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9. For simplicity and to ensure conservation, we calculated the salt flux by assuming that 100 percent of the salt content (35 per mil) was rejected immediately upon freezing. Similarly, melting was treated as a reduction in salt content of the top layer of the ocean proportional to the ice melt rate multiplied by a salinity of 35 per mil.
10. This forcing is done by adding additional source terms to the heat and salt conservation equations of the form $R(T_0 - T)$ and $R(S_0 - S)$. Here R is a relaxation constant taken to be 0.333 per year, and T_0 and S_0 are, respectively, the mean annual temperature and salinity fields.
11. The main open ocean boundary occurs five grid cells south of Iceland, where a wall has been assumed. Over the four rows of grid cells nearest this wall the diagnostic forcing is made stronger.
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14. In the selection of forcing fields, the approach was to use climatological data wherever possible. However, it is important to use daily winds to force the ice model in order to simulate the deformation-induced ice growth. Since buoy drift data (*15*) were available for the FGGE year, this year was chosen for forcing winds. Although the mean climatological winds may differ from the FGGE mean winds, these differences will not have major effects on the baroclinic currents, which are largely forced by the diagnostic terms in the ocean model. However, for prognostic simulations it would be important to use wind fields whose annual mean is closer to climatological data.
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7 October 1983; accepted 29 December 1983

Early Land Animals in North America: Evidence from Devonian Age Arthropods from Gilboa, New York

Abstract. *A new fossil site near Gilboa, New York, is one of only three where fossils of terrestrial arthropods of Devonian age have been found. The new Gilboan fauna is younger than the other two but richer in taxa. Fragmentary remains and nearly whole specimens assigned to Eurypterida, Arachnida (Trigonotarbida, Araneae, Amblypygi, and Acari), Chilopoda [Craterostigmatomorpha(?) and Scutigeromorpha(?)], and tentatively to Insecta (Archaeognatha) have been found. The centipedes and possible insects may represent the earliest records known for these groups.*

Although the earliest records of terrestrial animal life occur in the Silurian, the record is sparse (*1, 2*). Silurian and Devonian fossil scorpions, long held to be the earliest land animals, have now been shown to have been fully aquatic and to have shared the marine or brackish sublittoral zone with their close relatives, the eurypterids (*3, 4*). On the other hand, some xiphosurans (*5*) and a few eurypterids (*4*) had adaptations suggesting that they were capable of brief excursions on land. There is weak evidence for land animals in the Silurian, consisting of fragmentary remains of millipede-like myriapods, including *Necrogammarus* of Ludlow time, formerly interpreted as a crustacean. Genuine myriapods appear first in the Scottish Old Red Sandstone, the relevant part of which now appears Silurian (Upper Pridoli), rather than Devonian, as had been presumed (*2*). Land plants had begun to emerge in the Silurian as well (*6*), but records are relatively scarce until Devonian time, when a complex flora of rhyniophytes, zosterophylls, trimerophytes, lycopods, and progymnosperms was abundantly preserved.

A rich deposit of plant fossils was discovered in 1971 in lenses in the Panther Mountain Formation near Gilboa, New York, during excavations for the Blenheim-Gilboa pumped storage project (*7, 8*). The fossil-bearing rocks, fine-grained black mudstone, were deposited in the Middle Devonian "Catskill Delta" in the Tioughniogan Stage of the Erian Series, corresponding to the Middle Givetian in Europe, about 376 to 379 million years old (*9*).

Material of a new lycopsid, *Leclercqia complexa*, was recovered by hydrofluoric acid digestion (*8*). During the preparation of material, hundreds of fragments were discovered that appeared to be arthropod cuticles, as well as several whole and partial specimens of identifiable arthropods. We ruled out the possibility of recent contamination because of (i) the presence of extinct or extopic taxa, or both; (ii) the extensive and characteristic alteration of the remains; and (iii) the ordinary precautions taken to exclude contamination by recent plant material such as spores and pollen. Because arthropod remains have been found only in association with the leafy axes of *L. complexa*, we hypothesized that mats of these stems acted as filters, removing remains and exuviae of small arthropods from the water percolating through them.

The mode of preservation of these arthropod fossils is unusual. Flattened almost to two dimensionality, the fossils are translucent and appear to retain many characteristics of unaltered cuticular material. They are flexible and tough

Table 1. Devonian localities yielding terrestrial animal remains.

