

THE KINNEY BRICK QUARRY LAGERSTÄTTE, LATE PENNSYLVANIAN OF NEW MEXICO, USA: INTRODUCTION AND OVERVIEW

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Abstract—The Kinney Brick Quarry, located in the Manzanita Mountains of central New Mexico, is a world-famous fossil locality in deposits of a marine embayment of Late Pennsylvanian age. The quantity and quality of fossil preservation identify Kinney as a Konservat Lagerstätte. This volume presents the results of recent research on the Kinney rocks and fossils, as well as new research based on older collections. Here, we provide a review of previous work and of the context within which to understand the Kinney Quarry Lagerstätte and the articles in this volume. A new look at Kinney, the environment, the animals, plants, and ichnofauna preserved there, was initiated by a controlled excavation carried out in 2014. This excavation revealed additional, more refined information about the sedimentology of the Kinney deposits, and additional information about the distribution of organisms during the period of accumulation.

INTRODUCTION

The Kinney Brick Quarry (Figs. 1-3), located in the Manzanita Mountains of central New Mexico, is a clay pit actively mined for the making of bricks at the Kinney Brick Company plant in Albuquerque, New Mexico. The quarry is also a world-famous fossil locality. These fossils come from deposits of a marine embayment of Late Pennsylvanian age and are remarkable for their diversity, abundance and quality of preservation, which includes the preservation in some cases of soft tissues that normally do not readily fossilize, and a variety of large and exceptionally complete plant remains not well known from correlative deposits. The quantity and quality of preservation identify Kinney as a Lagerstätte (Lucas and Huber, 1991; Kues and Lucas, 1992; Zidek, 1992a).

Scientifically significant fossils were discovered at Kinney by students studying at the University of New Mexico in the early 1960s. In 1992, the first 30 years of research at Kinney were brought together in an edited volume that detailed the stratigraphy, age, sedimentology and paleontology, among other aspects of the Lagerstätte (Zidek, 1992a). The next two decades saw only sporadic research on the Kinney Lagerstätte. In 2009, renewed interest in the stratigraphic position and age of the Kinney deposit ultimately led to the first controlled excavation at Kinney, in April 2014. This renewed research interest and the controlled excavation have produced a wealth of new data on the Kinney biota and its preservational environment. This volume presents the results of this recent research, as well as new research based on older collections. Here, we provide a review of previous work and of the context within which to understand the Kinney Quarry Lagerstätte and the articles in this volume.

SOME HISTORY

The Kinney Brick Company, originally owned by the Kinney family, began to quarry clay and manufacture bricks in 1928. Though the exact date is not certain, quarrying at the current clay pit in Pennsylvanian strata in the Manzanita Mountains began sometime after World War II, in the early 1950s according to Kelley and Northrop (1975), or in 1946 according to Elston (1957). In the 1980s, the family sold the company to Robert Jurgena and Gordon Skarsgard, and they sold it to Ralph Hoffman in 1996. Currently (2018 figures), about 9,000 tons of clay are extracted from the quarry each year to make about 8-9 million bricks at the company's plant in Albuquerque (R. Hoffman, pers. comm., 2020).

Fossils were discovered at the Kinney Brick Quarry in the early 1960s by two University of New Mexico (UNM) students who went on to careers in paleontology, Sidney R. Ash (1928-2019) and John P. Bradbury (1936-2005). Ash discovered fossil insects and plants at Kinney in 1961, and Bradbury found the first fossil fishes there in 1963. These discoveries were reported to Charles B. Read (1907-1979), a paleobotanist who was in charge of the U.S. Geological Survey's office in Albuquerque. Read visited the site and made some preliminary collections. He then contacted Smithsonian Curator David H. Dunkle (1911-1984), who collected at Kinney in 1964, and U. S. Geological Survey paleobotanist Sergius H. Mamay (1921-2008), who collected there in 1967 and 1969 (Fig. 3).

