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Paleobotany of the classic redbeds (Clear Fork Group – Early Permian) of north central Texas

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Abstract

Recent collecting in the Clear Fork Group of north central Texas has resulted in an extensive collection of Early Permian floras that complement an excellent record of terrestrial vertebrates collected over the past 130 years. Nearly all plant macrofossils occur in mudstones deposited in small lakes or sluggishly moving channels, making samples 'isotaphonomic' through the Clear Fork. Thus, knowledge of the vegetational landscape is restricted to riparian and pond-side settings. The regional species pool consists of 30–40 taxa and the flora at any given locality is a subset of this larger species pool. The most commonly occurring elements also are the most abundant quantitatively. These include species of *Comia*, callipterids, *Taeniopteris*, gigantopterids, and conifers. There are many rare elements that occur as one to five specimens each in most collections. The composition of the species pool changes gradually through the Clear Fork as new taxa appear and others disappear, retaining the basic seed-plant dominated aspect of the vegetation. This taxonomic turnover may be driven by changes in regional climate. The sedimentology and paleosols indicate a general trend towards increasing aridity. Clear Fork floras, however, do not reflect this trend clearly. The plants tend to indicate seasonal dryness, reflecting their dependence on the water tables near the rivers and ponds along which they grew, rather than on rainfall alone. Rare deposits, scattered throughout the Clear Fork, are dominated by tree ferns and suggest the existence of very wet places on some parts of flood plains. The persistence of the species pool throughout this interval is not unique in the Paleozoic tropics. It parallels patterns in vegetation from wetlands of Pennsylvanian age, suggesting that persistence at the level of species pool is a common phenomenon on time scales of millions of years.

Keywords: paleoecology, red beds, Permian, Clear Fork, paleobotany, Texas, ecological persistence.

Introduction

The Early Permian of north central Texas (Fig. 1) is characterized by a thick series of terrestrial red beds, largely mudstones and some sandstones, assumed to have accumulated under a strongly seasonal climate that was changing from wetter to drier conditions, on average. These deposits have attracted the attention of vertebrate paleontologists for more than 130 years (Olson, 1958, 1989; Romer, 1958) and have been the source of a great number of specimens, which form the core of our perception of the Early Permian fauna in the northern Hemisphere. Paleobotanists also have shown interest in north central Texas for almost as many years. Most notable are I.C. White (late 1800's) (White, I.C., 1892), David White (early 1900's) (White, D., 1912), Charles Read (mid 1900's) (Read and Mamay, 1964), and Sergius Mamay (mid to late 1900's) (Mamay, 1960, 1967, 1975, 1986). The efforts of these individuals focused on the light gray beds found mainly in rocks older than those of the Clear Fork or on the relatively rare gray beds within the Clear Fork. Even though the red sediments of the Clear Fork Group have been the source of many vertebrate specimens, the red color was thought to indicate oxidation, which was presumed to have destroyed plant remains. It wasn't until the early 1990's that the quality, quantity, and importance of floras in

