PIPE/SHAFT PHENOMENA IN NORTHLAND*

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seepage below dams
n slump & earth flow debris
then volume increases downslope, subsurface corrasion due to turbulent flow.

SUMMARY

Two types of pipe/shaft features, largely confined to slopes of less than about 12 degrees, are described from an area near Whangarei. Their development appears to depend on the localisation of subsurface water and the presence within upper soil horizons of clays which swell and disperse on wetting and crack on drying. On steeper slopes subsurface erosion by similar processes contributes to both slow and rapid forms of mass movement.

It is suggested that a greater recognition of the importance of subsurface erosion processes in some humid environments is necessary.

INTRODUCTION

Piping and the typically associated processes of subsidence and collapse are phenomena long-known to engineers.‡ Similar processes have been studied by geomorphologists, primarily in semi-arid areas, and several attempts have been made to set up the parameters that circumscribe the conditions under which pipes may occur. Field evidence gathered by the present writer suggests, however, that for the North Island of New Zealand at least some modification of previous ideas is necessary. Subsurface erosion and the features produced (such as pipes, shafts, and subsidence hollows) may be more important in landform evolution in humid environments than a reading of the literature would indicate.

This paper is primarily concerned with examples of pipe/shaft features found in an area of some 60 square miles to the west of Whangarei, arbitrarily termed the Poroti Area (Fig. 1). Other examples have been observed by the writer to occur extensively on a variety of parent materials in Northland, in the Hunua Hills (south-east of Auckland) and on the Volcanic Plateau.

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* This paper is based on fieldwork carried out during 1965 and 1966 in the course of preparing a Masters thesis. (Ward, 1966).

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‡ Piping is the process which produces tubular subsurface drainage channels in insoluble clastic rocks.' (Parker et. al, 1964, p.394). Solution in limestone rocks produces similar forms but the study of these is outside the scope of this paper.

FORM AND DISTRIBUTION

In the terminology used here, pipe refers to an underground horizontal or quasi-horizontal channel. Where collapse of material has broken the ground surface above a pipe the resultant features are termed shafts or collapse shafts. In some cases collapse is incomplete and subsidence hollows or depressions are formed. These are not bounded by bare scarps as is the case with shafts.

Two major types of pipe/shaft features are described from the Poroti Area. The differences in size and form which distinguish these two types appear to reflect differing stages of development rather than any basic differences in process.

Examples of type 1 are shown in Figs 2a and 2b. The collapse shafts are typically about 36 inches deep and are circular to subangular in plan. Shaft walls are near vertical along prismatic soil structure faces. The floor, often partly-covered by collapsed turf blocks, may show seepage or flow along the almost impermeable and unstructured Bg or C soil horizon.

In type 2 the shafts are larger and rather longer in plan than they are broad (Figs 3a, 3b). Shafts are seldom more than 48 inches deep, although depths vary somewhat from example to example. The pipes, which are almost circular in cross-section except for the irregularly flat floor, may be as much as 30 inches in diameter. Seepage occurs along the floor under all but the driest weather conditions.

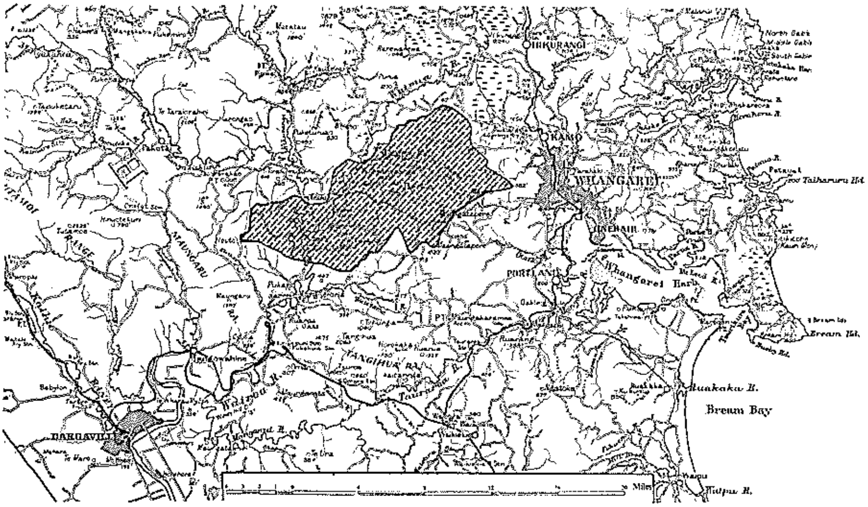
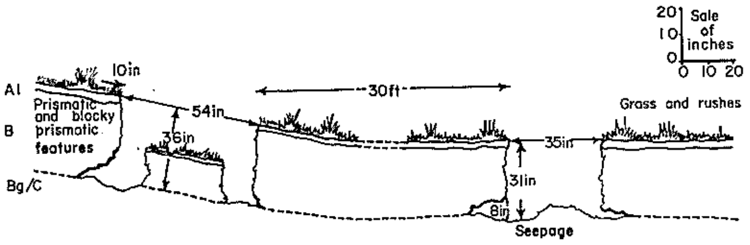
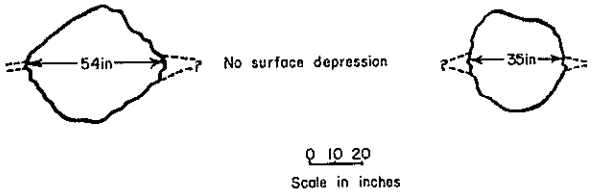


