Middle Devonian paleosols and vegetation of the Lashly Mountains, Antarctica

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Fossil plants are rare in the Devonian Aztec Siltstone (McLoughlin and Long 1994) because it consists primarily of highly oxidized paleosols that are unsuitable for plant preservation (McPherson 1979, 1980). Nevertheless, the paleosols contain root traces and their profile form reflects general vegetation types. Paleosols of the Aztec Siltstone are especially impressive for their development of subsurface clayey horizons and large root traces of the kinds usually associated with woody vegetation. These paleosols may represent an early phase in the evolution of woody vegetation and its soils. These are the oldest known soils of such vegetation given the geological age of the Aztec Siltstone, which Young (1993, pp. 208–251) estimates using fossil fish and pollen as later Middle Devonian or, more specifically, the *hernani-cristatus* and *varcus* conodont zones of the Givetian (rather than Late Devonian or Fammenian, as previously thought).

Our detailed observations were confined to the central part of the Aztec Siltstone on a steep ridge southeast of Mount Crean [77°52.4'S 159°32.0'E; 43–91 meters (m) in section L2 of the formation of Askin et al. (1971), corresponding to *Bothriolepis askinae* and younger *B. kohni* zones of Young 1988]. This part of the formation was measured and described (figure 1), with particular attention to paleosol development, color, and reaction with acid (following Retallack 1988, pp. 1–20). These and other features of the paleosols were used for a field classification into five pedotypes (paleosol types), which are thought to reflect particular ancient environments (Retallack 1994b). Pedotypes can be named after localities, but because localities are rare in Antarctica, we named them after antarctic geologists Barry McKelvey, Ken Woolfe, Janet Crump, Peter Barrett, and Rosemary Askin. Both Barry and Ken pedotypes have relict bedding, root traces, and burrows, but Barry profiles are red claystone and Ken pedotypes are gray to orange sandstone. Peter pedotypes are massive to weakly bedded, complexly cracked green claystones, with root traces and burrows. Janet and Rosemary pedotypes are a meter or more thick and red, with a subsurface accumulation of carbonate nodules better developed than subsurface accumulations of clay in Janet profiles and subsurface clay more impressive than carbonate accumulation in Rosemary pedotypes. Janet paleosols also were abundant at the end of the long ridge extending southeast from Mount Crean [section L1 of Askin et al. (1971); illustrated by Barrett et al. (1971), figure 4, and McPherson (1979) figure 6]. The red, calcareous Janet and Rosemary paleosols show impressive development for profiles of such great geological antiquity and provide new insights into Devonian climate and vegetation.

A subhumid paleoclimate is indicated by Janet and Rosemary profiles studied in detail (47 and 91 m in figure 1). These have horizons of calcareous nodules 46 and 115 centimeters (cm) below the surface, respectively (figure 2*A*). These are two extremes of an average depth for nodules in these paleosols of about 1 m (McPherson 1979). Depth of calcareous nodules in modern soils is related to mean annual rainfall and biological productivity (Retallack 1994a). For paleosols, the measured depth must be corrected for compaction during burial. A local measured overburden of 735 m includes little of the likely Jurassic volcanic sequence that increases overburden to 975 m north of the Mackay Glacier (Coates, Striker, and Landis 1990). Depth of burial was probably more like 2 kilometers (km) considering low volatile bituminous rank of coals in the overlying Weller Coal Measures distant from local heating effects of dolerite, or 3 km if local semianthracite coals are due to burial rather than being heated by dolerite intrusions (Coates et al. 1990). The most likely estimate of 2 km can be used in a standard equation of Sclater and Christie (1980) to calculate original depth of the calcic horizon as 55 cm for Janet pedotype and 140 cm for Rosemary. These depths correspond to mean annual rainfalls of 456±141 millimeters (mm) and 779±141 mm, respectively, using the formula of Retallack (1994a). These results are not significantly changed for burial depths in the range 1–3 km, which give original depths to the calcic horizon of 52–59 and 129–147 cm and rainfall of 437–471 and 747–797 mm per year for Janet and Rosemary pedotypes, respectively. The rooting, the depth of ferruginization, and weathering of minerals in these profiles are suggestive of a warm climate, probably subtropical to tropical. It was also a seasonal climate judging from intergrown carbonate and ferruginized surfaces in nodules of the paleosols (figure 2*A*) and from abundant sand-filled cracks within the paleosols (figure 2*C,D*). Modern soils comparable to Janet and Rosemary pedotypes are found in floodplains of India, particularly Sadhu and Gogji Pather Series soils of Murthy et al. (1982) and profiles PA6 and PA7 of Srivastava et al. (1994), which are Vertic Ustochrepts and typic Haplustalfs, respectively, forming under monsoonal tropical climates of 580–820 mm mean annual rainfall.

