narrow border of a few metres; on very few years, it is completely free of ice, and waves are operative. Five or six higher older beaches, parallel to the actual beach, have been studied by our American colleagues.

CHEMICAL ACTIONS — COATINGS — CONCRETIONS

(a) Distinction of coatings

In many cases, one can observe, on boulders and elsewhere white, gray, cream or rusty coatings. White coatings, soluble in water, are mirabilite, SO_4Na_2, $10H_2O$. Among others, effervescence with HCl distinguishes calcareous coatings. Rusty coatings are ferruginous, and some gray ones, presumaby siliceous. Detailed observations were made under the binocular.

(b) Mirabilite

At Mc Murdo NAF, on the volcanic boulders 60 cm high, it forms isolated patches from 2 to 6 cm, about 40 cm above the ground. On the pebbles of which the lower, buried part has a calcareous coating, mirabilite forms a border of some millimetres immediately above the limestone, or patches. It is very abundant in the alcoves occupied by snow for a long time principally on their sides.

Below the windows of the Headquarter's building, ground was free of snow at the beginning of January; then 2 or 3 cm of snow fell; January, 10th, 1961, snow smelt away, but it gave place to white efflorescences of mirabilite, in bushy crystallizations; bushes project from 20 to 200 microns above the ground, they have 50 to 200 microns in diameter; their crystals have 10 to 50 microns; a drop of water causes the sudden subsidence of those bushes, by dissolution. On the ground, mirabilite forms also in the traces of vehicles; on some olivine crystals, it forms a crust; others, bigger ones bear no mirabilite; their compacity has probably prevented the circulation of solutions; inside, in the ground, nothing is to be seen, the ground is porous and very friable, favourable to water circulation.

At Marble Point, in a boulder of disintegrating granite, if we widen the small virtual fissures, we see that they are furnished with a dust in bushy agglomerates, made out of small mineral particles from 10 to 30 microns (quartz, feldspar... etc.), maintained by a binding; under the action of a drop of water, the whole collapses immediately, showing that the binding was probably mirabilite. In other points of the same boulder, we must use HCl in order to cause the collapse. Finally, the same boulder also shows, in its fissures, the calcareous coating that will be described in the following pages. Had mirabilite also a role in the disintegration?

At Cape Royds, mirabilite is very abundant at 100 m from the hut, facing SE, 5 or 6 m above sea-level, in a flat pass. Toward 200 m in height, there is still a small amount of mirabilite.

At Lower Victoria Valley, it forms a border or stripe on stones and sand, principally near the streamlets that have recently flown. It is very abundant near the front of Lower Victoria Glacier where it forms a crust on eolian sand.

On the south band of Vida Lake, where snow remained some time, until 70 cm above the lake level, mirabilite is abundant. The 1st and 2nd of February, snow falls; towards February 4th, it has disappeared; the fringe of 70 cm is wet, mirabilite has disappeared almost everywhere. The 5th of February, it is again abundant, exactly towards the top of the wet part, which is 60 cm high on that day. A hole dug with a piolet at 1 m from the lake, at a relative height of 15 cm above lake-level, shows water coming until the phreatic level. Higher and further away, it must rise by capillarity; the efflorescences of mirabilite are thus explainable.

If, under the binocular, we dissolve mirabilite in a drop of water and if we let it evaporate, we get in a few minutes a rose of soda sulfate; but it is much bigger than the original drop. With the aid of fixed marks on the glass mount, we remark that, when the first crust appears, solution penetrates below towards the side of the crust, bursts it, spills beyond, and gives again a new roof of crust, penetrates again below it towards the outside: and so on. In an experiment lasting 4 minutes, the radius of the rose grew up to 300 microns. Evidently capillary tension is involved. Possibly does it play a role in the tendency of mirabilite to creep in and to break objects (either in nature, or in laboratories, where Na_2SO_4 is used to this aim, for instance for preparing microfaunas).