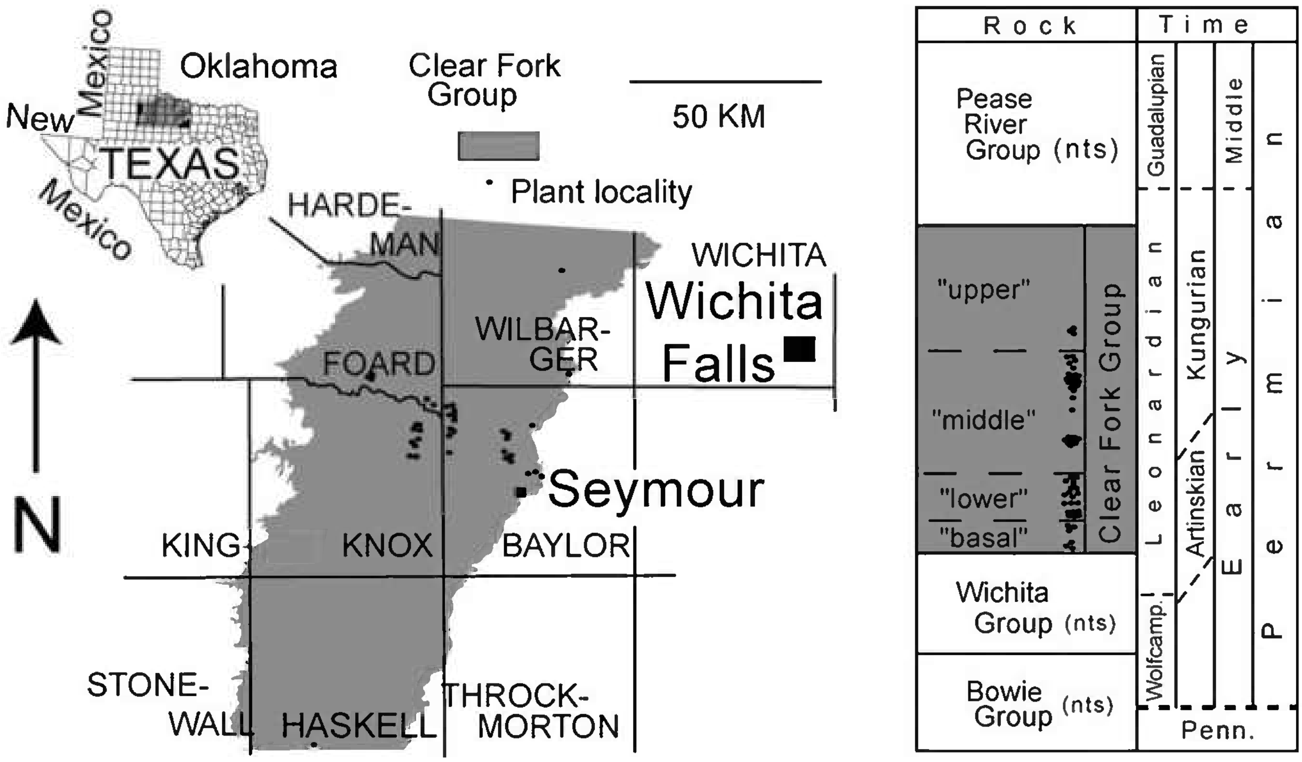

Fig. 1. Index Geologic Map and Stratigraphic Column. Small dots represent approximate positions of plant localities. Thickness of the rock units for the Bowie, Wichita, and Pease River Groups are not to scale. Clear Fork Group, to scale, is approximately 320 m thick. The approximate thicknesses of the divisions of the Clear Fork are 'basal': 30 m, 'lower': 50 m, and both 'middle' and 'upper': 120 m.

the red beds was recognized, and in a matter of two years the number of known localities in the Clear Fork increased from 2 to more than 80. Most of these localities produce fossil plant remains from red clay and siltstones.

Geologic setting

The name Clear Fork was first used by Cummins in 1890 for strata found in Jones County (100 km south of the study area). A year later Cummins (1891) more formally and fully described the Clear Fork strata. In Runnels County (200 km south of the study area) the Clear Fork Group was divided by Beede & Waite (1918) into three formations, which are not recognizable in the study area along the Wichita River (Nelson et al., 2001). In Runnels County the Clear Fork Group consists of inter-bedded marine and terrestrial strata, which facilitate division of the group into three formations – from lowest to highest – Arroyo, Vail, and Choza. Ongoing studies of subsurface data may, in the future, facilitate correlation of the north central Texas exposures with those in Runnels County.

Clear Fork plant fossils are found uniformly in channel-form deposits, and thus, can be considered 'isotaphonomic' in character at that scale (Behrensmeyer & Hook, 1992). These deposits are primarily of two types: finely laminated claystones to silty claystones that accumulated in abandoned channels, and siltstones to fine sandstones that accumulated in sluggish but active channels. In the former, the plant fossils occur often in isolation and frequently as goethite permineralizations. In the active channel deposits, plant fossils generally are found in troughs of active bars, formed during times of slack water. In either case, it is likely, based on actualistic studies of modern environments (Burnham, 1989; Scheihing & Pfefferkorn, 1984), that the parent plants grew on the margins of the channels and thus create the impression of wetter local conditions than may have existed on the landscape in general.

The base of the Clear Fork Group is defined as the top of the Lake Kemp dolomite of the underlying Leuders Formation. The Clear Fork Group in north central Texas is predominantly red silt and fine to medium sand. The lowest 30 m (herein referred to as the 'basal' unit) is a mixture of red paleosols (vertisols) (Tabor et al., 2002), which overprint primary sediments, gray fluvial and coastal plain deposits (Fig. 2A), and thin >0.10 m thick dolomites representing shallow restricted marine transgressive events. Almost all fossil plant remains in the 'basal' Clear Fork are derived from the gray deposits. Above this is ≅50 m (here in referred to as the 'lower' Clear Fork) of coastal plain deposits consisting mainly of red silts,

