Compaction of Devonian lycopsid stems from the Beacon Heights Orthoquartzite, southern Victoria Land

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Just as sand resists compaction during burial better than does clay, so do fossil shell and bone resist compaction better than does wood, and various kinds of fossil wood show an array of compaction that varies depending on their content of woody vs. fleshy tissues (xylem vs. parenchyma). This research to quantify compaction of the fossil lycopsid *Haplostigma irregularis* from the Beacon Orthoquartzite of southern Victoria Land aims to determine whether it was woody or herbaceous. These fossils also are important analogs for understanding burial compaction and nature of Ediacaran fossils, which are preserved in similar deeply buried quartz sandstone (Retallack 1994).

Slender stems of the fossil lycopsid *Haplostigma irregularis* (Schwartz) Seward (1932) have been known for some time from southern Victoria Land (Plumstead 1962, 1964). Although McLoughlin and Long (1994) referred leafless axes of this plant to *H. lineare*, specimens collected for this study (Condon Collection, University of Oregon F35025-6, from L2892) include a variety of axes with oval scars and roots (F12576A) and short mucronate, keeled leaves (F12577I), as well as elongate leaf scars, identical to South African *Haplostigma irregularis* (Anderson and Anderson 1985) and similar to *"Drepanophycus" schopfii* from Marie Byrd Land, Antarctica (Edwards 1990, pp. 89–101). Fossil plants were collected from the north-facing slope 300 meters (m) west of the northwest spur of West Beacon, at a point 40 m below the dolerite-capped knoll, in the Beacon Heights area of southern Victoria Land (77°49.190'S 160°49.432'E, elevation 2,346 m). In addition to containing lycopsid remains, the locality contains the trace fossil *Beaconites antarcticus*, thought to be the burrow of a myriapod (Bradshaw 1981), within a single stratigraphic level that was traced for 400 m along strike. The monospecific assemblage of lycopsids are in growth position within a thin, very weakly developed sandy paleosol, that can be identified as a Psamment in the U.S. soil taxonomy (Soil Survey Staff 1990). A large slab of fossils was cut like a loaf of bread with a diamond saw so that the distribution of the rhizomes and stems could be plotted to reconstruct them (figure 1). Abundant cross bedding and other sedimentary structures have been used to interpret these beds as