Other members of the paleontological community were soon alerted to the Kinney Brick Quarry as a source of important fossils. In 1971, two high school students living in Albuquerque, Neil Lafon and Thomas Lehman (both went on to careers in geology), found a fossil amphibian at Kinney that was sent to David Berman, a curator at the Carnegie Museum of Natural History in Pittsburgh. Berman (1973) named the amphibian *Lafonius lehmani* after its discoverers and went on to make a substantial collection at Kinney now housed at the Carnegie Museum.

The first scientific publications about Kinney paleontology thus appeared in the 1970s and 1980s (Berman, 1973; Zidek, 1975; Schram and Schram, 1979; Mamay, 1981; Ash and Tidwell, 1982; Kues, 1985). In the late 1980s, the University of Kansas and the New Mexico Museum of Natural History (NMMNH)

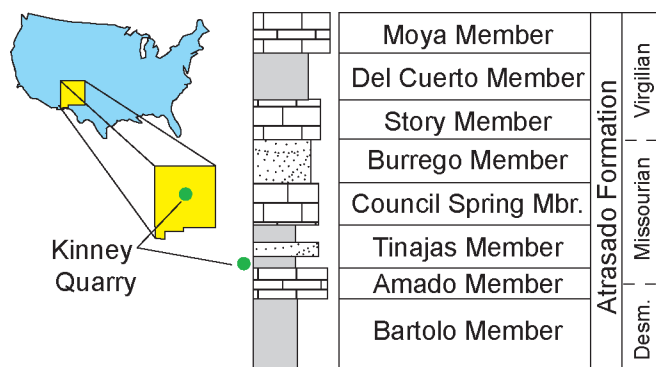


FIGURE 1. Index map and generalized stratigraphy showing location of the Kinney Brick Quarry in central New Mexico.



FIGURE 2. Photograph of part of the Kinney Brick Quarry in 2012. The floor of the quarry (lower right) exposes the basal limestone overlain by the primary fossil-producing interval of mostly dark gray shale. The higher wall of the quarry exposes delta-front and channel sandstones (compare to Figure 7).

both began collecting programs at Kinney. The Kansas collectors focused on the fossil fishes at Kinney and brought in geological collaborators who studied the sedimentation of the deposits at the quarry. The NMMNH collections were made primarily by Phillip Huber, then a student at UNM working with one of us (SGL) (Fig. 3).

However, by 1990, no comprehensive publication on the Kinney Lagerstätte had appeared. In that year, Huber, and Jiri Zidek of the New Mexico Bureau of Mines and Mineral Resources suggested to one of us (SGL) that a special session on Kinney be held at the 1991 meeting of the Rocky Mountain Section/South-central Section of the Geological Society of America (GSA) in Albuquerque. That session was held and brought together much research on Kinney (Archer and Clark, 1991; Feldman et al., 1991; Gottfried, 1991; Huber and Lucas, 1991; Lehman, 1991; Lorenz and Lucas, 1991; Lucas, 1991; Mamay and Mapes, 1991; Mapes, 1991; Shear et al., 1991; Willard, 1991; Zidek, 1991). The GSA session became the basis of the volume edited by Zidek (1992a); it published many new data on Kinney and represented the first synthesis of the stratigraphy, sedimentology and paleontology of the Lagerstätte.

Subsequent collecting at Kinney was sporadic for nearly two decades, mostly by NMMNH volunteers. A fieldtrip of the New Mexico Geological Society visited the quarry in 1999 (Lucas et al., 1999), and, some years later, a fieldtrip took place

during the Carboniferous-Permian transition conference ran by the NMMNH in 2013 (Lucas et al., 2013a). Research interest in the quarry was renewed in 2009. The completion of a detailed study of the Pennsylvanian stratigraphy and biostratigraphy in the Cerros de Amado of Socorro County (Lucas et al., 2009) raised questions about the stratigraphic position and age of the Kinney deposit. Fieldwork commenced and expanded to re-evaluate the entire Pennsylvanian section exposed in the Manzano and Manzanita mountains (Lucas et al., 2011, 2013a, b, 2014, 2016; Vachard et al., 2012, 2013; Allen and Lucas, 2018). This research placed Kinney in a different stratigraphic position and assigned it an older age than that of most workers who contributed to the 1992 volume (Lucas et al., 2011) (Fig. 4). Additional research on the fishes at the quarry was undertaken by another UNM student, Sally Williams, who, in collaboration with SGL studied the taphonomy of the Kinney fishes (Williams and Lucas, 2013).

