ROYAUME DE BELGIQUE

MINISTERE DES AFFAIRES ECONOMIQUES
ADMINISTRATION DES MINES - SERVICE GEOLOGIQUE DE BELGIQUE

13, rue Jenner - 1040 Bruxelles

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PROFESSIONAL PAPER 1974 N° 3

Dejonghe

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GEOLOGICAL SURVEY OF BELGIUM - PROFESSIONAL PAPER 1974/3.

FROST WEDGE FORMS IN RELATION TO THEIR GEOMORPHOLOGICAL AND STRATIGRAPHICAL POSITION IN TAYLOR VALLEY (ANTARCTICA) (x).

R. PAEPE and E. PAULISSEN

(Geological Survey of Belgium,
and Vrije Universiteit, Brussels)

National Centre for Geomorphological Research, Leuven).

I. INTRODUCTION

Investigation of ground wedges occurring in terrace levels and morainic deposits in the Lower Taylor Valley lead to the recognition of specific forms depending on nature of the deposits. For the description of the terrace levels and their relation to the morainic deposits the paper by PAULISSEN and PAEPE (In press)is referred to.

The climatic conditions of the 1970 summer especially the lack of snow cover were very favourable for this kind of study. It was therefore relatively easy to clear profiles along the lowest terraces (below 100 m) around Lake Fryxell and within the V-shaped deep canyon which drains the meltwaters of the Commonwealth-glacier to the Ross Sea (unofficially called T.E. Berg Canyon in this paper).

These profiles allow some more general conclusions to be drawn. It should be stressed that as well the sedimentological as the stratigraphical and even the geomorphological context of the data were considered.

(x) Thanks to a generous invitation extended to the Belgian Antarctic Expeditions - 1 Rue de Louvain - 1000 BRUSSEL by the Office of Polar programs (National Science Foundation Washington) the authors were able to join the U.S. Antarctic Research Program as exchange scientists during the 1970 austral summer. The writers are also indebted to Dr. T. Van Autenboer.

2. TERRACE LEVELS AROUND LAKE FRYXELL

2.1. General Aspects

As was pointed out by E. PAULISSEN and R. PAEPE, six terrace levels had been established since the time that Lake Fryxell was separated from the Ross Sea and evolved as a closed basin. The lowest terrace (below 2 m above Fryxell) can be subdivided into the three sub-levels and may be considered as fluctuations of the present floodplain. Polygons are of the oriented orthogonal type (A.H. LACHENBRUCH, 1962) and show a concordant disposition with the present lake shore. Actually, fissures perpendicular to the shoreline can be followed on the ice surface of Lake Fryxell. Also, the polygonal net extends without interruption over the whole of the terrace levels and even climbs up the rim of the neighbouring moraine deposits. In the latter the pattern changes into a random orthogonal system (A.H. LACHENBRUCH, 1962).

Outspoken terrace levels occur as of 8 m above Fryxell. They all are situated in deeply eroded gullies debouching into Lake Fryxell. They are valley fillings with a flat smoothly dipping surface which latter abuts laterally against the uprising surface of morainic deposits with which it forms a sharp knickpoint line. Whereas the moraine surfaces are covered with a heterogeneous assemblage of boulders, the terrace platforms consist of a well-sorted medium gravel pavement which characteristic contributes highly to their distinction in the field. As said before, their clear cut forms offer good walls for geological profiles.

2.2. Profile 1 - Terrace 27 m (8 m)

2.2.1. Location

This terrace occurs along street Delta at a distance of roughly 500 m from Lake Fryxell and at an altitude of 8 m above Fryxell (27 m above sealevel)(x).

(x) Fryxell is situated at 19 m above sealevel.

The general downwards bending of the sediment layers in the vicinity of the wedge wall may indeed point to such transformation. Also the gravel filled apophyses are thought to be original icelenses pointing to the former presence of permafrost. Finally, the irregular wedge walls may be a result of the original icewedge being syngenetic.

Finally it should ne noted that crack depth is roughly 4 m and crack spacing 15 m and more. The lack of raised rims around some of the younger wedges, though upturned layers occur nearby the larger, or first order ones, seems to point to truncation of the first order wedges before new ones developed into it.

At point 24 m of the section, the location of the first order wedge encompasses the presence of contorted layers below. Therefore it is quite feasible that this zone of perturbation acted as a preferential zone to raise tension in the permafrost layers above.

Second order wedges penetrate all first order ones and consist of sands and gravels. They are of the slender elongated type with smooth surfaces, sometimes with wide openings at the top, (i.e. at 11 m and 24 m). Crack depth is almost 2 m and crack spacing apparently smaller than for the first order wedges. According to A.H. LACHENBRUCH (1962), this would be the result of less deeper cooling. Measuring the width between the widest rims, their active phase would have lasted not longer than thousand years.

Third order wedges still occur and as the ones before they do also penetrate in the former built frost wedges, although they also appear alone. They all have the inverted arrow form and are completely filled with pediment gravel. Crack depth is generally of the order of 1 m and crack spacing is about 8 m; this would infer another less deep cooling then before which persisted only a few hundreds years and is probably still going on.

Third order wedges occur as needlelike, pediment gravel filled wedges, penetrating former ones or occurring alone (at point 26 m). Their similarity with those of the same order in profile 1 is striking. Since width at the rims usually is of the order 0.15 m, the evolution should have lasted longer than 150 years.

2.3.3. Conclusion - Terrace 64 m

The sediment sequence of terrace 64 m very much resembles the sequence described for terrace 27 m, but for the lack of cryoturbation in the lower layers. One deals again with a series of deltaic deposits, wich are slightly older than those described for terrace 27 m from the topographical point of view. However, as all frost wedges are present, they antidate frost wedge development.

2.4. Profile 3 - Terrace 54 m (35 m)

2.4.1. Location

In between both former described terraces, in a wider part of street Delta, a large entrenched terrace occurs. A section of 104 m was chosen and the parts with frost wedges recorded. Good insight was gained in the underlying deposits since 15 m of these were cropping out.

2.4.2. Profile description of Terrace 54 m (Fig. 4).

- green black fine sands appear at the bottom of the left part of the section. They end with a sudden abrupt in the downstream direction.