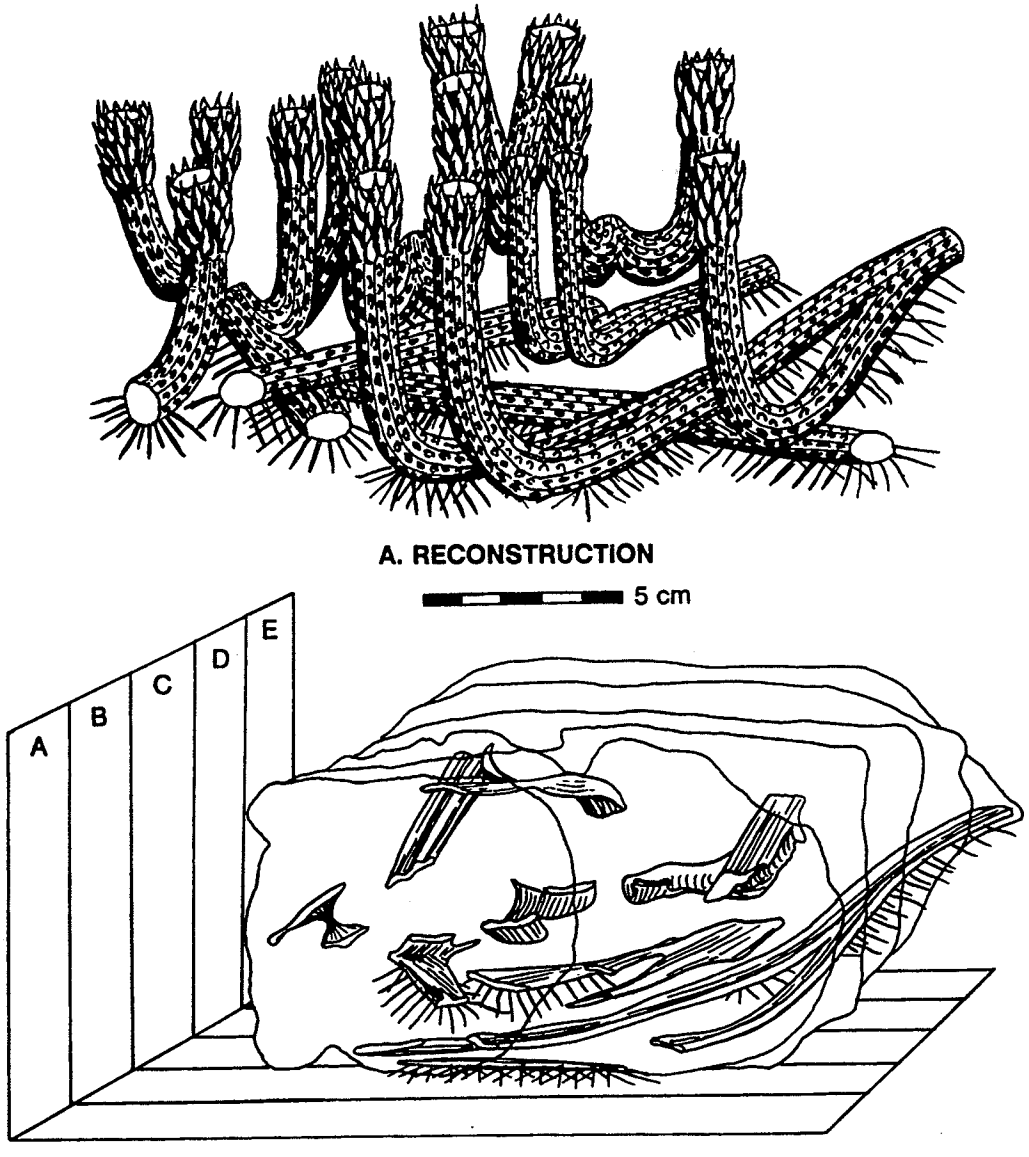

Figure 1. Reconstruction of the lower part of a stand of the Middle Devonian lycopsid *Haplostigma irreularis* from West Beacon, Antarctica (*A*), based on the three-dimensional distribution of sunken compressions in a large slab (*B:* Condon collection F35026A-E).

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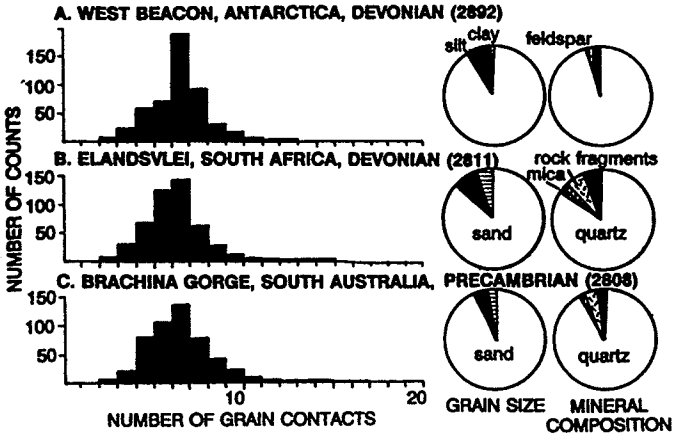

Figure 2. Petrographic data on matrices of Devonian *Haplostigma* from Antarctica (this article) and South Africa and of Precambrian Vendobionta (from Retallack 1994), illustrating comparable burial compaction (grain contacts per grain), grain size, and mineral composition (pie diagrams).

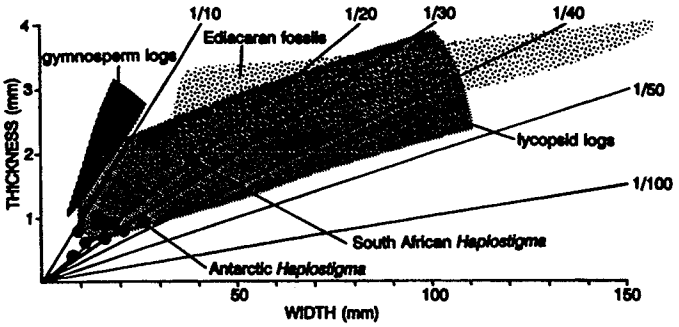

Figure 3. Compaction of deeply buried antarctic *Haplostigma* (this article), compared with South African *Haplostigma*, North American conifer and lycopsid stems, and South Australian Precambrian Vendobionta (from Retallack 1994).

deposits of low-sinuosity braided streams draining a deeply weathered terrane to the southwest (Barrett and Kohn 1975). The *Haplostigma* bed is at a stratigraphic level of 169 m within the Beacon Heights Orthoquartzite (in section B2 of Askin et al. 1971) and is probably the source of *Haplostigma* fossils found in float by Harrington and Speden (1962; Plumstead 1962, 1964). The geological age of the fossils is Middle Devonian, based on correlation of these plants and of fish faunas in the overlying Aztec Siltstone with similar fossils of Australia and South Africa (Anderson and Anderson 1985; Edwards 1990; Young 1993; McLoughlin and Long 1994).