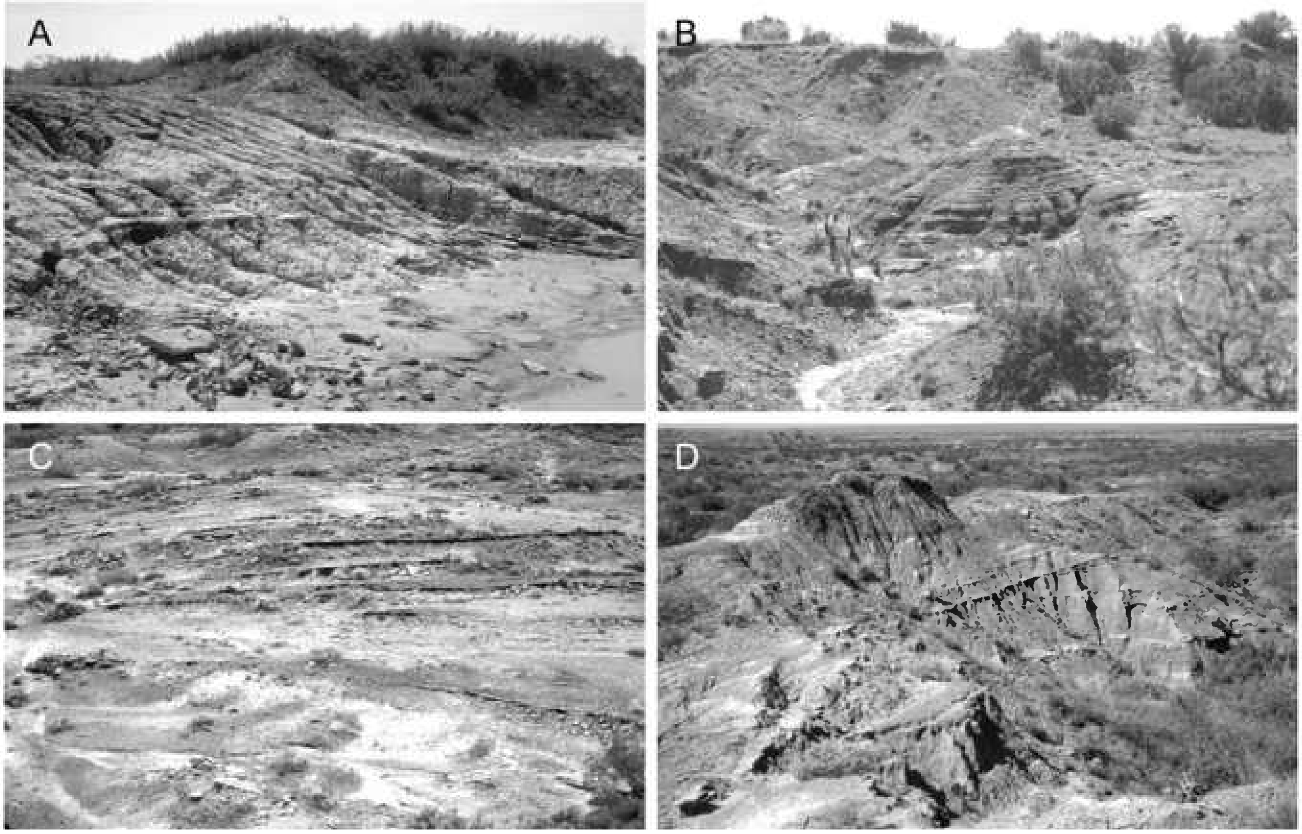

Fig. 2. Clear Fork Outcrops. (A) Harmel Quarry 'basal' Clear Fork sandy light gray beds that produced many of the specimens seen in Fig. 3. (B) North of Cedar Top locality typical of 'lower' and 'middle' Clear Fork clay plugs. The 'U' cross-sectional shape of the deposit is depositional, not tectonic, in origin. Specimens from similar deposits are seen in Figs 4 & 5. (C) Don's Dump area, 'middle' Clear Fork. View from above of erosionally exposed sandstone accretion ridges that underlie clay-filled channels. Note the arc formed by the ridges, typical of an accretionary bar in a meandering channel. (D) Ignorant Ridge 'middle' Clear Fork, red clay and sandstone foreset beds. Specimens are often recovered from the toe of these foresets; such specimens are illustrated in Fig. 5.

many of which are pedogenically overprint (calcic vertisols), and prominent sandstone filled channels. It is in this interval that finely laminated claystone deposits (clay plugs) (Fig. 2B) are prominent, probably sediments that accumulated in ox bow lakes. The vast majority of fossil plant remains found in the 'lower' Clear Fork come from these red clay plugs. The 'middle' and 'upper' Clear Fork are each ≅120 m thick. The 'middle' Clear Fork consists of a combination of clay plugs, paleosols and active channel belts with accretion sets (Fig. 2C) that have forset beds, up to 5 m in height (Fig. 2D). In the upper part of the 'middle' Clear Fork gypsum first occurs as bun shaped nodules indicating syndepositional evaporate conditions (minor secondary gypsum occurs lower in the Clear Fork). As exposed in the Wichita River drainage the 'upper' Clear Fork consists of flat laying red and green clays interbedded with gypsum layers. The fossil plants from the 'middle' and 'upper' Clear Fork occur in both the red clay plugs and the red forset beds. The top of the Clear Fork in north central Texas is marked by an erosional contact with sandstones of the San Angelo Formation.

Age

The Clear Fork Group is Leonardian in age. On the global scale, the Leonardian is equivalent in part to the Artinskian and Kungurian, placing the Clear Fork in the later Early Permian. The Clear Fork Group straddles the Kungurian–Artinskian boundary but due to lack of suitable fossils precise correlation of this boundary is not possible in the study area (DiMichele et al., 2001).