- green olive loams overly the black sands, first as a small layer and becoming increasingly thicker in the downstream direction; finally they end up in an abrupt, too.

- green black sands flow next, again as a thin layer first and then suddenly becoming thicker downstream the abrupt noticed on the underlying green olive loams. Once more, their extension ends with an abrupt.

- olive green loams cover as a continuous thick layer all of the former deposits with a gently general dipping in downstream direction.

- stratified grid sands with a basal relatively thin dark green sand-layer form the top bed; the whole is rapidly thickening in the downstream direction. The stratification is dipping at first and becomes subhorizontal where deposits reach the utmost thickness. Sometimes a finer sandbody (downstream from 87 till 104 m).

- desert pavement with various types of frost wedges occur.

- first order wedges are of the elongated, rootlike form with a long and peaky tail; they are filled with brown sands, just as the rectangular type of the same order in previous sections. Despite differences in form, wedge size is of the same order, which might infer a same duration of development. The upturned rims do not often encompass the intersection of wedge walls and pavement surface. Therefore, it is believed that these wedges have been truncated and that here the upturned rims belong to younger wedges. Also, while the narrowing with depth of the wedge tail proceeds gradually it is felt that change in compression at depth occurs continuously. The explanation herefore may be found in the assumption that this is due to the homogenity of the parent material, the stratified grid sands. Indirectly, this explains the form of the rectangular frost wedge type which small tail is developed in a different medium, thus infering a sudden break in the rate of compression at depth.

Crack depth is of the general order of 4 m again just as in profile 1; crack spacing 15 to 20 m. According to A.H. LACHENBRUCH (1962) this would be a result then of the medium or parent material being relatively non-plastic, thus permitting the tension crack to penetrate deep into the compressional zone. The deep evolution of the cracks must not necessarily be due to a higher degree of cooling. Moreover, as the increased depth of cracking results in wider zones of stress relief, wider spaced cracks and larger polygons (A.H. LACHENBRUCH, 1962) will occur.

- Second order wedges of the elongated type with sand and gravel fillings penetrate in the first order ones to slightly more than two metres; when first order wedges are lacking they appear alone.

Crack spacing may than be estimated at 16 till 20 m. Crack width is of the order of 0.2 m pointing to an evolution of 200 years at the utmost.

- Third order wedges of the needle form and composed of gravels do occur inside older wedges or alone. Sometimes they are restricted in evolution in depth, and then triangular in form, but most often they reach a crack depth of 1 m; crack spacing is 10 m and crack width of the order of 0.2 m, invoking an evolution period of 200 years.

Notice that here, too, these frost wedges are generally longer if compared with those of the order in other profiles.

2.4.3. Interpretation - Terrace 54 m

It is beyond any doubt that deltaic deposits build up the body of this terrace too. No traces of wedges are found in it, unless at the top.

For this particular terrace, the fluviatile-deltaic activity went on till the formation of the desert pavement and frost wedges.

As for the basal gridsands in profile 1 (terrace 27 m) and the stratified (graded) grid sands of profile 2 (terrace 64 m), one may deal here with another delatic deposit of intermediate age but all older than the combined age of the wedge development of all three orders.

2.5. Interpretations about Fryxell Lake Terraces

- Terraces around Fryxell Lake formed as deltaic deposits during subsequent stages of the dropping water level.

- From the sediments study it can be assumed that the deltaic deposits along Fryxell are similar in nature but of different age. On each of the terraces common periglacial activity is observed on the newly emerged delta surfaces. Therefore it is believed that deltaic development occurred under rather similar climatic conditions which are thought to have been warmer and moister.

- The dropping water level of Lake Fryxell may coincide with an evolution towards colder climatic conditions as may be derived from the presence of periglacial features in the lowermost delta deposits, from the establishment of a desert pavement covering all deltaic deposits and finally the formation of at least three generations of frost wedges on the pavement.

- Shape, size and number of frost wedges are almost alike for all terraces concerned. Therefore they are thought to have originated within the same period probably Late Holocene. Moreover, somewhat larger wedges of the first order are observed on the lowest terrace, so that growth rate seems to be more a result of local conditions rather than differences in duration of development. Indeed, cracking depth is of the same order for all first order wedges, so that a common sudden drop in temperature at a very same moment is assumed for their origin.

Since duration of development of first order wedges is estimated between 1,000 and 1,500 years, (wedge width of the order of the 1 to 1,5 m) separated by truncation from the following wedge formation cycle which was lasting respectively for 200 years and 150 years, it is assumed that shrinkage of Lake Fryxell to its present extension was achieved at least some 1,500 to

2,000 years ago. It is not likely that hiatuses between cycles of wedge formation should have lasted longer than the periods of active wedge development themselves.

This could infer changing climatical conditions which would then be recorded in the changing nature of the sediments, which is not observed; on the contrary, pedimentation went on without interruption. It is our believe now that after establishment of the first order and major wedges, the cold peak diminuished gradually but stepwise. As a result the following cold peaks were of minor intensity which is pictured in the evolution of the frost wedges.

- As to the rectangular form of the first order wedges, it is a charachteristic of a great deal of the deposits of this age. They help in identifying terraces of the same age which, as said before, should have ended to form some 2,000 years from now.

3. DEPOSITS AROUND ROSS SEA TERMINAL MORAINE

3.1. General Aspects

At the mouth of Taylor Valley, west of the Commonwealth-glacier, one of the Ross Sea terminal moraines * bar the entire valley and forms a crescend with an opening to the sea. Its altitude is constant and reaches 120 m above sealevel. The body of this ridge consists of silty varve and basal gravelly deposits with ice bodies, protected by endmoraine boulders on top. The present ridge morphology is thought therefore to be due partly to selective erosion which opinion is stressed by the presence of dry valleys cutting through the ridge. A narrow V - shaped valley (BERG Canyon) drains the meltwaters from the Commonwealth-glacier directly to Ross Sea, across the moraine barrier. As a consequence good sections are to be observed along its valley walls which in places are more than 50 m in height.

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* This terminal moraine was never mentioned and is younger than the Ross Sea drift I of G.H. DENTON _et al._ (1970). In this paper we will call it "Ross terminal moraine".

All layers show very little inclination except for some upper ones occurring above the line of unconformity. Therefore, it is believed that they belong to a former lake system which occupied the whole of Lower Taylor Valley, extending far more seawards.

