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Infilled Fissures in Loess, Banks Peninsula, New Zealand

By Stuart A. Harris*

Summary: Infilled fissures are described from the interface between two loess deposits on Banks Peninsula, South Island, New Zealand. Both loesses differ from the other loesses by having a solifluction deposit at their base consisting of angular basalt fragments of the same angularity as fresh frost shattered basalt mixed with the loess. Typically, the fissures are narrow and up to 160 cm deep while the infilling of the overlying loess shows no obvious structure. They occur mainly at higher elevations on south (poleward) facing slopes, and the host loess forms a fragipan of high density. They are most readily explained as being seasonal frost fissures or more probably ice-wedge casts, which would have required either permafrost or deep seasonal frost for their formation. If permafrost had existed, this would imply a cooling of the mean annual temperatures by at least 16 to 18° C.

Zusammenfassung: Gegenstand dieses Aufsatzes sind gefüllte Spaltenstrukturen an der Grenze zweier Lößablagerungen auf der Halbinsel Banks im südlichen Neuseeland. Beide Lößablagerungen unterscheiden sich dadurch von anderen, daß sie an ihrer Basis Solifluktionsschutt aus Basalt mit der gleichen Eckigkeit aufweisen wie frostverwitterte Basaltstücke, die dem Löß beigemischt sind. Die Spaltenstrukturen sind im allgemeinen schmal und bis zu 1,6 m tief, während die Füllung aus überlagerndem Löß keine Strukturen zeigt. Sie treten vorwiegend in höheren Lagen an südexponierten Hängen auf, wobei der Löß, in dem sie vorkommen, stark kompaktiert ist. Es handelt sich wahrscheinlich um fossile saisonale Frostspalten oder Eiskeilpseudomorphosen, die zu ihrer Bildung Permafrost oder tiefe saisonale Gefrornis voraussetzten. Im Falle von Permafrost impliziert dies eine Herabsenkung der Jahresmitteltemperatur um mindestens 16° bis 18° C.

INTRODUCTION

WILLETT (1950) first suggested that the nonglaciated part of the South Island of New Zealand may have experienced a tundra climate during the late Pleistocene glaciations. This received some support with the description of ice-wedge infillings from near Wellingthon by COTTON & TE PUNGA (1955). They, and others, also identified solifluction deposits (STEVENS, 1957; RAESIDE, 1964; SOONS, 1962: 78; LESLIE, 1973). Neither stratified screes (SOONS, 1962) nor cryoplanation terraces (LESLIE, 1973) prove the existence of former tundra conditions (TRICART, 1956; HARRIS, 1975). The patterned ground reported by MCGRAW (1959) could be the result of permafrost, but similar micro-scale forms can also form in areas without permafrost (WASHBURN, 1979: 140—152). Finally, the limited information on fossil seeds from proglacial lake deposits suggests non-tundra conditions (BURROWS in HARRIS, 1975).

While driving across the Banks Peninsula in April 1974, the writer observed fissures or wedges developed in loess and slope deposits which demanded description and explanation. They occur in the Summit silt loam series (SOIL BUREAU, 1968), and the structures have been included in the gammate structure of GRIFFITHS (1973).

METHODS USED

The writer mapped the distribution of fissures and other features associated with the gammate structure. The slope, elevation, and aspect was recorded for over 80 occurrences and loess samples were collected for laboratory analysis (Fig. 1). Pins were inserted on either side of the fissures and the distance between them was measured at regular intervals from dry autumn soil conditions through into the late spring period of maximum moisture. Undisturbed cores were taken to determine the density of the materials.

In the laboratory, the samples were air dried and sieved to separate the fine fraction. Grain size (USDA li-

* Prof. Dr. Stuart A. Harris, Department of Geography, University of Calgary, 2500 University Drive N. W., Calgary, Alta. T2N 1N4 (Canada).