(c) *Limestone*

It forms coatings principally on boulders and pebbles at their lower part and in their fissures. Coating is frequent in volcanic areas (Hut Point, Cape Evans, Cape Royds) and at Marble Point, where marbles outcrop. It is less frequent at Victoria Valley, where the main rocks are granite and gneiss and, upstream, siliceous Beacon sandstone. Thus there is a relation between the possible origin of limestone and the presence of coating. But in the details, coating can be seen also on granite pebbles, gneiss, quartzite, as well as on marble and calcic volcanic rocks. So its matter comes, at least in part, not from the pebble itself, but from surrounding waters.

Colour of coatings, according to the Expolar Code, may be White, Light-gray C 81, Gray E 90, Dark-gray F 90, Light brown-gray D 81, Pale-yellow B 82, Pale-olive D 82, Olive E 82, Gray-brown E 81, Yellow-brown D 72, Dark gray-brown E 61 (the names are the same as in Munsell Color Chart). Olive is in many cases the color of the coatings from lower parts, embedded in the ground.

Coating has from 0.1 to 1 mm in thickness, sometimes more, principally towards its superior boundary, where it can form an edge or a projecting crest. Sometimes it looks like a uniform lamina, compact or finely porous, adherent but often easy to detach; or like several superposed similar laminae, stratified, sometimes overlapping; or again like juxtaposed little bushes in form of cauliflowers.

With HCl, in some cases there is no residue, in other cases (for example on a gneiss of the north side of Lower Victoria Valley, with a dark gray brown coating) there remains a brown stroma. The marble pebble of Marble Point, in process of disintegration, as mentioned above, shows fissures that I enlarge under the binocular. On their side there is a dry, pale-brown membrane, more or less transparent, twisted, of blue algae, to which adhere from place to place, some calcareous secondary crusts pure white or cream-white. Is this calcareous coating due to algae? Or is it of chemical origin?

It will be interesting to compare the calcareous coatings of Antarctica to those of semi-arid areas and to calcareous tuffas (= in French: *calcins*) on pebbles of Quaternary gravels or grounds of France, England... etc.

North of Vida Lake, in gravelly old dissipating areas, I have found on the ground, at two places about 100 m in distance, gray calcareous concretions, very flat, smooth and thin: 2 to 4 mm in thickness; 1 to 8 cm in diameter.

(d) Ferruginous impregnations

They plaster the fissures of basalt and dolerite, and the surface of some pebbles, for example quartzite. South of Vida Lake, a white pebble of white quartzitic sandstone shows a rusty aureole, limited to 1 or 2 mm in depth; this aspect is insignificant under other climates (temperate or warm) but it is interesting to find it here.

Colors of ferruginous coatings observed at Marble Point: Brown-yellow D 66 and D 68, Light-brown D 54, Light yellow-brown D 74, Brown E 54 and Strong-brown E 68.

(e) Siliceous coatings

At Mc Murdo NAF, below a wind-worn volcanic pebble, a hard budding coating, cream, is not attacked by water nor by HCl.

(f) Conclusions on chemical actions

They are very striking, some are very curious (mirabilite). They result from strong aridity, approaching that of warmer deserts. Briefly, they are in opposition with those of humid areas, temperate or warm, by their characteristics and by their weakness. Here, rocks disintegrate much more mechanically than chemically; chemical attack, though curious in its aspects, is very insignificant in the total balance; felspars are fresh, little or not altered. Correlatively, is their alteration product, clay, scarcer than in other climates ? Let us touch that point now.

CLAYS AND SILTS

Even in three months of observations, I have found no clay sample neither on the bedrock, nor in the fissures, nor in the Quaternary or actual sediments. Morainic sediments are not boulder-clays, but boulder-gravels and boulder-sands; fine sand, towards 0.100 mm exists in them; but silt (50 to 10 microns) is scarce, and clayey fraction still rarer.