Modern soils such as the Janet and Rosemary pedotypes support monsoon forest vegetation of sal (*Shorea robusta*), but such dicot trees have a fossil record no older than early Miocene (Retallack 1991). The Aztec Siltstone was deposited at a time of the oldest known fossil trees, which are best known in upper New York state where they include tree lycopsids such as *Eospermatopteris* (Pigg 1992) and progymnosperms such as *Archaeopteris* (with trunks of *Callixylon*; Banks, Grierson, and Bonamo 1985). The Aztec Siltstone also has yielded fossil wood. Although J. Collinson (personal communication to Edwards 1990) considered that these specimens fell from overlying Permian or Triassic strata, Plumstead (1964) states that they were collected in place with Devonian fish remains. One of us

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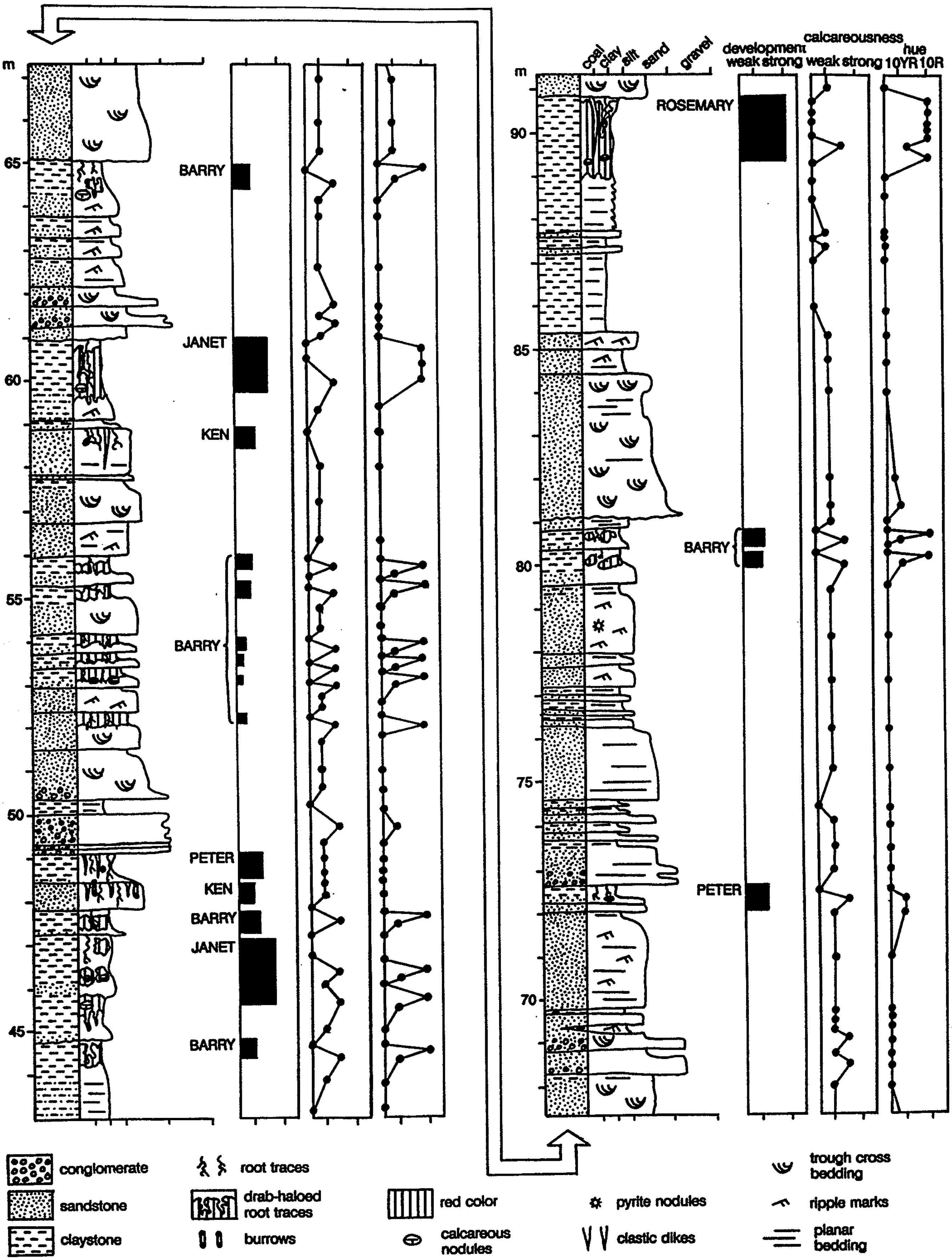

