

Solution Pipes and How to Make Them

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INTRODUCTION

The "Petrified Forest" at Cape Duquesne, west of Bridgewater Bay, is a particularly good example of the many exposures of vertical pipes in calcareous dune sands which are seen in coastal areas of western Victoria, South Australia and Western Australia (Figure 1). Similar features also occur in other parts of the world (eg. Southern Africa, the Caribbean and Bermuda - see reference list) where the host sand is known as calcarenite or aeolianite.

Typically the pipes in the Gambier–Portland region are 0.3 to 1.0 m across and the exposed part is 1-3 m high (with the top removed by erosion and the base hidden below the surface). In a few places we see them up to 20 m deep. They can occur as isolated individuals, widely spaced sets (eg. 5-10 m spacing) or in dense fields (as at the "Petrified Forest") with spacings as close as 1 metre (Figure 2). They form smooth vertical cylinders which may narrow towards a rounded base ("cigar shaped" is a common description) or terminate abruptly in a hemisphere (Figure 3). They commonly, but not always, have a calcareous cemented rim around them that is a few centimetres thick. These rims may have concentric layers, and some have traces of thin calcareous root structures (rhizomorphs) and calcareous veins embedded in them (as does the surrounding sand). The exposed pipes tend to be empty, or are filled with a red or pale brown soil (silty sand). The pipes are commonly, but not always, associated with an old soil horizon - either descending from it (Figure 4), or cutting through a calcified band that could be a sub-soil hard-pan. Occasionally, as noted by Boutakoff, the pipes may bottom in a paleosol.

Rhizomorphs are hard calcified root structures. They are common in the calcareous dunes of the region and have an obvious branching root structure. These form from carbonate that has been precipitated around the root, and are thus much thicker than the original root - which may be identifiable as a thin hollow core if that has not been infilled by younger cement.

A PETRIFIED FOREST?

In 1963, N. Boutakoff interpreted the pipes in the Portland region as having formed where an advancing dune had engulfed a forest of trees. Boutakoff argued that after the sand had been cemented into a soft rock, and the trunks had rotted away, the pipes were left as open holes which were locally filled by later soil that developed on the surface of the engulfing dune. He rejected the alternative hypothesis that these were solution pipes (which had been argued by Woods (1862) and others); but he did allow that occasional deeper solution pipes occurred as solutional modifications of the tree molds. Calcified traces of what are recognisably old roots (rhizomorphs) occur together with the pipes and were cited in support of his hypothesis. Boutakoff claimed to have seen "unmistakable rooted tree stumps" and bark, logs and other "woody structures". He illustrated his argument with an imaginative diagram (his figure 17, which is reproduced here as Figure 5); that unfortunately shows large roots spreading out from the base of the "trunks", that do not appear in the real outcrop!

Boutakoff has overstated his case: these features are either capable of alternative interpretations or cannot now be found in the area.

Boutakoff's interpretation is attractive at first sight, and his diagram is deceptively beguiling. It has been cited on numerous occasions in the local literature and appears on newly erected interpretative signs in the area. However, his 1963 interpretation was rapidly challenged. Blackburn & others (1965, p.39ff), described numerous areas of pipes just across the border, in South Australia, and referred to Boutakoff's site (and others) as having "indisputable solution pipes". Jennings (1968) favoured solution as the main process, and commented that "secretion round the roots of vegetation growing down into the sand" seemed more likely than burial of a forest. Coetzee (1975) also argued against Boutakoff's concept from a study of similar features in Africa. There was initially some support from workers in Bermuda, where the pipes were regarded as molds of palmetto stumps; but recent work has discredited this (Herwitz, 1993). Palm trunks have a rounded basal form more akin to the shape of the pipes than other trees, but no native palms are found in the Portland region.

