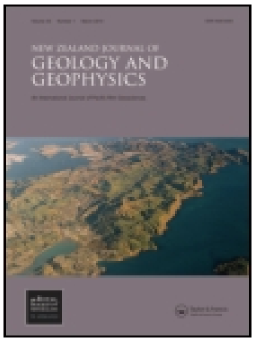

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SOILS OF TAYLOR DRY VALLEY, VICTORIA LAND, ANTARCTICA, WITH NOTES ON SOILS FROM OTHER LOCALITIES IN VICTORIA LAND

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ABSTRACT

A map and descriptions of the soils of Taylor Dry Valley, Victoria Land, Antarctica, are presented. Soils from Hallett Station, Ross Island, and other places around McMurdo Sound are briefly described and compared with those of Taylor Dry Valley. The role of the soil-forming factors and the nature of the soil-forming processes in Victoria Land is discussed. Soils on "normal sites" (e.g., on slightly elevated gentle slopes on moraine or similar parent material) may be regarded as zonal soils. They are virtually lithochromic, coarse textured, structureless, and without humic horizons. Two groups are recognised: (*a*) Those in arid Taylor Dry Valley, which have a surface or subsurface layer slightly to moderately cemented with calcium carbonate or gypsum and are underlain at depths of about 12 in. by frozen ground. (*b*) Those outside Taylor Dry Valley, e.g., at Hallett Station and Ross Island and also at high elevations; more moisture is available, probably from more frequent summer snowfalls, and soluble materials are distributed throughout the soils and do not form surface crusts. Soils with much moisture and those rich in organic matter are classed as intrazonal.

INTRODUCTION

During the summer of 1959–60 two members* of the New Zealand Soil Bureau spent three months in Victoria Land, Antarctica, examining and mapping soils and collecting samples. The party spent a month preparing a detailed soil map of Taylor Dry Valley (Fig. 1) and brief studies were made of soils at Cape Royds, Cape Evans, and Hut Point Peninsula on Ross Island (Fig. 2); Dailey Islands; and Cape Hallett, Marble Point, and Koettlitz Glacier on the mainland.

Previous Work

When reporting on four samples (three from Cape Royds and one from Taylor Valley) collected by Shackleton's 1907–09 expedition, Jensen (1916) pointed out the main features of Antarctic soils—very slight chemical weathering and leaching, and the presence of alkalinity, soluble salts, and negligible organic matter.

Blakemore and Swindale (1958) analysed a soil sample from Scott Base (Pram Point, Ross Island) and reported a high content of phosphate, exchangeable potassium, and sodium.

*Dr G. C. Claridge, physical chemist, and J. D. McCraw, senior pedologist.

Glazovskaya (1958) working near Mirny (approximately 93° E) first mentioned accumulation of calcium carbonate near the surface, and detected clay formation, alteration of feldspars, and movement of soluble salts. Kelly and Zumberge (1961) found that the brown appearance of quartz diorite at Marble Point was caused by oxidation of ferrous iron in biotite and pyrrhotite to ferric hydroxides. Other minerals were little altered and no clay minerals were found.

Workers in the Wright Valley, Victoria Land (Ugolini, 1963; Ugolini and Bull, 1965), showed that a quantitative knowledge of some parameters such as the proportion of fines, moisture content, salt concentration, depth to the ice-cemented layer, and degree of oxidation could be used cautiously as indicators of soil development. They showed also that degree of soil development could be used as an aid in separating glacial deposits of different ages.

Recent work by Ugolini (1965) points out that soils at high elevations on Mt Erebus have acid reactions and considerable microbiological activity. The presence of allophane and gibbsite in these soils is attributed to hydrothermal phenomena and volcanic activity in the neighbourhood.

A preliminary note on the field characteristics of some of the soils examined during the Soil Bureau expedition has already been published (McCraw, 1960) and data from laboratory investigations of some of the samples collected have been described and discussed by Claridge (1965). It is intended that this present paper should be complementary to that of Claridge.

THE ENVIRONMENT

Victoria Land is a mountainous region 20–100 miles wide extending southwards, according to Helm (1958) from Cape Adare (71° 17′ S) to 78° 00′ S. The mountain ranges, which average 6,000 ft to 9,000 ft with some peaks reaching 13,000 ft, lie roughly parallel to the western shore of the Ross Sea. The continuity of the mountain chains is broken at intervals by wide transverse valleys mainly occupied by immense glaciers discharging ice from the continental ice cap to the Ross Sea or Ross Ice Shelf. Several offshore islands lie close to the western shore of the Ross Sea and the largest of these, Ross Island, with its active volcano, Mt Erebus (13,350 ft), is separated from the mainland by the 30-mile-wide McMurdo Sound.

Not all of Victoria Land is ice covered. Gunn and Warren (1962) estimate that at least 3,000 square miles of the region between the Mulock and Mawson Glaciers are free from permanent ice or snow and considerable areas of ice-free country are known to exist elsewhere in Victoria Land. The largest known ice-free tract—the so-called "dry valley" region—lies between the Ferrar Glacier in the south and the MacKay Glacier in the north (*see map in* McKelvey and Webb, 1962, fig. 1, p. 144).

One of the best known and most accessible of the dry valleys is the lower part of Taylor Valley which opens into New Harbour (Fig. 2) on the western side of McMurdo Sound at approximately 77° 33′ S, 163° 25′ E. Taylor Valley stretches for about 50 miles in a south-westerly direction towards the Polar Plateau and is 4–8 miles wide. The Taylor Glacier flows

SOIL MAP OF TAYLOR DRY VALLEY, ANTARCTICA

Legend and Summary of Soil Properties

Soils Classed According to Topography	Parent Material	Summary of Properties	Map Symbol
Soils of flood plains and stream channels	Gravelly sand or bouldery gravel from recent alluvium	No carbonate accumulation; smooth surface with no stone pavement; some surface salt; sparse moss	1
Soils of the terraces	Low terrace alluvium	Very slight carbonate accumulation near surface; indistinct stone pavement; frost cracks in surface	2
	Intermediate terrace alluvium	Slight carbonate accumulation near surface; distinct stone pavement; raised-border polygons on surface	3
	High terrace alluvium	Moderately developed carbonate accumulation near surface; stone pavement; well developed raised-border polygons	4
Soil of the moraines			
Soil of moraines on the valley floors	Terminal moraine	Slight carbonate accumulation but patchy; polygons rare; weakly developed stone pavement	5
	Lateral moraine	Weakly developed accumulation near surface; moderately developed polygons on surface; weakly developed stone pavement	6
	Moraine over water-laid silts	Weakly developed carbonate horizon near surface but patchy; undulating surface with well developed polygons; complex of large blocks and stone pavement over sand and gravel	7
	Moraine over water laid silts	Slight carbonate accumulation near surface; stone pavement over well developed platy structure, over "silt ball" subsoils	8
	"Dark" moraine with scoria	Moderate accumulation of carbonate near surface; well developed polygons and stone pavement	9
	"Brown" moraine with little scoria and much granite and metamorphic rocks	Moderate accumulation of carbonate near surface; well developed polygons and stone pavement	10
Soils on moraines of the uplands	Weathered moraine at medium altitudes	Weakly developed carbonate occumulations below surface; cavernous weathering and desert varnish on boulders; well developed polygons and stone pavement	11
	Weathered moraine (mainly dolerite) at high levels	No carbonate near surface, some salt at depth; polygons poorly developed; most rocks except dolerite disintegrated	12
Soils on cones and patches of scoria	Recent basaltic scoria and sand	No carbonate accumulation, some salt; no polygons; no stone pavement but surface stones wind polished	13
Soils of solifluction slopes	Mainly weathered metamorphic rocks and sand or lateral moraine	Slightly developed carbonate horizon on surface, some salt; no stone pavement or polygons	14
Soils of scree slopes	"Frozen" scree mainly of metamorphic rocks and moraine; "dry" scree mainly of dolerite.	Weakly developed carbonate horizon near surface in soil pockets on dry scree; soil formation almost nil on dry scree	15
Soils of rock slopes	Dolerite (16), granite (17), metamorphic rocks (18)	Mostly bare rock; soils confined to crevices and small ledges; no carbonate or stone pavement	16 17 18
Soils of the felsenmeer	Blockfield and broken rock	Soils in rare crevices	19
Soils of the high plateaus	Dolerite and sandstone	Soils not inspected	20

Flat, undulating and easy rolling surfaces	u	Moderately steep and steep slopes	s
Rolling and strongly rolling surface	r	Very steep and precipitous slopes	p

Fig. 1—Soil map of Taylor Dry Valley, Victoria Land, Antarctica. For explanation see facing page.

into the western part (Upper Taylor Valley), but the eastern part (Lower Taylor Valley) is almost free from permanent ice or snow and it was this that Scott named "Dry Valley" after its discovery in 1903 (Scott, 1905). It is with this "dry" part of the Taylor Valley (or "Taylor Dry Valley" as it has become known) that this report deals.

Taylor Dry Valley is divided into an upper and lower part by the 3,000-ft-high Nussbaum Reigel, which extends almost across the valley. The lower part is a broad flat-floored valley about 4 miles wide and 8 miles long, partly filled with moraines of different ages and from several different sources. The upper part of the valley, which stretches westwards from the Nussbaum Reigel for nearly 20 miles, has a narrow valley floor occupied by several frozen lakes and, in the most westerly part, by the shrunken Taylor Glacier. A broad moraine-covered bench, lying 1,000 ft above the valley floor and more than a mile wide, runs along the southern side of this part of the valley from the reigel until it is covered by the ice of the glacier. Remnants of narrow benches at similar and higher elevations occur on the northern side of the valley.

The valley walls rise steeply, culminating in rounded summits 2,000–3,000 ft above the valley floor in the lower valley, and in sharp or flat-topped peaks 5,000–6,000 ft high in the upper valley. Screes flank most of the mountains and felsenmeer and blockfields cover easier slopes on the uplands. Bare rock is exposed only on steep cliffs and in a few places on and around Nussbaum Riegel where the moraine covering is thin.

Numerous alpine glaciers descend from the ice fields in the mountains flanking the valley and two large ones (the Canada and Commonwealth Glaciers) spread for at least a mile over the valley floor. Shallow stream

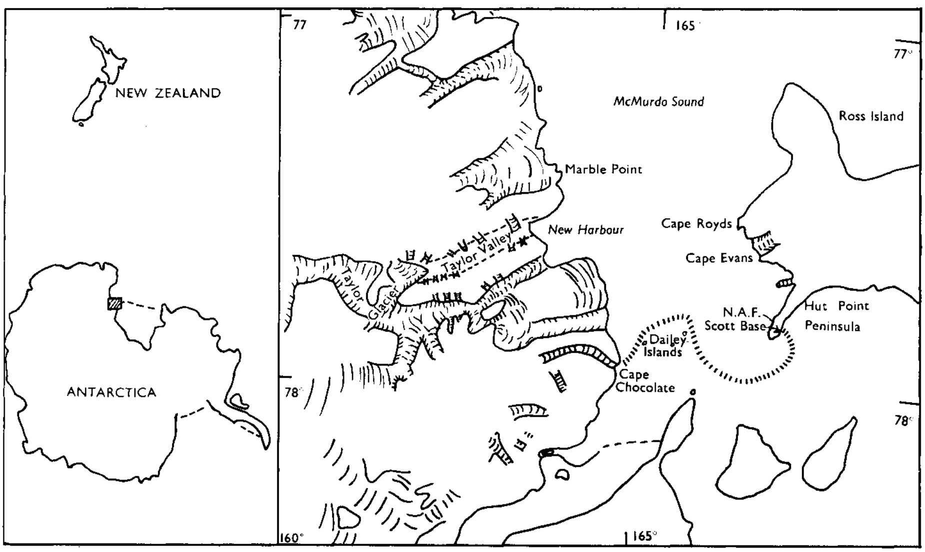

Fig. 2—Locality map McMurdo Sound Region, Victoria Land, Antarctica.

courses drain meltwater from the glaciers into numerous lakes, the largest of which Lakes Bonney (about 3 miles long and more than ¼ mile wide), Chad, and Fryxell. None of these lakes has an outlet and most are saline (Tedrow and Ugolini, 1963).