Climate

The Clear Fork was deposited at sea level and in the equatorial belt (Hentz, 1988 and Hentz & Brown, 1987), proximate to sources of marine water in the Midland Basin. Deposition appears to have occurred under a seasonally dry, generally warm and humid climate, moisture generally becoming more limiting during the time of deposition. The best indicators of climatic conditions in the Clear Fork are paleosols (Tabor et al., 2002), which are virtually all vertisols, many with a strongly developed calcic component, formed in modern settings in seasonally wet environments. Studies of red bed origin have found them to be indicators of warm climates rather than dry climates (Gardner & Pye, 1981). Increasing moisture limitation through time is indicated by the appearance of primary gypsum in the middle Clear Fork and its abundance in the upper Clear Fork. However, because plants preserved in channels are derived primarily from streamside habitats, they present a somewhat 'wetter' signature than is inferred from lithological data (DiMichele et al., 2006), although the flora is strongly dominated by seed plants, including many with xeromorphic leaf morphologies. Nonetheless, calamites and pecopterids are rare but persistent elements of the flora, indicating continued existence of wet habitats on the landscape, probably due to ponding of local ground water.

Flora

Plant localities are not uniformly distributed in the Clear Fork (Fig. 1). Taxa of the Clear Fork are listed below by stratigraphic interval and include the number of localities and collections from each interval. A locality is a single, uniform sedimentary environment in a geographically restricted area (usually restricted to a single outcrop); a collection is a single excavation, generally of a square meter or less in surface area confined to this single sedimentary deposit. The lower three intervals have approximately the same number of taxa, whereas only 5 taxa have been identified in the upper unit. Most of the dominant taxa are found at all localities in a given interval. In other words, the floras from an interval are spatially uniform and the lists from each interval are not composites. Obviously, there are rare taxa represented by one or two specimens, known from one or two collections only. The most common and the rarest elements are indicated as such in the floral list.

Those taxa that have affinities for the wettest conditions on the landscape are indicated by H_2O after their names in Table 1. These are spore-producing plants that reached their zenith of abundance and diversity in the Late Carboniferous. They occur in the Permian in much lower diversity, and are rare elements of the regional species pool by the time of deposition of the Clear Fork beds.

Discussion

The flora of the 'lower' and 'middle' Clear Fork Group, and into the basal part of the 'upper' Clear Fork, is remarkably uniform from site to site and through time. Species turnover unquestionably occurs, but newly appearing species generally occur within genera common in the older rocks and usually replace those prior species. Such changes in species composition co-occur with changes in lithological character of the rocks, associated with the transitions between the informally subdivided portions of the group. This flora is dominated almost entirely by seed plants, with rare occurrences of plants that specialize on or require wet substrates. This latter group is represented most commonly by tree ferns (*Pecopteris*), which can occur in stratigraphically and spatially isolated mono-dominant assemblages, and sphenopsids (mainly calamite stems but rarely *Annulara* foliage and *Sphenophyllum*). Very rarely lycopsid stems and various kinds of pteridosperm foliage also may occur.

The flora (Fig. 3) derived from the gray sediments in the 'basal' Clear Fork Group is distinct from those found in the red clays and siltstones of the 'lower' through 'upper' Clear Fork. These assemblages are dominated by taxa that are common to abundant in the later Clear Fork, such as conifers and peltasperms. However, the 'basal' Clear Fork contains a greater number of wet elements than the rest of the Clear Fork. The vertic-paleosols into which the channel deposits are eroded indicate a seasonal climate. It is very difficult, however, to show temporal relationships between the recovered floras and the associated paleosols beyond their co-occurrence in the same interval of the Clear Fork. Nonetheless, the basic isotaphonomic nature of the plant-bearing deposits throughout the section allows the inference of wetter conditions during accumulation of the 'basal' Clear Fork than in the older Virgilian strata of the Bowie Group, and the development of progressively drier conditions during the subsequent history of accumulation.

The 'lower' (Fig. 4) and 'middle' (Fig. 5) Clear Fork intervals have floras that also most likely represent riparian habitats. A remarkable floristic consistency characterizes each of these intervals with the main elements being callipterids, gigantopterids, comioids, taeniopterids, and conifers. Between the 'lower' and 'middle' interval there are notable changes in species composition, but these changes occur almost entirely within genera and the relative proportions of genera remain approximately the same at the landscape level. Diversity also remains essentially the same. Taxa considered to require everwet conditions (spore producers), more common in 'basal' Clear Fork, persist or reappear in isolated spots in 'middle' and 'upper' Clear Fork, occurring as singletons or, rarely, as the dominant element in nearly monotypic assemblages. In the latter instance the dominant elements are almost always pecopterid tree ferns (Figs 3, 4, and 6).

Table 1. Flora of the Clear Fork Group by 'unit'.