The meltwater of glaciers is very limpid, all the previous observers have stressed it and I have noted the fact for the meltwater of Lower Victoria Glacier; therefore, I could not collect a water sample in order to study the eventual turbids in suspension: water carries sand only, by saltation near the stream-bed. This proves the weakness of purely glacial wearing, at least under this extreme climate.

Clays were already uncommon in the Beacon formation. Antarctica is a continent without clay, or at least very poor in clay. Let us mention that the study of the soils of Kerguelen islands by Aubert de la Rue has given very similar results.

With regard to loams or silts, I have collected some samples, but they are composed of fine sand principally. Loams and silts are very scarce, almost absent; at most there is a silty fraction in the soils, under stones. Their absence on the surface raises an important problem, because one admits that mechanical frost-disintegration may generate silty particles, specially under periglacial conditions and for the formation of loesses. If such particles are generated by fragmentation in Actual Antarctica, as they were in Quaternary Europe, we must wonder why they do not give rise to loess covers in Antarctica.

This is probably due to the absence of phanerogames, of vegetal cover. Fine particles are blown out by wind transported in suspension above the ground, and when they fall, on the ground they cannot be fixed because vegetation is lacking, and they are then transported again. Finally, they fall on the sea-ice and then into the sea. Actually, dredgings in Mc Murdo Sound have shown me a high percentage of the silty fraction. Briefly, dusts coming from rock disintegration and transported by the wind, which in the Arctic fall on a grassy soil, are retained and give loess, in Antarctica would finally fall into the sea and would form the silty fraction of the glacial terrigenous sediments, where they are mixed with boulders, pebbles, sands and silts abandonned by the meltwater of icebergs.

CONCLUSION

Thus, owing to most of its characters, Antarctica is an original continent, that forces us to change or adapt our methods and even our attitudes of thought.

It differs greatly from most parts of the Arctic. But in the Antarctica itself, judging from the litterature, there are great variations from place to place. Here, as elsewhere in the world, it will be necessary, in the near future, to subdivide the periglacial features into several types. K. K. Markov has yet opposed the subantarctic type, with solifluction and vegetation, to the antarctic one. Now on the continent itself, and on the adjacent islands, we may distinguish at least two new types:

1° Bungerian type. Ex: Bunger oasis and probably western part of Antarctic Peninsula and Scotia Arc. Mean annual temperature is not very low: —5° to —10°C. In summer, the ground thaws to 120 cm. Precipitations rather high: circa 400 mm. Solifluction frequent, polygonal and striated soils with sorting of stones also. Eolian deposits scarce: a few near-shore dunes or trails. Mirabilite not very common. Vegetal covering 2 to 8% of the area.

2° Mcmurdian type. Ex: Mc Murdo Strait, interior of the continent. Mean annual temperature very low: —15° to —40°C. In summer the ground thaws to 20—30 cm only on the average. Precipitations very small: 200 to 50 mm. Hence, solifluction very unfrequent, soils with sorting of stones also. Prominent feature in the landscape: net of big contraction wedge polygons, often tetragonal. In plains, dunes and niveo-eolian covers may be present. Mirabilite is frequent. Vegetal covering very small, less than 1%.

Thus the contribution of Antarctica to our knowledge of periglacial features is an important one. Our gratitude is then greater with regard to those that allowed us to have acces to it and to translate and publish our observations.

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References

Cailleux, A., 1962 — Etudes de géologie au détroit de Mc Murdo (Antarctique). *CNFRA*, no. 1; p. 1—41, Paris.

Cailleux, A., 1963 — Géologie de l'Antarctique. 1 vol., 210 p., *SEDES*, Paris.

Cailleux, A. et Taylor, G., 1951 — Code expolaire pour déterminer la couleur des sols. Boubée.

Cailleux, A. et Tricart, J., 1959 — Initiation à l'étude des sables et des galets. 3 vol., 776 p.

Calkin, P. and Cailleux, A., 1962 — A quantitative study of cavernous weathering and its application to glacial chronology in Victoria Valley, Antarctica. *Ztschr. f. Geomorphologie*, N.F., Bd. 6, H. 3—4; p. 317—332.