The largest stream course is a chasm at least 50 ft deep cut through moraines and lake sediments between the snout of the Commonwealth Glacier and the sea. Most stream channels carry meltwater (some in considerable quantities) for a few weeks during the summer. Where these streams change their grade alluvial plains are formed, and their points of entry to the lakes or sea are generally marked by deltas. In some places extensive flights of terraces have been cut in deposits of alluvium, and former high lake levels can be traced by old high-level beach deposits and deltas.

Geology

The geology of Southern Victoria Land has been described by McKelvey and Webb (1961), Gunn and Warren (1962), Gunn (1963), and many others. The basement rocks are a thick series of greywacke, schist, and marble overlain and intruded by granite, granodiorite, and gneiss, and by swarms of lamprophyric and porphyritic dikes. The peneplained surface of this basement complex is overlain by the Beacon sandstone which is believed to range in age from early Devonian to early Jurassic. Several thick sills of dolerite (of possible late Mesozoic age) are intruded through the Beacon sediments, between the sediments and the basement rocks, and in some places through the basement rocks. Pliocene to Recent vulcanism has given rise to large volcanoes (one, Mt Erebus, is still active) and many small scoria cones.

The predominant rock in Taylor Dry Valley is grey granodiorite (Larsen Granodiorite). In the lower valley it is associated with the metamorphosed sediments of the basement complex, but these are rare to the west of Nussbaum Riegel (Haskell *et al.*, 1965). Outcrops of pink granite (Irizar Granite) occur on the slopes of Mt Falconer north of Lake Fryxell and on the cliffs north of Lane Bonney, and coarsely banded gneiss (Olympus Granite-gneiss) forms wide belts across the valley in several places. The summits of the highest peaks are capped with Beacon sandstone or remnants of dolerite sills. Many small cones and patches of scoria occur on the broad glacial benches in the upper part of the valley (McCraw, 1962).

Climate

The only meteorological stations in Victoria Land are on Ross Island and at Hallett Station. Mean monthly temperatures do not rise above freezing point at Scott Base and maximum temperatures rise above freezing point only during December and January. Rough measurements of temperature recorded in Taylor Dry Valley were consistently higher than those taken simultaneously at Scott Base, and this trend is confirmed by recordings taken by other parties working in neighbouring valleys (Calkin, 1964). Gunn and Warren (1962) point out that the existence of the dry regions is primarily due to reduced ice inflow from the west, low precipitation, and greatly increased ablation because of the large areas of bare rock.

Few data are available for earth temperatures. Measurements made at Scott Base during 1957–58 (Hatherton, 1961, p. 120) show that surface temperatures were above freezing point from late December until mid-January, whereas at a depth of 6 in. temperatures did not rise above freezing point. Presumably in the Taylor Dry Valley where air temperatures appear to be higher, earth temperatures would be higher for longer periods.

In the McMurdo Sound region precipitation is light and falls as snow. Records for McMurdo Station on Ross Island (quoted by Péwé, 1960) show that precipitation was 6·38 in. of water for 1957 and only 1·47 in. water for March to December of the same year. It is likely that the mean annual precipitation at McMurdo Station is between 2 and 6 in. of water and that precipitation in the dry region on the mainland is less. Beyond the "arid zone" (Gunn and Warren, 1962) precipitation is higher and ranges from 9 in. of water each year at Cape Royds (David and Priestley, 1914) to 20 in. at Cape Adare (Wright and Priestley, 1922), Gunn and Warren's opinion that snow falls are heavier at high elevations is confirmed by measurements carried out by Calkin (1964) in the Victoria Valley.

In Taylor Dry Valley up-valley (north-east) winds of 8–10 knots blow constantly except for a regular short calm at about 5 a.m. Occasionally this wind is replaced by a warm katabatic gale of over 40 knots which blows down valley (south-west) from the Polar Plateau.

Plant and Animal Life

Although plants have been collected from Cape Adare in the north to the Horlick Mountains only 100 miles from the South Pole, they are sparse and confined to lichens (less than 40 species recorded (Murray, 1933)), moss, and algae. Apparently nothing approaching the relatively dense vegetation noted by Siple (1938) and by Giaever (1954) in Western Antarctica has yet been seen. Plants are rare in the arid regions, but are locally plentiful where more moisture is available, as, for example, in Terra Nova Bay (Campbell, 1913), Cape Hallett (Rudolph, 1963), and on the slopes behind Scott Base on Ross Island. Algae (green, blue-black, and less commonly, red) are plentiful in and around lakes and tarns and on boulders in many stream beds. A thin film of green algae was noted growing on the surface between penguin nests at Cape Hallett and a similar growth was recorded from Cape Royds (Murray, 1909, p. 235).

According to di Menna (1960; 1966) and Flint and Stout (1960) micro-organisms are associated with mosses and algae, but also occur in soils without vegetation. Already strains of yeast, bacteria, terrestrial algae, and a few fungi have been identified along with protozoa, rotifers, and other animals (Llano, 1962).

Springtails (Collembola) and mites, found among mosses and lichens, are the most widespread terrestrial organisms (Eklund, 1956; Llano, 1962).

Plant life in Taylor Dry Valley is sparse. Not more than a dozen patches of moss, growing in hollows in moraines or in stream beds, were seen. Lichens occur on rock faces high above the valley floors but are rare at low altitudes. Blue-green algae are most common in stream beds near the terminal faces of the glaciers, whereas green algae are abundant in the frozen lakes. A few specimens of red snow algae were noted on small frozen ponds.

The Adelie penguin (*Pygoscelis adeliae*) nests in large numbers at some places on the coast of Victoria Land and Ross Island (R. Taylor, 1964) but, apart from a single bird, was not seen in Taylor Dry Valley. Skua gulls (*Catharacta skua maccormicki*) were noted bathing in ponds in the valley but no nests were found.

SOILS OF TAYLOR DRY VALLEY

Taylor Dry Valley is arid and some soil characteristics are similar to those of desert soils outside the polar regions. Clays are sparse and textures coarse because physical weathering is dominant over chemical weathering, leaching is weak because of low precipitation, and humic horizons are virtually absent because vegetation is sparse.

The factor that sets the soils apart from desert soils is that for the greater part of the year they are frozen, and although the uppermost foot or so thaws during the summer, they are underlain by permafrost. The term "permafrost" is used in this paper to mean permanently frozen ground and the upper boundary of this is the "permafrost table". Above the permafrost table is the "active layer" which freezes and thaws seasonally. Early in summer frozen ground will be encountered close to the surface, but this is not necessarily permafrost. No term has been found in the literature available for the upper surface of temporarily frozen ground, and it is proposed to use the term "frozen ground table" in this report. The frozen ground table sinks during a thaw until, at the period of maximum thaw, it coincides with the permafrost table (Fig. 3). Permafrost generally consists of almost impenetrable, ice-cemented ground, but in some places the uppermost few feet may consist of loose, "dry-frozen" material. This material is below the limit of seasonal thawing, but contains insufficient moisture to form cementing ice. It is sometimes difficult to distinguish, by field observation, between the active layer and the dry-frozen part of the permafrost.

Most soils show little change in texture or colour within the profile and the most striking feature is a zone of calcium carbonate or gypsum accumulation in the form of a horizon or surface crust of weakly cemented gravel and sand. The soils have surface efflorescence of soluble salts and most are protected by a pavement of lag gravel.

Field Methods

Soils were examined by excavating shallow pits with a spade. In most places a depth of only 9–12 in. could be reached before frozen ground was encountered and not one of the tools available was suitable for digging below this depth. It was very difficult to prepare a vertical face suitable for profile description as the dry, loose "topsoil" streamed into the pit. Only in the rare gulches cut by streams was it possible to examine deep profiles.

When experience had been gained in recognising different soils an attempt was made to construct a soil map of the valley (Fig. 1). Fixing localities accurately was difficult as no base map was available and only part of the valley had been covered by air photographs. A mile-long base line was measured out across Lake Fryxell and from this a base map was constructed by compass resection. The sluggishness of the compass and the widely different magnetic variation in different parts of the valley no doubt caused many inaccuracies. For this reason the soil map must be regarded as a picture of the soil pattern rather than an accurate map.

DESCRIPTION OF SOILS

The soils of the valley are described according to the topography on which they occur:

	Map Symbol
Soils of flood plains and stream channels	1
Soils of the terraces	
Soils of the low terraces	2
Soils of the intermediate terraces	3
Soils of the high terraces	4
Soils of the moraines	
Soils of moraines on the valley floors	
Soils on moraines with high relief	
Soils on terminal moraines	5
Soils on lateral moraines	6
Soils on moraine over water-laid sands	7
Soils on moraines with low relief	
Soils on moraine over water-laid silts	8
Soils on "dark" moraine with undulating surfaces	9
Soils on "brown" moraine with benched surfaces	10
Soils on moraines of the uplands	
Soils on moraines at medium elevations	11
Soils on moraines at high elevations	12
Soils of cones and patches of scoria	13
Soils of solifluction slopes	14
Soils of screes	15
Soils of rock slopes	16, 17, 18
Soils of the felsenmeer	19
Soils of the high plateaus	20

Soils of the Flood Plains and Stream Channels

Stream courses are of three kinds: wide flood plains of alluvium, narrow bouldery channels, and channels of intermediate width with boulders set in a matrix of alluvium.

The most extensive alluvial plains are at the eastern ends of Lakes Bonney and Fryxell, where a number of small lakes have been infilled, and on small deltas where meltwater streams enter lakes or the sea. The surfaces of the plains and deltas are generally smooth but marked by shallow, braided stream channels. They are free from polygons but crossed at wide intervals by cracks up to 3 in. wide.

Where streams have cut through moraines some channels are narrow and floored with large boulders, but others are wider and floored with boulders set in a matrix of alluvium. Bouldery flood plains are extensive in front of the terminal faces of several of the glaciers on the southern side of the valley and also occur in the stream channels that carry off the meltwater.

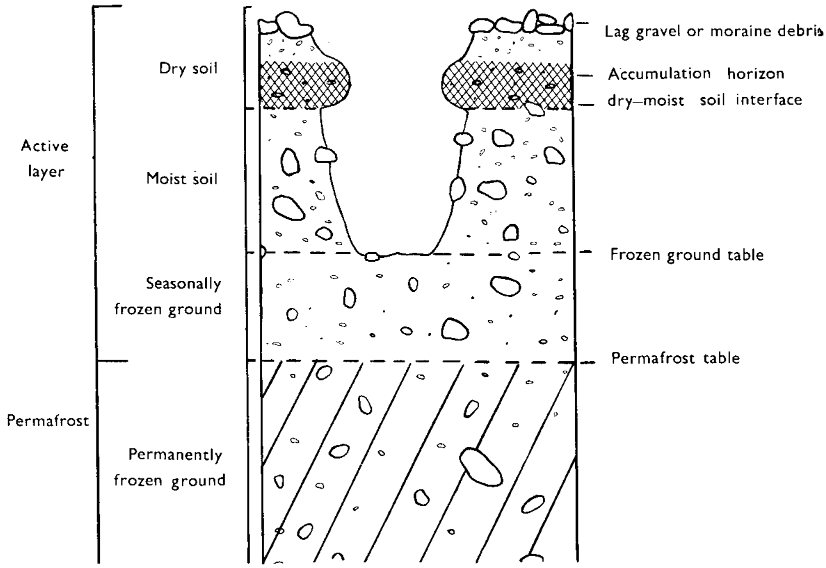

FIG. 3—Idealised diagram of a soil profile (with excavated pit to show protruding horizon of accumulation) from Taylor Dry Valley at approximately mid-thaw, with nomenclature used in this report.

Some of the boulders, especially those covered with water during the thaw, are coated with blue-green algae, and rare patches of moss grow in the shelter of boulders just above water level.

The flood plains and bouldery stream beds remain ice-cemented almost to the surface until air temperatures rise above freezing, when for a short time before meltwater from glaciers and snowbanks enters the channels, the ground becomes soft and wet so that walking is difficult.

