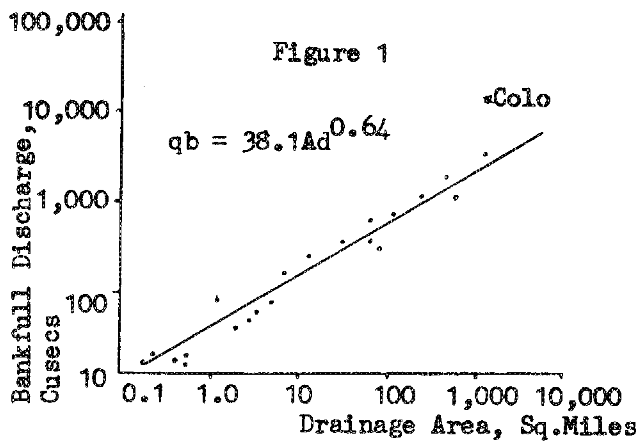
Downstream variation in drainage area, important as a direct cause of change in depth, width, and velocity, serves as an independent variable for purposes of analysis. The relationship between stream length and drainage area, which was obtained for the 12 streams, is well defined with 68 per cent. of cases ranging no more than 23 per cent. above or 19 per cent. below the regression equation

$$Ld=1{\cdot}17Ad^{0{\cdot}62} \quad .... \quad (1)$$

where Ld is stream length in miles and Ad is drainage area in square miles. This relationship is very similar to norms obtained elsewhere (Hack, 1957; Leopold, Wolman and Miller, 1964). Since the Colo basin seems not unusual in this respect, it follows that bankfull discharge/drainage area relationships for the Colo will differ from corresponding relationships elsewhere according to differences in other factors such as lithology, vegetation and micro-climate.

However, an examination of 15 cases shows the 1·58 year flood for the Colo River greatly exceeds the limits set by American rivers in spite of a wide variation there in these factors. It seems likely that bankfull discharge derived from gauging records on the Colo is incorrect.



As Figure 1 shows, the Colo plots anomalously on a graph relating bankfull discharge to drainage area for a group of 15 rivers near Sydney. The discharges used to construct this diagram are referred to bankfull level as defined in the field by point bars. Wolman and Leopold (1957) have pointed out that point bars tend to build up to the flood plain surface. If it is assumed that well-developed point bars represent natural flood plain elevation, then they can be used as indicators of bankfull level and in the measurement of width between banktops. Dury (in preparation) has applied this criterion to the Colo near Upper Colo, commenting that, if water should rise over the point bar, it is liable to be slack and contribute little to discharge.

The field data in Figure 1 are closely grouped around the regression equation

$$qb=38{\cdot}1Ad^{0{\cdot}64} \quad .... \quad (2)$$

in which qb is bankfull discharge. The correlation coefficient of +0·98 is significant at the 0·001 level. Sixty-eight per cent. of the values vary by no more than 38 per cent. above or 27 per cent. below the regression estimate, the value for the Colo being only 14 per cent. greater than this estimate. The value obtained from stream gauging records is, however, 315 per cent. greater than the regression estimate.

The data in Figure 1, consistent over a wide range of drainage areas, is supported by similar studies elsewhere. The inferred inaccuracy in the gauging of the Colo can probably be attributed to the brevity of the record, to shifting control at the gauging site, and to the fact that discharges above 10,000 cusecs have been estimated throughout.

Records for some other streams also give cause for doubt. The relationship illustrated in Figure 1 may well be a more accurate guide to discharge at natural bankfull of streams in the Sydney area than that provided at present by gauging data. Although maximum deviation of the field data from the regression estimate is quite substantial, at 110 per cent., it is nevertheless far smaller than the 820 per cent. and 315 per cent. for gauged values on O'Hares Creek and on the Colo River respectively.

Equation (2) could probably serve as a reasonable guide to the behaviour of ungauged rivers in this area, and as a check on the accuracy of gauging records where these exist.