Calkin, P. and Cailleux, A., 1963 — Orientation of hollows in cavernously weathered boulders. *Biuletyn Peryglacjalny*, no. 12; p. 147—150.

David, T. W. E. and Priestley, R. E., 1914 — Glaciology, physiography, stratigraphy and tectonic geology of South Victoria Land. British Antarctic Expedition, 1907—1909. *Geology*, vol. 1; p. 1—319.

Debenham, F., 1921 — Recent and local deposits of Mc Murdo Sound region. Brit. Ant. (Terra nova) Exped. 1910. *Geology*, vol. 1, n. 3; p. 63—100.

Ferrar, H. T., 1907 — Report on the field-geology of the region explored during the „Discovery" Antarctic Expedition 1901—1904. *Bull. Mus. Nat. Hist.*, London.

Harrington, H. J., 1959 — Narrative account of the New-Zealand geological and survey antarctic Expedition 1958—59.

Kelly, W. C. and Zumberge, J. H., 1961 — Weathering of a quartz-diorite at Marble Point, Mc Murdo Sound, Antarctica. *Jour. Geol.*, vol. 69; p. 433—446.

Kobendzina, J., 1961 — Some phenomena accompanying eolian processes on dunes of the Kampinos forest. *Przegl. Geogr.*, t. 33; p. 539—542.

Markov, K. K., 1960 — Journey to Antarctica and all round the world. 1 vol.; 285 p., Moscow, (in Russian).

Michel, J. P., 1964 — Contribution à l'étude sédimentologique de l'Antarctique. *CNFRA*, no. 5; 91 p., Paris.

Péwé, T. L., 1959 — Sand-wedge polygons (tesselations) in the Mc Murdo Sound region, Antarctica; a progress report. *Am. Jour. Sci.*, vol. 257; p. 545—552.

Péwé, T. L., 1960 — Multiple glaciation in the Mc Murdo Sound region, Antarctica; a progress report. *Jour. Geol.*, vol. 68; p. 498—514.

Queney, P., 1951—1953 — Classification des rides de sable et théorie ondulatoire de leur formation. *Coll. Intern. CNRS*, t. 35; p. 179—196, Paris.

Różycki, S. Z., 1961 — Changements pléistocènes de l'extension de l'inlandsis en Antarctide orientale d'après l'étude des anciennes plages élevées de l'oasis Bunger, Queen's Mary Land. *Biuletyn Peryglacjalny*, no. 10: p. 257—284.

Steward, D., 1960 — Petrography of some erratics from Cape Royds, Ross Island, Antarctic. *Jour. Geophys. Research.*, vol. 64.

Taylor, G., 1914 — Physiographical and glacial geology of East Antarctica. *Geogr. Sout.*, vol. 44; p. 365—382.

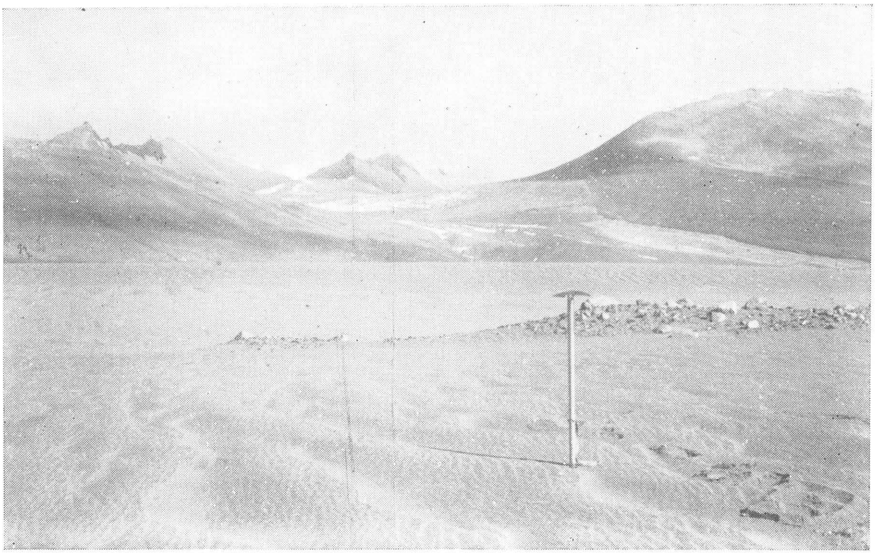
Taylor, G., 1922 — The physiography of the McMurdo Sound and Granite Harbour Region. *Brit. (Terra nova) Ant. Exped. 1910—1913.* 1 vol.; 246 p., London.