Apart from a thin and discontinuous surface efflorescence of soluble salts in some places, there is no evidence of soil formation on the flood plains or in the stream channels. There is generally an interval of only a few days each season between the time the soils thaw and the commencement of lateral leaching by flowing water, and there is apparently no opportunity for calcium carbonate to accumulate in the profile. While the streams are running, detritus is constantly moving and thus fresh surfaces are exposed to soil formation each year. This, and the fact that soils are either frozen or wet results in negligible wind erosion.

Soils of the Terraces

Alluvial deposits that are no longer flooded are widespread throughout the valley, but, with few exceptions, are of small extent. Some occupy depressions in moraines, others are deltas formed at former lake or sea shores and others are fluvio-glacial structures such as eskers and kames. The alluvium is similar in composition and grain size to that of the present stream beds and owing to the predominance of granite and other pale-coloured rocks it stands out prominently against the darker moraines. The angular to subangular pebbles, set in a matrix of sand, are remarkably uniform in size, ranging from 1–2 in. in diameter.

Flights of terraces cut in alluvium are particularly well developed near the mouths of streams draining into New Harbour (McCraw, 1960, fig. 2) and probably mark changes in sea level or in levels of a lake trapped behind glacial ice in McMurdo Sound (Speden, 1960). Other terraced alluvial deposits occur at several distinct levels along streams draining into the present lakes and almost certainly mark deltas formed at higher lake levels.

Although as many as seven or eight distinct terraces occur in some places, they are grouped into three broad categories: low, intermediate, and high terraces. It is not intended that this grouping should be used as a basis for deducing information about former sea or lake levels.

Soils of the Low Terraces

Soils on terraces of up to 4 ft above present stream beds are no longer flooded but show little soil development. Free calcium carbonate can be detected in the soils, but cementation is almost negligible as shown by a profile from near the mouth of the stream draining Wales Glacier.

8 in. slightly rounded pebbles (less than 1 in.) of quartz, granite and greywacke; matrix of coarse, slightly rounded sand; dry; not compact; very thin coat of soluble salts; distinct boundary;

3 in. as above; damp; no salt;

on frozen ground.*

The youth of these terrace surfaces is indicated by the absence of wind-abraded pebbles and by the indistinctness of the desert pavement. Frost cracks are evident, but they have not developed raised borders nor have they united to form polygons.

Soils of the Intermediate Terraces

Soils on terraces that lie 15–30 ft above stream level have slightly cemented surface horizons and distinct, but open, desert pavement. Well developed raised-border polygons mark the terrace surface.

Soils of the High Terraces

Not all of the high surfaces which stand 50–120 ft above present stream level are remnants of old flood plains or deltas. Some are fluvio-glacial deposits. The most extensive of these lie along the north shore of New Harbour and are distinguished from normal alluvial deposits by the presence of lenses of morainic debris and by numerous kettle holes in the surface. Soils on the high surfaces have thick, weakly to moderately cemented sur-

*"Frozen Ground" in profile descriptions means ice-cemented ground sufficiently hard to prevent further excavation. It does not mean dry-frozen ground nor does it necessarily imply permafrost.

face horizons and a close desert pavement of polished and wind-abraded pebbles. The surface is marked by well developed raised-border polygons. A profile (McCraw, 1960, fig. 3) from a terrace about 1 mile south-west of Base Camp is:

Surface:	closed pavement, one stone thick; stones mainly less than 1 in. in diameter, polished and shaped by wind;
½ in.	loose dry grey sand;
½ in.	slightly cemented dry grey sand with fine gravel;
3 in.	weakly to moderately cemented fine gravel with few pebbles; coarse grey sand matrix; horizon protrudes from face of pit; distinct boundary;
on	frozen ground.

Analyses (sample 22a–c; Claridge, 1965) show that the cemented horizon is extremely alkaline (pH 9·8), but soluble salt content is low (0·46%) and there is only 0·6% of calcium carbonate.

Soils of the Moraines

Soils developed from morainic debris are by far the most extensive in Taylor Dry Valley. Moraines occur not only on the floor of the valley, but also on benches and shelves to at least 3,000 ft above sea level and were deposited by at least three advances of the Taylor Glacier, alpine glaciers descending from icefields on the mountains, and by a glacier from outside the valley (Péwé, 1960; Angino *et al.*, 1962). Moraines of different ages and from different sources contain different rocks and this feature, together with other factors such as position in the landscape, amount of weathering of rocks of similar composition, and overall colour of the debris, can be used for separating them. Much of the debris is thin and overlies water-deposited sediments or solid rock at shallow depths.

Small banks of wind-blown sand, either piled against morainic ridges or caught amongst large boulders, are widespread.* Many large boulders on the moraines have "tails" of sand on the down-valley side indicating that most sand is moved on the strong but infrequent westerly winds.

The wide variety of parent materials, topography, aspect, texture, and drainage encountered on the moraines leads to a wide variety of soils, and it would be difficult even on a large-scale map, to depict the numerous variations that occur. Nevertheless, it is possible to recognise features that are relatively constant over wide areas and the soils described in the following section are believed to be characteristic of those on the different moraines.

Soils of Moraines on the Valley Floors

Soils of moraines on the floors and lower slopes of the valley walls are separated into two groups; those on moraines with high relief and those on moraines with low relief.

Soils on Moraines with High Relief

This group includes soils developed on recent terminal and lateral moraines, and older moraine that has been thinly deposited over water-laid

*Sand dunes reported as being visible from the air in Taylor Dry Valley (Gunn and Warren, 1962, p. 139) are morainic hummocks.

sediments. Moraines deposited during the most recent advances of the glaciers (Fryxell Glaciation; Péwé, 1960) are of small extent and generally lie within a few hundred yards of their parent glaciers. The debris, which reflects the lithology of the course of the glacier, is generally fresh and little affected by wind erosion, although some rock splitting is evident. Polygons are developed but raised borders are rare. Owing to the prevalence of large boulders, soils are restricted to patches of fine debris in hollows between the ridges and to pockets of sand between boulders. Thin, slightly cemented surface horizons are developed on stable sites, but are lacking on slopes of more than 20°.

For 2 miles inland from the mouth of the valley, moraine lies on a series of long curved ridges up to 200 ft high and from 100–200 yards apart. Because the ridges are concave towards the sea Péwé (1960) has suggested that they are deposited by the Koettlitz Glacier, during a period when it had advanced down McMurdo Sound. The moraine is distinguished by an abundance of large tubular blocks of dolerite and large boulders of pink and grey granite and Beacon sandstone—an assemblage distinct from that of other moraines on the floor of the valley. Except for a few masses of boulders piled up to 20 ft high and deep layers of boulders lying on some ridge crests, the moraine does not appear to be more than a few feet thick and in many places is only one stone thick. On broad ridge tops, steep slopes, and in valleys, underlying stone-free bedded sands are exposed.

Soils developed on these moraines vary greatly. Where the boulder cover is thin and sands are exposed, soils with weakly cemented surface horizons are developed on stable sites, but on loose, sandy slopes the cemented horizons are lacking. There are no soils where the boulder cover is thick. A profile (Fig. 4) of a soil on the floor of a dry depression about ½ mile inland from New Harbour is:

Surface: large boulders up to 18 in. in diameter, underside with thin coating of calcium carbonate; stone pavement between boulders;

2½ in. slightly to weakly cemented coarse, pale grey sand; dry; very weakly developed platy structure; sharp boundary;

6 in. pale grey coarse sand; not cemented; moist; several thin layers and lenses of fine sandy silt; few small rounded pebbles;

on frozen ground.

In a slightly moist depression a soil was examined under a patch of moss:

Surface: closed stone pavement of stones up to 3 in. in diameter and several large boulders with carbonate coatings on undersides surrounding patch of moss 6 in. in diameter;

1 in. (under moss) coarse dark brown sand; friable, not cemented; sand slightly stained with organic matter and root fragments between grains; pale grey coarse sand with many subangular rock fragments; moist;

8 in. boundary indistinct;

on frozen ground.

Analyses (Claridge, 1965; sample 32 a–b) show that the pH values of the layer under the moss (pH 7·6) is lower than that of other soils sampled in Taylor Dry Valley and that although calcium carbonate is present (0·5%) it is in small amount and evenly distributed.

Soils on Moraines with Low Relief

This group includes soils developed on lateral moraines, ground moraines, and benches that mark beaches of former lake levels. Although the surfaces of these features are broken at intervals by stream channels and scattered hummocks, soil development is much more uniform than on moraines with high relief.

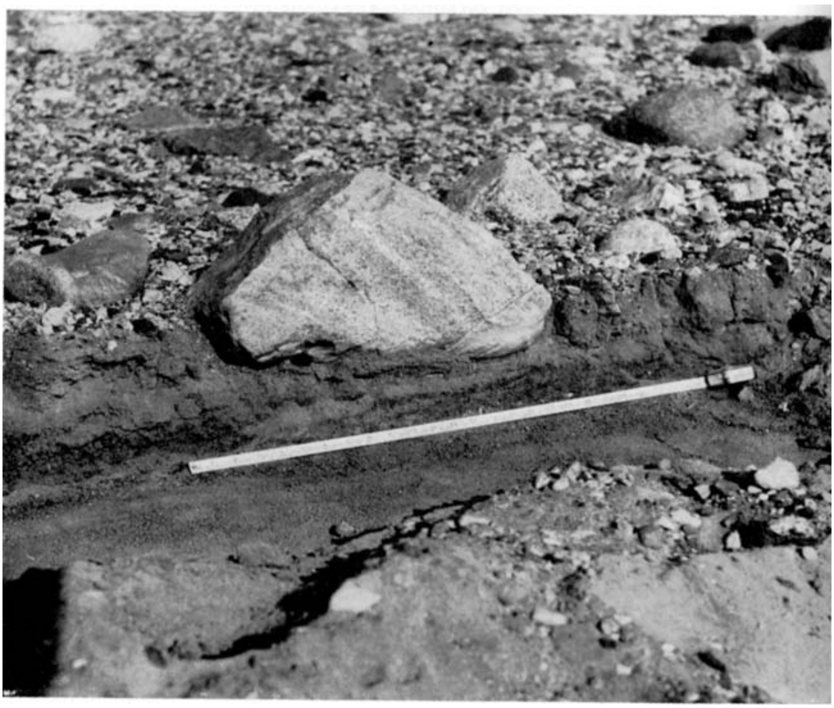

FIG. 4—Thin moraine over water-deposited sands in lower Taylor Dry Valley. Sands weakly cemented with calcium carbonate overlie bedded sands and silts. White coating of calcium carbonate on partly exposed underside of large boulder. Metal tape is about 27 in. long.

Encircling Lake Fryxell is a half-mile wide belt of soils developed on nearly flat land made up on thin moraine lying over silty, water sorted sediments. The morainic debris consists of small and medium sized boulders of grey granite and gneiss with only minor dolerite and Beacon Sandstone. The landscape has a curiously "flattened" appearance and was probably under lake water until recently. The soils are among the most striking encountered in the valley. Topsoils are slightly cemented and have a strongly developed, fine platy structure (McCraw, 1960, fig. 4) and subsoils consist of spherical or slightly elongated pellets of sandy silt (Fig. 5). The pellets are quite free and loose and when disturbed, stream from the side of an excavation like lead shot. A profile of a soil from a point on the south shore and a mile from the eastern end of Lake Fryxell is:

Surface:	well developed stone pavement, undersides of stones coated with calcium carbonate;
3 in.	pale grey (10 YR 7 : 1) sandy silt; strongly developed medium platy structure, plates about 1 in. diam. and $^1/_{16}$–$\frac{1}{8}$ in. thick; each plate firm, slightly cemented with calcium carbonate but crushes to gritty silt; distinct boundary;
2 in.	small (less than $\frac{1}{8}$ in. diam.) balls of gritty silt, each ball is firm, but horizon is loose and balls stream away from face when disturbed, matrix of fine, grey sand between balls; distinct boundary;
3 in.	fine grey sand; loose and friable;
on	frozen ground.

Thin lenses of similar "silt balls" (in some places slightly flattened or elongated) were encountered in moraine soils elsewhere in the valley, but they were always confined to the active layer of silty sediments. It is suggested that the platy structure of the topsoils is a function of wetting and drying and is similar to that formed outside the polar regions in the surface mud of dried-up ponds. The spherical structure of the subsoil is presumably a freeze-and-thaw phenomenon.

