drop through water with their flat sides normal to the direction of fall is incorrect and disproved by countless examples of dropstones piercing with their sharp edges or corners through the underlying lamination[3-5]. Even small dropstones penetrate the host rock lamination in this fashion; that has been demonstrated to Schermerhorn on a visit to the Numees Formation.

Schermerhorn and Stanton[8] state that "deposition of the tilloids was thus a type of geosynclinal turbidite sedimentation" and ". . . a subaqueous mudflow . . . even becomes a turbidity current". Also "The beds of quartzite (intercalated in mixtite—A.K.) must have arrived as turbidity currents".

The mixtites extend for more than 800 km in the West Congo Basin and no mechanism can explain this distribution satisfactorily by mudflow deposition.

The association of mixtites with carbonates is characteristic of most late Precambrian glaciogenic deposits[9] but, contrary to Schermerhorn's belief, it is not evidence against glacial deposition. The Numees tillite[3-5] and the Bthaat Ergil Group in, Mauretania[10], to cite only two well documented examples, are both undisputably related to ancient glaciation but, nevertheless, contain carbonate beds.

Dr Schermerhorn claims boldly but incorrectly that the Angolan mixtites are the best documented of all such sediments in Africa or in the Southern Hemisphere, though only one publication had appeared about them before ours. If it were true, the argument about their origin would long have been settled in favour of glacial deposition.

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[1] Kröner, A., and Correia, H., *Nature phys. Sci.*, **246,** 115 (1973).
[2] Kröner, A., *IUCS Geological Newsletter*, **4,** 286 (1973).
[3] Martin, H., *The Precambrian geology of South West Africa and Namaqualand* (Precambrian Research Unit, Univ. Cape Town, 1965).
[4] Kröner, A., and Rankama, K., *Geol. Soc. Finland Bull.*, **45,** 79 (1973).
[5] Kröner, A., *Trans. R. Soc. S. Afr.* (in the press); Bulletin of the Precambrian Research Unit, Univ. Cape Town, **13** (1974).
[6] Schermerhorn, L. J. G., *Am. J. Sci.*, **274,** 673 (1974).
[7] Reid, A. B., and Kröner, A., *Precambrian Research Unit, Univ. Cape Town, ann. Rep.*, 104, (1974).
[8] Schermerhorn, L. J. G., and Stanton, W. I., *Q. Jl geol. Soc. Lond.*, **119,** 201 (1963).
[9] Spencer, A. M., *Mem. geol. Soc. Lond.*, **6** (1971).
[10] Trompette, R. *Laboratoire associé au C.N.R.S. No.* 132, **B6** (1973).

Work of fracture of natural cellulose

THE work of fracture (that is, the energy needed in order to form a fracture surface roughly at right angles to the grain direction) is, for timber, exceptionally high in relation to other mechanical properties and density. It compares well, on a weight basis, with that of ductile metals. Our tests on air dry (12% moisture content) pitchpine (*Pseudotsuga taxifolia*) for instance, give a mean value of 0.92×10^4 J m^{-2}. That is far higher than the energy needed to break the interatomic bonds in any given cross section of timber (which can hardly exceed 2 J m^{-2}). It also seems to be noticeably higher than the energy that is likely to be absorbed by the fibre pull-out mechanisms which operate in conventional, artificial fibre composites[1]. There is reason therefore to suspect the existence of a special energy absorbing mechanism during fracture in trees and presumably, in other, plants.

Air dry timber has normally a macroscopic breaking strain in tension along the grain of about 1.0%, which is not very different from that of the cellulose fibrillae of which it is principally composed. Such a low breaking strain is not obviously compatible with the absorption of so much energy at fracture. Cowdrey and Preston[2] have shown, however, that in the cell walls of timber the cellulose fibrillae are disposed in a preponderantly helical manner, making an angle which may vary between 6° and 30° in different cells but which always has the same sense in any one tree.

Page *et al.*[3] have shown that when an individual cellulose cell is detached from its surroundings and pulled in tension, the walls buckle into the lumen in such a way that total longitudinal extensions of the cell of between 15% and 20% are possible. Page, however, was concerned with paper fibres and not with the fracture energy of timber.

We have made large (~ 2 mm diameter) model cellulose fibres by winding glass and carbon fibres into hollow helices with resin. When tested individually in tension, such tubes behave elastically up to a well defined yield point. Beyond that point the tube wall buckles and the equivalent of plastic yield takes place, enabling the tube to extend irreversibly by 10–20%, and thus to absorb a great deal of energy. We have made composite models resembling timber, by glueing together a number of parallel tubes of this type, and these exhibit experimental works of fracture up to about 40×10^4 J m^{-2}, which may be higher than any value previously recorded for a non-metallic material.

We have observed that the fracture behaviour of timber, watched under the optical microscope, much resembles that of our fibre-composite models. The first irreversible event to be observed is the lateral separation of many of the cells in the immediate neighbourhood of the fracture (see ref. 4). That enables the walls of the cells in that region to buckle, and the cells themselves to elongate. Thus, although the elastic strain in the timber as a whole seldom much exceeds 1.0%, the cells close to the fracture surface typically extend 15–20% before breaking, absorbing much energy as they do so.

The adoption of a helical arrangement of reinforcing fibrillae naturally, involves some reduction in the maximum attainable value of longitudinal Young's Modulus. By calculation this reduction seems to be proportional to the square of the cosine of the helical fibre angle. That is equivalent to the loss of about 1% for a 6° helix, increasing to 25% for a 30° helix. Such a loss of stiffness may well be regarded as an acceptable price to pay for the acquisition of so much fracture toughness.

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[1] Kelly, A., *Proc. R. Soc.*, **A319,** 95–116 (1970).
[2] Cowdrey, D. R., and Preston, R. D., *Proc. R. Soc.*, **B166,** 245 (1966).
[3] Page, D. H., El-Hosseiny, F., and Winkler, K., *Nature*, **229,** 252 (1971).
[5] Cook, J., and Gordon, J. E., *Proc. R. Soc.*, **A282,** 508 (1964).

Imparting strength and toughness to brittle composites

HIGH strength and high toughness are usually mutually exclusive in composites which have brittle filaments in a brittle matrix. The high tensile strength characteristic of strong interfacial filament–matrix bonding can, however, be combined with the high fracture toughness of weak interfacial bonding if the filaments are arranged to have alternate sections of high and low shear stress (and low and high toughness). Such weak and strong areas can be achieved by appropriate intermittent