The "tree mold" hypothesis has a number of problems, which I will expand on below:

- The spacing of the pipes (less than 1 metre in places) is too dense for a typical forest with trunks the size of these pipes.
- Where seen, the base of the pipes is a rounded hemisphere - nowhere are there thick-rooted tree structures such as those shown in Boutakoff's figure.
- Boutakoff claimed his pipes were based ("rooted") in a paleosoil layer and extended upward from it. This is unusual, usually the pipes are seen descending to varying depths below an old soil or unconformity.
- The forset cross-bedding of the dune sand shows no disruption where it passes the "trunks".
- Some pipes are up to 20 m deep (or high!), and are all unbranched vertical cylinders.
- The pipes are not restricted to dunes, they also occur in beach and marine sands.

Size and spacing

At the "Petrified Forest" site, and elsewhere, the spacing of the pipes (less than 1 metre) is too close for a typical forest with trunks the size of these pipes. In addition, Lundberg & Taggart (1995) report overlapping pipes in Puerto Rico, where younger pipes intersect older ones - though there are no good examples of this in our area. McNamara (1995) argued that the pinnacles at Nambung, WA, were remnant areas left between coalescing solution pipes.

The close spacing seen in the "Petrified Forest" could only occur with small trees such as paperbarks or ti-trees. Boutakoff recognised this problem, and argued for the development of a series of calcareous layerings around smaller trunks which makes them seem bigger. None-the-less, the hollow centre within the cemented rim is still larger than is compatible with the density of the "trunks". Also, if one accepts Boutakoff's suggestion of massive "thickening" of the original trunk size by cement rims, then one must consider also Jennings' (1968) suggestion that calcification around tap roots growing down into the sediment is a more likely explanation of the pipes than burial of a forest - though Jennings favoured solution as the primary process.

Lack of solid basal roots

The bases of the pipes are seldom seen at the "Petrified forest", but where we do see them (there and elsewhere) they end in a rounded hemisphere (figure 3). Nowhere have we found thick-rooted tree structures such as those shown in Boutakoff's figure 17. His photographs (his plates XIV-3 & 6) of a supposed stump with roots show small rhizomorphs running away from a pipe, but even without allowing for the exaggerated thickness of such calcareous overgrowths, these are too small to support a trunk of that size. Small calcified roots (rhizomorphs) do occur, but at all depths, not just at the base of the pipe.

Downward or upward development?

Boutakoff claimed his pipes were based ("rooted") in a paleosoil layer and extended upward from it. When observing the surface outcrops, as distinct from the cliff cross-sections, one frequently gets the impression that the pipes are ending just below the surface. This is because of the concave layered filling of partly cemented red soil and is misleading. Where seen in a good cross section (cliff or quarry) the pipes descend to variable depths, but have a uniform upper termination at the present surface or at an old unconformity surface which may have an associated paleosoil (Figure 4). Where pipes are seen to bottom uniformly in a basal soil (as in some parts of the "Petrified Forest"), that could be explained by reduced permeability and solubility of the soil material inhibiting further downward solution.

Lack of disruption to the dune bedding

The forset cross-bedding of the dune sand shows no disruption where it passes the "trunks" - there are no eddies or hollows on the lee side. This is not a strong argument, as Boutakoff argued that his calcareous growth layers extended out into the dune bedding and so would have destroyed any such distortions.

Some very deep pipes occur

The pipes at Cape Duquesne are only short (1– 3 m), but similar pipes elsewhere in the region can be up to 20m deep (and some give access to caves, Figure 6). These deep pipes are simple vertical unbranched cylinders - not tree-like. Boutakoff regarded these isolated long pipes as "secondary" solution pipes formed by modification of his tree molds.

Host sands are not all dunes

The pipes are a characteristic feature of dune limestones, but are not restricted to dunes. Similar pipes occur in beach sands associated with the dunes, and in the mid Tertiary marine Gambier Limestone - though the latter do not occur in the dense fields described by Boutakoff and so one cannot be sure that the genesis is identical. An example of solution pipes in marine limestone is seen in Brown Snake Cave (5U-14) at Naracoorte. This cave, in soft, sandy, Tertiary marine limestone, is entered via a 15m deep solution pipe that opens into the ceiling of a large chamber. This vertical pipe is perfectly cylindrical and about 60cm wide (apart from a constriction where it passes through a better-cemented band just above the ceiling of the chamber). Within the cave chamber there are 10 other blocked pipes in an area about 60m long; each with a conical soil cone below it indicating a connection with the surface.