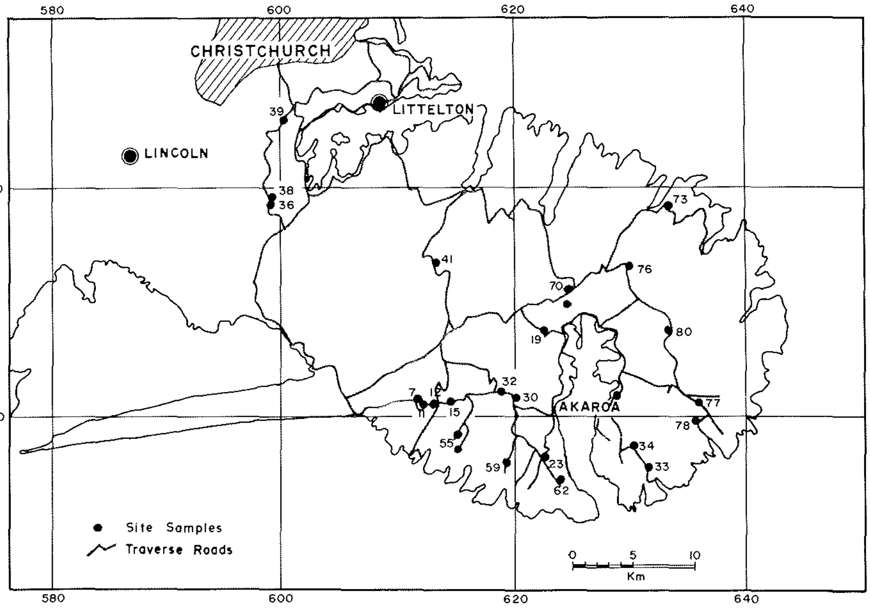


Fig. 1: Distribution of loesses, modified from GRIFFITHS (1973).

Abb. 1: Verbreitung verschiedener Lößarten, verändert nach GRIFFITHS (1973).

mits) was determined by the pipette method and wet sieving, using hydrogen peroxide pretreatments to remove organic matter, and calgon as the dispersing agent. Clay mineralogy was determined by CuK∞X-ray diffraction, using water solvation, warm 2N HCl solvation, glycerol solvation, and heating at 525 °C for 2 hours. pH was determined on a Beckman model 18 pH meter. The pebbles in the samples were classified using the Krumbein shape method (KRUMBEIN, 1941) and the grain size (Tab. 1).

ENVIRONMENT

The Banks Peninsula consists of two eroded and sea-breached calderas (Lyttleton and Akaroa) on the eastern shore of the Canterbury Plains. It apparently formed a stable island during nonglacial times (LIGGETT & GREGG, 1965) after the cessation of volcanic activity about 5.8 million K/Ar years ago (STIFF & MCDOUGALL, 1968). During glacial times, it would have lain some distance inland from the east shore of the South Island (RAESIDE, 1964: 813). Eventually, the coalesced alluvial fans extended far enough to connect it to the mainland in nonglacial times. Today, the highest point reaches 755 m above sea level (Mt. Herbert), and the landscape consists of steep side valleys incised within gently sloping former land-surfaces, some of which are relatively old. Lava flows, 224 m below sea level at Christchurch (SPEIGHT, 1943), suggest that sea level has risen at least that amount since about 10 million K/Ar years ago. This may explain the lack of substantial erosion in the last 6 million years (STIFF & MCDOUGALL, 1968). Underlying rocks are mainly basalts with some andesites west of Lyttleton.

The climate varies from subhumid to humid, from west to east and from sea level to mountain crest (mean annual precipitation varying from 650 to >900 mm). The native vegetation ranges from tussock grass in the subhumid zone, to bush and forest elsewhere.

During the Pleistocene, a number of loess deposits accumulated on the Peninsula. These have been des-

		Size Fraction (mm)									
		>15.88		15.88—11.11		11.11—7.79		7.79—6.35		6.35—4.00	
Deposit	Sample No.	Mean shape	n	Mean shape	n	Mean shape	n	Mean shape	n	Mean shape	n
Colluvium	8	—	0	0.31	6	0.30	19	0,40	31	0.38	64
Contemporary Scree	20	0.1	1	0.20	1	0.33	3	0.28	10	0.25	21
	2	0.20	3	—	0	0.28	4	0.30	1	0.30	13
Te Oka Slope	7	0.15	2	0.25	1	0.20	1	0.20	1	0.15	4
Deposits	12	0.15	2	0.13	9	0.15	17	0.20	17	0.18	34
	16	—	0	0.25	4	0.20	4	0.30	11	0.21	21
	Mean	0.17	7	0.16	14	0.18	26	0.24	30	0.21	72
	9	0.20	3	0.22	10	0.22	15	0.24	*14	0.27	88
Stone Bay	26	0.20	1	0.30	2	0.25	2	0.24	8	0.32	44
Slope	33	0.15	1	0.23	4	0.27	5	0.35	2	0.27	18
Deposits	48	0.25	4	0.30	2	0.25	4	0.18	6	0.20	21
	56	0.15	4	0.19	19	0.24	44	0.22	41	0.29	111
	63	0.15	2	0.16	12	0.23	87	0.23	88	0.25	145
	Mean	0.19	15	0.17	59	0.24	157	0.23	159	0.27	427

* Includes a Moa crop pebble composed of greywacke.

Tab. 1: Comparsion of mean shapes (Krumbein scale) for pebbles in colluvium, present-day scree, Te Oka slope deposits and Stony Bay slope deposits.