The author is indebted to Professor G. H. Dury for his advice and constructive criticism.

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3 August 1967.

References

Dury, G. H., Hails, J. R., and Robbie, M. B. (1963): *Aust. J. Sci.*, **26**, 123.
Gumbel, E. J. (1945): *Eng. News-Rec.*, 14 June, 97.
Gumbel, E. J. (1958): *J. Inst. Water Eng.*, **12**, 157.
Hack, J. T. (1957): U.S. Geol. Survey Paper 294–B, 63.
Leopold, L. B., Wolman, M. G., and Miller, J. P. (1964): *Fluvial Processes in Geomorphology*, p. 144 (Freeman: San Francisco).
Wolman, M. G., and Leopold, L. B. (1957): U.S. Geol. Survey Paper 282–C, 91.

Rapid Physiological Change in *Pinus radiata* following Attack by *Sirex noctilio* and its Associated Fungus, *Amylostereum* sp.

Attack by *Sirex noctilio* has resulted in the death of trees, mainly in the more or less suppressed crown classes, over wide areas in New Zealand, and locally in Tasmania and on the mainland of Australia.

Trees appear to show a range of genetic resistance to *Sirex* attack, although suppressed trees are in general susceptible, and vigorous trees resistant. Their resistance is due, at least in part, to the production of polyphenols, which restrict the growth of the symbiotic fungus (*Amylostereum* sp.).

It has been suggested that trees die after attack because growth of the fungus, which is injected into the stem by the insect's ovipositor, cuts off the sap supply to the crown (Rawlings, 1948). When the fungus develops in the sapwood, it causes the wood to dry out locally to an extent which would certainly make the wood non-conducting (Coutts, 1965), and previous work on tree physiology related to *Sirex* attack has been based on the assumption that symptoms of attack are related to this restriction to sap supply.

However, recent observations indicate that physiological symptoms of attack by *Sirex* are evident in the crowns some 5–10 days after oviposition. Such symptoms cannot reasonably be attributed to blocking of the sap stream by fungus growth since the fungus grows slowly in the stem, and in this interval mycelial growth is restricted to a region not exceeding one centimetre from oviposition holes. The cambium and phloem are not colonized in the early stages of the disease.

To investigate these early symptoms of attack, experimental infection of young (5–10 years) trees was obtained by allowing female *Sirex* with glued wings to oviposit on the lower parts of the stems.

The first visible change in the foliage was usually the yellowing of old needles. This occurred after heavy attack, whether trees died or survived. A more serious symptom was the wilting of young needles at shoot tips in the upper part of the tree, for no trees in this condition were observed to recover. Needles which wilted bent sharply just above the base, in the fascicle sheath, in a manner quite unlike death which follows from drought, or from desiccation on felled trees.

Three or four days after heavy attack, an increase in leaf starch could be detected throughout the crown and starch accumulated to reach a very high level two weeks after oviposition (Figure 1). It then decreased rapidly for a few days, followed by a more gradual decline in trees which died. Starch also increased in leaves of trees which resisted attack, and later decreased to normal.

Experiments were carried out to test whether the changes observed in the leaf could be brought about by obstruction of the sap stream by the fungus in the stem. *Sirex* attack was confined to an area of 2 feet in length extending half way round the tree.

This caused yellowing of the older suites of needles after a period of two to three weeks. When such a tree was felled to study the distribution of the fungus, three-quarters of the crown being dead, the fungus was found to have invaded a band of sapwood only 1·5 cm. deep, and that only on the attacked side of the tree. Control trees were injured mechanically by cutting more than half way through the stem at two points 2·5 feet apart and chiselling out the intervening wood. Much more sapwood was interrupted than in the attacked trees, yet no yellowing of the foliage resulted from this treatment.