Webb, P. N. and Mc Kelvey, B. C., 1959 — Geological investigations in South Victoria Land, Antarctica. *New Zealand Jour. Geol. Geophys.*, vol. 2; p. 120—136.

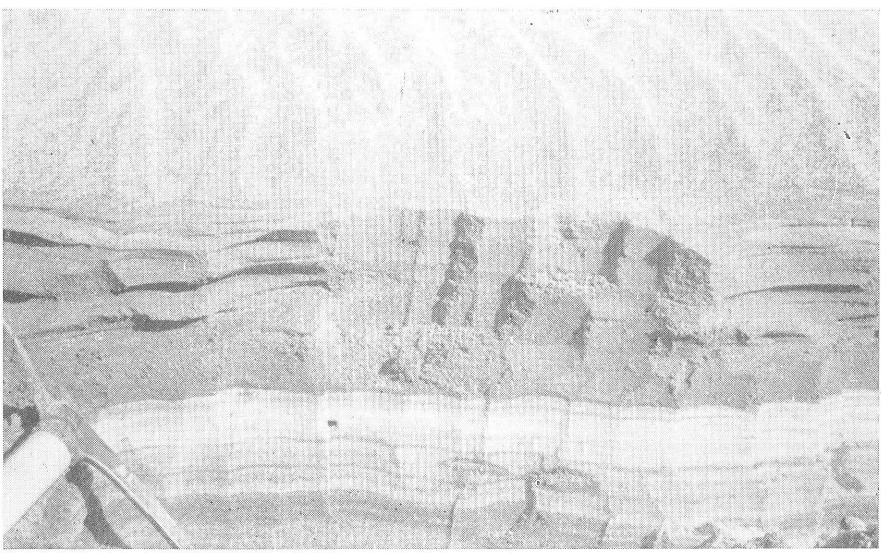
Antarctica in the International geophysical year (1956). *Am. Geophys. Un. Nat. Acad. Sci.*, Publ. n. 462; 134 p.

Pl. 1. Dunes. In the background, Packard Glacier, Victoria Valley; on the foreground, dry bed or terrace of Lower Victoria Stream