Tab. 1: Vergleich zwischen der mittleren Gestalt (nach Krumbein) von Kies in Kolluvium, rezentem Schutt, Te Oka-Hangablagerungen und Stony Bay-Hangablagerungen.

cribed and mapped by GRIFFITHS (1973) and are shown in Fig. 2. Also shown on the map are the locations of two new loesses, hereafter referred to as the Stony Bay and Te Oka loesses.

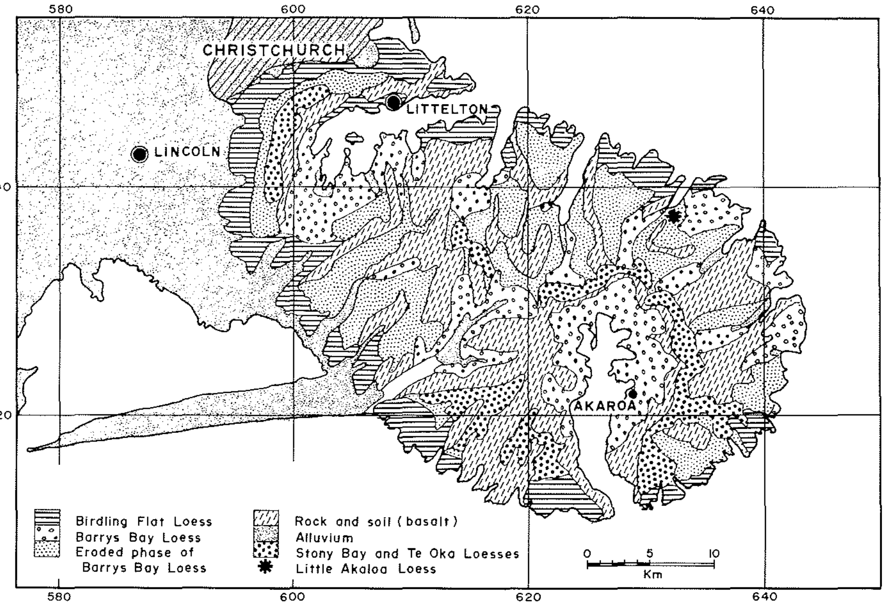


Fig. 2: Traverse roads and sample sites.

Abb. 2: Lage und Zugänglichkeit der Probenahmestellen.

LOESSES

Birdlings Flat and Barrys Bay loesses

As noted by GRIFFITHS (1973), two distinct loesses occur on the outer slopes of the Peninsula. The Birdlings Flat loess lies closest to sea level along the margins of the hills and is calcareous. By contrast, the Barrys Bay loess is mildly acid and lacks free carbonates. The Birdlings Flat loess is the youngest, and is cut into by the early postglacial (?) cliff erosion along the south-west of the Peninsula, south of Lincoln. The Barrys Bay loess at its type section contains four soils. At first, these were regarded as being about 17,450 $\pm$ 2,070 radiocarbon years old (NZ 1163, BAILEY, 1971), but subsequent work has shown that very different ages are obtained with different organic components (GOH et al., 1973).

Topographically and stratigraphically above the Barrys Bay loess on south-facing slopes occurs the Summit silt loam (Fig. 2). Study of this material showed that it had a stratigraphy as in Fig. 3. Unconformably overlying the basalt at many sites is a slope deposit consisting of angular fragments of basalt in a matrix of loess. This usually grades upwards into pure Stony Bay loess. Above an unconformity, a second slope deposit with similar angular fragments in a more yellowish matrix of loess grades upwards into Te Oka loess. Overlying this at many sites is reworked colluvium and slope deposits with a modern soil present. Locally, midden deposits of the Moa Hunter (pre-Maori) and pre-European settlement, top the succession. Individual loesses may be up to at least 2.5 m thick, while the slope deposits are generally somewhat thinner. Due to the presence or absence of either the slope deposit or the loess in each section, a series of different profile combinations occurs at different places. However, the basic stratigraphy remains the same.

The Summit silt loam has been mapped where a thin layer of Te Oka loess overlies Stony Bay loess. The latter was regarded as the B horizon with a definite pan of higher density present (previously described in other loess soils in the South Island by RAESIDE, 1964). This pan has also been called a 'fragipan' (TAYLOR & POHLEN, 1962), and was regarded by RAESIDE (1964: 833) as currently being destroyed under the present climatic conditions. The reason for the reinterpretation is that the layers increase in thickness most dramatically in some road sections and it appears quite unreasonable for the A_2 horizon to range in thickness from 5 cm to 190 cm in a horizontal distance of 3.5 m (see for example Fig. 4). Again it is difficult to explain the patchy presence of angular basaltic stones by soil-forming processes alone.