Leaf water deficit is a sensitive indicator of the water relations of the tree, and was measured in various experiments to test whether the water supply to the leaf was being cut off by the fungus in the stem. Trees were detopped and pruned to leave two whorls of branches. A cut was made encircling the stem between the whorls and severing the three outermost growth rings. This treatment did not affect leaf water deficit above or below the cut. *Sirex* were induced to attack the lower parts of the stems of four such trees. All four died, but one of them showed pronounced wilting of needles on the branches *below* the cut soon after the attack and at a time when the upper whorl still looked green and healthy.

In another experiment, 18 trees which resisted *Sirex* attack showed yellowing of their oldest needles two to three weeks after the attack, yet leaf water deficit of their young needles did not differ from that of control trees.

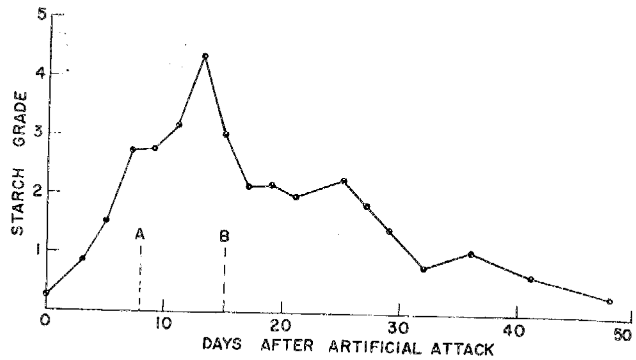

Figure 1

Changes in amounts of starch in the pine leaf after *Sirex* attack on the stem.

At the maximum grade all mesophyll cells were densely packed with starch grains. *A*, time of growth check and attack by wild *Sirex*. *B*, time of rapid decrease in leaf moisture content

The observations suggest that as a result of attack, some substance or substances are produced in the stem, and move to the crown, where they prevent the translocation of photosynthate, and also lead to the death of the foliage. Some changes in the overall physiology of the stem may then be secondary, resulting from changes in the needles.

In experiments on 30-foot trees, a check to radial growth occurred about eight days after heavy artificial attack, and the growth check coincided with a period of attractiveness to wild *Sirex*.

To isolate the possibility that these physiological symptoms are due to other causes than restricted sap flow, and to implicate more directly the presence of translocated products stemming from the site of attack during initial growth stages of the fungus, water was drawn through infected and control logs under vacuum, and the extracts were fed into the sapstream of young trees. In small preliminary trials, extracts from logs which had been attacked two months or five days previously caused an increase in leaf starch and subsequent death of much of the foliage. Extracts from control logs had no such effects.

Shade rather than root competition seems to be the important factor in suppression, and trees which were artificially shaded died much more readily after *Sirex* attack than unshaded trees. The efficiency of the resin and polyphenols mechanism (Coutts and Dolezal, 1966) in the stem may be reduced by shading. Yet when *Sirex* attack was induced low down on stems, certain of the branches above being artificially shaded, the shaded foliage generally died sooner than that on unshaded branches.

The results suggest that, as well as the more important mechanism of stem resistance, the trees may have a varying degree of resistance in their leaves, to some substances translocated from the site of attack. One might expect that needles with a vigorous metabolism would most effectively inactivate or tolerate these substances. But the concentration of such a substance in the foliage would depend on the size of the tree's crown relative to the amount of translocate produced in the stem. Dominant trees, which generally survive a *Sirex* epidemic, have the advantages both of vigour and large crown size.

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11 September 1967.

References

Coutts, M. P. (1965): Forestry and Timber Bureau, Bulletin 41.
Coutts, M. P., and Dolezal, J. E. (1966): Forestry and Timber Bureau, Leaflet 101.
Rawlings, G. B. (1948): *N.Z. J. For.*, 5, 411.