3.2. Profile 8 - Middle BERG Canyon

3.2.1. Location

This outcrop occurs at the place of highest development of the Ross Sea end moraine, half way in between Ross Sea and Commonwealth-glacier.

3.2.2. Description (Fig. 6)

The lithological sequence continues the afore described valley wall profile of which it forms the very top layers. The basal silts at point 22 m of the profile belong to the beds connotated as "silts with sporadically pebbles" of the vertical profile description. The sands and gravels are the last described series of the same name in the vertical description. Above, the deposits are truncated by layers dipping upstream. They consist of a series of loamy, sandy and sporadically gravelly layers, giving proof of a fluviatile, most probably of a deltaic depositional sequence.

All layers are very much contorted, especially in the vicinity of large frost wedges which are starting from the surface sown with pediment gravels and morainic boulders and show a cracking depth varying between 5 m and 8 m. Crack space is of the order of 15 m.

Most striking is the inversed pearlike from of the frost wedges, starting with a relatively fine tail and rapidly evolving into a widely opened funnel (point 22 m) which in turn may become closer again at the very top (point 7 m).

Inside the wedge consists of white, vertically stratified layers with an inner homogeneous darker sand boy. The latter very much resembles the wedge fillings observed in the rectangular shaped wedges of first order occurring on the terrace around Fryxell.
Also the rectangular form is found back (at point 7 m) so that we believe that the inner, dark coloured wedge is from the same age as the oldest ones on the Fryxell terraces. Actually crack depth of the inner wedge is of the same order, too.

Let us have a closer look now at the wedge morphology. First, the upturning of the contored sediment layers starts at the point where the inner wedge reaches greatest depth, say at 3 m.
Below layers are turned downwards. Secondly, the bulge (at point 7 m) of the outer wedge coincides with the narrowing of the upper neck of the inner wedge. As of the latter point, the outer wedge's walls bend over towards the wedge centre, thus giving proof of some compression.

The features are not so obvious for the wedge at point 22 m where instead of a narrowing, an even wider opned funnel is observed for the inner wedge. The knickpoint, however, occurs at the same depth from where the narrowing of the neck in the former case started.
We think that the difference just lies in the fact that the wedge's activity at point 7 m stopped after thawing until the bulge level which activity still went on hereafter at point 22 m. Actually in this case one may notice present day wedge activity in the formation of a small gravelfilled wedge. It resembles the third order wedges of the Fryxell terraces.

In conclusion, we believe that after establishment of the outer wedge till compression depth, bulging went on, fluctuating around the lower limit of the thawing zone which should be situated around 1.50 m below the surface then. Narrowing of the inner wedge's neck would be either the result of subsequent compression of the widest part of the outer wedge, or while the thawing phase at that moment reached the same lower limit again. Both factors may have acted simultaneously.

Anyhow, subsequent truncation of both inner and outer wedges occurred and resulted in the establishment of a desert pavement on which several wedges have developed.

The polygonal net is of the badly oriented orthogonal type similar to those described on the Fryxell terraces and should be classified amongst the random orthogonal ones in which cracks lack a preferrential orientation.

As so the duration of devolopment a rough estimate based on the width of the truncated upper part, points to the possibility of a 3,000 till 5,000 years of evolution.

3.3. Profile 5 - Upper BERG Canyon

3.3.1. Location

Slightly upstream from the end moraine top another section was recorded to a depth of more than 17 m.

3.3.2. Description (Fig. 7)

It is possible that a complete sequence of the deposits is observed here above a huge basal ice body wich is nowadays eroded by the river.

Alternating coarse gravels and sands with many fluviatile structures and a thin loam and fine sand layer at the base, overly the ice body. Injection ice-tongues pearces into the gravel and, in all cases studied, are connected with frost wedges and/or ice wedges.

In one case an ice wedge which has the normal pear form starts to be partially replaced by clastic sediments and is connected by a narrow neck with a gravel filled frost wedge of the funnel type. The transition of both wedge types occurs at the contact between the gravels and sands and the overlying very coarse gravels. Unfortunately, it was impossible to follow the frost wedge higher up because of tumbling boulders but we assume that it stopped at the upper limit of the coarse gravels.

A syngenetic wedge is found a few meters aside from the ice wedge giving proof of the cold conditions under which the gravels and sands were deposited.

Medium coarse gravels, five meters thick overly the coarse ones. They are followed by fine alternating sands and loams. Those latter are in turn overlain by loamy deposits which truncate all lowerlying sediments series. These loamy deposits build up terraces which can be followed over great distances along BERG Canyon.

From the surface build up by desert pavement and morainic deposits, large frost wedges penetrate into the underlying deposits to a depth of 10 m almost.

In one particular case a double tailed, twin wedge could be recorded in detail. One of the wedge branchs develops as a very fine tail when entering the fine alternating sands and loams. The other one continues across the sands loams in the middle of which it becomes an ice wedge. As of entering the lowerlying middle coarse gravels, the ice wedge splits up into two branches and stops after only 1 m penetration depth.

The presence of a darker coloured sand filled wedge inside an outer pear-shaped wedge points to the composite structure of these wedges as well. Some threads of gravel in the middle of the darker sands reminds to the wedge fillings of the second order wedges along Lake Fryxell.

The tail of the inner darker coloured wedge extends downwards till it reaches and envelopes the ice wedge which forms its extension into the middle coarse gravels. The bending between "sand" wedge and ice wedge is in our opinion a result of the bending in the polygonal cracks at the surface of which we record its projection on an oblique wall.

Replacement of ice by clastic sediments such as coarse sand and gravels is shown here, though we think that in its presents state we deal with a fossil phase of this evolution. It can clearly be seen that the twin frost wedge at the surface is truncated, so that once more no raised rims testify its presence at the surface. Also, no contact exists between the sand filled inner wedge body and the present subaerial conditions. Therefore replacement of ice by sand is fossilized and reached greater depth during the dark coloured inner "sand" wedge evolution than during the older outer pale coloured "sand"wedge. The latter is indeed forming a rectangular bend as it stops on the fine alternating sands and loams.