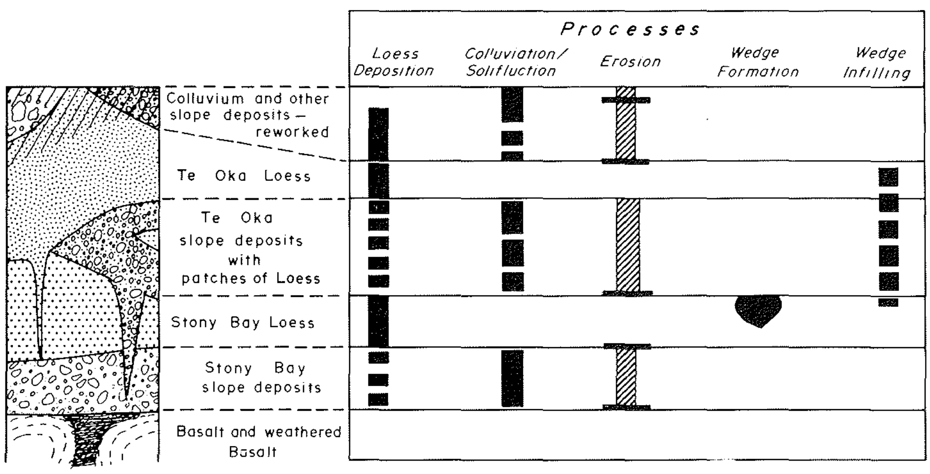


Fig. 3: Generalized stratigraphy, Stony Bay and Te Oka loesses.

Abb. 3: Schematisierte Stratigraphie der Lösse von Stony Bay und Te Oka.

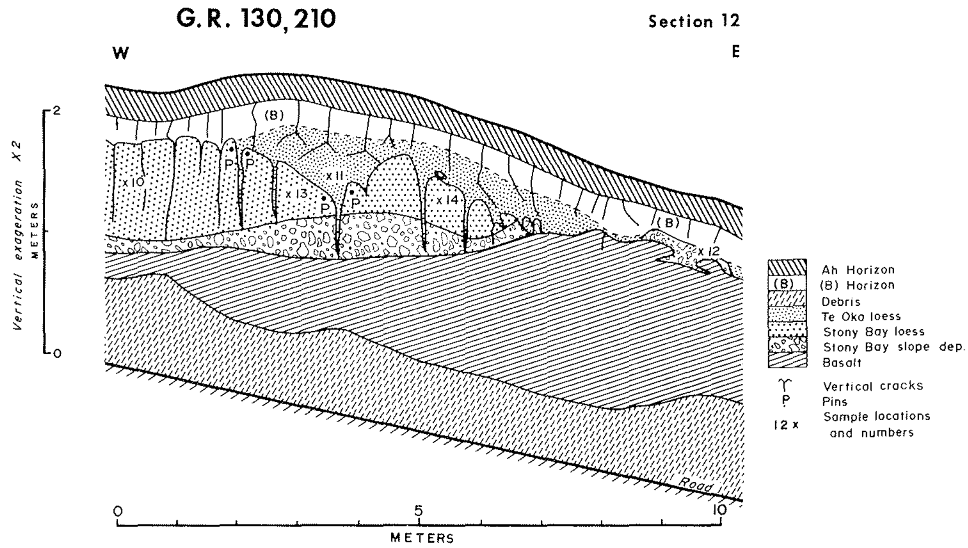
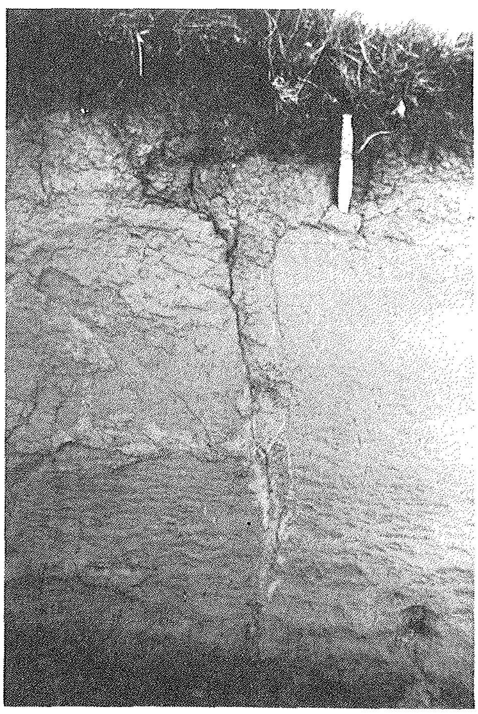


Fig. 4: Road section at GR 130,210 which is the type section for the Stony Bay and Te Oka loesses.

Abb. 4: Straßenaufschluß bei GR 130, 210, Typlokalität der Stony Bay- und Te Oka-Lösse.

Stony Bay and Te Oka loesses

The two loesses forming the "Summit Silt Loam" are herein named the Stony Bay loess (lower, older) and the Te Oka loess (younger, upper) after two locations where they were found. The road section at GR 130,210 is used as the type section (see Fig. 4).