"Basal" Clear Fork (Fig. 3A–F) 11 Coll./6 Loc.	"Lower" Clear Fork (Fig. 4A–L) 30 Coll./20 Loc.	"Middle" Clear Fork (Fig. 5A–H) 56 Coll./42 Loc.	"Upper" Clear Fork (Fig. 6) 5 Coll./3 Loc.
Pecopteris (common) H_2O	*Pecopteris* sp. (one monotypic loc.) H_2O	*Pecopteris* sp. (one monotypic loc.) H_2O	*Pecopteris* sp. (one loc. dominant) H_2O
	Sigillaria brardii Brongniart 1828 (one specimen) H_2O		
Calamites (several specimens) H_2O		*Calamites* sp. H_2O	
Annularia (common) H_2O	*Annularia* sp. (two specimens) H_2O		
Sphenophyllum cf. S. thonii Von Mahr (1868) (several specimens) H_2O	*Sphenophyllum* sp. (two specimens) H_2O	*Sphenophyllum thonii* Von Mahr 1868 (one specimen) H_2O	
Walchian conifers	Walchian conifers	Walchian conifers	
Cordaites sp.	*Cordaites* sp.	*Cordaites* sp.	*Cordaites* sp. (one specimen)
	Comia sp.	comioid	
Neuropterid			
	Odontopteris sp.		
		Compsopteris/*Supaia* sp.	
Alethopteris schneideri Sterzel 1918	*Alethopteris schneideri* Sterzel 1918		
Brongniartites sp.	*Brongniartites* sp.	*Brongniartites* sp.	
Peltaspermum sp.			*Peltaspermum* sp. (one specimen)
	Sandrewia texana Mamay 1975	*Sandrewia* spp.	
Phasmatocycas kansana Mamay 1973			
	?Phasmatocycas spectabilis Mamay 1976		
Callipterids	Callipterids	Callipterids	
	Taeniopteris coriacea Göppert 1864	*Taeniopteris coriacea* Göppert 1864	
Taeniopteris (at least two forms)	*Taeniopteris* (2–3 additional forms)	*Taeniopteris* (2–3 additional forms)	*Taeniopteris* (2 or 3 forms)
Cathaysiopteris yochelsonii Mamay 1986	cf. *Cathaysiopteris*	*Cathaysiopteris yochelsonii* Mamay 1986	
Zeilleropteris wattii Mamay 1986	*Zeilleropteris wattii* Mamay 1986		
		Evolsonia texana Mamay 1989	*Evolsonia texana* Mamay 1989
Wattia texana Mamay 1967	*Wattia texana* Mamay 1967	*Wattia* sp.	