Moraine with undulating or benched relief covers the greater part of the floor of the lower valley. A distinction was made between "dark" moraine and "brown" moraine. Brown moraine has a predominantly benched topo-

FIG. 5—Close up of "silt balls" in subsoil of soil on silty lake sediments.

graphy and covers the gently sloping valley floor near the foot of the mountains. It contains a great deal of pale coloured granite, quartzite, and metamorphic rocks contributed by the side glaciers, and the brown appearance is due to staining on the leeward side of the boulders. The dark moraine has an undulating surface. It lies near the centre of the valley and appears to have been laid over the brown moraine. The dark appearance is due to the large amount of scoria in the moraine which presumably post dates the eruptions of scoria in the upper part of the valley (McCraw, 1962).

A profile of a soil on a brown moraine ¾ mile NW of the Wales Glacier at an altitude of 480 ft and on a western slope of 4° is:

Surface:	close stone pavement, ventifacts, and severe wind abrasion; brown staining on leeward (south-east) side of boulders; accumulations of soluble salts under some stones;
2 in.	pale olive grey (5Y 6 : 2) coarse sand, moderately cemented. but crushes readily to free sand; few small angular stones less than ¼ in. diam.; sharp boundary;
4 in.	pale olive grey fine sand matrix, many stones up to 1 in. diam.; uncemented; diffuse boundary;
8 in.	pale olive (5Y 6 : 4) fine gravel and sand;
on	frozen ground.

Analyses (Claridge, 1965; sample 34 a–c) show that the soil has a higher content of soluble salts (0·1%) and calcium carbonate (1·4%) in the surface horizon than in the subsoil. pH values range from 9·8 in the topsoil to 8·8 in the subsoil. Claridge points out that there is little difference in type and content of clay minerals between this soil and that developed on the high alluvial terraces.

Soils on Moraines of the Uplands

Moraines occur on prominent high benches on both sides of the upper part of Taylor Dry Valley. The bench on the south-eastern side of the valley lies at an elevation of about 2,000 ft and is thinly covered with moraine that consists mainly of granite and gneiss. Noteworthy is the presence of huge boulders, some more than 15 ft in diameter, marked with flutings, caverns, desert varnish, and other signs of weathering. The ice that deposited this moraine destroyed numbers of scoria cones and in many places the moraine is locally heavily charged with scoria (McCraw, 1962). Patches of similar moraine occur on the uplands of Mt Falconer and adjacent hills on the northern side of the lower valley.

The soils have weakly cemented topsoil horizons and a pale yellowish brown colour that seems characteristic of soil developed from granitic detritus. Raised-border polygons and stone pavements are well developed. A profile of a soil a mile north of Mt Falconer at an altitude of 2,000 ft on a 2° northerly slope is:

Surface:	close stone pavement; many large boulders of granite with distinct desert varnish;
3 in.	pale yellowish brown (2·5Y 6 : 4) coarse sand, with many small round pebbles of granite; horizon slightly to weakly cemented; sharp boundary
5 in.	similar to above but not cemented; slightly moist; diffuse boundary;
4 in.	as above but very moist;
on	frozen ground.

In this soil Claridge (1965, sample 39 a–c) found no free calcium carbonate and only a low content of soluble salts, although the topsoil has a pH 9·8. It is possible that the topsoil is cemented with gypsum rather than calcium carbonate. He also reports 0·3% to 0·4% of extractable iron oxides and relatively large amounts of clay (in the form of mica), and small amounts of expanded micas.

At higher levels, on a bench at about 3,000 ft altitude, another moraine occurs, but this is mainly confined to the northern side of the upper part of the valley and to a few small patches on the southern side. The moraine consists almost entirely of dolerite fragments and minor amounts of weathered Beacon Sandstone. Much of the sandstone is weathered to the point where it crushes readily in the fingers and even the dolerite is much shattered and crumbly. The active layer is more than 2 ft thick and polygons poorly developed. A profile (Fig. 6, McCraw, 1960) from a point about 4 miles NW from the snout of the Taylor Glacier on a 4° south slope at an altitude of 3,020 ft is:

Surface: small boulders of shattered dolerite and small fragments of weathered Beacon Sandstone; no carbonate coatings on stones; no salt; stone pavements indistinct;

9 in. dark grey (10 YR 3 : 1) stony sand; fragments of dolerite up to 1 in. diameter and sparse larger stones of weathered Beacon Sandstone crumbling in fingers; no cementation;

on weathered bedrock or large boulder; no ice-cemented ground reached.

Fig. 6—Profile of soil on scoria cone, Taylor Dry Valley. Note dry surface horizon overlying moist gravel.

The lack of calcium carbonate, relatively low pH values, and rising soluble salt content in the lower part of the profile (Claridge, 1965; sample 25 a–c) indicate that this soil has undergone leaching from the surface. Tests near this soil pit showed the active layer to be at least twice as thick as on the floor of the valley. This could mean that the uplands are warmer (perhaps through receiving longer hours of sunshine) and more water is available for leaching.

Soils of Cones and Patches of Scoria

The occurrence of cones of basaltic scoria and irregular patches of scoria (some mixed with moraine) on high benches in the upper part of the valley have been described previously (McCraw, 1962).

A profile (Fig. 6) of a soil in the crater of a cone about ¾ mile east of the Marr Glacier is:

Surface:	stone pavement of slightly wind-polished scoria; very thin coating of calcium carbonate on underside of stones;
2 in.	yellowish brown fine sand; very friable and loose; not cemented; few to many fragments of scoria; soil dry; boundary distinct;
18 in.	dark reddish black scoria; loose, unweathered but in some fragments there are vesicles full of white, loose material, not calcium carbonate, possibly sodium sulphate, some vesicles lined with a yellow film, probably sulphur; horizon moist;
on	frozen scoria, each fragment cemented to its neighbour by ice crystals.

The yellowish brown sand in the surface horizon of this soil is very similar to that derived from granite and it is probably blown sand from the weathering of nearby granite.

Soils of Solifluction Slopes

Active solifluction in the valley is confined to saturated debris that lies on slopes of more than 2°. The most extensive patches lie along the foot of the southern hills in the lower valley. Here numerous glaciers supply abundant meltwater and, as many of the drainage channels are ill-defined in their upper reaches, much water soaks into the morainic debris on the sloping valley floor. Debris affected by solifluction has a flattened appearance as if it had been rolled by a roller—stones and even large boulders have sunk into the waterlogged debris until they are nearly flush with the surface. Large boulders that have their lower parts embedded in frozen ground are partly overwhelmed by flowing debris on their up-slope side, but have a "cavitation" hollow down-slope. Lobed solifluction terraces are rare and occur only where large boulders are picked up by the moving mass. Apparently the boulders resist the flow sufficiently for terraces to form in the same manner that vegetation obstructs flow and forms terraces in other regions. Flow can occur only during the thaw, but debris moves quickly once water enters the material. A boulder was seen to overturn and fall from a terrace front during a few minutes' observation.

Solifluction slopes are a poor environment for soil development owing to the instability of the surface. No evidence of cementation was observed, but a thin efflorescence of soluble salts occurred on some surfaces. A pit revealed a water-saturated mass of jumbled sand and stones.

Soils of Screes

Screes are abundant along the steep walls of the valley and are of two kinds, dry screes and frozen screes: (*a*) Dry screes are similar in appearance and mode of origin to those of the temperate regions. The surface is comprised of loose, angular blocks, smaller at the head of the scree and large at the foot. Any fine material is confined mainly to the head of the scree. Dry screes are particularly well developed below dolerite outcrops mainly because the closely spaced hexagonal jointing makes this rock particularly susceptible to breakdown into blocks (Gunn and Warren, 1962), which are resistant and do not readily break down further. Most dry screes lie at angles of about 36°. (*b*) Frozen screes have much fine material mixed with larger blocks and generally lie below outcrops of the less resistant metamorphic rocks in the lower valley. Frozen material lies within 2 ft of the surface, which is not smooth but consists of a series of lobate terraces each with a near vertical scarp about 4 ft high consisting of large boulders and a sloping tread of fine material. Debris at the foot of the scree is invariably finer than that at the apex—the reverse of that obtaining on dry screes. The large amount of fine material holds meltwater from snow of the terrace treads and in many places this is supplemented by meltwater from slopes above the scree. During thaw periods movement of the scree surface takes place by solifluction. Frozen screes lie at lower angles (ranging from 14°–32°) than dry screes.

Soils are rare on dry screes owing to the lack of fine material and moisture. A soil was examined at the apex of a scree formed from granitic moraine about 2 miles north-west of the snout of Taylor Glacier on a slope of 15°:

Surface:	layer of small stones, mainly less than 1 in. diameter, no carbonate coating on undersides;
1 in.	pale olive (5 Y 6 : 3) sand; loose and friable; many small subangular and rounded pebbles of pink and grey granite and minor dolerite; distinct boundary;
9 in.	olive (5 Y 5 : 4) sand with many small stones; slightly compact; indistinct boundary;
10 in.	pale yellowish grey fine gravel with sand matrix; loose and friable; no frozen material reached at 30 in.

The deep active layer could allow some leaching from the surface and analyses (Claridge, 1965; sample 26 a–c) show an increase of soluble salts and calcium carbonate in the lower horizons. Claridge points out that clay minerals are more developed (vermiculite A, some montmorillonite, and chlorite) than would be expected from this site but suggests that much of the weathering probably took place on the moraine from which the scree was derived. Only soils with very weakly cemented surface horizons are developed on the unstable solifluction terraces of the frozen screes.

Soils of the Rock Slopes

The valley walls in the upper part of the valley are, in many places, sheer cliffs of dolerite and granitic rocks (Fig. 7). Although a few ledges where soils might be expected to form were seen from a distance, no soils from the dolerite cliffs were examined.

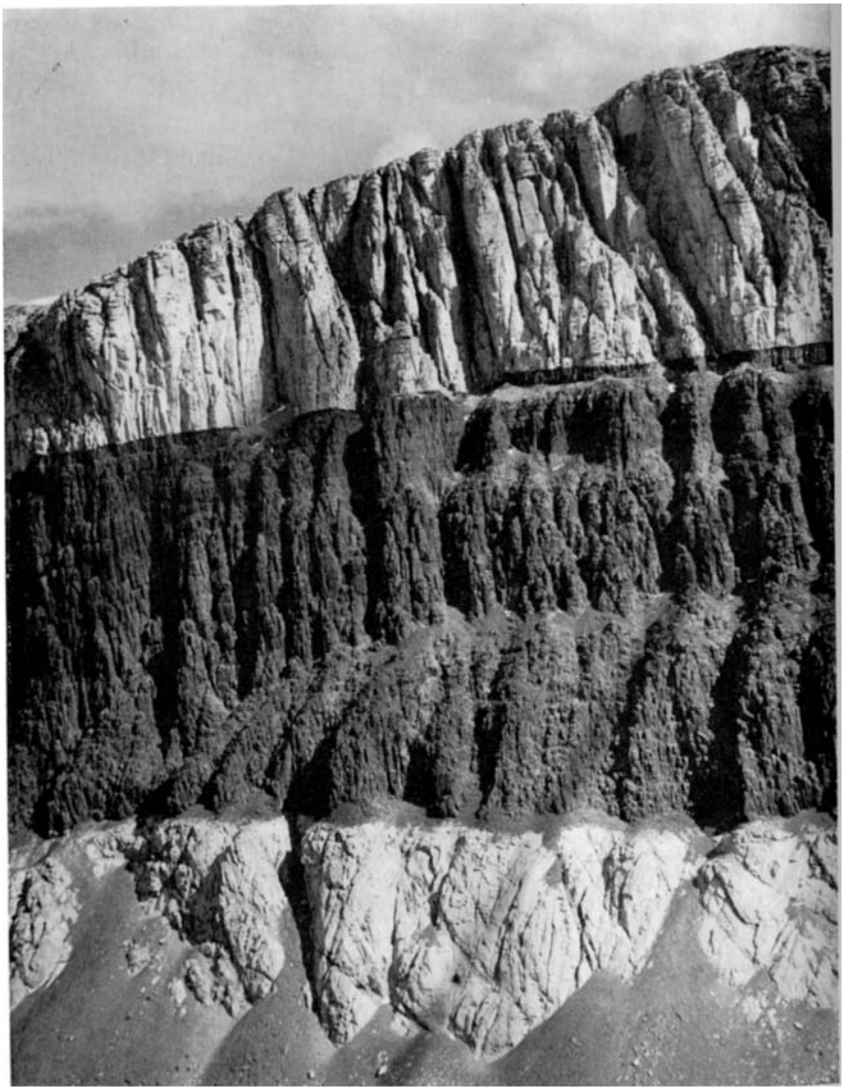

FIG. 7—Precipitous cliffs of gneiss and dolerite in Upper Taylor Valley. Soils in pockets and crevices. "Dry" screes of dolerite detritus below. The dolerite sill is more than 500 ft thick.