Grain size analysis of the deposits showed that clay was present in only minor proportions in the deposits. Wetting and drying of disturbed and undisturbed cores in the laboratory failed to show any shrinking or swelling, and the seasonal variation in distance between pins placed in the loess in the field was under the 1 mm limit of accuracy of measurement. Clay mineral analysis (Tab. 1) showed that swelling clays were absent, unlike weathered basalt. Both loesses had similar compositions and pH values, suggesting that the material came from a similar source area.

Slope deposits

The basaltic pebbles in the slope deposits are remarkably angular when compared with similar pebbles in present-day colluvium. The pebbles are the only obvious difference between the overlying loess and the slope deposits.

Fig. 5: A typical fissure developed in Stony Bay loess at the type section.

Abb. 5: Frostspalte in der Typlokalität des Stony Bay-Löß.

	Sample Number	Quartz	Feldspar	Kaolinite	Illite	Chlorite	Illite-Chlorite	Vermiculite	Vermiculite-Illite	Halloysite	Expanding Interstratified
				Clay Minerals (%)							
Weathered Basalt	24	0	56	0	0	0	0	0	0	0	44
Te Oka Loess	1	62	24	5	2	2	3	2	0	0	0
	11	22	5	16	4	20	0	14	0	0	0
	23	26	10	20	21	23	0	0	0	0	0
	30	43	44	5	1	1	1	3	2	0	0
	32	21	28	13	4	7	7	13	6	0	0
Te Oka Slope Deposits	2	17	11	25	5	27	15	0	0	0	0
	3	28	44	11	3	2	2	7	3	0	0
	7	22	9	28	6	23	12	0	0	0	0
	12	30	6	13	6	13	15	15	0	0	0
Stony Bay Loess	10	21	6	26	16	15	6	0	0	10	0
	13	35	26	11	10	8	5	5	0	0	0
	14	27	10	27	10	18	8	0	0	Tr.	0
	22	29	8	20	6	4	3	17	13	0	0
	31	40	23	15	8	5	2	3	1	0	0
	34	27	6	25	15	8	8	10	0	0	0
Stony Bay Slope Deposits	1	27	8	27	19	2	3	19	0	0	0
	18	23	15	17	16	23	6	0	0	0	0
	33	31	6	28	12	6	0	10	8	0	0

Tab. 2: Clay mineralogy of the Te Oka and Stony Bay loesses and slope deposits and weathered basalt.

Tab. 2: Tonmineralogie der Te Oka- und Stony Bay-Lösse sowie von Hangablagerungen und verwittertem Basalt.

Tab. 2 shows the mean shapes of pebbles in present-day colluvium, present-day scree, Te Oka slope deposits and Bosso slope deposits. The shapes of the pebbles in the slope deposits match the shapes of the pebbles in the scree, but are far more angular than the pebbles in contemporary colluvium. With the exception of the Moa crop pebble, the lithology of the pebbles was basalt. Thus the slope deposits represent a

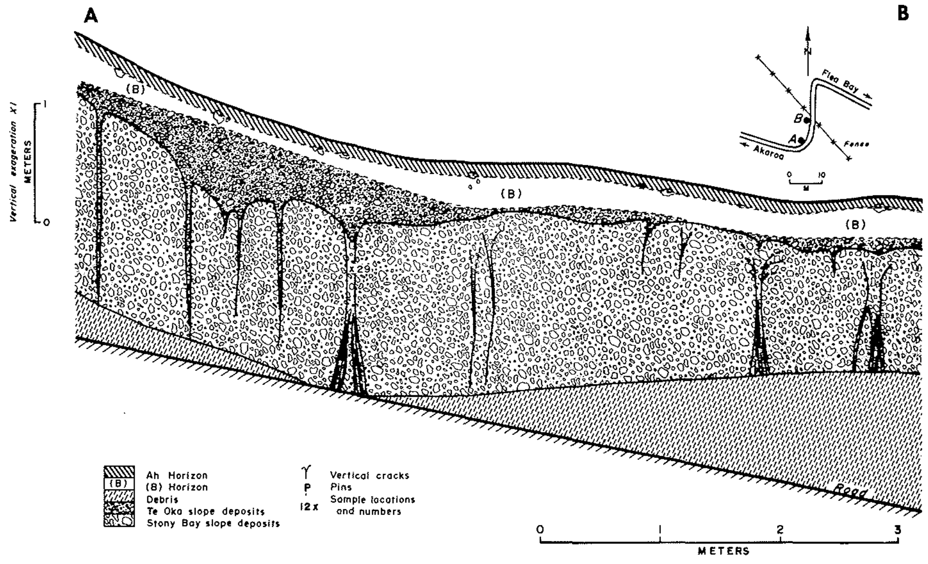


Fig. 6: Section at GR 320,173, Flea Bay road, showing wedges within the Stony Bay loess.