The pear form with its bulging shape at low depth under the surface reminds to the previously described profile of the BERG canyon. It should not be confused with the overall bending trend of the wedge which again might be due to changes in orientation of the polygonal system. The widely opening funnel terminating in a bulge shape nearby the surface seems to us as responding to the same conditions of formation as described above under profile 8. Its width which is also of the same order of magnitude induces 4,000 - 5,000 years of duration for wedge development.

3.4. Interpretation of Features in Sediments of the BERG Canyon

- Sediment series attest the formation of a lake interrupted by phases of deltaic activity both under cold conditions (ice and syngenetic frost wedges).

- The biggest ground wedges occur at the present surface which is sown with morainic deposits. They often show a characteristic inverted pear form and are of composite nature. According to form and wedge filling, the inner dark coloured wedge corresponds to those of first order occurring on the Lake Fryxell terrace. The big pear form wedges are thus older than the oldest ones on the Lake Fryxell terraces. They seem to have originated under more moist conditions than those on the Fryxell terraces as they appear to replace original ice wedges of which relicts can still be seen.

- By their specific shape they date morphologically all lake and deltaic deposits under the end morainic cover of Ross Sean 1.

3.5. Evidence of Ice-Pushed Varve Sediments - Profile 7

Upturned varve and lake sediments were found in an outcrop (fig. 8) in between profiles 5 and 8.

The upturned layers consist of a series of ice-covered fine loam layers with interbedded stratified green fine sands, the whole being of the same origin as the other lake deposits along BERG canyon. Towards the Ross Sea this series has been ravinated by cross bedded sands and gravels, which are assumed to be meltwater deposits.

In the upturned layers frost wedges with dark brown sand fillings penetrate to a depth of 2.5 m. Some are of the rectangular type and have a relict of the ice core in the bottom part. Notice that the latter is preserved on the contact between the enlarged rectangular part and the fine bottom tail of the wedge.

These single wedges notice much affinity to the inner wedge of the above described pear shaped composite ones, and to those rectangular wedges occurring on the Fryxell terraces.

Since no pear shaped wedges were observed in this outcrop, it may only be stressed that upturning and tilting of the lake deposits occured before establishment of the rectangular wedges, whereas it is assumed that perturbation of the deposits is the result of the Ross terminal moraine riding over them.

4.4. It has been stated clearly that composite wedges do not necessarily continue to develop continuously and that considerable time gap may occur between two successive phases of frost wedges. In this light we are of the opinion that datings obtained by T.L. PEWE (1962) and R.F. BLACK and T.E. BERG (1963) are not as contradictory as could be thought at first.

In agreement with R.F. BLACK and T.E. BERG, the Fryxell terraces as described here would have formed before some 1,500 to 2,000 years ago.

Also, in agreement with T.L. PEWE (1962), G.H. DENTON & R.C. ARMSTRONG (1970) morainic deposits of Ross terminal moraine which is to be situated between 35,000 y.B.P. and 9,500 y.B.P., may then overly still older lake deposits on top of which the pear shaped wedges are found. Given the 5,000 years duration of development, a hiatus of roughly 28,000 years could then affect the continuity in growth phases of the inner and outer member of such composite wedges.

4.5. Actually, it was shown that most composite wedges habe been truncated several times during their evolution ant that a great deal of them stopped evolution entirely at present.

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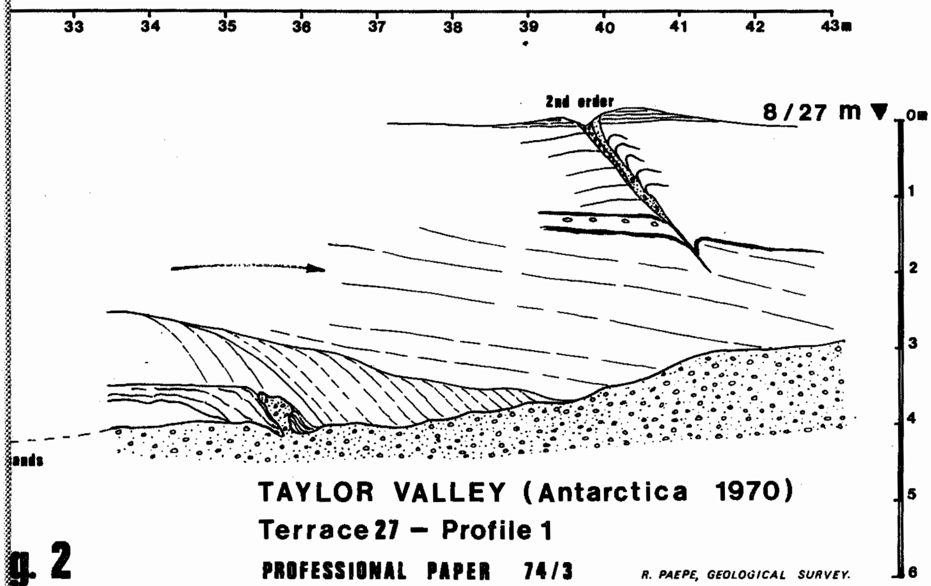

TAYLOR VALLEY (Antarctica 1970)
Terrace 27 – Profile 1

g. 2

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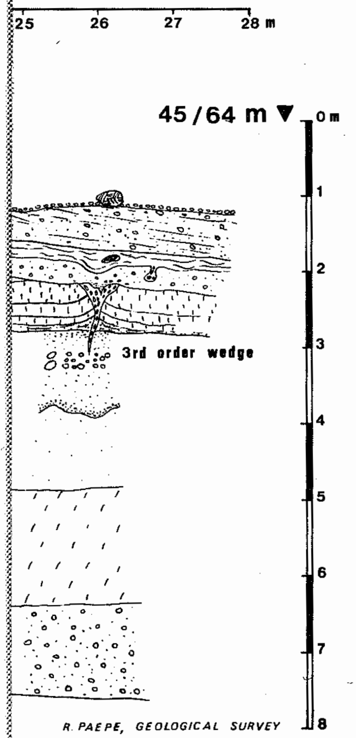