OR SOLUTION PIPES?

A recent review of solution pipes is given by Lundberg & Taggart (1995) - who advocate "dissolution pipe" as being a more correct term. They note that dissolution by focussed downward vertical flow of under-saturated rain or soil water through the porous sediment can explain all the features of the pipes: the uniform, vertical cylindrical form, the dense clustering in places, and the cemented rims (where dissolved material is re-precipitated at the edges of the pipe). The associated rhizomorphs are simply formed around rootlets that have penetrated the sands from above, possibly following the soil-filled pipes by preference and radiating out from them. As the pipes are developing downward from the surface or from a soil cover the infilling material will progressively fill them as they deepen.

But why is the downward water flow focussed into the pipes rather than travelling evenly throughout the uniformly porous sand? In hard limestone, pipes usually form where flow is concentrated along the intersections of joints or steeply-dipping bedding planes. But in soft sandy limestone there are no vertical joints, and the initial inter-granular porosity is uniform apart from occasional horizontal hard-bands - the dune cross-bedding seems to have little effect on flow directions. Three methods of concentrating the flow have been suggested by Lundberg & Taggart (1995, drawing on earlier authors): surface hollows, roots and stem-flow; to those I will add a fourth: patches of higher porosity in the developing soil hard pan (Figure 7).

In passing, it is worth noting that similar vertical pipes occur in the giant podsoles that develop on the quartz sand dunes of the Queensland coast (Thompson & Bowman, 1984, p.282). These have a deep leached A2 horizon over a humic-rich B horizon, with pipes of the leached A2 from a few centimetres to nearly half a metre wide penetrating several metres down into the enriched B horizon. I have also seen analogous, soil-filled, pipes formed in ferruginous duricrusts associated with deep-weathering profiles in tropical Australia. In both cases, focussing of downward water flow seems to be involved.

Stem-flow is the process whereby the leaves of a tree intersect rain, and direct it down the branches so that it is concentrated at the base of the trunk. The concentrated inflow would cause localised solution and pipe development (Figure 7-a). Herwitz (1993) measured stem flow under a variety of trees in Bermuda and showed that it could generate significant concentrations of water and noted that multiple generations of trees could produce the dense spacing of pipes which is observed in places.

The influence of **tree roots** was suggested by Jennings (1968) and later by Bird (1970). Roots generate organic acids and raised CO₂ levels that enhance solution in their vicinity (Figure 7-b). A vertical tap root could therefor form an initial thin pipe which would enhance water flow and enlarge with time. This is a self-perpetuating process as a pipe, with soil fill, would be a preferred place for continuing root growth and organic activity.

Surface hollows were suggested by Coetzee (1975) and others (Fig 7-c). If hollows exist (on a partly indurated surface, or on the top of the soil hard-pan) then water will accumulate in these and the base of the hollows will be lowered by solution at a faster rate than the surrounding higher areas - the process becomes self-perpetuating.

General Presentations

A possible fourth process involves **uneven cementation of the hard-pan**. Rain dissolves carbonate grains as it penetrates the soil, and some of this is re-precipitated lower down to form a hard pan or calcrete band near the base of the soil. In the initial stages this band would not develop evenly (Figure 7-d). The early-cemented areas would tend to deflect flow laterally to places which retained more of their original porosity and concentrated inflow would occur there, inhibiting further cementation, and allowing solution pipes to form below.

In all four cases, once the inflow is concentrated at a point, solution will progressively deepen a vertical pipe beneath the focal point. Lateral movement of saturated water out of the pipe would form the cemented rim (Figure 8).