On the low (3,600 ft) peak of Mt McLennan yellowish brown sandy soils were collected from crevices in the steep granite cliffs. Claridge (1965; samples 35 and 36) reports that analyses showed 2% of clay, 0·4% extractable iron oxides, and 24% of calcium carbonate in one sample and 0·09% clay, 0·08% iron oxides and no calcium carbonate in the other.

In the lower part of the valley the softer metamorphic rocks give rise to convex slopes with few cliffs. Exposed rock is rare, but on a site on the face of Mt Falconer soil was collected from a crevice in granite. Analyses showed it contained more than 29% of calcium carbonate.

Soils of the Felsenmeer

Felsenmeer or blockfields cover much of the uplands of the rounded hills in the lower valley. Generally they consist of angular blocks up to 2 ft in diameter and are only one or two stones thick. Even on slopes of 10° movement is rare for the course of underlying dikes can be traced by the sharp colour difference between the rubble from the dikes and that from the adjacent rock. Soils occur only in rare pockets of fine material among the boulders.

Soils of the High Plateaus

Some of the high peaks in the upper valley have flat summits formed from either dolerite or Beacon Sandstone and as these plateaus appeared to be free from snow in summer it is likely that soils are developed on them. However, as the peaks could not be reached in the time available no information about these soils was obtained.

SOILS OF OTHER LOCALITIES IN VICTORIA LAND

Although the main object of the Expedition was to examine soils in Taylor Dry Valley, brief visits were made to other localities. Owing to the short time available, profile descriptions and notes on only a few soils were obtained and no attempt was made to map soils.

Hallett Station (72° 18′ S, 161° 00′ E)

Hallett Station lies on Seabee Hook, a small, hook-shaped gravel spit that projects into Edisto Inlet from the north side of Cape Hallett. The Spit is almost entirely occupied by a large rookery of Adelie penguins. Most of the penguins seem to favour a long ridge standing about 10–12 ft above sea level which runs along the spit on the seaward side, but many nest in numerous, isolated, low hummocks that are scattered over the low ground behind the ridge. Many of these hummocks may have been enlarged or perhaps formed entirely by penguins bringing in stones for nest building. The spit ends against an apron of scree that has formed at the base of the high cliffs of Cape Hallett. Hallett Station is slightly warmer than Scott Base and the thaw period longer. Precipitation is higher and vegetation (mosses, lichens, and algae) much more plentiful (Rudolph, 1963) than in Taylor Dry Valley.

Soil on Scree

Site: half mile south of Hallett Station on dolerite scree; slope 27°, slope of site 18° N; altitude 100 ft; site is about 200 ft below a glacier which contributes much meltwater; used as nesting place by skua gulls:

Surface:	angular stones of dolerite 3–5 in. diameter, some with lichens; feathers and algae; *Collembola* under some stones; skua dung;
2 in.	coarse loamy sand, dark brown (10 YR 2 : 2); abundant coarse black grit; very slightly cemented; some fibrous organic matter;
on	angular stones cemented by ice, many cavities lined with ice.

The soil is much more acid (topsoil pH 6·4) than the soils in Taylor Dry Valley. It has a low content of soluble salts which consist mostly of sodium chlorides and sodium sulphate (analyses: Claridge, 1965; sample 10 a–c).

Soil from Beach Gravel

Site: 600 yards east of Hallett Station, 100 yards from sea beach; possibly once occupied by penguins.

Surface:	flat, smooth water-worn and wind polished dolerite stones up to 4 in. diameter; scattered plants of moss;
2 in.	coarse sand and fine gravel; loose, not cemented; stones up to 2 in. diameter; dry; distinct boundary;
4 in.	black (5 YR 2 : 1) coarse sand and fine gravel; wet;
on	frozen ground.

Analyses (Claridge, 1965; sample 11 a–c) show that this soil is also acid pH 6·1 topsoil, pH 6·9 subsoil) and that soluble salts are low but slightly concentrated in the topsoil (0·10%).

Soil from Guano

Site: 600 yards east of Hallett Station and about 40 yards from sea beach; altitude 15 ft; penguins nesting.

Surface:	white (10 YR 8 : 2) fibrous very thin plates (like rough paper) firm; sharp boundary;
¼ in.	pale red (10 R 6 : 1) fibrous plates up to 2 in. diameter, thin, like sheets of blotting paper; no grit; distinct boundary;
¼ in.	pale brown (7·5 YR 6 : 4) fibrous, some grit; distinct boundary;
1½ in.	reddish brown (5 YR 4 : 4) guano; sticky, greasy; many small stones and much grit; indistinct boundary;
2½ in.	dark reddish brown (5 YR 2 : 2) very sticky guano, some feathers; much grit and many small stones; indistinct boundary;
on	frozen ground, dark brown (10 YR 2 : 2) matrix between many stones and some up to 2 in. diameter.

Analyses (Claridge, pers. comm.) show that this soil is slightly alkaline (pH 7·4) and contains 3·5% of soluble salts, mainly sodium sulphate with some phosphate and nitrate.

Cape Royds, Ross Island (77° 33′ S, 166° 07′ E)

A roughly semi-circular tract of bare land covering about 8 square miles is centred about Cape Royds on the west coast of Ross Island. Although the relief is low the topography is rugged owing to the large numbers of outcrops of kenyte, some of which are weathered into fantastic forms. The land surface is covered with a layer of debris consisting mainly of kenyte fragments, including many large loose crystals of plagioclase, and minor amounts of granite, and other rocks presumably transported from the mainland by ice. The surface of the soils is protected by a well developed stone pavement broken in places by frost cracks filled with sand. Polygons are not well developed. Surface coatings of soluble salts are widespread and especially near the coast are thick and continuous.

Soil from Kenyte Debris

Site: 300 yards north of Shackleton's Hut, altitude 165 ft; topography, rolling with many outcrops of weathered kenyte occupying about 50% of surface; slope of sample site 5° NW.

Surface:	close stone pavement consisting of about 10% of stones up to 2 in. diameter coated with calcium carbonate on undersurfaces; remainder small stones completely coated with carbonate. Efflorescence of salt general between stones;
1 in.	dark grey sand (2·5 Y 3 : 0) with about 90% clear quartz or feldspar grains; dry; very friable;
2 in.	dark greyish brown (10 YR 3 : 2) coarse sand with few small stones up to ¼ in. diameter slightly cemented; distinct boundary;
2 in.	dark greyish brown (2·5 Y 3 : 2) coarse sand with many small stones;
8 in.	dark grey (2·5 Y 3 : 0) fine sand with few small stones, very friable;
on	frozen ground.

Claridge (1965, sample 3 a–e) reports that the pH is about 9 throughout the soil and that there is a high concentration of soluble salts (11·6%) in the topsoil, but very little in the lower horizons. The salt is mainly sodium chloride.

Soil from Kenyte Scree

Site: Blacksand Beach ½ mile NW. Shackleton's Hut; scree of kenyte detritus falling to beach; slope 33° NW.

Surface:	stone pavement of slightly wind polished stones 1 in. diameter. Salt efflorescence on and between stones;
1 in.	fine dark grey sand; dry; distinct boundary;
8 in.	coarse sand and much angular kenyte; damp; abundant salt in pockets between stones (has appearance of small snowflakes) in upper 2 in. of this horizon, salt decreases with depth;
on	coarse kenyte fragments with sand matrix.

no ice-cemented ground at 36 in.

Soil from Guano

Site: Adelie penguin rookery 150 yards west of Shackleton's Hut; altitude 40 ft; aspect 4° slope SE (Fig. 8).

Surface:	smooth, compacted by penguins, many nests of stones of 1–3 in. in diameter. Top $\frac{1}{8}$ in. bleached white;
$\frac{3}{4}$ in.	pale brown (10 YR 6 : 3) guano, gritty when crushed; moderately developed medium platy structure; distinct boundary;
$1\frac{1}{4}$ in.	mainly small smooth stones up to 1 in. diameter with matrix of brown guano (7·5 YR 4 : 4); distinct boundary;
2 in.	smooth small stones with matrix of dark brown (10 YR 2 : 2) coarse sand; many specks of white salt;
on	frozen ground.

Analyses (Claridge, pers. comm.) show that this soil is neutral in reaction (pH 6·7 at the surface and pH 7·5 in the top 5 in.) and contains 4% of soluble salts, mainly sodium sulphate with some phosphate and nitrate.

Cape Evans, Ross Island (77° 38′ S, 166° 24′ E)

The topography and rocks at Cape Evans are similar to those at Cape Royds, but the snow-free land is of much smaller extent. Salt efflorescences on the soil surface are possibly even more prominent than at Cape Royds.

Soil from Kenyte Debris

Site: 400 yards south of Scott's Hut on top of sea cliff; altitude 60 ft; aspect 8° SE; topography, easy rolling; parent material, kenyte colluvium from outcrop 4 yards north-west.

Surface:	pavement of angular kenyte stones $\frac{1}{4}$–$\frac{3}{4}$ in. diameter resting in, and in some places covered by, thick coating of soluble salts;
$\frac{1}{2}$ in.	angular kenyte fragments ($\frac{1}{2}$ in. diameter) in matrix of coarse sand; slightly cemented; abundant salt; distinct boundary;
2 in.	angular kenyte fragments in matrix of coarse black sand; slightly cemented; much salt especially in small pockets between stones;
4 in.	small angular stones up to $\frac{1}{4}$ in. diameter in matrix of coarse black (5 Y 2 : 1) sand, not cemented; many clear grains of feldspar:
on	frozen ground.

The pH of this soil is about 9 throughout the profile (Claridge, 1965; samples 6 a–c) and soluble salts reach 11·3% in the top inch, but the concentration falls to 0·4% at 4 in. The salt is mainly sodium chloride almost certainly derived from the sea as wind-driven spray. Claridge reports the presence of mica in the clay minerals and suggests that it was probably derived from dust blown from the sedimentary rocks on the mainland.

Scott Base, Ross Island (77° 50′ S, 166° 44′ E)

Scott Base lies on a lava flow (Wellman, 1964) and the slopes behind the Base rise evenly over old basalt flows to an elevation of 1,000 ft at the summit of Crater Hill. The surface is covered with broken and crumbly scoria mixed with minor amounts of granite and quartzite pebbles. Solifluction is active during the summer and poorly developed stone nets, stone circles, and terraces occur on the upper parts of the slopes. The soils are very wet during the thaw and moss is relatively plentiful on the lower slopes.

Soil from Basaltic Scoria

Site: top of bluff in north-west corner of the "aerial farm" about 1 mile west of Scott Base; topography undulating to easy rolling, aspect 5° N.

Surface:	pavement of slightly polished black scoria 1–3 in. diameter; stones with white coating on undersides;
3 in.	dark greyish brown (2·5 Y 4 : 2) very gritty loamy sand, very slightly compact; moist; indistinct boundary;
3 in.	dark greyish brown (2·5 Y 3 : 2) grit; weakly compact; moist; distinct boundary
4 in.	small stones, loose and open; thinly coated with gypsum very friable; dry;
on	frozen ground.

Although the pH of this soil ranges from 8·6 in the topsoil to 9·3 in the subsoil (Claridge, 1965; samples 43 a–c) soluble salts (mostly sodium sulphate) are very much lower (0·23%) than in the soils at Cape Evans and Cape Royds. 0·4% of calcium carbonate is present in the topsoil, but Claridge reports that the coating on some of the stones at the surface and in the subsoil are gypsum. The compaction of the 3–6 in. horizon is unusual and probably a function of surface leaching in this rather wet environment.