Figure 1. Measured section of the central part of the Aztec Siltstone in ridge 1 km southeast of Mount Crean, southern Victoria Land, Antarctica (meter levels as for section L2 of Askin et al. 1971). Hue is from a Munsell Color chart; calcareousness and development are from scales of Retallack (1988).

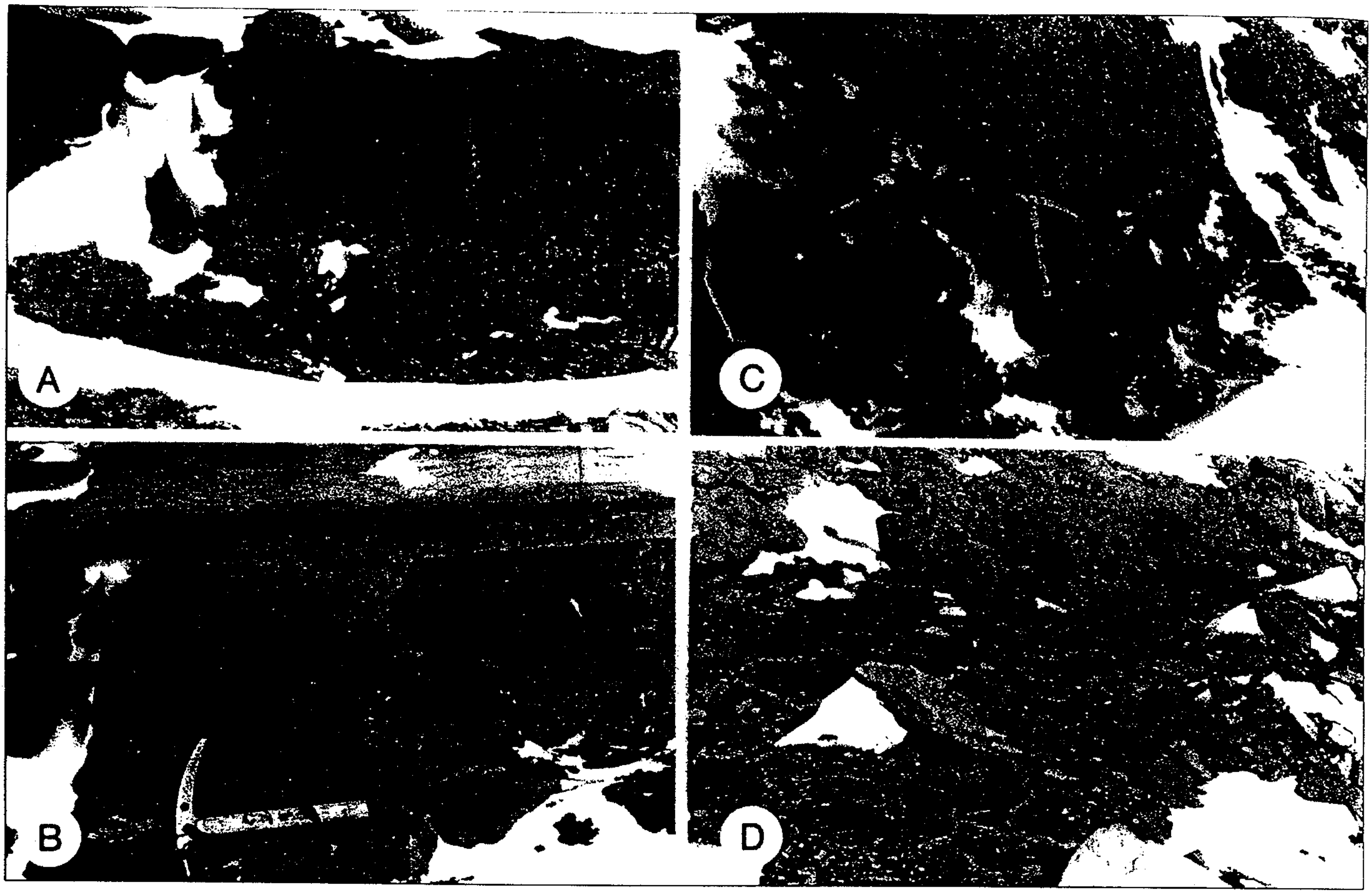

Figure 2. Paleosols in the Aztec Siltstone at Mount Crean, southern Victoria Land. A. Drab-haloed root traces in type Janet paleosol 1 km southeast of Mount Crean (47 m in figure 1). Hammer shows scale. B. Cradle knoll (treethrow structure) in Janet paleosol 3 km southeast of Mount Crean (57 m in section L1 of Askin et al. 1971). Ice axe shows scale. C. Deep cracks in section of Janet paleosol 3 km southeast of Mount Crean (50 m in section L1 of Askin et al. 1971). Hammer shows scale. D. Deep cracks in plan of type Rosemary paleosol 1 km southeast of Mount Crean (50 m in section L1 of Askin et al. 1971). Ice axe shows scale.

(Retallack) has examined these specimens in the New Zealand Geological Survey at Lower Hutt. One (B686.1) is a woody stem 5.1 mm wide with alternate branches and the other (B686.2) is a fragment of woody trunk that is incomplete, as can be seen from disrupted growth rings, but 34.8 mm wide. Both are compressed and coalified, so that petrographic thin sections were not revealing. Nevertheless, these specimens are similar to trunks and plagiotropic shoot systems of *Archaeopteris*, which is known to have produced