DISCUSSION

Boutakoff himself admitted that some of the pipes were solutional in origin, but argued that most were tree molds. I argue the opposite: most are solutional and while it is possible that a forest could be buried and rot away to leave molds resembling the pipes, this would probably be a rare event and there is no unambiguous evidence for it at the "petrified forest".

The focussed solution process seems a better hypothesis for general interpretation of both isolated pipes, and the dense fields of pipes which are a distinctive feature of dune limestones throughout the world.

Rhizomorphs are common in dune sands and form around small roots growing through the sand. Such roots would preferentially follow the organic-rich soils that fill the solution pipes and branch out from them. Thus, rhizomorphs could be called petrified roots, but the pipes are not petrified trunks.

So, while "Petrified Forest" provides a picturesque name for the features at Cape Duquesne, the name should be kept in quotes, and not confused with the real process by which these features were formed. The recently erected interpretation signs are incorrect.

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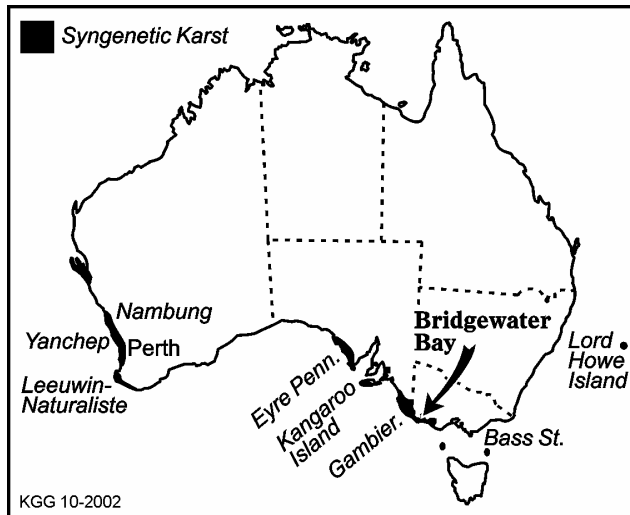


Figure 1 - Dune limestone areas in Australia



Figure 2 - Stereopair of the main cluster of pipes at "The Petrified Forest", Victoria



Figure 3 - Stereopair of a pipe with rounded base at "The Petrified Forest", about 30 m west of the main group shown in Figure 2. Scale-bar is 10 cm.



Figure 4 - Red paleosoil and soil-filled pipes beneath a younger sand dune exposed in a cliff at Canunda National Park, South Australia

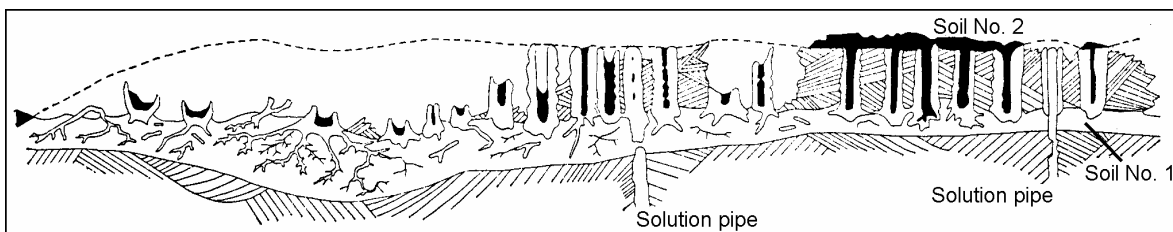


Figure 5 - Boutakoff's figure 17 shows many features of the "Petrified Forest" correctly but grossly exaggerates the thickness and extent of root development at the base of the pipes. Black is soil fillings.