Abb. 6: Aufschluß an der Flea Bay-Straße mit Keilstrukturen im Stony Bay-Löß.

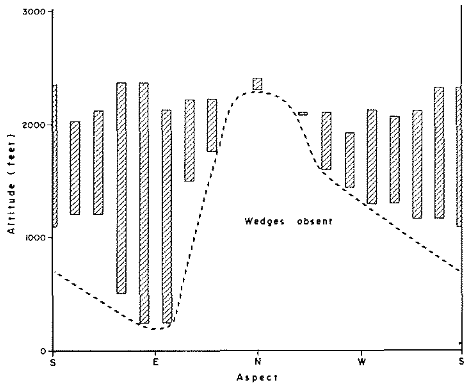


Fig. 7: Distribution of loess wedges with elevation and aspect.

Abb. 7: Verbreitung der Lößkeile in Abhängigkeit von der Höhe und Exposition.

mixture of loess and angular basalt fragments derived from the cliffs upslope of the deposits.

NATURE OF THE INFILLED FISSURES

The fissures (Fig. 5) are polygonal in plan. They occur in two situations, the normal one being in the surface of the Stony Bay deposits with an infilling of Te Oka loess on slope deposits (Fig. 4). At one location at GR 302,173 on the Flea Bay road, it also occurs within the Stony Bay loess (Fig. 6).

At many locations, the fissures extend downwards across the boundary between the Stony Bay loess into the Stony Bay slope deposits. They tend to occur on south (poleward) facing slopes, being concentrated at the higher elevations (Fig. 7). The fissures are up to 165 cm deep and show no obvious breaks or strati-

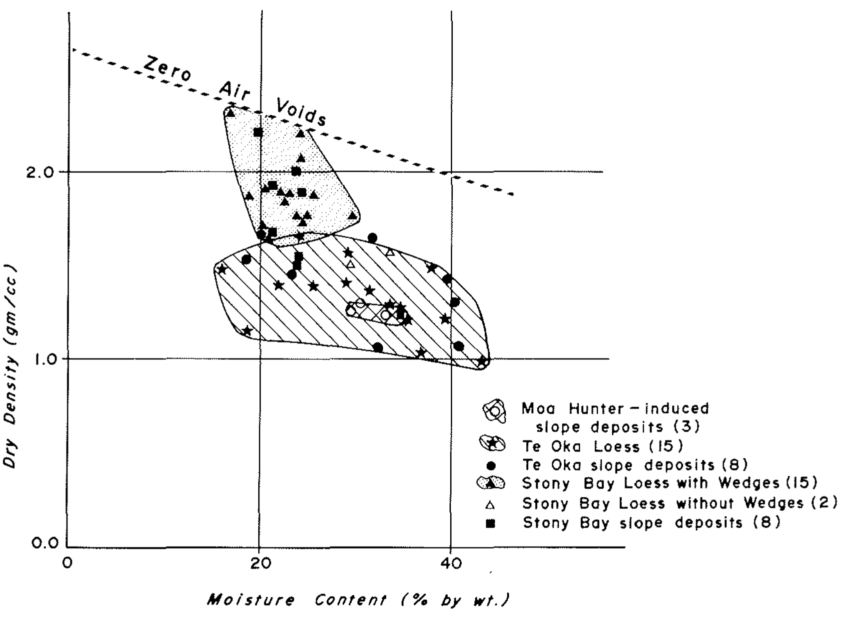


Fig. 8: Dry densities of the Te Oka and Stony Bay deposits.

Abb. 8: Trockene Dichtewerte der Te Oka- und Stony Bay-Ablagerungen.

fication in the infilling. Elongate stones in the infilling tend to be oriented vertically. The upper width of the infilled fissure is commonly about 5 to 15 cm, but may range up to 60 cm.

The host loess displays high density in contrast to locations where the Stony Bay loess lacks fissures (Fig. 8), and fits the description of fragipans. These have been related to permafrost conditions by VAN VLIET & LANGOHR (1981). The fissures average about 18 cm per metre horizontal distance in the section which is of the correct order of magnitude to account for the change in air voids. The relative densities of Stony Bay deposits with and without fissures did not change with altitude.

The size of the fissures shows no correlation with overburden thickness. The lack of a palaeosol on the Stony Bay deposits and the frequent presence of slope deposits at the base of the Te Oka loess indicates severe erosion prior to the deposition of the loess under conditions which did not allow for infilling of the fissures if they had already formed.

Comparison of their distribution with the occurrence of gleyed Stony Bay and Te Oka loesses with altitude (Fig. 9) and aspect (Fig. 10) shows vastly different patterns. Clearly, they are quite different in origin, although the marked aspect and altitudinal control suggests a climatic influence.