Locality and age	Aquatic or amphibious fauna	Terrestrial fauna	Plants	Deposition and habitat
Alken an der Mosel Lower Emsian (*3, 4*)	Many eurypterids, a possible merostome, one aquatic scorpion	Two possible genera of trigonotarbids, one arthropleurid, one unidentified arthropod, one possible spider	Lycopsids and psilopsids	Fine-grained black shale laid down in standing water; shallow brackish lagoon with emergent and marginal vegetation
Rhynie Upper Emsian? (*2*)	One lepidocarid crustacean, possible merostome	Three or more possible species of trigonotarbids, one mite, one (unlikely) spider, one collembolan, unidentified chitinous jaws	Bog- or peat-forming algae and lycopsids	Bog or lake margin; suddenly flooded by hot silicified water, producing chert
Gilboa Givetian	Probable eurypterid	Two or more trigonotarbids, two centipedes, one mite, possible amblypygid, one spider, undetermined arachnids, possible insects	Terrestrial progymnospermopsids and lycopsids	Delta deposit of black mudstone; material transported, probably not far; no evidence of tidal deposition

enough to be removed from the acid bath with forceps, washed, and mounted on slides. Examination with light in the compound microscope revealed cuticular sense organs, fine setae, and details of microsculpture. These fossils are fully comparable to the eurypterid cuticles etched from Silurian limestones (*10, 11*).

The fossils of terrestrial arthropods include arachnids, centipedes, and possible insects, as well as pieces too small or fragmentary to diagnose. The arachnid material includes complete and partial specimens of at least two distinct members of the extinct order Trigonotarbida, one of which differs at the generic level from any previously known (Fig. 1A). Trigonotarbids first appear in the fossil record in the Early Devonian and continue into the Late Carboniferous; they are evidently the sister group of the extant orders Araneae and Amblypygi taken together. Both of these orders may be represented among our fossils. The leg tip shown in Fig. 1B closely resembles that of living spiders, with a small deflexed median claw and terminal group of setae, both adaptations to handling silk. The lateral claws differ from those of most web-building spiders, however, in that they lack teeth. This leg tip does not resemble the two-clawed tarsi found in a few trigonotarbids. The appendage tip shown in Fig. 1C may be from the pedipalp of an amblypygid.

The most complete fossil is an oribatid mite (Fig. 1D) diagnosed by R.A.N. as a member of the supercohort Palaeosomata, family Ctenacaridae. This specimen is the oldest known oribatid mite and also represents the only identifiable component of the fauna so far recovered that is probably not a predator. Living ctenacarids feed on fungi or decomposed leaf material.

Chilopoda, centipedes, are found in our material with two possible orders represented. The forcipules (poison jaws, first trunk appendages) shown in Fig. 1E have features that ally them to living members of the order Craterostigmatomorpha, a group now known only from Tasmania and southern Australia. These features include the combination of complete distal podomeres with a divided coxal plate bearing on each side a distinct toothed process. The evolutionary position of this order, which includes only a single described species, is controversial (*12*). Fragments of legs with distinctive sawtooth edges, as well as fragments of tergites with characteristic microsculpture, may belong to a member of the order Scutigeromorpha. The oldest fossils of centipedes previously known are from the Carboniferous Mazon Creek (Illinois) locality, and include a scutigeromorph and a putative scolopendromorph (*13*).

Disarticulated annuli and flagella variously represent arthropod tarsal elements, antennae of myriapods or hexapods (or both), potential cerci and terminal caudal filaments of hexapods, and perhaps parts of the apically annulated sensory forelegs of amblypygids. A portion of a head capsule bearing a globose compound eye with massed hexagonal facets (Fig. 1F) may be insectan (*14*). Several partial terga have distinctive transverse rows of empty coffin-shaped sockets for now-absent scales. Among recent terrestrial arthropods, the shape and pattern is found only in the insect order Archaeognatha, specifically the scaly Machilidae. The eye fragment is also reminiscent of Archaeognatha. If confirmed by subsequent finds, these would be the oldest insect remains (*15*). The earliest fossil Insecta at present are Pterygota from several sites and levels of the Namurian of the Upper Carboniferous (*16*).