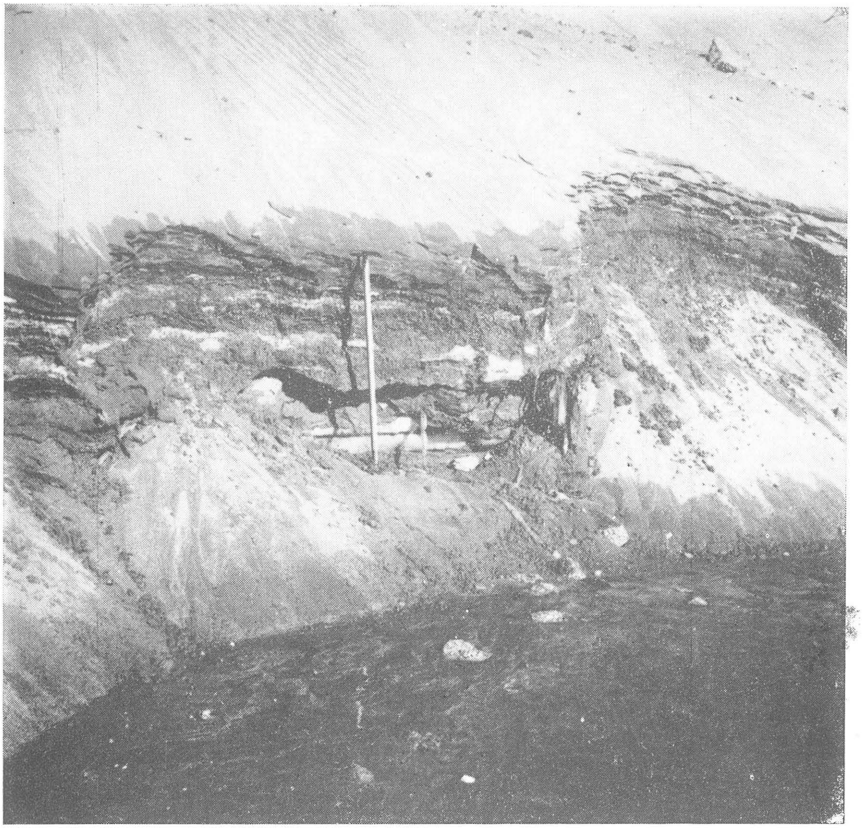
Pl. 2. Cross-section of a niveo-eolian cover. Interstratified compacted snow and sand. Victoria Valley



Pl. 3. Thin niveo-eolian cover, with big and small ripples. Victoria Valley



Pl. 4. Cross-section of a niveo-eolian cover. Interstratified compacted snow and sand. Victoria Valley



Pl. 5. Concave outer part of a meander on the outlet of the Lower Victoria Glacier
Mixed blanket of alternating sand and snow, cut by the stream erosion

Pl. 6. Sandy bed of Lower Victoria River, near the front of Packard Glacier, seen from the West

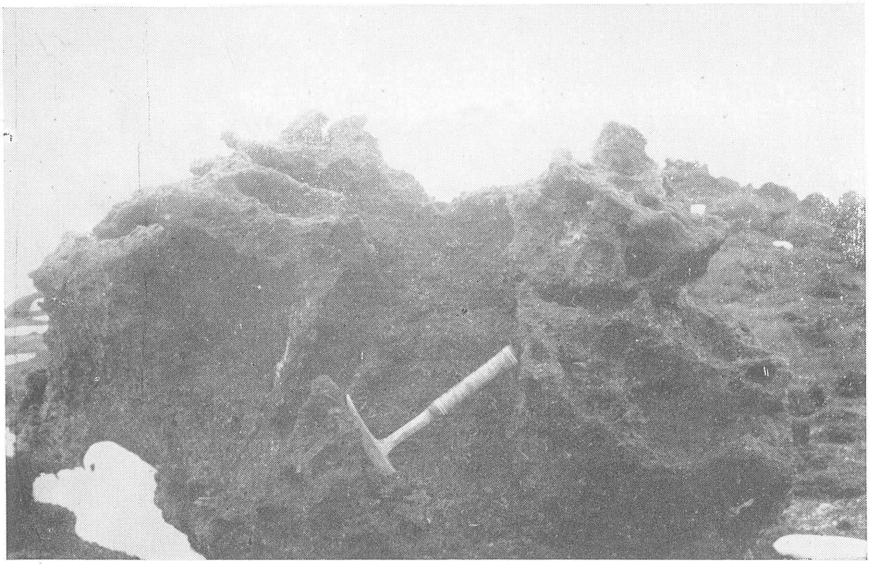
The active bed is well marked on the left; it is covered with young ice. The strong east wind blows out the sand (light-colored bands in the middle-distance)

Pl. 7. Near the front of the Lower Victoria Glacier, a wedge in stratified sand (retraction ?)