The most recent phase of collecting at Kinney took place in 2014, when a controlled excavation was completed over the course of two weeks (Fig. 3). Previous collecting at Kinney had been by splitting rock to collect the most complete or interesting fossils. The controlled excavation delineated a 3 x 2 meter grid and collected it layer by layer through the lower 3 m, recording the detailed stratigraphic and spatial positions of all the fossils found. This has allowed a much better understanding

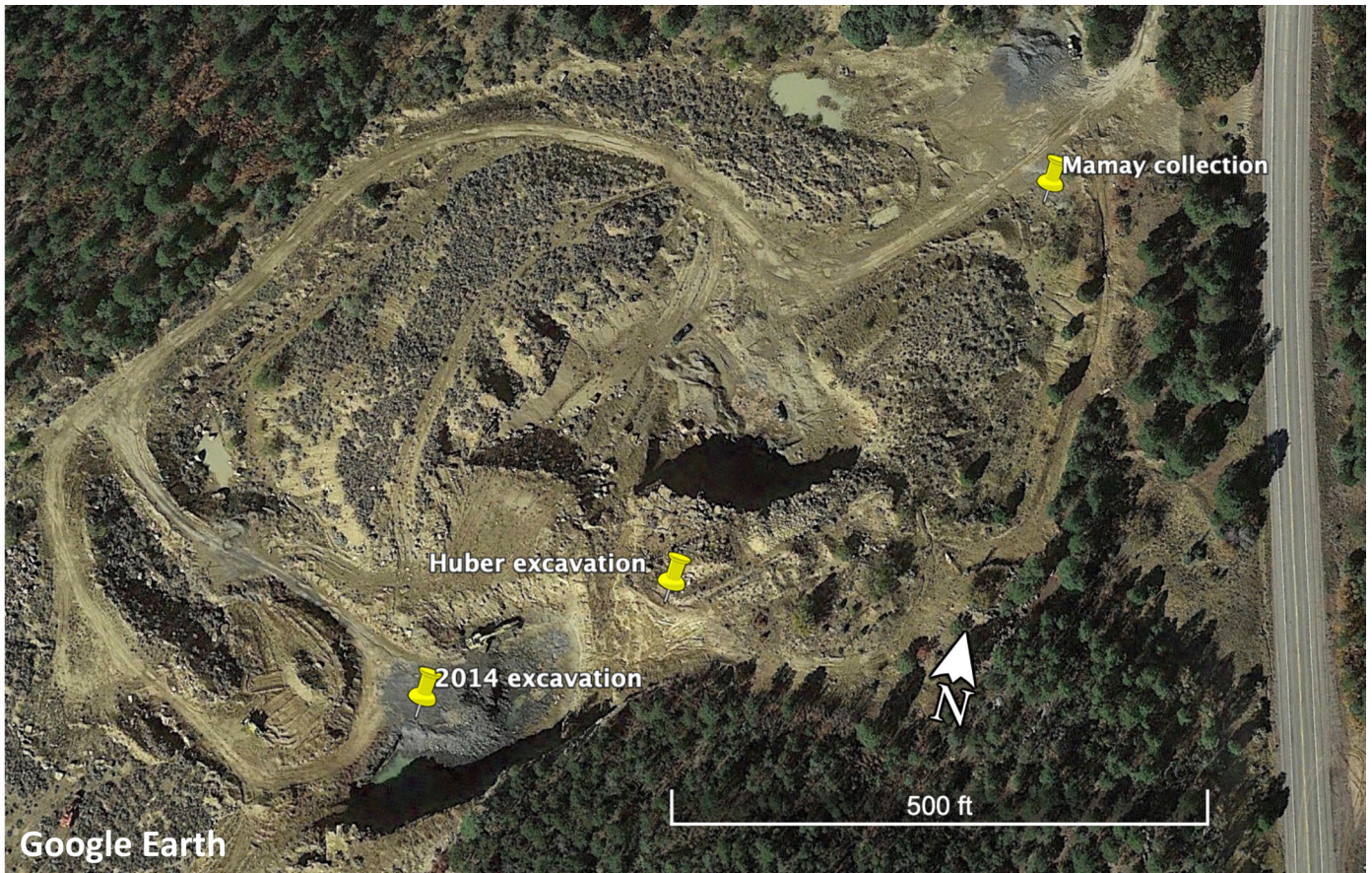


FIGURE 3. Google Earth image of the Kinney Brick Quarry in 2020 showing locations of the three principal excavations, by Mamay in the late 1960s, by Huber in the late 1980s and the controlled excavation of 2014.

of the taphonomy of the fossils, especially of the plant fossils. The results of that excavation and the analysis of the collected material are a major component of this volume.

STRATIGRAPHY AND AGE

In a UNM masters thesis, Stukey (1967) made the first attempt to establish the stratigraphic position and age of the Kinney Brick Quarry. He located Kinney stratigraphically low in the “arkosic limestone member” of the Madera Formation (Fig. 4). However, Charles Read claimed to have found what was then considered a Permian index fossil, the plant *Callipteris*, at Kinney (this claim has never been substantiated or replicated). Thus, Stukey (1967), and later Kelley and Northrop (1975, p. 49), considered that Kinney might be of Permian age and in strata equivalent to the lower Permian (Wolfcampian) Bursum Formation.