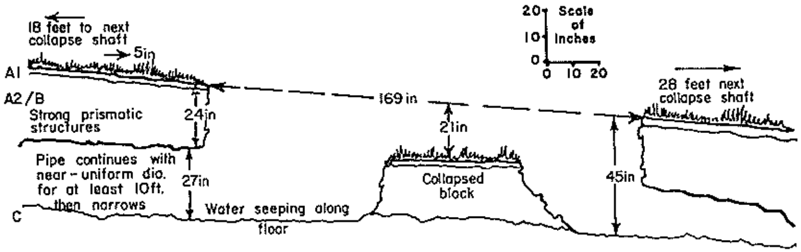
Fig. 1 — THE PORITI AREA.



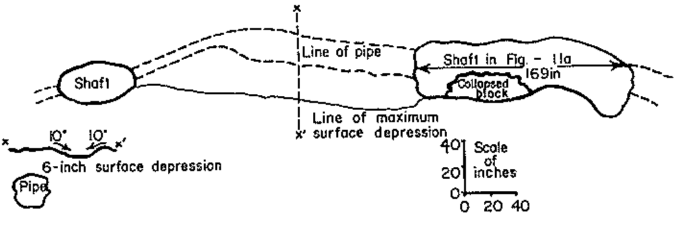
2A



2B



3A



3B

Fig. 2A — DOWNSLOPE CROSS-SECTION — Type 1 Pipe/Shaft Features.

Fig. 2B — Type 1 Pipe/Shaft Features.

Fig. 3A — DOWNSLOPE CROSS-SECTION — Type 2 Pipe/Shaft Features.

Fig. 3B — PLAN AND CROSS-SECTION — Type 2 Pipe/Shaft Features.

Shafts commonly occur in lines as much as 150 feet or more in length. Features along any particular line may be of either type 1 or type 2 and the pipes leading away from the shaft bases are either continuous or, in some examples, blocked by fallen debris. The distance between successive shafts in a sequence is variable but is often of the order of 30 feet. The ground surface may show some depression between shafts but depression lines often do not follow the line of shafts and visible pipes, as in figure 3b.

Shafts and pipes are widespread in the Poroti Area in soils derived from sedimentary parent material. They have not been observed on basalt lithologies or on alluvial flood-plain deposits. Three major type-situations can be differentiated:

(1) Shafts with connecting pipes (usually, but not necsarily, of type 1) are typical of many small tributary valleys near their heads. A sequence of shafts is commonly developed in colluvial/alluvial material along drainage line segments in which surface water flow is intermittent and/or subsurface seepage is responsible for most of the drainage.

(2) Pipes and shafts of type 2 in particular are found predominantly along seepage lines down slope of artificial reservoirs.

(3) The features are also often developed on the intermittently moving bodies of incipient sheet-slides (discussed below) and on displaced landslide masses.

Pipes and shafts are found under manuka scrub but are most common on pastured slopes of less than about 12 degrees. Collapse shafts with often poorly developed or partly blocked pipes have been observed in valley-head situations under bush, but it has not proved possible in the Poroti Area to examine them under primary-growth forest that has been culturally unmodified or little modified.

PROCESS AND DISCUSSION

All pipes and shafts studied in the Poroti Area are confined to the soil mantle and penetrate only a short distance, if at all, into a subsoil that is highly weathered and of fine texture. A-horizons are generally structureless but subject to cracking on dessication — and this is particularly the case on soils where pipes and shafts are best developed. Water penetrating such fissures is readily able to permeate through B-horizons that are characterised by well developed prismatic structures which become angular blocky at depth. Below the B, the C-horizon typically comprises impermeable clay of massive structure.