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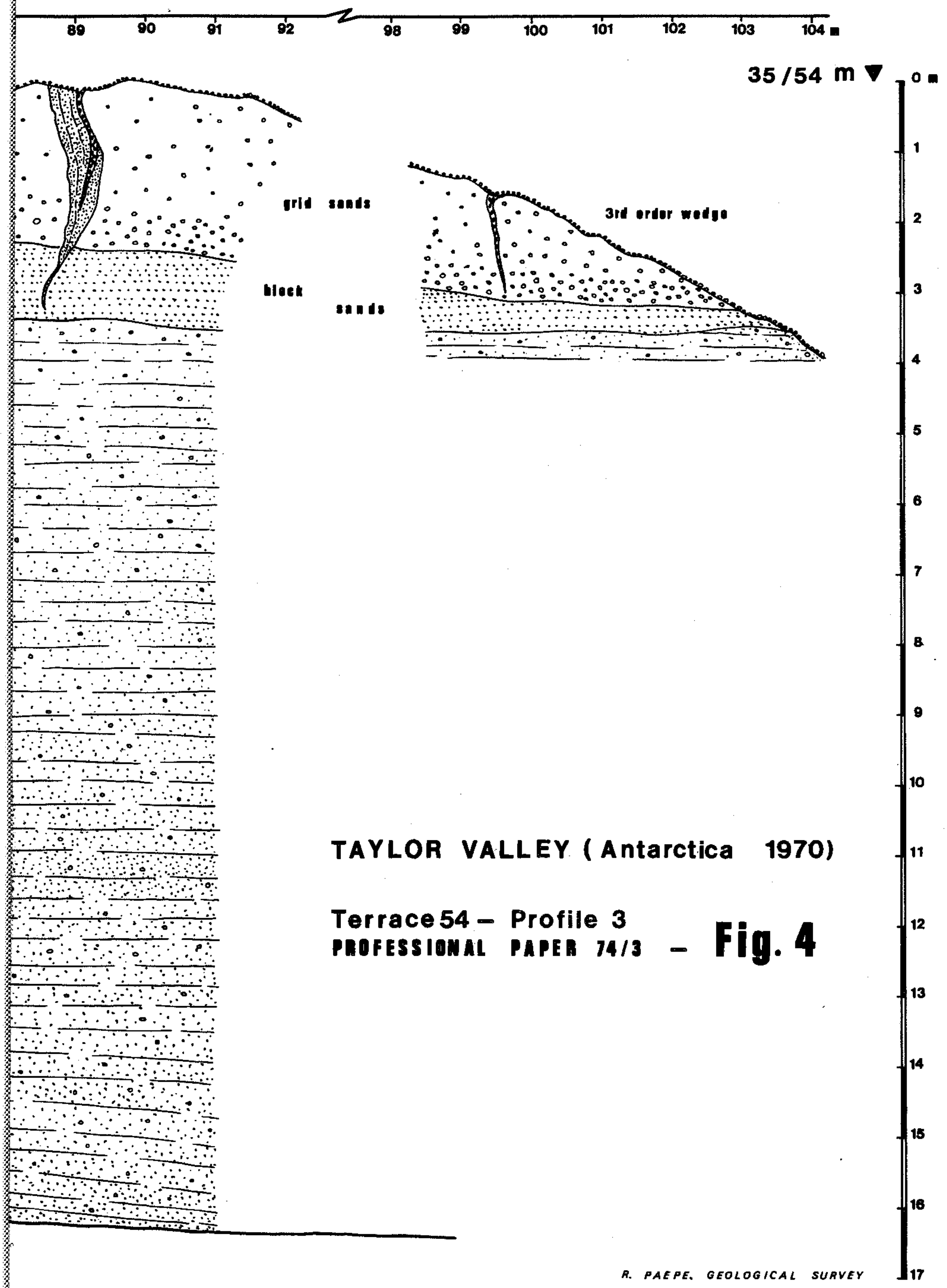

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Terrace 54 – Profile 3
PROFESSIONAL PAPER 74/3 – **Fig. 4**

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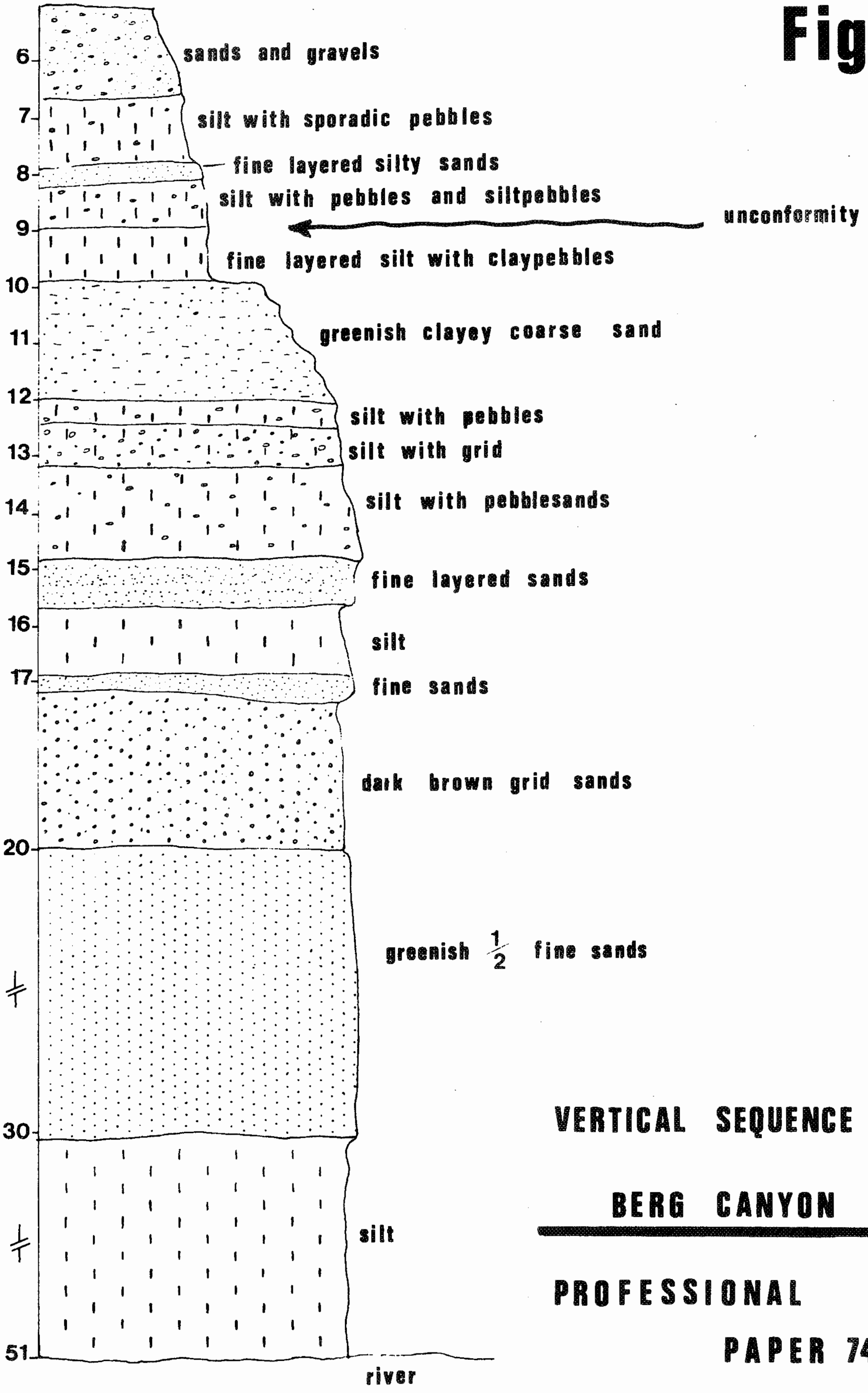
Fig. 5