In the 1960s and 1970s, Donald Myers of the U. S. Geological Survey revised the Pennsylvanian lithostratigraphy in the Manzano and Manzanita mountains and also developed a fusulinid biostratigraphy of those strata (e.g., Myers, 1973, 1982, 1988a,b). Myers and McKay (1976) mapped the geology of the Kinney Brick Quarry and the surrounding area. Their mapping placed the Kinney Brick Quarry in their Pine Shadow Member of the Wild Cow Formation, a unit of early-middle Virgilian age based on fusulinid biostratigraphy (Myers, 1988a, b). Note, however, that Myers knew of no fusulinids from Kinney and the immediately surrounding area, and he never mentioned the fossil deposit in any of his publications. Thus, most workers assigned the Kinney Lagerstätte a Virgilian age (see articles in Zidek, 1992a). An exception was Huber (1992), who regarded Kinney as Missourian based on the presence of the chonetid brachiopod *Chonetinella flemingi*.

Lucas et al. (2011, 2014, 2016), Vachard et al. (2012, 2013) and Allen and Lucas (2018) restudied the Pennsylvanian stratigraphy and biostratigraphy in the Manzano and Manzanita mountains. They rejected Myers’ Pennsylvanian lithostratigraphic nomenclature, and replaced his lithostratigraphic names by the 1940s nomenclature proposed by Thompson (1942) and Kelley and Wood (1946), as modified by Rejas (1965) and Lucas et al. (2009) (Fig. 4). This revised lithostratigraphy located Kinney in the lower part of the Tinajas Member of the Atrasado Formation (Figs. 4-5), strata of Missourian age to the south of the Manzano Mountains. Indeed, fusulinids from a bed a few meters below the stratigraphic level of the Kinney fossil deposit and conodonts from the fish bed at Kinney indicate an early Missourian age (Lucas et al., 2011).

DEPOSITIONAL ENVIRONMENTS

The Pennsylvanian strata at the Kinney Brick Quarry were deposited in the northeastern portion of the Orogrande basin, one of the depositional basins of the Ancestral Rocky Mountains in New Mexico (Fig. 6). At Kinney, the quarrying operation has exposed about 30 m of the Tinajas Member of the Atrasado Formation (Fig. 7).