spores of *Geminospora lemurata*, also found in the upper Aztec Siltstone (Playford 1990, pp. 51–70). Also in the Aztec Siltstone are stems of the protopteridophyte *Praeramunculus alternatiramus* and the lycopsid *Haplostigma lineare* (McLouglin and Long 1994). Both are herbaceous plants and found in quartzite, so are possible candidates for the slender root traces found in Ken paleosols. Janet and Rosemary paleosols, on the other hand, contain a variety of fossil roots and other features suggestive of some of the oldest woodlands. Both pedotypes are riddled by drab-haloed, woody root traces (figure 2*A*) of a kind common in paleosols of woodland and forests (Retallack 1976, 1991). Both pedotypes also show common, large, irregular disturbances in the upper part of the profile (figure 2*B*) comparable to disruption created by tree fall. Asymmetric upheavals of the soil surface are created when trees fall over so that a soil mass is held within the disk of stout surface roots and then falls back after the trunk rots (Johnson et al. 1987; Schaetzl 1990). Such large disruptions could be confused with shallow vertebrate burrows, but the Aztec Siltstone predates the late Devonian evolution of tetrapods (Ahlberg 1995). The drab-haloed root traces and surface disruptions, together with the impressive thickness and development of Janet and Rosemary paleosols, are evidence that they represent some of the oldest woodland ecosystems.

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