VERTICAL SEQUENCE IN

BERG CANYON

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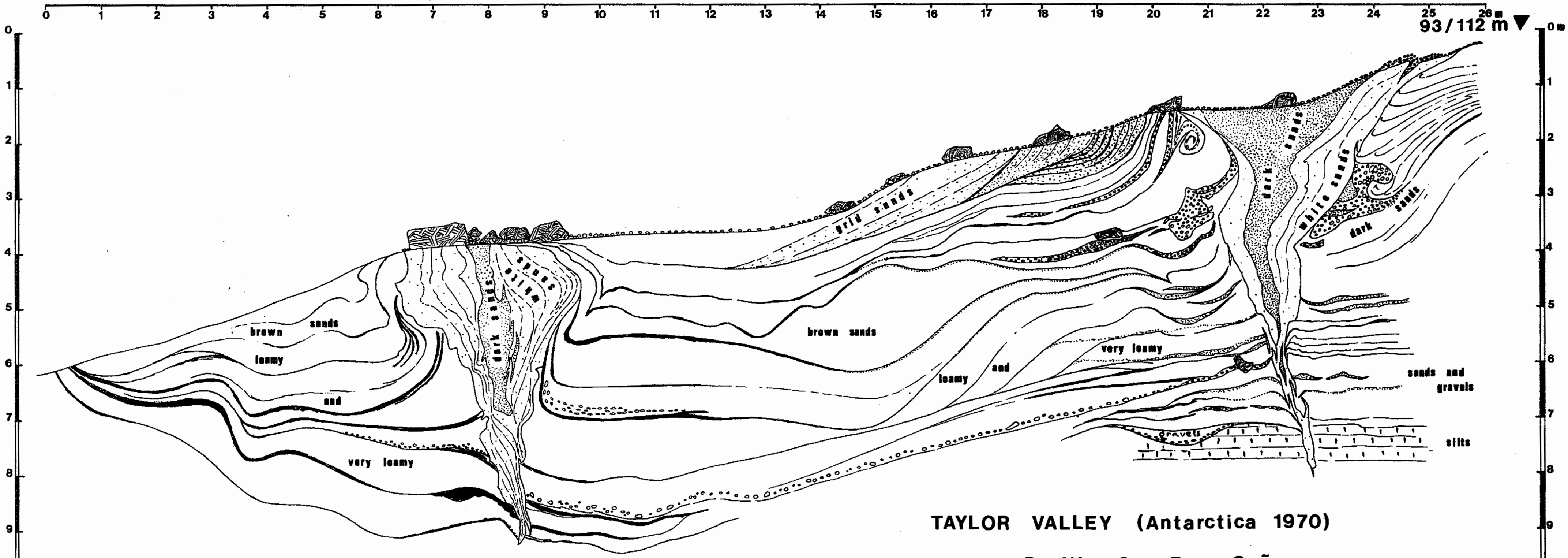

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Fig. 6– Profile 8 – Berg Cañon
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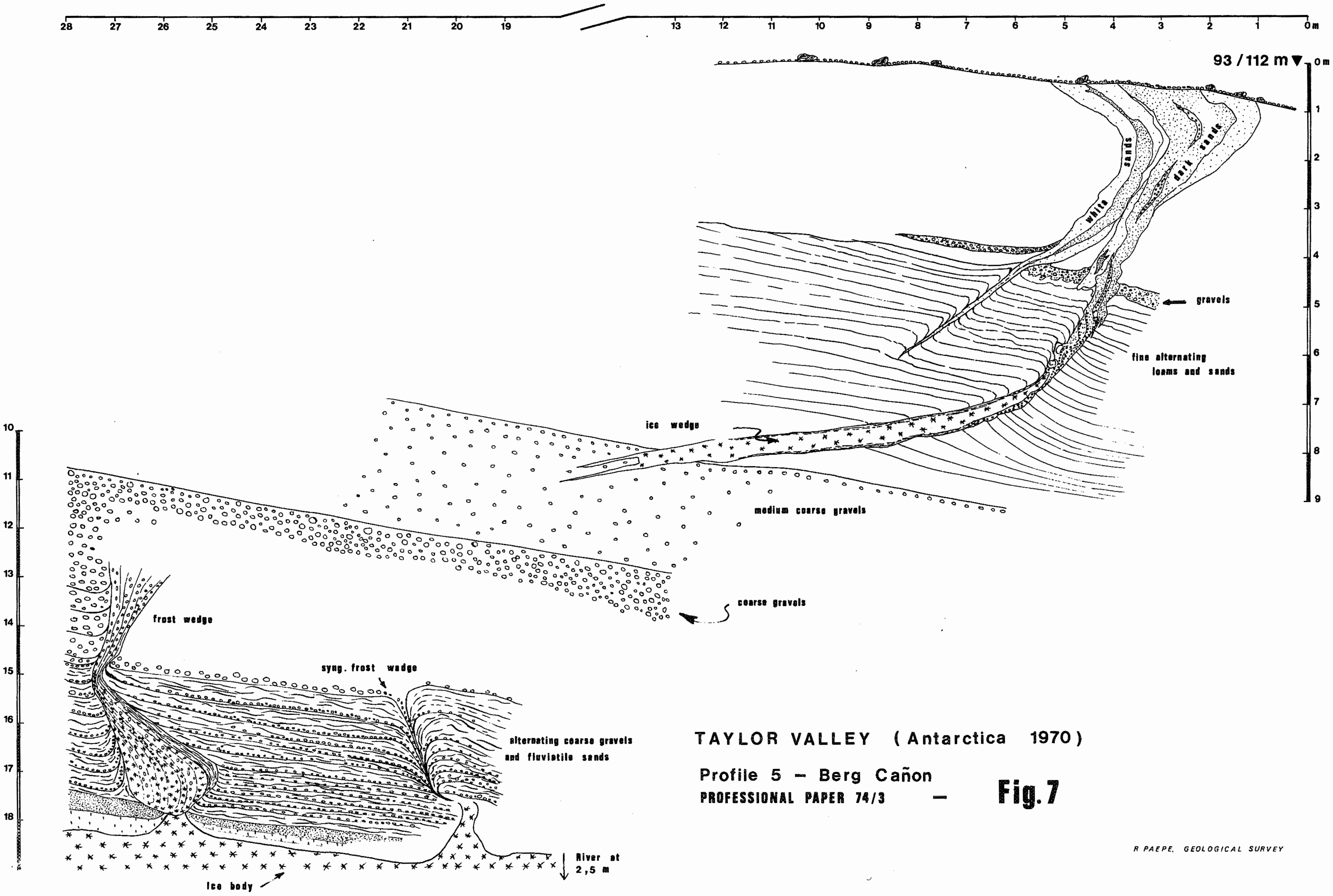