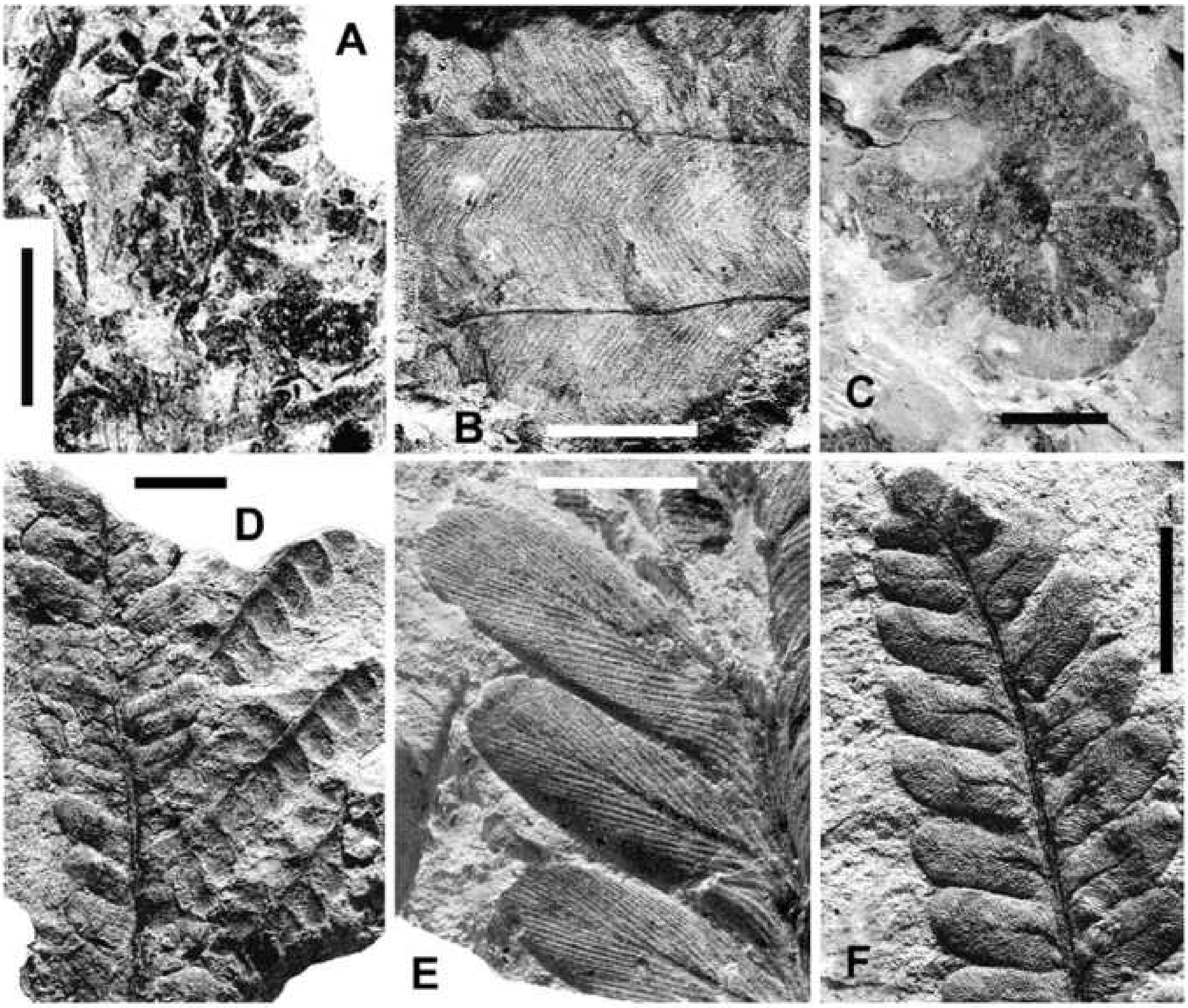

Fig. 3. Flora of the 'basal' Clear Fork Group. (A) *Annularia* sp. USNM 528496, foliage of calamitean sphenopsids, and a dominant element in many Upper Pennsylvanian deposits from north central Texas. (B) *Cathaysiopteris yochelsonii* Mamay 1986, USNM 528495 gigantopterid foliage. (C) *Peltaspermum* sp. USNM 528490, peltasperm reproductive organ. (D) *Pecopteris* sp. USNM 528493, tree fern foliage and a common element in Upper Pennsylvanian deposits. (E) *Callipteris* sp. USNM 528494, peltasperm foliage. (F) *Alethopteris schneideri* Sterzel 1918, USNM 528489, pteridosperm foliage. All bar scales = 1 cm.

The floras from the 'upper' (Fig. 6) Clear Fork are depauperate, consisting of monotypic assemblages with one or two elements. Each locality in this interval is distinct, indicative of the relatively poor preservation and limited number of samples. Plant fossils are known only from the basal most portion of the upper Clear Fork, below the common occurrence of interbedded evaporitic layers. The evaporites suggest a much drier climate in which evaporation greatly exceeded rainfall. The disappearance of plant remains indicates a sparsely or un-vegetated landscape and/or a change in taphonomic parameters such that plant remains were not preserved.

In summary, the flora of the Clear Fork Group is a relatively low diversity seed-plant dominated assemblage consistent with seasonally dry climatic conditions. There is ample plant evidence that wet to swampy areas continued to persist within this seasonally dry landscape, but to an ever-shrinking extent through time. The exceptional preservation of the plants from these rocks, iron permineralizations with outstanding surface and, occasionally, anatomical features, permits many of its components to be characterized to an unusual degree. The association with a variety of animals suggests productive, open vegetation, at least on flood plains, capable of supporting a complex diverse food web.