The depositional setting of Kinney has long been interpreted to be that of a shallow marine embayment (often referred to as an “estuary” or a “lagoon”) fed by a river delta (Archer and Clark, 1992; Feldman et al., 1992; Lorenz et al., 1992). Lorenz et al. (1992) identified several distinct depositional environments in the strata exposed at Kinney that make up a regressive sequence in which limestone grades up through prodelta and deltaic clastics to a capping delta-plain facies (Fig. 7).

In this volume, Schneider et al. re-evaluate sedimentation at the Kinney Quarry. The depositional environment of the

Stukey (1967)		Myers & McKay (1976)		this paper	
Abo Formation	Permian	Abo Formation	Wolfcampian	Abo Formation	Perm
Bursum Formation		Bursum Formation		Bursum Formation	Wolfcampian
Madera Limestone	Permian?	Wild Cow Formation	Virgilian	Atrasado Formation	Virgilian
arkosic limestone member	La Casa Member	Moya Member	Desmoinesian	Desmoinesian	
gray limestone member	Pine Shadow Member	Del Cuerto Member			Desmoinesian
	Sol Se Mete Member	Story Member	Desmoinesian	Desmoinesian	
		Burrego Member			Desmoinesian
		Council Spring Member	Desmoinesian	Desmoinesian	
		Tinajas Member			Desmoinesian
		Amado Member	Desmoinesian	Desmoinesian	
		Bartolo Member			Desmoinesian
		Los Moyos Limestone	Desmoinesian	Desmoinesian	
					Desmoinesian
Sandia Formation		Sandia Formation	Atokan	Sandia Formation	

■ = stratigraphic position of the Kinney Brick Quarry

FIGURE 4. Evolution of Pennsylvanian stratigraphic nomenclature in the Manzanita Mountains showing changing ideas about the stratigraphic position of the Kinney Brick Quarry (from Lucas et al., 2011).

brackish-marine laminated mudstones at Kinney was previously interpreted as a tide-dominated estuary (Archer and Clark, 1992; Feldman et al., 1992) or as a non-tidally influenced prodelta (Huber, 1992). However, the implied rapid deposition of tidal deposits contradicts some paleobiological and taphonomic observations. Schneider et al. interpret the depositional environment of the laminated mudstone at Kinney as a tidally modulated bayfill sequence controlled by several factors: (1) an embayed shoreline led to tidal amplification; (2) the embayed coastline protected the environment from storm-wave influence; (3) the prograding bayhead delta supplied nutrients to the embayment and resulted in increasingly brackish-water conditions; (4) restricted circulation, poor mixing and elevated bioproductivity resulted in dysoxic to anoxic bottom water conditions; and (5) the main sediment input occurred during seasonal river discharge into the embayment. Two superimposed orders of lamination are observed in the mudstones. Thicker packages of laminae representing seasonal river discharge commonly exhibit internal laminae caused by waxing/waning flow related to tidal acceleration and deceleration of the river and the associated sediment plume entering the basin. Poorly

oxygenated bottom water and the resulting lack of infaunal activity led to the unique preservation of both fossils and lamination structure in the Kinney Brick Quarry mudstones.

The basal limestone at Kinney (Fig. 7, units 1-2) represents deposition in a nearshore marine environment that received some input of freshwater and clastic sediments. Note its lithology (especially the high black-clay content of this micrite) and unusual fauna (some stenohaline brachiopods and other groups, but dominated by euryhaline taxa, such as the inarticulate brachiopod *Lingula* and the bivalves *Myalina* and *Solemya*). The black-clay content, terrestrial plant debris, and euryhaline elements of the fauna (especially abundant *Lingula*) are consistent with deposition near the shoreline with a significant freshwater input.