CLIMATIC SIGNIFICANCE

The production of large quantities of angular basaltic fragments which became mixed with loess on the slopes ot the mountains requires intense frost action coupled with solifluction. This type of action is normally associated with periglacial (i. e., cryogenic) weathering conditions (HARRIS, 1982: 55). It is generally accepted that the loesses correspond to periods of glaciation (GRIFFITHS, 1973), but the Te Oka and Stony Bay loesses are unique in being intercalated with the angular basaltic slope deposits.

There are many suggested origins for similar infilled fissures and cracks in sediments and soils. Most are associated with either cold or dry climates, or both (e. g., WASHBURN, 1979). The lack of swelling properties and the lack of similarity to gleying eliminate those related to moisture. Furthermore, the shape of the wedges is quite different to contemporary erosion gullies (suggested by P. J. TONKIN).

If the fissures are a form of frost crack, it is important to distinguish between seasonal and perennial frost cracks and soil wedges (see FRENCH, 1976: 21—27). The narrowness of the cracks tends to argue

Fig. 9: Distribution of loess wedges and gleyed Te Oka and Stony Bay loess with elevation.

Abb. 9: Verbreitung von Lößkeilen und vergleytem Te Oka-sowie Stony Bay-Löß in Abhängigkeit von der Höhe.

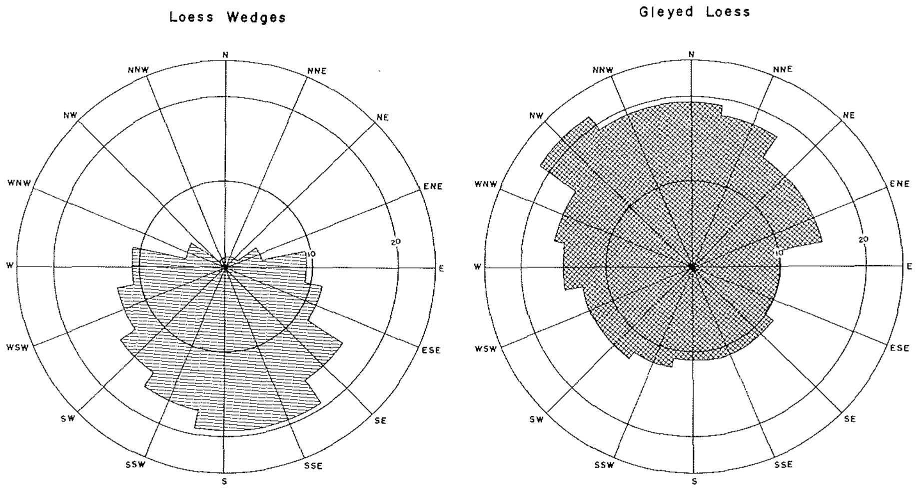


Fig. 10: Distribution of loess wedges and gleyed Te Oka and Stony Bay loess with aspect.

Abb. 10: Verbreitung von Lößkeilen und vergleytem Te Oka- sowie Stony Bay-Löß in Abhängigkeit von der Exposition.

for a short-lived period of perennial thermal contraction or a limited number of seasonal contraction cracks. The fissures exhibit some properties of each of the forms of cracking and so their interpretation is problematic.

The features of the fissures suggesting an origin as small ice wedges are the homogeneity of the infilling, its lack of structure, and the fact that the infilling is similar to the material above. The growth of ice would produce the pressure on the surrounding host material that would aid in the production of the fragipan. The active layer would have been confined to the overlying Te Oka loess. However the arguments against this are the lack of other evidence for the presence of permafrost, and the lack of evidence of the existence of the active layer. The fissures could not be traced into the Te Oka loess.

The features of the fissures suggesting an origin as seasonal frost cracks are the relationship of the fissures to a possible former land surface, the close spacing of the fissures, and their general narrowness. The wider ones would have to be the product of localized ice segregation. The arguments against this would seem to be the problem of infilling the fissures with a different loess, without disturbing any of the material in the host loess, either at the surface, or along the side of the fissure between cracking phases. This explanation would also imply that the host soil failed to expand to its original volume when it became warmer after each contraction phase. This is not in accordance with the field measurements made to date, although it could certainly be the cause of overcompaction and fragipan formation in cold regions. The infillings lack the numerous vertical stratifications described by BERG (1969) and others from sand wedges.

The fissures do not appear to be soil wedges since they are obviously related to soil horizons as opposed to stratigraphic beds. There is no downturning of the host loess. Thus it would seem that the fissures are most likely related to thermal contraction cracking under cold conditions which may have been similar to the temperatures at which ice wedges form. Some, at least, indicate the presence of wedge-like ice masses, but the evidence is too conflicting to prove the nature of the moisture regime at the time of the formation of all of the features. If permafrost was present, then this would imply a mean annual air temperature 16° to 18° C lower than today.