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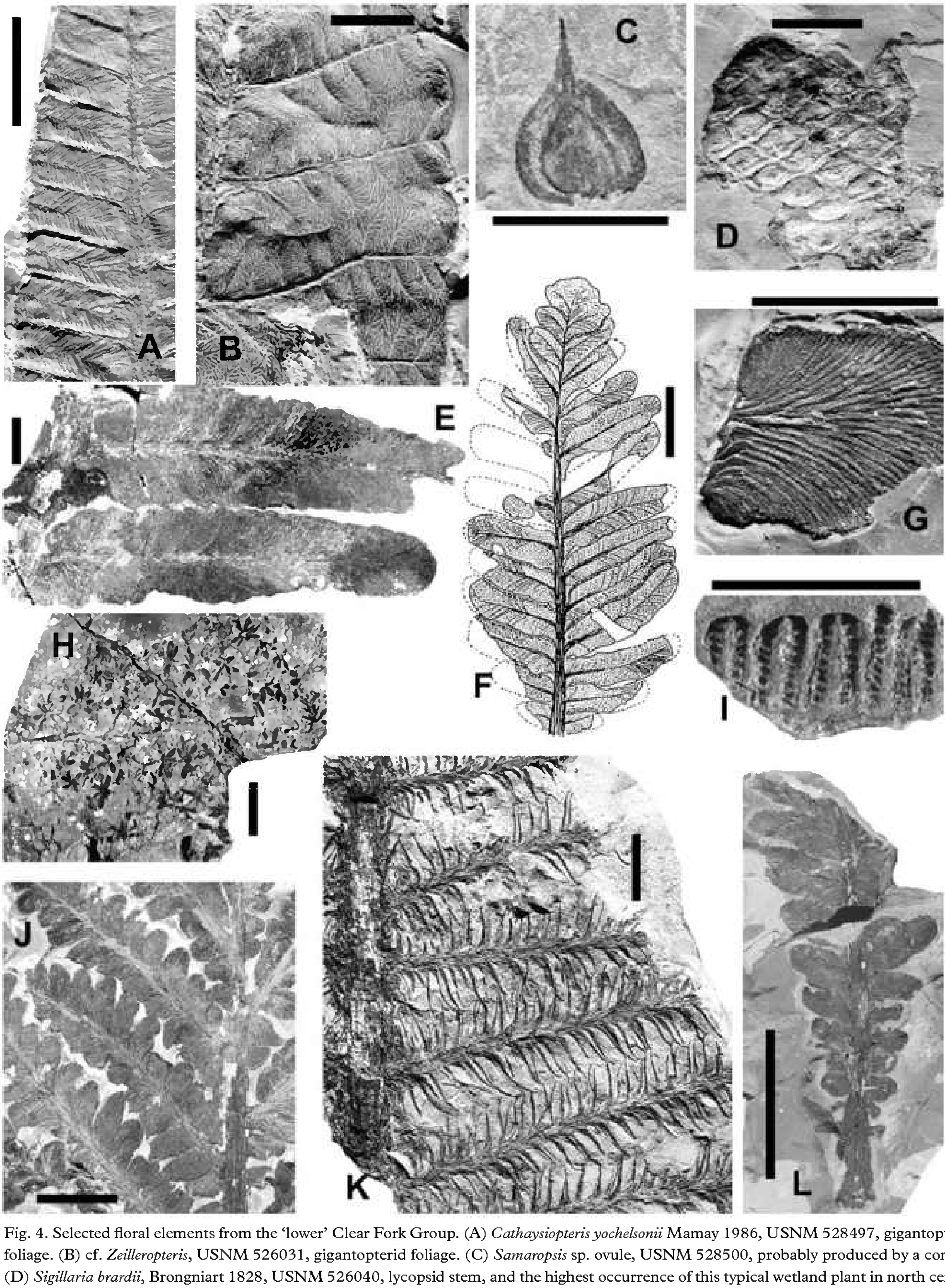

Fig. 4. Selected floral elements from the 'lower' Clear Fork Group. (A) *Cathaysiopteris yochelsonii* Mamay 1986, USNM 528497, gigantopterid foliage. (B) cf. *Zeilleropteris*, USNM 526031, gigantopterid foliage. (C) *Samaropsis* sp. ovule, USNM 528500, probably produced by a conifer. (D) *Sigillaria brardii*, Brongniart 1828, USNM 526040, lycopsid stem, and the highest occurrence of this typical wetland plant in north central Texas. (E) *Comia* sp. USNM 508138, probably peltasperm foliage. (F) *Comia* sp. USNM 508138, camera lucida of whole leaf of (E) showing pinnate architecture. (G) *Odontopteris* sp. USNM 528498, pinnule, pteridosperm foliage. (H) *Annularia* sp. USNM 526041. (I) *Pecopteris* sp. USNM 528488, fertile pinnules. (J) Common callipterid, USNM 526035, peltasperm foliage. (K) cf. *Culmitzschia* sp. USNM 528499, conifer foliage. (L) Problematic likely peltasperm foliage that we are attributing to *Brongniartites* sp. USNM 528116. All bar scales = 1 cm except F and L = 5 cm.