**Figure 6 - A deep, open, solution pipe that forms a cave entrance
Ladder rungs are spaced 30 cm (Photo by R.K. Frank)**

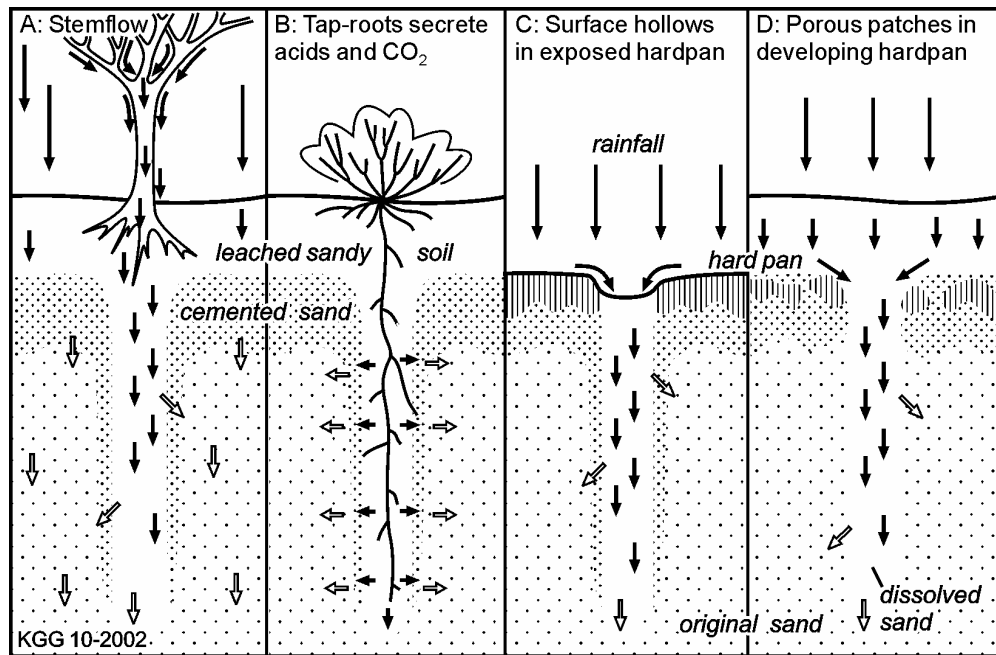


Figure 7 - Alternative ways to focus downward flow and generate solution pipes
 Note: the alternatives are not mutually exclusive, they could all contribute in different settings.

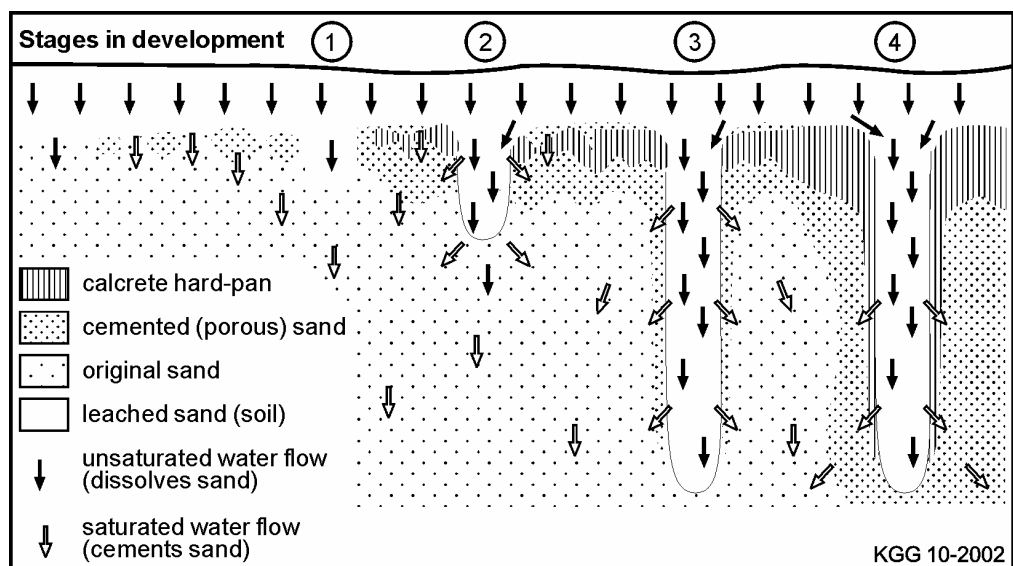


Figure 8 - How a solution pipe deepens and develops a rim