Finally it should be noted that if permafrost or deep seasonal frost occurred close to sea level near Christchurch, it should also have occurred elsewhere on the South Island. It makes the interpretation of COTTON & TE PUNGA (1955) seem less isolated. The writer has seen similar structures along the highway to Pukaki in Burkes Pass, and P. J. TONKIN (pers. communication) has seen the same structures in loess in the eastern foothills of the Southern Alps.

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References

Bailey, J. M. (1971): Extraction and radiocarbon dating of dispersed organic material from loess in the South Island, New Zealand. — N. Z. J. Sci. 14: 490—493.

Berg, T. E. (1969): Fossil sand wedges at Edmonton, Alberta, Canada. — Biul. Peryglac. 19: 325—333.

Brown, R. J. E. (1967): Comparison of permafrost conditions in Canada and the U.S.S.R. — Polar Record 13: 741—751.

Brown, R. J. E. (1970): Permafrost in Canada. — 234 pp., Toronto.

Cotton, C. A. & M. T. Te Punga (1955): Solifluction and periglacially modified landforms at Wellington, New Zealand. — Trans. Roy. Soc. N. Z. 82: 1001—1030.

Fields, M. (1968): Clay mineralogy. — In: Soils of New Zealand, P+2 (6): 22—39, Soil Bureau Bull. 26, N. Z. DSIR.

Flint, R. F. (1971): Glacial & Quaternary Geology. — 892 pp., Toronto.

French, H. M. (1976): The periglacial environment. — 309 pp., London — New York.

Garnier, B. J. (1958): The climate of New Zealand. — 191 pp., London

Goh, K. M., Molloy, B. P. J. & T. A. Rafter (1973): Radiocarbon dating of Late Pleistocene loess from Banks Peninsula, New Zealand. — Abstracts, 126—127, 9th INQUA Congress, Christchurch.

Griffiths, E. (1973): Loess of Banks Peninsula. — N. Z. J. Geol. Geophys. 16: 657—675.

Harris, S. A. (1975): Petrology and origin of stratified scree in New Zealand. — Quat. Res. 5: 199—214.

Harris, S. A. (1982): Identification of permafrost zones using selected permafrost landforms. — In: H. M. French, Ed., Proceedings of the 4th Canadian Permafrost Conference, Calgary, Alberta, 49—58, National Research Council, Ottawa.

Krumbein, W. C. (1941): Measurement and geological significance of shape and roundness of sedimentary particles. — J. Sed. Pet. 11: 64—72.

Leslie, D. M. (1973): Definiton of the Portobello soil set in relation to regolith stratigraphy and landscape periodicity. — N. Z. J. Sci. 16: 259—285.

Liggett, K. A. & D. R. Gregg (1965): The geology of Banks Peninsula. — N. Z. DSIR Info. Ser. 51: 9—25

McGraw, J. D. (1959): Periglacial and allied phenomena in Western Otago. — N. Z. Geographer 15: 61—68

Raeside, J. D. (1964): Loess deposits of the South Island, New Zealand and soils formed on them. — N. Z. J. Geol. Geophys. 7: 811—838.

Soil Bureau (1968): Soils of New Zealand. — Soil Bureau Bull. 26, N. Z. DSIR, 3 vols, Christchurch.

Soons, J. M. (1962): A survey of periglacial features in New Zealand. — In: M. McCaskill, Ed., Land and Livelihood, N. Geogr. Soc. Misc. Ser. 4, 74—84, Christchurch.

Speight, R. (1943): The geology of Banks Peninsula — A revision. Pt. II: The Akaroa volcano. — Trans. R. Soc. N. Z. 74: 232—254.

Stevens, G. R. (1957): Solifluxion phenomena in the Lower Hutt area. — N. Z. J. Sci. & Techn. 38B: 279—296.

Stiff, J. J. & I. McDougall (1968): Geochronology of the Banks Peninsula volcanoes, New Zealand. — N. Z. J. Geol. Geophys. 77: 1239—1260.

Tricart, J. (1956): Contes des phénomènes périglaciares Quaternaries en France. — Memoires pour servir à l'explication de la carte géologique detaillée de la France, Ministère de l'Industrie et de Commerce, Paris.

Van Vliet, B. & R. Langohr (1981): Correlations between fragipans and permafrost with special reference to Weichsel silty deposits in Belgium and northern France. — Catena 8: 137—154.

Washburn, A. G. (1979): Geocryology. — 406 pp., London.

Willett, R. W. (1950): The New Zealand Pleistocene snowline, climatic conditions, and suggested biological effects. — N. Z. J. Sci. & Tech. 32B: 18—48.

Woodcock, A. H. (1974): Permafrost and climatology of a Hawaii volcano crater. — Arctic & Alpine Res. 6: 49—62.