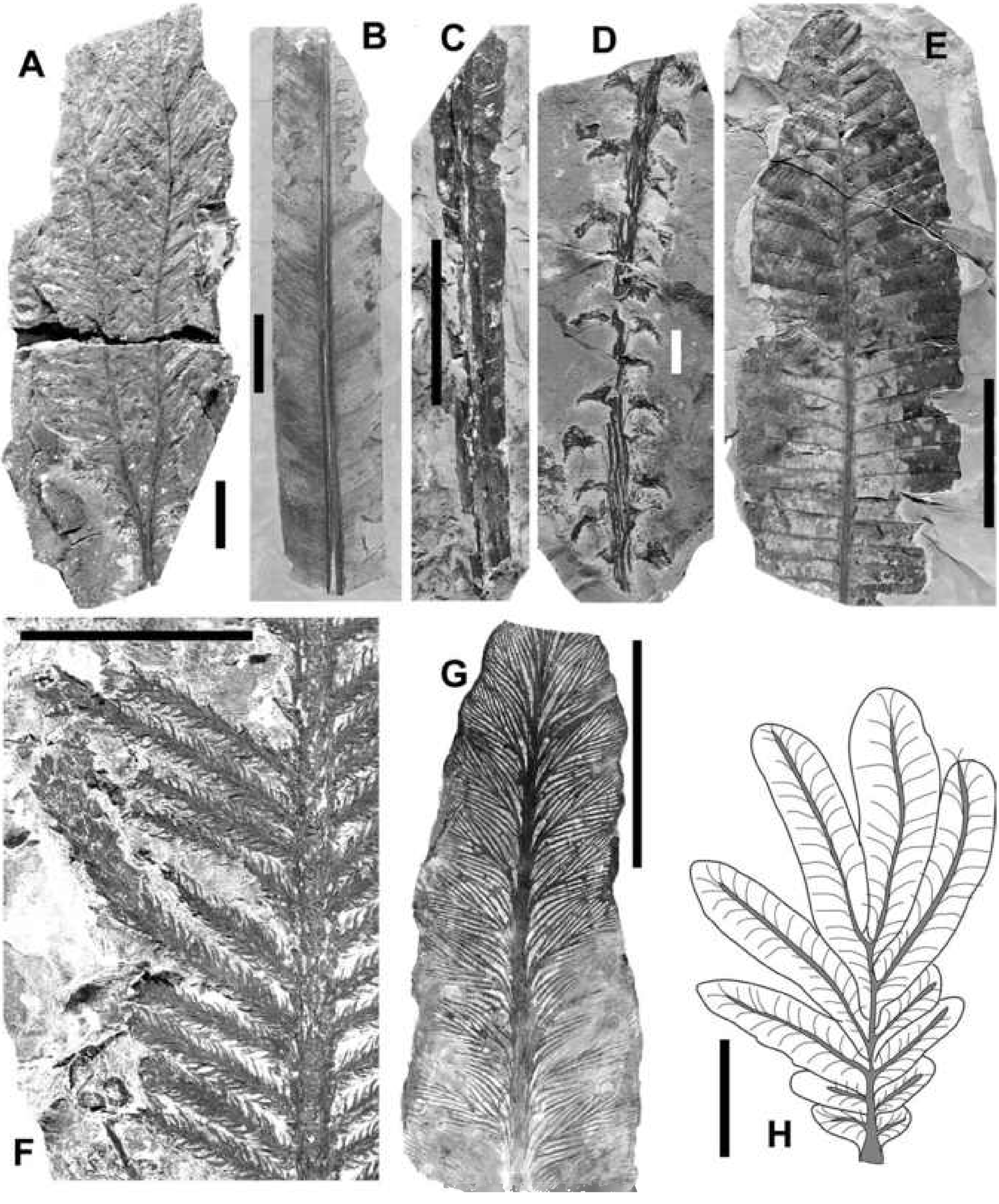

Fig. 5. Selected floral elements from the 'middle' Clear Fork Group. (A) Problematic likely peltasperm foliage that we attribute to *Supaia* sp. USNM 526032, bar scale = 5 cm. (B) *Taeniopteris* sp. USNM 526033, probable cycadophyte foliage, bar scale = 5 cm. (C) *Taeniopteris coriacea*, USNM 528501, foliage of cycad-like plants, bar scale = 1 cm. (D) *Sandrewia texana* Mamay 1975, USNM 528491, peltasperm reproductive organ/inflorescence, bar scale = 1 cm. (E) *Evolsonia texana* Mamay 1989, USNM 528205 gigantopterid foliage. Bar scale = 10 cm. (F) cf. *Walchia piniformis*, Sternberg 1825 emended Clement-Westerhof 1984. USNM 528503, Conifer foliage, bar scale = 5 cm. (G) Comioid, USNM 508137, possibly a new peltasperm genus with venation and leaf architecture, shown in (H) distinct from *Comia* sensu stricto. Bar scale = 5 cm. (H) Camera lucida of comioid leaf architecture. USNM 508135, bar scale = 10 cm.

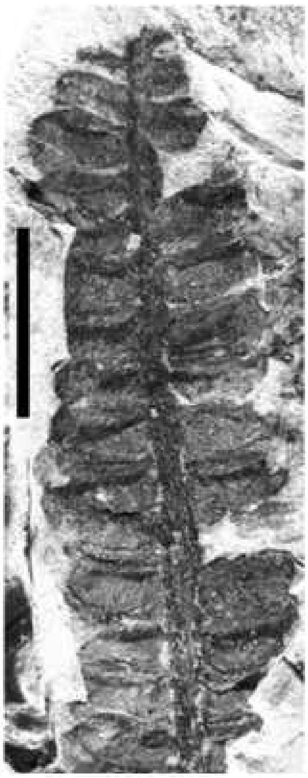

Fig. 6. *Pecopteris* sp. from the 'upper' Clear Fork Group. *Pecopteris* sp. USNM 528502. Other plants in this part of the group are also found in the 'middle' Clear Fork. This is the highest occurrence of tree fern foliage in the north central Texas section, bar scale = 1 cm.

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