Dailey Islands (77° 53′ S, 165° 15′ E)

The Dailey Islands are a group of five small islands lying near the mouth of the Koettlitz Glacier. The largest of the islands was visited. It appeared to be comprised mainly of dark scoria with abundant granitic moraine. Evidence of intense physical weathering included widespread disintegration of granite boulders. Wind erosion was active and ventifacts abundant. Well developed polygons covered the island and on the steep west slopes (38°–40°) they were elongated to form stone garlands. A few poorly developed sorted stone circles about 10 ft in diameter occur on the summit. No vegetation was seen.

Soil from Scoria

Site: 50 yards east of main ridge, 400 yards north of summit of island, centre of a large polygon about 30 ft in diameter; aspect 6° slope SE, altitude 100 ft.

Surface: pavement of wind-polished and faceted scoria up to 3 in. diameter with matrix of small gravel;

1 in. yellowish brown loose coarse sand, distinct boundary;

2 in. slightly cemented pale yellowish brown sand with few small pebbles; distinct boundary;

5 in. very friable coarse sand with many stones up to 1 in. diameter; many small lenses of fine yellowish brown sand about ¼ in. thick and 2 in. long; most stones are slightly stained on undersides with white coating; sharp boundary;

5 in. layer of pale grey sand without stones; slightly cemented;

on frozen ground.

Cape Chocolate (77° 58′ S, 164° 37′ E)

The soils on the flights of terraces (Speden, 1960) were examined and found to be similar to those on the terraces in Taylor Dry Valley. Much of the moraine in this region is very thin and lies over undisturbed water-deposited sands and silts. Topsoils were moderately cemented and analysis of a sample (Claridge, 1965; sample 16) shows 2·7% of calcium carbonate.

FIG. 8—Profile of soil at Cape Royds penguin rookery showing white guano on surface and soluble salt layer at depth of 3 in.

Marble Point (77° 26′ S, 163° 48′ E)

Between the sea and the Wilson Piedmont Glacier, flat and easy undulating land stretches southwards from Gneiss Point to south of Marble Point. The topography then changes to sloping lateral moraines, solifluction slopes, and screes, which continue southwards round Cape Bernacchi to link with those of the Taylor Dry Valley. The flat land at Marble Point is mostly covered with thin till consisting of angular rock fragments set in a matrix of coarse sand, but low hillocks of shattered basement rock protrude here and there. The till plain is criss-crossed with many stream channels draining the glacier and several large lakes and many small ponds are dotted over the landscape. Numerous well developed terraces marking old beaches flank the shore line (Nichols, 1961). During the summer running water is abundant and the high moisture content of the soils is reflected in the abundance of algae and moss along stream banks, the prevalence of solifluction, and in the downward leaching of soluble materials in soils.

Soil from Till Plain

Site: about 200 yards west of Marble Point Camp; topography, easy undulating; aspect 1° slope north.

Surface:	Coarse sand between angular stones (mainly marble and gneiss) up to 8 in. in diameter;
3 in.	greyish brown (2·5 Y 5 : 2) coarse sand with many small stones; loose, no cementation; distinct boundary;
2 in.	greyish brown (2·5 Y 5 : 2) coarse sand; slightly sticky; moderately cemented; few small stones up to ½ in. diameter coated with calcium carbonate; sharp boundary;
4 in.	olive grey (5 Y 5 : 2) gritty silt with moderately developed medium blocky structure; slightly calcareous; few small stones;
on	frozen ground.

Analyses (Claridge, 1965; sample 42 a–c) confirm a distinct rise in calcium carbonate (4·0% topsoil, 7·6% at 3 in.) in the cemented horizon. Alkalinity is extremely high (pH 10), but soluble salts are low and consist mainly of sodium chloride.

Soil from Marble

Site: about ½ mile inland from mouth of "South Valley Creek" and 200 yards north of the creek. On small knoll of marble, mainly bare rock but somewhat shattered; soil was taken from small gutter in the marble; aspect 5° S.

Surface:	small (up to ¼ in. diameter) marble chips;
½ in.	abundant angular marble chips, matrix of fine sand very slightly cemented especially at surface, no platy structure, distinct boundary;
2½ in.	pale olive brown (2·5 Y 5 : 4) fine sand, many small marble chips, loose; indistinct boundary;
2 in.	olive (5 Y 4 : 3) sand with many marble chips; weakly to moderately cemented; matrix slightly sticky, indictinct boundary;
1 in.	olive (5 Y 4 : 4) fine sand with abundant marble chips; weakly cemented and slightly sticky;
on	marble.

Analyses (Claridge, 1965; sample 44 a–c) show a steady rise in calcium carbonate content down the profile (6·8% topsoil to 12·9% in subsoil) and an accumulation of salt (mainly sodium chloride) at the surface. The pH values are lower than in the soil from the till plain. Claridge also points out that there are relatively large amounts of montmorillonite in the subsoil which he attributes to prolonged weathering under a semi-arid environment in conditions of high base-status.

Soil from Algae

Site: dried up lake about 300 yards north-west of Marble Point Camp.

Surface:	pale grey thin plates of dried algae;
1 in.	layered plates of recognisable algae; dry; pale brown; distinct boundary;
2½ in.	greyish brown compacted algal remains; moist;
on	frozen compact algae.

The deposit is merely a mass of compacted, undecomposed algae.

SOIL-FORMING FACTORS AND PROCESSES

In this section the role of the main soil-forming factors is discussed in relation to the soils of Taylor Dry Valley and other localities visited.

Parent Material

(Fig. 9)

The main difference noted in the field between soils developed from different kinds of rocks, was that of colour. Soils developed from schist, greywacke, or marble were predominantly grey, whereas those from granite were yellowish brown or olive, and those from dolerite (collected by members of the Victoria University of Wellington Antarctic Expedition in Victoria Valley) were reddish brown.

Few soils in Taylor Dry Valley are developed from rock *in situ*—the majority are formed on transported debris containing a wide range of different rocks. It is apparent that it is the texture of the parent material and the available moisture supply that is important in determining the character of the soils formed. Soils do not form on dry, coarse-textured materials such as bouldery moraines, scree, felsenmeer, and shattered rock. Recognisable soil structure is developed only in soils formed on finely textured parent materials such as silts and clays.

Weathering

The prevalence of broken and shattered rock is a striking feature of the ice-free regions. On steep faces the broken rock falls away to form scree at the foot of the slope, but on easy slopes the debris remains as a felsenmeer. On moraines shattered and fragmented boulders are abundant. Each kind of

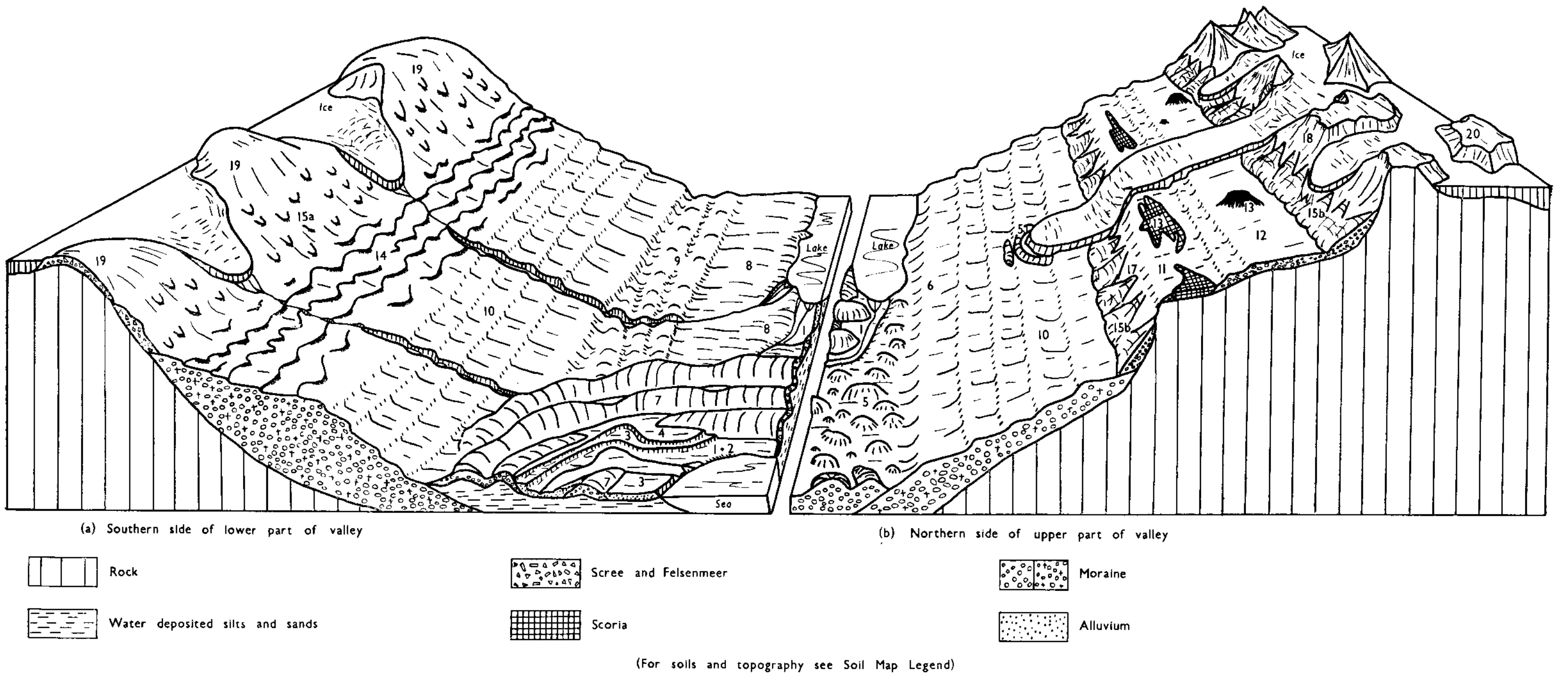

FIG. 9—Idealised block diagram (not to scale) showing relationship of soils to topography and parent material in Taylor Dry Valley.

rock has a distinctive shatter pattern which can be recognised from a distance; some, such as schist, split into thin leaves and others, such as granites, tend to fret and break down to small, gravel-sized fragments. Gneisses break up into thin curved fragments, whereas dolerites, perhaps the most resistant of all, split into angular blocks.

Where moisture is available there is little doubt that the freeze-and-thaw process (Reiche, 1950) is responsible for most of the rock breaking, but it is unlikely to be solely responsible for the destruction of large massive boulders of dolerite and other rocks perched high up on dry morainic ridges. Although insolation weathering has been discredited as an effective agent of rock breaking (Blackwelder, 1933), recent work by Ollier (1963) supports the view that, where extremes of daily temperatures are great, this process can cause rock splitting.

Wind not only plays an important part in the transport of fine debris loosened by other means, but also actively erodes by abrasion with sand, gravel, and ice particles. Abundant examples of ventifacts were observed on the moraines of the dry regions. It was noted that different kinds of rock are abraded and polished in different ways; fine-grained rocks such as dolerite and some granites were abraded and polished to a smooth surface, whereas coarse, phenocrystic porphyry was grooved and fluted through elongation of pits and vesicules. Possibly the most important effect of wind is the formation of lag gravel or desert pavement.

The physical breakdown of rocks by growth of soluble salt crystals in crevices is a factor that cannnot be overlooked. Enlargement of caverns and vesicules by salt fretting is active in schist rock in the semi-arid climate of Central Otago, New Zealand, and accumulations of salt were observed in similar caverns in kenyte at Cape Royds and in trachyte at Cape Armitage. In both places small fragments of rock had been loosened by salt crystallisation.

Chemical weathering, although much weaker than physical weathering, is widespread. Field evidence is abundant. Staining of the basement rocks lends a distinctive brownish tinge to the coastal hills and the dark reddish brown colour of many dolerite outcrops is a feature of the inland regions. An exfoliating surface crust, up to $\frac{1}{8}$ in. thick, was noted on boulders of gneiss on older moraines.