TAYLOR VALLEY (Antarctica 1970)

Profile 5 – Berg Cañon
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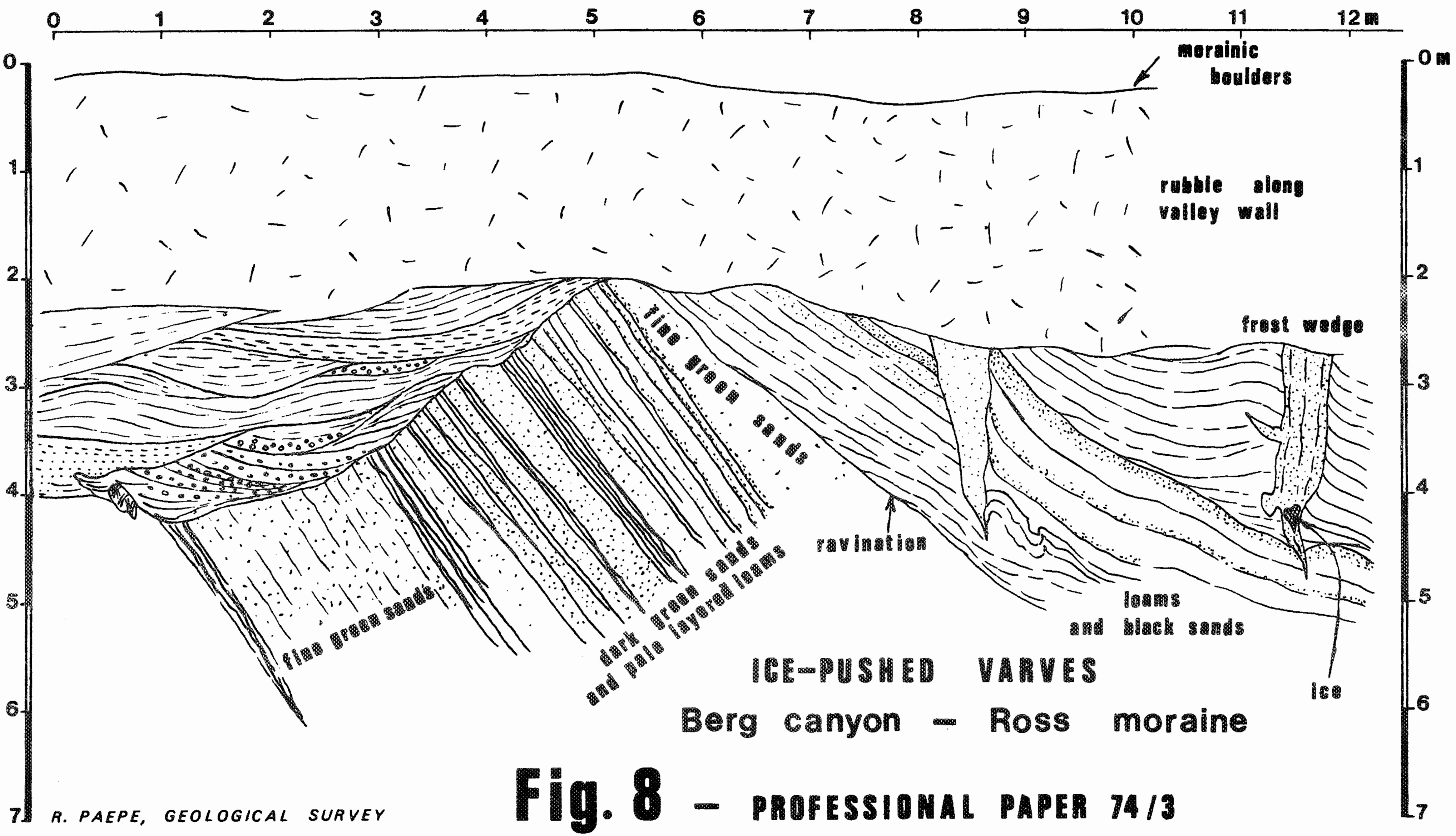
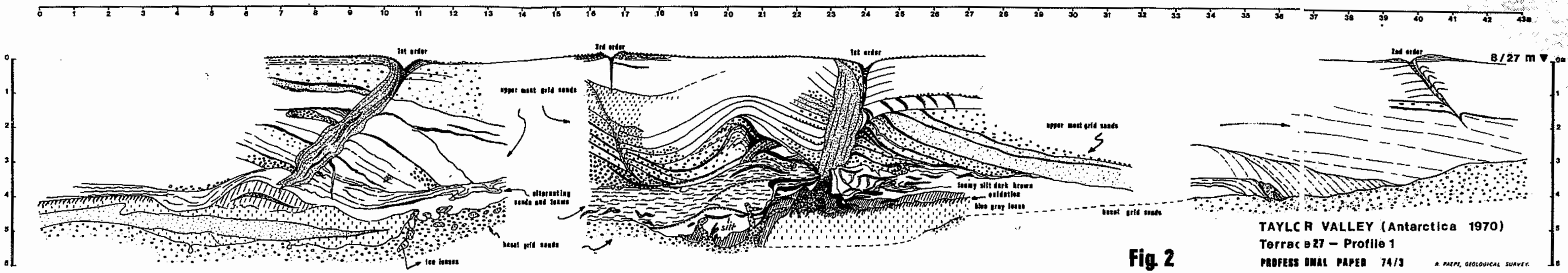