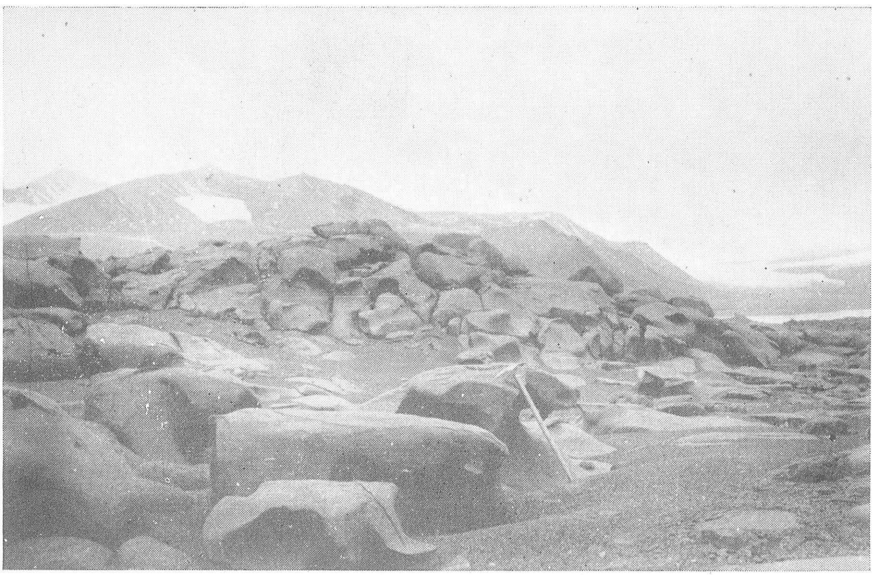
Pl. 8. Frost-fracturing. The white boulder was three-quarters buried; its top seemed rounded (here, on the upper left)

When unburied, the bottom part appears perfectly angular (lower right corner). The rounding of the top was only apparent, due to granular disintegration. Marble Point

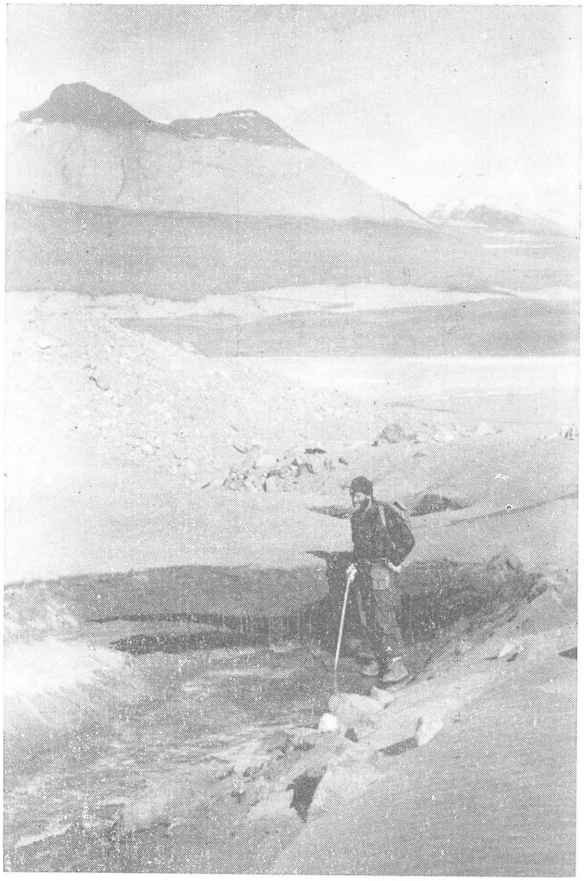
Pl. 9. Exfoliation of a coarse white marble. Marble Point



Pl. 10. Alveolar erosion of kenyite (a volcanic rock), Cape Evans, Ross Island



Pl. 11. Weathering dolerite: disintegration, formation of taffonis. South-west of Lake Vida, Victoria Valley



Pl. 12. A small stream disappears under the foot of a dune, N of lake Vida (the stream comes out again 15 to 20 m downhill)

In the background, on the mountain, note sharp contact between gneiss (light) and dolerite (dark) showing that there is practically no solifluction