Thickness of the Earth's Crust in Papua New Guinea and the British Solomon Islands

In Papua New Guinea neither the depth to the upper mantle nor its velocity is known, although there is some evidence from gravity surveys (St. John and Green, 1967) to suggest that the crust is much thicker in mainland New Guinea than in the Solomon Islands and New Britain areas. In 1966 the Bureau of Mineral Resources organized a crustal study in the Cape York Peninsula region and the Geophysics Department of Hawaii University conducted a sparker marine seismic survey around the Solomon Islands. To date no results from this work have been published.

The purpose of this note is to present crustal thicknesses determined by an analysis of the P-wave spectrum from deep earthquakes recorded at three locations. The method used is that developed by Fernandez (1965), and has been applied with success to the St. Louis University network of stations in the United States, where the crustal structure was comparatively well known.

Fernandez's method consists of considering the motion recorded at the earth's surface to be a result of the incident seismic energy, the elastic properties of the layers of the earth's crust beneath the recording station and the response characteristics of the recording instruments. Using a matched three-component station it is possible to eliminate the response of the instruments by dividing the spectrum of the vertical component of motion by the spectrum of the horizontal component. The result is a simple ratio which depends on the angle of incidence of the ray and the system of layers beneath the recording station. The numbers obtained can be compared with master curves calculated for different crustal parameters. The best fit between the observed and calculated curve gives an estimate of the crustal structure in that region.

In this study earthquakes recorded by the long-period instruments of the World Wide Standard Seismographs at Port Moresby, Rabaul and Honiara were used. Large deep earthquakes nearer than 50° were selected for the analysis. In this way events such as sP, pP and PcP which often interfere with the first arrival do not occur until well over a minute after the initial P phase.

The traces were digitized at 0·5 second intervals and the frequency analysis was performed on the C.S.I.R.O. C.D.C. 3600 computer in Canberra using Fernandez's original program modified for the 3600. A velocity for the upper mantle of 8·0 km./sec. was assumed in each case and the results are tabulated below.

Earthquake (from U.S.C. and G.S.):

Date: 25 August 1963	Origin time: 12 18 12·5
Lat.: 17·5° S. Long.: 178·8° W.	Depth: 565 km.
Region: Fiji Islands	Magnitude (CGS): 6·1

Crustal solutions:

	Port Moresby	*Rabaul*	*Honiara*
Epicentral distance:	34·2°	31·7°	22·2°
Average P velocity:	6·4 km./sec.	6·0 km./sec.	6·4 km./sec.
Thickness:	29·5 km.	14·5 km.	17 km.
Quality of fit with master curves:	Fair	Fair	Very poor

Earthquake (from U.S.C. and G.S.):

Date: 15 December 1963	Origin time: 19 34 45·5
Lat.: 4·8° S. Long.: 108·0° E.	Depth: 650 km.
Region: Java Sea	Magnitude (CGS): 6·4

Crustal solutions:

	Port Moresby
Epicentral distance:	39·1
Average P velocity:	6·4 km./sec.
Thickness:	32·0 km.
Quality of fit with master curves:	Good

Both the Port Moresby determinations give similar values for the crustal thickness and crustal velocity, the mean thickness being about 31 km. At Rabaul and Honiara the crust appears to be only about half as thick. The quality of the Honiara data is poor and the value of 17 km. could well be changed as more earthquakes are analysed.

These preliminary results clearly indicate large differences in crustal thickness between Port Moresby and the Solomon Islands-New Britain region.

I wish to thank Mr. B. G. Cook for adapting the computer program for the C.S.I.R.O. 3600, and the Director of the Bureau of Mineral Resources for permission to submit these results for publication.

D. Denham.

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Port Moresby, Papua.
13 July 1967.

References

Fernandez, L. M. (1965): 'The Determination of Crustal Thickness from the Spectrum of P Waves', Vela Uniform Contract No. AF19(604)–7399, Project No. 8652, Task No. 865201.
St. John, V. P., and Green, R. (1967): 'Topographic and Isostatic Corrections to Gravity Surveys in Mountainous Areas', *Geophysical Prospecting*, 15, No. 1.