Claridge (1965) found free lime in samples of most soils from Taylor Dry Valley, but its field distribution is irregular. Most of the soils developed in sands or gravels have a slightly compacted horizon at or near the surface comprised of sands slightly cemented with calcium carbonate or gypsum (Fig. 10). Although widespread, this cemented horizon was not continuous and was best developed on stable sites, where moisture was close to the surface, and where aspect encouraged evaporation. In older soils the cemented horizon was at some depth below the surface.

Calcite veneers on the underside of boulders on moraines and elsewhere were widespread and are a clear indication, according to Nichols (1963), that they were formed in a dry climate by evaporation of water that had moved upward by capillarity. The veneers, which were up to $\frac{1}{8}$ in. in thickness, were a useful indicator as to whether a stone had remained in one position for some time or had been moved recently by solifluction.

Soluble salts form an almost continuous encrustation on the soil surface at coastal localities such as Cape Royds, Cape Evans, and at the mouth of Taylor Dry Valley. Much of this salt is sodium chloride and is probably derived from spray carried inland from the sea (Ball and Nichols, 1960; Kelly and Zumberge, 1961), during the short period each year when there is open water along this part of the coast. But soluble salt encrustations are also abundant far inland. Surface efflorescences were noted at the foot of slopes at Lake Bonney in Taylor Dry Valley, and thick subsurface deposits are reported from the Lower Wright Valley (Nichols, 1963) and Victoria Valley (Gibson, 1962). The saline waters of some of the many inland lakes in the dry regions have been investigated by recent workers (Nichols, 1962; Tedrow and Ugolini, 1963), and all have concluded that most of the salt was formed by weathering of rocks in the lake catchments and that little, if any, of the inland salt is derived from sea salt.

The most conclusive evidence of chemical weathering in Antarctica has been put forward by Claridge (1965) in his studies of the clay mineralogy of soils collected during the expedition. His conclusions are that clays are actively forming at the present time and that most of the clays are derived from the slow hydration of micas. In the most weathered soils the clay is vermiculite and in a few, montmorillonite.

FIG. 10—Profile of soil on lateral moraine near Lake Bonney showing cemented and protruding surface horizon.

Moisture Régime

Antarctic soils are, in general, very dry but, for a short time each summer, most contain some moisture and some are even wet. Rain is practically unknown in Victoria Land and must be discounted as a source of moisture. Soil moisture is from three main sources: (*a*) Melting of snow cover; (*b*) thawing of the active layer; (*c*) meltwater from permanent snow and ice fields.

Melting of Snow Cover

Snowfall on the floor of the dry valleys is generally light. Most snow falls during the winter and only a few deep drifts persist through the summer. Most is removed by sublimation and patches can be seen growing smaller each day, with little evidence of melting, until the thickness has been reduced to 1½–2 in. The whole patch then begins to melt and water drips from the edges and wets the soil for a short distance round the margins. Finally, the snow disappears completely leaving a temporary damp patch. Thus, although winter snowfall may be thick, it contributes only a small amount of water to the soil. However, not all soils receive the same amount of water from melting winter snow, as exposed ridges and high places may be swept clear by wind before melting commences.

Probably in some places summer snowfalls are a more important source of soil moisture. Although they disappear quickly and the amount of water entering the soil during the melting of each fall is small, it may be sufficient to leach downward some soluble materials. It was noticed that the floor of Taylor Dry Valley received fewer summer snowfalls than the adjacent hills and apparently fewer than neighbouring regions.* Lack of downward leaching may in part account for the prevalence of surface crusts of soluble materials in the soils of the valley floor.

It is possible that the number of summer snowfalls is more important than the total precipitation in determining whether accumulation of soluble materials occurs near the surface or at depth.

Thawing of the Active Layer

Frozen ground affects soil formation in the arid regions in at least three ways: (*a*) It forms an impervious layer that effectively prevents downward leaching and drainage; (*b*) it provides a supply of moisture in the lower part of the soil during the thaw; (*c*) it provides a surface on which water-saturated soil can move under the influence of gravity.

The thickness of the active layer† depends on aspect, texture of the parent material, and supply of moisture. Hence the permafrost table does not lie

*Calkin (1964, fig. 10) records 10 falls of snow in Victoria Valley between mid-November and the end of January 1961–62 and 14 falls for a similar period in 1958–59; snow fell on 33 days from December–February 1957–58 at Scott Base (Thompson and MacDonald, 1961); no snow fell on the floor of Taylor Dry Valley during the period of the survey (mid-November to late December 1959.)

†*See* p. 504 for definition of terms.

parallel to the surface, but is somewhat similar to a water table in that it is closest to the surface in hollows and deepest on the summits of narrow ridges, but this generalisation can be upset by changes in any of the factors mentioned above. Few quantitative data are available about seasonal activity within the active zone as most earth temperature measurements (Hatherton, 1961; Robertson and MacDonald, 1962) have been made for special purposes with thermocouples buried at depth intervals too far apart for changes in the active layer to be followed accurately. Fluctuations in soil temperatures were measured at different depths in several soils in the Wright Valley (Ugolini, 1963; Ugolini and Bull, 1965) and showed that at these sites temperatures did not rise above 0°C below depths of 15 cm. As field parties are seldom camped at one spot for long periods, and certainly not over a full year, field observations of the annual freezing and thawing cycle are not available.

Excavations under and near snow banks lying on the steeply sloping sides of a small gully in morainic material showed (Fig. 11) that there were 3 in. of loose, dry, frozen sand and gravel between the base of the snow and the frozen ground table. For a few inches downslope from the snowbank the surface layers was moist from either melting snow or thawing frozen ground. Within a foot of the snow bank the frozen ground table was at a depth of 10 in. and was overlain by 8 in. of damp sand and 2 in. of dry sand at the surface. At the foot of the 30° slope, about 12 ft below the snow bank, the soils were moist to the surface and carried a surface efflorescence of soluble salts. On the floor of the gully the frozen ground was within 2 in. of the surface and was overlain by damp soils. A possible reconstruction of events taking place over a year, based on the above observations and supported by observations in other places is:

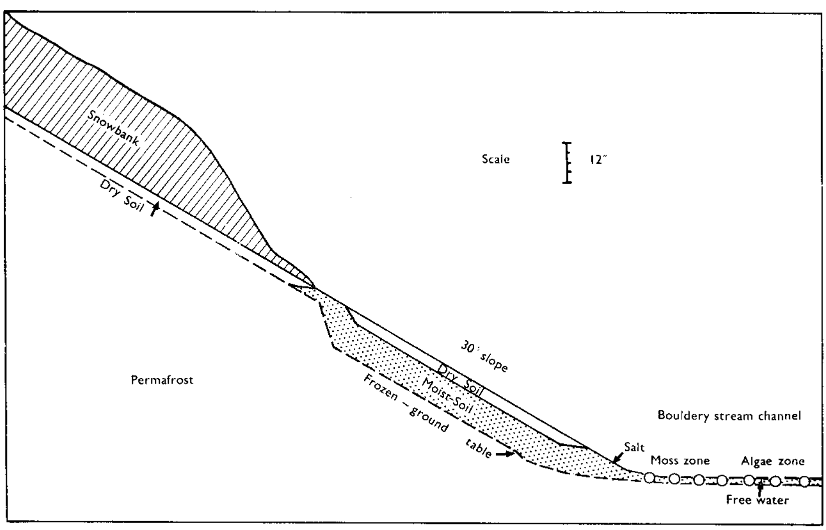

FIG. 11—Moisture régime under, and close to, retreating snow bank, Taylor Dry Valley.

(*a*) At the period of maximum thaw the frozen ground table coincides with the permafrost table, the active layer is of maximum thickness and consists of damp sand and gravel overlain by a thin layer of dry sand.

(*b*) At the end of the thaw the active layer begins to freeze, the moist zone becomes ice-cemented but the surface layer remains dry and loose.

(*c*) Snow falls, but as air and surface temperatures are below freezing, it does not melt and the surface of the soil remains dry.

(*d*) Sublimation of the snow probably begins in late October or November and as the snow cover thins and breaks into patches the exposed soils begin to thaw and become moist. As the season progresses water from the melting snow soaks into the thawing ground. Some comes to the surface at the foot of the slope where it evaporates and deposits soluble salts, which include gypsum and calcium carbonate, taken into solution from soils on the slope.

(*e*) As air temperatures continue to rise the snow patch retreats, thins, and disappears, and the surface of the soils is dried by evaporation. The frozen ground table sinks to the permafrost table.

Though air temperatures may be far below freezing point, temperatures at the soil surface and for a few inches below are above freezing point on sunny days. Table 1 shows the results of rough measurements taken with a thermometer buried at various depths in the active layer and, although probably far from accurate, the figures show that there is a wide variation between air, surface, and earth temperatures. The drying of the surface layer is confined to a few inches in depth in silts and sands, but extends much deeper in loose open debris such as dry screes.

TABLE 1—Relation Between Air Temperature and Soil Temperature*

Locality and Soil	Shade Air Temp. F° (at 4 ft 6 in.)	Surface F°	3 in. F°	6 in. F°
Cape Royds: Penguin rookery, soil from guano Ice-cemented ground at 8 in.	19	33	12	4
Cape Evans: 400 yds south of Scott's Hut; soil from kenyte debris Ice-cemented ground at 10 in.	9	25	15	8
Daily Islands: 400 yds north of summit of largest island; soil from scoria Ice-cemented ground at 13 in.	19	31	26	23
Cape Hallett: 800 yds east of Hallett Station; soil from scree Ice-cemented ground not reached.	27	55	42	25

*Temperatures were obtained with an ordinary thermometer by burying the bulb at the appropriate depth for 5 minutes. Though it is realised that accurate results could not be obtained in this way, errors are probably sufficiently constant for the results to be used for deducing trends.

In stream beds and in some hollows the surface does not dry out. Thawing in these sites begins late in the season when there is already much seepage and run-off from neighbouring slopes.

Ugolini and Bull (1965) point out that on old surfaces the thickness of loose overburden above the ice-cemented permafrost is much greater than on younger surfaces. Following Black and Berg (1963) they suggest that moisture has been gradually lost from the older soils. This may explain why, on old surfaces 2,000–3,500 ft above the floor of Taylor Dry Valley, the loose material above the ice-cemented layer is in some places, nearly twice as thick as on the valley floor. But aspect and moisture supply also control the depth to the permafrost table. Increased soil temperatures resulting from longer hours of sunshine could account for the increased depth. It was not possible to ascertain whether the active layer did in fact extend through the full depth of the loose material or whether the lower part was dry-frozen permafrost. It was noted that where there was a supply of water from melting snow the ice-cemented layer was at shallow depths.

The control exercised by aspect on depth to permafrost was demonstrated on moraine ridges at Cape Evans. On dry north-facing slopes the active layer was 30 in. thick and increased to more than 36 in. on the shoulders of ridges. On the south facing slopes it was less than 15 in. thick and decreased to less than 4 in. on the floor of the valley.

Meltwater from Permanent Snow and Icefields

From early or mid-December air temperatures rise above freezing point for longer periods each day and snow and ice begin to melt. Thaw streams cascade from hanging and piedmont glaciers and meltwater begins to flow from deep snow banks and high-level snowfields. In some places this meltwater finds its way into defined channels forming streams, some large in volume, which flow towards lakes or the sea. Soils become moist for a distance of several yards on either side of the stream channels.

Where there are no defined channels meltwater seeps down the hillsides until soils are saturated and active solifluction commences. The presence of permafrost is not sufficient in itself to cause solifluction nor was solifluction noted on slopes where the only moisture available came from thawing frozen ground or winter snow cover. It is apparent that substantial amounts of water must enter the soils from an outside source and the main part played by permafrost is in providing a watertight layer that prevents downward drainage of this water and at the same time provides a firm surface on which the water-saturated waste can slide.

Movement and Deposition of Soluble Materials

In soils other than those subject to flushing by meltwater the only downward leaching that can occur is by the small amount of water that enters the soil during melting of the snow cover. The subsequent fate of this water and its dissolved salts depends largely on the position of the soil in the landscape (Fig. 12).