Aquatic or amphibious arthropods are represented by patches of cuticle and fragments, probably of leg coxae, from a very small eurypterid. These bits and pieces closely resemble the more complete specimens of *Baltoeurypterus tetragonophthalmus* (*11*).

Definitively terrestrial arthropods of Devonian age are known from only two

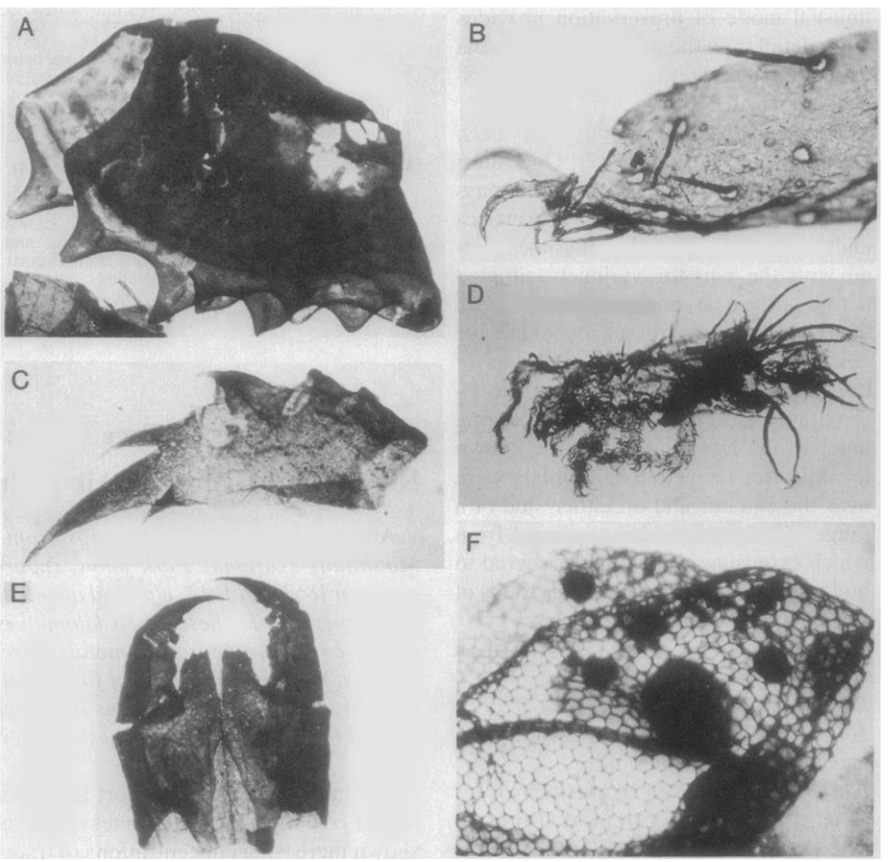

Fig. 1. Fossils of Devonian terrestrial arthropods recovered by hydrofluoric acid digestion from mudstones in the Panther Mountain Formation near Gilboa, New York. (A) Carapace (2 mm long) of a new genus of Trigonotarbida in lateral view. The three-dimensional appearance of the fossil is illusory; the specimen is compressed laterally. The open spaces at the anterior end are eye lenses; evidently each lateral eye consisted of three large-lensed units and four small-lensed ones. A pair of median lenses occurs on the dorsal surface between the lateral eyes. (B) Tip of a leg tarsus (0.35 mm wide) diagnosed as belonging to a spider. The details of cuticular sculpture and setation visible are typical of the better preserved Gilboa fossils. (C) Terminal segment of an appendage (0.65 mm long) diagnosed as the pedipalp tarsus of an amblypygid. The fossil differs from extant examples in the apparent lack of a suture between the tarsus and the claw and in the presence of what appear to be macrosetal sockets on the prolateral side (uppermost in this photograph). (D) Whole specimen of a mite (0.42 mm long) assigned to the extant family Ctenacaridae. The fossil seems to differ from previously known forms in the distribution of the large, presumably erectile, setae on the posterior part of the body. (E) Forcipules (poison jaws, maxillipeds, first thoracic appendages) of a centipede resembling those of modern craterostigmatomorphs (width at appendage bases, 0.9 mm). (F) Lens complex of a compound eye tentatively identified as belonging to a machilid insect. (The individual facets are 0.026 mm in diameter.) The presence of machilids is also based on characteristically sculptured and ornamented scraps of tergites.