Analysis of the clay fractions in soils of the area are unfortunately incomplete and in some cases tentative. Swelling clays, primarily metahalloysite (kaolin) and montmorillonite, characterise the surface and subsurface horizons of the piped soils analysed (Fields, 1957; Cox, 1966, pers. comm.). Following dessication these clays swell on wetting. The change in bulk volume is considerably affected by the original density of the material but under high load (conditions likely to pertain beneath a compacted surface soil horizon) very large pressures may be generated (Grim, 1962, p.247-51). In saturated B-soil horizons such pressures may be of importance in the formation of pipes down which water is forced. Ready dispersion of the clay particles further assists the subsurface movement leading to increased mechanical eluviation, pipe ensurface channels, once initiated, become the routes for water movement leading to increased mechanical eluiation, pipe enlargement and the operation of collapse processes to form the characteristic pipe/shaft features. This is a possible explanation of an important difference between piping as described in the literature and piping in the Poroti Area. Many of the pipes the writer has observed are developed up-slope of bog zones (which are characterized by slow surface and subsurface seepage) rather than free faces associated with gullies or slump heads. In these cases water flowing into pipes emerges down-slope as seepage rather than as channelled (surface or subsurface) flow. Only a limited number of examples of pipe discharge into gullies (formed by collapse and modified by subsequent subaerial processes) have been found in Northland.

The channelling of subsurface flow requires the differential collection at the surface and the subsequent infiltration of water. Thus, as expected, preferred locations for pipe/shaft features are down-slope of water collecting zones, for example near valley heads, artificial reservoirs, and in ground depressions caused by slumping or sliding. The fuller development of type 2 (as opposed to type 1) below reservoirs is probably a reflection of the more continuous supply of seepage water to the horizons subject to piping processes.

That shafts and pipes do not always follow the line of surface depressions reflects a relatively recent change in the line of seepage-water movement. Alternatively, the surface channel may be formed under run-off conditions rather than by subsidence over pipes.

Piping and the attendant processes of collapse have been studied from both the engineering and geomorphological points of view but only in recent years have attempts been made to combine the two approaches in landform studies.

Terzaghi and Peck (1948) discuss piping in a man-made fill structure. Subsurface erosion starts at springs near the down-stream toe and proceeds up-stream along the structure base or some bedding plane. 'Failure occurs as soon as the up-stream or intake end of the eroded hole approaches the bottom of the reservoir. The mechanics of this type of piping defy theoretical approach.' (Terzaghi and Peck, 1948, p.230). As a pipe lengthens it taps an ever-increasing water intake area in the fill with a consequent steady increase in the erosive capacity of the spring. Collapse normally occurs some distance from the point of pipe discharge.

In the non-engineering literature a number of terms have been used to describe features developed by similar processes to those described here as leading to the formation of pipes and shafts.* Most workers appear to consider them characteristics of culturally-modified sub-humid, semi-arid, and arid environments which are subject to occasional high-intensity rainstorms.

Rubey (1928) and Buckman and Cockfield (1950) have discussed the formation of gullies by ground sinking in the Great Plains of the United States and in British Columbia. Water penetrating the soil moves laterally towards existing gullies eluviating clay-sized material from the silty matrix. Elliptical depressions in the surface are formed and these 'deepen by continued sinking and complete disintegration of the sunken sod and coalesce by concentric cracking, tunnelling and headward erosion until they become a loosely connected chain of pits or water-holes similar to the lines of water-holes common throughout the semi-arid West.' (Rubey, 1928, p.419).

The features Buckman and Cockfield (1950) describe from arid areas of British Columbia are most common near terrace fronts or the edges of steep gully walls. Funnel-shaped depressions 50 to 100 feet in diameter and up to 50 feet deep are connected by nearly horizontal passage ways 3 to 4 feet high.

Gibbs (1945) and Downes (1946) discuss gully formation by similar processes in Marlborough and in Victoria: 'The gullies are the result of the collapse of surface soil into tunnels scoured in the deep (non-calcareous silt) subsoil by accelerated run-off into fissures and rabbit-holes.' (Gibbs, 1945, p.135).

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* For example: Gullies formed by sinking of the ground (Rubey, 1928; Buckman & Cockfield, 1950); squirrel holes (Sharpe, 1938); tunnel-gully erosion (Gibbs, 1954); tunnelling erosion (Downes, 1946); subcutaneous soil erosion, underrunners, tunneling (Cumberland, 1947); soil piping (Carroll, 1949); large subsurface air spaces (Thomas, 1960); and piping (Fletcher et. al., 1954; Parker, 1963; Parker et. al., 1964).