On elevated flat sites such as the treads of terraces, soil water cannot easily escape by lateral drainage, but is lost by vapour transfer (Ugolini, 1963), capillarity, and evaporation. Materials carried upwards in solution are deposited at or immediately below the surface and form an horizon 2–3 in. thick of weakly cemented gravels. The cement is mainly calcium carbonate or gypsum, but in a few places strong brown colours indicated the presence of iron. When a hole is excavated in soils with a well developed cemented horizon, loose material falls away from beneath the compact layer so that it protrudes in a characteristic manner (Fig. 10). Less well developed calcareous layers can be easily detected with hydrochloric acid.

On sloping sites moisture is removed not only by evaporation, but by downslope drainage through the soil and presumably soluble materials are removed by this moving water. Although cemented horizons are well developed on slopes of less than 5° they become weaker, thinner, and more patchy in occurrence as slopes become steeper, and they finally become unrecognisable on slopes over 20°. The reason for this is not clear, but it is possible that instability of the steeper slopes may interfere with the formation of cemented layers.

At the foot of slopes, where frozen ground is generally close to the surface, moisture, charged with soluble materials, comes to the surface and evaporates, and here the thickest carbonate-cemented layers and efflorescences of soluble salts occur.

Soluble materials are not always deposited close to the surface. Where the active layer is thick, as for example at high elevations in Taylor Dry Valley or on north-facing slopes, drying of soils may extend to some depth and accumulation occurs at the interface of dry and moist horizons. At Hallett Sation, Ross Island, and Marble Point cemented surface crusts are poorly developed, but carbonate accumulates just above the frozen ground table.

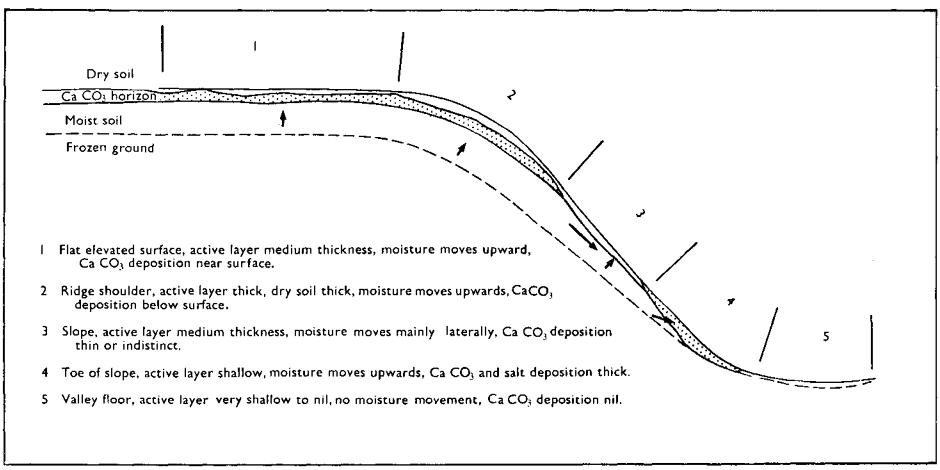

FIG. 12—Relationship of topography to moisture movement and deposition of calcium carbonate in soils.

This is, in part, attributed to downward leaching by moisture from the surface, supplied either from meltwater from nearby glaciers and snow fields or from melting of frequent summer snowfalls.

Although it is reasonably certain that the position of accumulative horizons reflect the direction and possibly the amount of water movement, it is less certain that the amount of accumulation reflects the degree of chemical weathering. Before this could be assessed, factors affecting the site, especially the amount of carbonate-rich rock in the parent materials, must be taken into account.

Organic Factor

Little is known about the contribution of plants and animals to Antarctic soils. Plant life is so sparse that the amount of organic matter supplied must, except in a few favoured sites of small area, be almost negligible. It was found that when compared with adjacent soil without moss cover, a soil developed under moss had: a thin humus-stained horizon less than 1 in. thick; lower pH values in uppermost horizon; soil surface not dry; no calcium carbonate cemented horizon; and the frozen ground table was nearer the surface. It was evident that the moss was insulating the soil and retarding thawing and evaporation.

Lichens do not appear to play any part in soil formation, although Gunn and Warren (1962) report etching of rock to a depth of ¼ in. by lichen colonies. No lichens were seen growing on soils.

Former ponds and higher lake levels are generally marked by patches of dead algae, which in a few places are up to 12 in. thick. In places wind transported fragments of dead algae were found scattered over the surface hundreds of yards from the nearest source.

Of the semi-terrestrial animals the most important contributor of organic matter to the soils is the Adelie penguin. Guano several inches deep has accumulated on the surface in the rookeries, but is generally well mixed with small stones brought in for nest building. The guano, which decomposes slowly, has a fresh appearance and is sticky to a depth of several inches. Campbell and Claridge (1966) have shown that in an abandoned rookery the guano slowly disappears. They also point out that penguins modify soils by adding small stones, fine material, and fragments of egg shell.

The skua gull also contributes organic matter to the soils of the coastal regions mainly through droppings, debris from meals, and odd pieces of moss and feathers used in nest building.

Although seals contribute little to soils, dead crabeater seals (*Lobodon carinophagus*) have been found far inland (Péwé *et al.*, 1959). Some 20 carcasses were counted in Taylor Dry Valley (Claridge, 1961) and according to Péwé some of these are up to 2,600 years old. However, most are well preserved and the increment of organic matter to the soil must be slow and limited in area.

Although the breakdown of the small amount of organic matter available is probably very slow owing to the low temperatures and sparseness of micro-organisms, the fact that a microfauna and microflora does exist in most of the soils examined so far suggests, according to Flint and Stout (1960) ". . . the presence of an organic cycle comparable with that found in more developed soils and supports the view that the rock waste of this region may be properly referred to as soil".

Time Factor

Although some processes such as physical weathering and solution of calcium carbonate may be speeded up in a cold climate, most are slowed down. As soil formation is limited to the period, ranging from a few days to four months each year, when moisture is available, a wide range of soil development may occur through variations in the factors that control moisture. If, for example, soils on an old moraine are frozen for most of the year they may show less development than those on a younger moraine exposed to more warmth.

In Taylor Dry Valley, where soil development is weak, it was difficult to distinguish the effects of time from other variables such as moisture, texture, and aspect. Nevertheless by carefully comparing soils on young surfaces with those on similar sites on older surfaces some differences were recognised. Parent materials on the older surfaces were more weathered and the soils contained more fine material, the frozen ground table was at greater depth, and calcium carbonate and soluble salts were distributed through the soil rather than concentrated near the surface.

DISCUSSION AND CLASSIFICATION

Claridge (1965) has compared soil-forming processes in Arctic soils, mountain soils, and soils formed under semi-arid climates with Antarctic soils. Most Arctic soils are developed under vegetation and it is only in the far north where plant life is very sparse that the soils (*see* Tedrow (1966) for description of Polar Desert soils) apparently resemble Antarctic soils. Taylor and Pohlen (1962) classed Antarctic soils as "frigic soils" and defined these as soils that have subsurface permafrost and are stirred by frost action. As Claridge (1965) has pointed out, frost stirring is apparently of limited importance in preventing soil formation in the dryer parts of McMurdo Sound region. He had redefined frigic soils as soils from stable sites characterised by a permafrost layer, and he regards soils so defined as the zonal soils of Antarctica. One difficulty with this very broad definition is that it probably embraces all soils in Antarctica and leaves no scope for separating intrazonal or azonal soils, for these, no matter how defined, will still be underlain by permafrost. The term "frigic soils" is accepted for the zonal soils of Antarctica but it is not proposed, in view of the very small area of the continent examined, to attempt an embracing definition of these soils.

As experience of frigic soils widens it will be necessary to subdivide them, but it is unlikely that soils will be found in Antarctica with less profile development than that attained by soils formed on alluvium and morainic material in the arid region west of McMurdo Sound. Therefore these soils may be regarded as frigic soils with minimal profile development and those that occur in moister regions or are old will fall into other groups in a development sequence. Frigic soils with the greatest degree of profile development will probably be found on the Antarctic Peninsula or on the neighbouring outlying islands.

The soils discussed in this report may be divided into several groups:

Frigic Soils (Zonal Soils)

Frigic soils with very weak profile development are subdivided according to the position of accumulated soluble materials in the profile. This is assumed to reflect the kind of leaching and in turn, the moisture régime under which the soils developed.

(1) Soils with accumulations of calcium carbonate and gypsum at or near the surface.

These soils are developed under arid conditions where the main movement of soluble materials is in an upward direction. Downward leaching is probably restricted by the small amount of water entering the surface from winter snow melting. Efflorescences of soluble salts on the surface are widespread. Soils of the group can be arranged into a sequence according to the degree of development of the accumulation horizon supported by evidence from the type of patterned ground, degree of development of desert pavement, and weathering of parent materials.

Soils of this group are widespread on the terraces, moraines, and foothills of Taylor Dry Valley and the region west of Koettlitz Glacier.

(2) Soils with calcium carbonate, gypsum, and soluble salts more or less evenly distributed through the soil or with accumulation of these materials at depth.

These soils occur only at high altitudes in Taylor Dry Valley, but may be widespread in the ice-free regions outside the valley. It is thought that through moistening by frequent summer snowfalls they are subject to much more downward leaching than those in Group A. Vegetation is more common than on the soils of the arid group. Soils on Scott Base and Marble Point (at both localities meltwater enters the soils from nearby snowfields and glaciers) and on the high hills and moraines in Taylor Dry Valley, are included in this group.

Intrazonal Soils

Soils which reflect the influence of some dominant local factor are regarded as intrazonal. However, Claridge (1965) states that in the soils examined there are insufficient differences in clay minerals in the soils on different parent materials to warrant placing any of them in the intrazonal class.

Soils that are regarded as intrazonal are those with large amounts of organic matter (on guano and algae), those that are wet and unstable (on solifluction slopes), and those that are constantly wet when not frozen. Other soils that may be intrazonal are (1) those with relatively low pH described by Ugolini (1965, 1967) around fumaroles near the summit of Mt Erebus, and (2) the soils on the beach at Hallett Station, which are affected by run-off from the penguin rookery.

Azonal Soils

Soils which have not developed recognisable zonal characteristics include those on recent alluvium, windblown sand, beaches, dry screes, and steep and precipitous mountain slopes.

Classification of Some Soils of Victoria Land

The soils dealt with in this report are listed according to the categories described above:

Zonal Soils (Frigic Soils)

(1) Soils with accumulations of calcium carbonate and gypsum at or near the surface.

(*a*) Soils with very slight to slight accumulations.
Soils on intermediate alluvial terraces (Cape Chocolate; Taylor Dry Valley.
Soils from scoria (Taylor Dry Valley; Dailey Islands).

(*b*) Soils with slight to weak accumulations.
Soils on intermediate alluvial terraces (Cape Chocolate; Taylor Dry Valley).
Soils on wet scree (Taylor Dry Valley; Cape Hallett).
Soils on terminal moraines (Taylor Dry Valley).
Soils on moraine over water-laid sands (Taylor Dry Valley; Koettlitz Valley).
Soils on moraine over water-laid silts (Taylor Dry Valley; Koettlitz Valley).
Soils on moraine at medium elevations (Taylor Dry Valley).

(*c*) Soils with weak to moderate accumulations.
Soils on "dark" moraine (Taylor Dry Valley).
Soils on "brown" moraine (Taylor Dry Valley.
Soils on lateral moraine (Taylor Dry Valley; Koettlitz Valley).
Soils on high alluvial terraces (Taylor Dry Valley; Cape Chocolate).

(2) Soils with no surface accumulations of calcium carbonate or gypsum, but some accumulation at depth:
Soils on moraines at high elevations (Taylor Dry Valley).
Soils from scoria (Scott Base).
Soils from till (Marble Point).
Soils from dolerite and sandstone on high plateaus (Taylor Dry Valley).

Intrazonal Soils

Soils from guano (Cape Royds; Cape Hallett).
Soils from algae (Marble Point).
Soils of solifluction slopes (Taylor Dry Valley; Marble Point).

Azonal Soils

Soils of flood plains and stream channels (Taylor Dry Valley; Marble Point; Cape Chocolate).
Soils on dry scree (Taylor Dry Valley; Cape Royds).
Soils of rock slopes (Taylor Dry Valley; Cape Hallett).
Soils of felsenmeer (Taylor Dry Valley).

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