other localities: Rhynie, Scotland, and Alken an der Mosel, West Germany (*2*). Paleoecological data on these two sites and on Gilboa are summarized in Table 1. Modes of preservation differ. The Alken fossils appear as carbonized films in a fine-grained black shale, though some of the eurypterids are represented by thicker pieces of carbonized cuticle. These classic fossils, although well preserved, lack detail. The Rhynie fossils are found embedded in a brittle, glassy chert, thoroughly mixed with silicified plant material. The preservation is excellent but the fossils have not been removed from the matrix, and most of them have been discovered accidentally while chipping specimens for studies of plants. The Gilboa fossils are the youngest of the three assemblages, but their unusual mode of preservation provides more detail than the others and the fauna appears to be richer in undoubted terrestrial animals.

Devonian paleogeography has been variously reconstructed (*17*). One interpretation (*18*) shows a continental mass composed of the present North America and northern Europe (Laurussia), located with the equator variously situated across either its northern or southern quarter, and transgressed by extensive epicontinental seas. Reconstructions of the paleoclimate and lithofacies of western Laurussia (*19*) suggest that during much of the Devonian, the three known localities for terrestrial arthropods were near the equator and on either side of a range of mountains (the Acadians) from which extensive sediments weathered to build the massive noncalcareous rocks of the Devonian system in this area.

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12. We retain a separate ordinal name for this group, although it has also been placed near or in the Lithobiomorpha or Scolopendromorpha. R. Crabill (personal communication) believes it to be closest to the lithobiomorphs, but one of us (E.L.S.) believes the forcipules, some partial head capsules, and some legs belong to a primitive lithobiomorph type unrelated to Craterostigmatomorpha, which are considered highly specialized.
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15. This does not affect the status of the collembolan *Rhyniella* from the Rhynie Chert of the Middle Devonian Eifelian Stage, preceding the Givetian of the Gilboan assemblage. Springtails, primitively wingless hexapods, together with Protura and Aptera form the sister group to the Insecta. The most generalized Insecta are the primitively wingless Archaeognatha. The earliest record of the Archaeognatha is in the Muscovian Stage of the Upper Carboniferous, where they appear as members of the specialized suborder Monura. The earliest record of Machilidae is in the Carnian of the Upper Triassic [W. Hennig, *Insect Phylogeny*, A. C. Pont, Transl. and Ed. (Wiley, New York, 1981), pp. 87–119].
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8 November 1983; accepted 23 February 1984

Trace Elements in Tree Rings: Evidence of Recent and Historical Air Pollution

Abstract. *Annual growth rings from short-leaf pine trees in the Great Smoky Mountains National Park show suppressed growth and increased iron content between 1863 and 1912, a period of smelting activity and large sulfur dioxide releases at Copperhill, Tennessee, 88 kilometers upwind. Similar growth suppression and increases of iron and other metals were found in rings formed in the past 20 to 25 years, a period when regional fossil fuel combustion emissions increased about 200 percent. Metals concentrations in phloem and cambium are high, but whether they exceed toxic thresholds for these tissues is not known.*

Our investigations with short-leaf pine (*Pinus echinata*) in East Tennessee have shown increasing concentrations of trace metals in annual growth rings since the 1950's and relatively high concentrations in the cambial area. For most elements, ring content was serially correlated with growth; however, since the 1970's metals content in rings increased while growth rate decreased. In the Great Smoky Mountains National Park (GSMNP) iron not only increased since the 1950's, as did regional increases in fossil fuel combustion emissions, but also between 1863 and 1912 when trees may have been exposed to SO_2 and combustion products from copper ore smelting at Copperhill, Tennessee. These observations suggest that multielement analysis of tree rings can provide information on temporal changes in air pollution, acid deposition, or both.

Tree rings have been used to construct records of climate (*1*), document heavy metal pollution (*2–4*), and study the relation between growth and air pollution (*5*). Now they are being used to examine the relation between growth and acid rain (*6*). Ulrich (*7*) proposed that acid precipitation increases concentrations of Al and Fe in the soil solution. If such an increase is reflected in the chemical composition of wood, then patterns of change of these and other metals in tree rings could be used to infer temporal changes in rain acidity and associated increased metals deposition from burning of fossil fuels in recent years (*8*). We