The Beacon Heights Orthoquartzite is remarkably quartz rich, and comparable in mineralogical composition to the Middle Devonian Blinkberg Sandstone with *Haplostigma* in South Africa and the Late Precambrian Rawnsley Quartzite with Ediacaran fossils in South Australia (figure 2). These three fossil matrices are also similar in having a clear mode at 7 grain contacts per grain (figure 2), an indication of deep burial. The average number of grain contacts is 3 at burial depths of 1 kilometer (km) but increases to 5 by 2.5 km, as grains are forced together by compaction (Taylor 1950). The thickness of overburden above the Ediacaran fossils is about 5.8 km, and above the South African *Haplostigma* is 5.7 km (Retallack 1994). Only 1 km of overlying sediments are known from Victoria Land if one includes the likely Jurassic volcanic sequence of the Coombs and Allan Hills (Coates, Stricker, and Landis 1990). Depth of burial was probably more like 2 km considering the low volatile bituminous rank of coals in the overlying Weller Coal Measures distant from heating effects of dolerite or 3 km if local semianthracite coals are a result of having been buried rather than heated by dolerite intrusions (Coates et al. 1990).

The measured lycopsids all consist of a length of axis suitable for multiple determinations of width, as well as a covered portion that was cut perpendicular to the axis with a diamond saw to allow multiple measurements of thickness. Measurements were made with Vernier calipers accurate to 0.1 millimeter (mm), and means and standard deviations were calculated (table). Only maximum values were plotted for comparison with other fossils (figure 3), because this was where the complete diameter of the cylindrical stem was represented in horizontal and vertical planes. The former thickness of fossil logs is equal to their width, because their lateral spread is checked by lithostatic pressure at the sides (Walton 1936; Briggs and Williams 1981; Rex and Chaloner 1983). Thus, compaction of fossil logs can be calculated as a fraction of thickness over width (figure 3). Antarctic *Haplostigma* was compacted to between a 10th and a 40th of its former diameter. These fossils fall within and near the field defined by Pennsylvanian lycopsids (figure 3). Gymnosperm logs are much more resistant to compaction, but Ediacaran fossils show comparable compaction to lycopsid trunks.

These data can be used to constrain the physical strength or thickness of the fossils. The outstanding compaction resistance of gymnosperm wood buried 4.4 km in quartz sand-

Thickness and width of antarctic* Haplostigma *stems

Specimen	Width (mm)					Thickness (mm)				
	n	Average	σ_n	Minimum	Maximum	n	Average	σ_n	Minimum	Maximum
F35025A	16	14.25	0.31	14.1	15.3	11	0.65	0.20	0.3	0.9
F35025B	12	24.73	0.96	23.2	26.5	25	0.60	0.10	0.3	0.9
F35025C	5	13.14	0.33	12.7	13.5	13	0.66	0.21	0.3	1.0
F35025D	21	9.55	0.89	8.1	10.8	9	0.44	0.08	0.3	0.6
F35025E	5	12.88	0.57	12.2	13.6	10	0.71	0.15	0.4	0.9
F35025F	7	19.00	1.38	16.6	20.7	14	0.55	0.17	0.3	0.8
F35025G	16	6.77	0.32	6.4	7.4	10	0.31	0.07	0.2	0.4
F35025H	13	15.33	0.46	14.8	16.1	13	0.53	0.13	0.3	0.7
F35025I	11	9.06	0.43	8.5	9.8	10	0.52	0.15	0.3	0.8
F35025J	10	17.22	0.76	15.4	18.1	13	0.75	0.12	0.5	0.9

stone (Retallack 1994) may be due to their dense, xylem-rich (pycnoxylic) wood. Lycopsids by contrast had secondary cortex and wood that is softer with fleshy cells (manoxylic; Taylor and Taylor 1993). Antarctic *Haplostigma* buried some 2 km is compacted to a similar degree to South African *Haplostigma* buried 5.7 km or Pennsylvanian *Syringodendron, Knorria,* and *Stigmaria* buried 4.4 km (Retallack 1994). The antarctic *Haplostigma* were thus manoxylic woody plants comparable to Pennsylvanian lycopsids better known from permineralized specimens (Taylor and Taylor 1993). The antarctic lycopsids were neither succulent nor completely herbaceous. They were also comparable in compaction resistance to the enigmatic Ediacaran fossils, if one assumes that Ediacaran fossils were as thick as they are wide. This seems unlikely considering the discovery of Ediacaran fossils on slabs as thin as 6.7 mm created by a single ripple train (Condon collection specimen F34288; argument recently suggested to me by J.J. Sepkoski). These measurements are thus evidence that Ediacaran fossils had some kind of tough biopolymer, comparable to lignin of vascular plants, perhaps the chitin of lichens (Retallack 1994). Measured thickness of compressed fossils in quartz sandstone can thus be used to assess former physical properties of organisms.

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