ICE-PUSHED VARVES
Berg canyon – Ross moraine

R. PAEPE, GEOLOGICAL SURVEY

Fig. 8 – PROFESSIONAL PAPER 74/3



TAYLOR VALLEY (Antarctica 1970)

Terrace 27 – Profile 1

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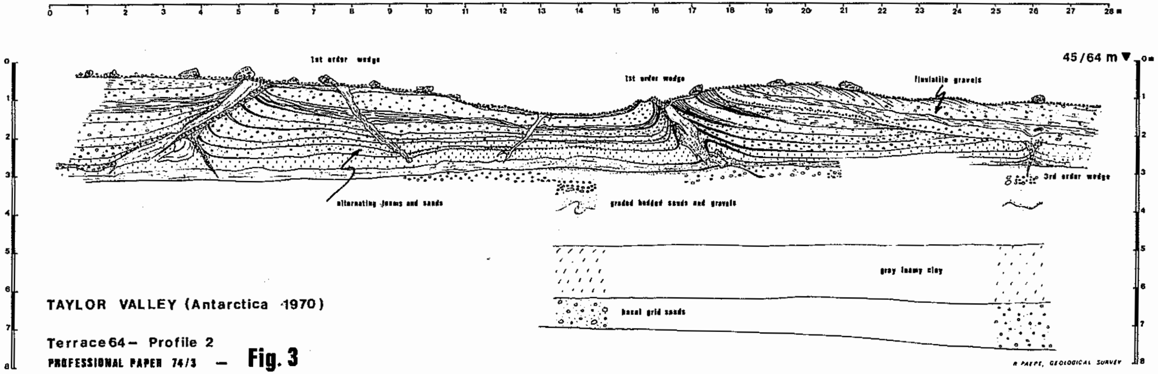
Fig. 2



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Terrace 64 – Profile 2

PROFESSIONAL PAPER 74/3 – Fig. 3

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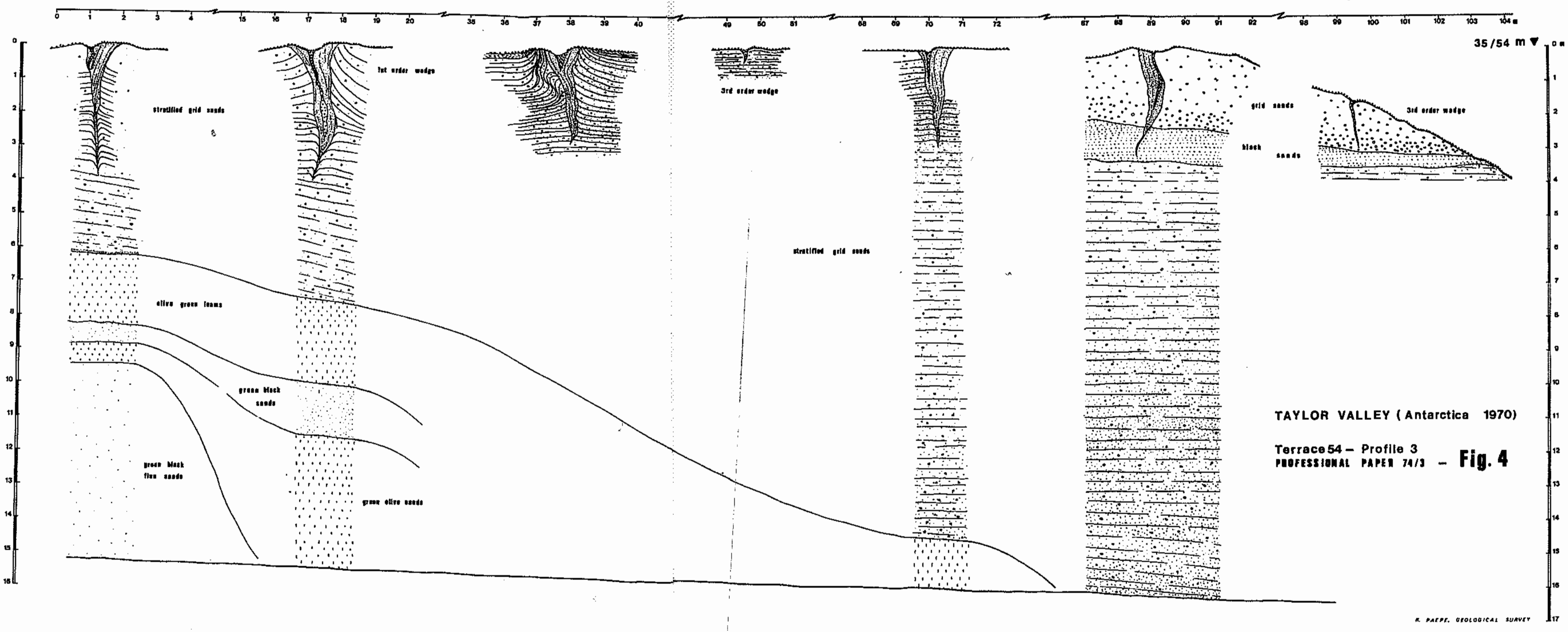

TAYLOR VALLEY (Antarctica 1970)

Terrace 54 – Profile 3
PROFESSIONAL PAPER 74/3 – **Fig. 4**

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