The pipe and shaft features in Victoria and Marlborough are rather smaller (18 to 60 inches deep and 6 to 38 inches wide; Gibbs, 1945, p.140) than those in British Columbia. These writers stress grain-by-grain removal of fine clay or silt-sized materials in suspension through a coarser matrix as the mechanism leading to the formation of continuous underground voids and the collapse of unsupported parts of the surface. Soil characteristics are also similar in both areas. The poorly structured surface horizons become hard, compact, and almost impermeable (except for dessication cracks and animal burrows) following removal of the vegetation cover. The subsurface horizons, within which the pipes develop, contain materials which become plastic and impermeable (though easily dispersed) on wetting, and individual particles are readily moved in suspension.

Fletcher et. al. (1954, p.258) consider five conditions essential to pipe formation.

(1) there must be a source of water,
(2) the surface infiltration rate must exceed the permeability rate of some subsoil layer,
(3) there must be an erodible layer just above the layer of retarded permeability,
(4) water above the retarding layer must have a hydraulic gradient to make it flow; and
(5) there must be an outlet for the lateral flow.

Parker (1963) is in general agreement but suggests that there is no requirement for the presence of an impermeable layer below the erodible layer — although if present it may influence the pipe course. Studying eight semi-arid locations in the United States, he concludes that:

(1) Cracking potential exists in the soil profiles of all piped areas, and that the potential is greatest at depths where the pipes are developed.

(2) Containment of one or more of the swelling clays (particularly montmorillonite) is common in subsurface horizons of piped soils. These clays become highly dispersed on wetting, producing an impermeable material, but on drying they shrink, leaving deep fissures between aggregates.

(3) The parent materials are in general of very variable texture (clay to sand) from site to site.

(4) Pipes are usually developed in the vicinity of gullies (which provide an outlet for the subsurface flow and a 'free face' for pipe initiation) on near-flat alluvial and terrace deposits. This contrasts with Gibbs's (1945), Downes's (1946) and Cumberland's (1947) examples (which are confined typically to slopes of more than about 10 degrees) as well as with most examples observed by the writer in Northland.

(5) A vegetation cover reduced by over-grazing disposes an area to gullying and to piping — a point stressed by many workers.

With the exception of the piped areas described by Blong (1965) and possibly some of the areas discussed by Cumberland (1947), subsurface erosion has been considered to be best developed where precipitation is less than about 15 inches annually. Characteristic of most piped areas, and of the Poroti Area, is the prevalance of high intensity aperiodic rainstorms.* During such storms existing pipes are undoubtedly enlarged by increased subsurface corrasion and collapse both within pipes and at the surface. In the Poroti Area at least, however, it would appear that the localization of a continuous or near-continuous supply of subsurface seepage water is more critical in the development and perhaps the initiation of piping, than are large water flows during storms.

Pipe/shaft features as described above are seldom found on slopes greater than about 12 degrees in the Poroti Area. At least one mass-movement type, characteristic of slopes of up to 38 degrees on some sedimentary lithologies, appears to be formed by processes very similar to those responsible for piping. These features, termed incipient sheet-slides, are similar in appearance to grassed-over sheet-slide scars. Since, however, soil depths on the scars are typically equal to if not greater than those on adjacent undisturbed slopes, it is apparent that catastrophic sheet-sliding has not in fact taken place. Subsurface eluviation of material below the incipient sheet-slide body allows it to subside slowly. The subsiding mass is bounded up-slope and on each flank by a crescentic scarp, 4 feet or more in height on well developed examples. Once the mass has settled to an angle of less than about 12 degrees pipe/shaft features commonly develop within the surface-soil horizons.

Subsurface erosion may also play an important role in the preparation of slopes for landsliding during and following storms by reducing the cohesion of the soil mantle. Embryonic pipes (which may be little more than slightly enlarged continuous voids between soil structure units) also allow a rapid disposal of surface runoff intercepted by dessication and tension cracks. If sufficient water enters a potentially unstable slope the increase in weight of the potential slide body may be great enough to trigger landsliding.

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* Rainfall varies between 50 and 70 inches annually in the area. Six-hour rainstorms with more than 3 inches of precipitation occur with a return period of 2 years. (Robertson, 1963).

CONCLUSION

Soil and other conditions allowing, pipe/shaft features have been found to be relatively important phenomena on many gentle slopes in Northland. On steeper slopes processes similar to those producing pipes and shafts contribute to both slow and rapid forms of mass movement. In humid areas the effects of subsurface erosion are often masked by other processes. It is suggested, however, that a recognition of their importance in at least some humid environments is necessary.

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