The overlying highly fossiliferous shales (Fig. 7, units 3-4) were deposited in a calm marine embayment with significant freshwater input. Uniform and fine grain size, fine lamination and lack of bioturbation, dark colors, and preservation of soft-bodied forms suggest deposition in quiet, oxygen-poor waters with restricted circulation. A mixed hygromorphic-xeromorphic plant assemblage, dominated by pteridosperm remains, and

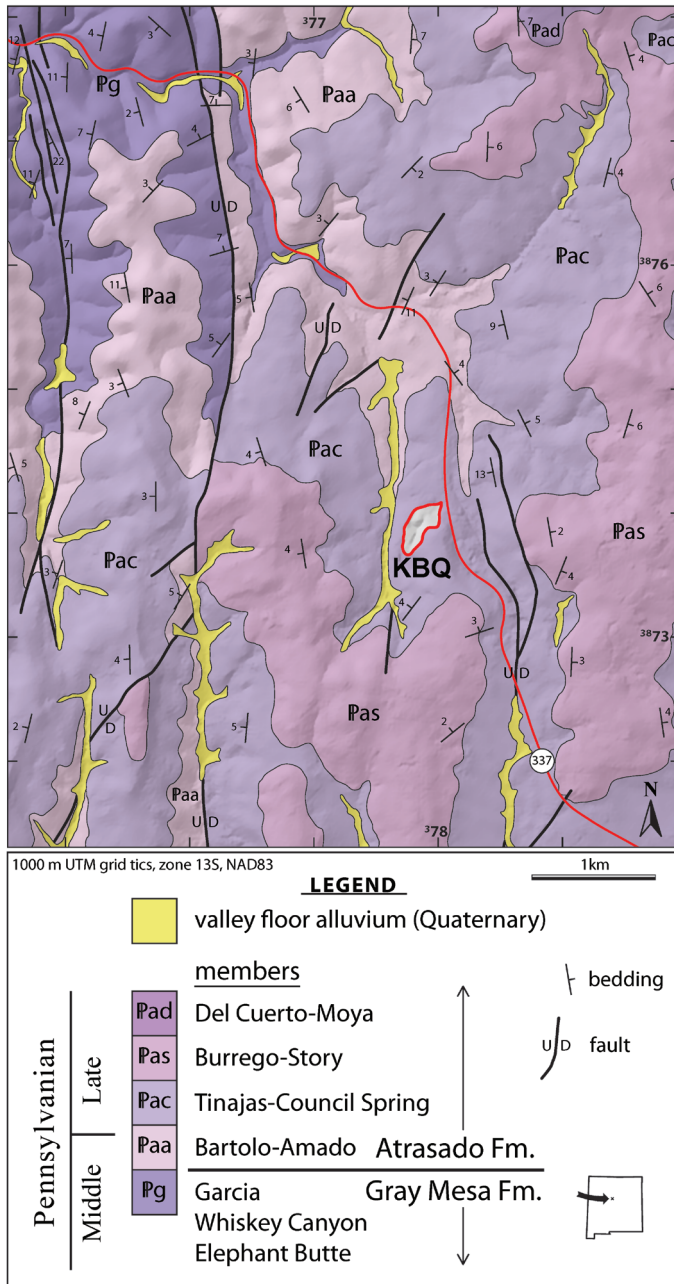


FIGURE 5. Geologic map of the area around the Kinney Brick Quarry (KBQ) (from Allen in this volume).

freshwater faunal elements (especially conchostracans and a few salamander-sized amphibians) suggest low salinity. Overlying shales (Fig. 7, units 5-7) represent a similar facies, but probably with a greater freshwater influence. Dominant fossils are *Dunbarella*, a euryhaline bivalve, and terrestrial plants, particularly conifers.

Overlying silty shales (Fig. 7, units 8-9) represent increased sedimentation rates in a prodelta environment, brought about by the onset of significant fluvial discharge. Plant remains are few, and the flora is conifer-dominated, with sparse, small *Dunbarella*. Most of the relatively xeromorphic elements of the floral assemblage may have been floated a short distance into an environment characterized by frequent shallow ponding and deposition on a surface better drained than the underlying shales.

Overlying laminated and ripple-laminated sandstone ledges and intercalated shales and claystones (Fig. 7, units

10-14) are interpreted as delta front, distributary mouth bars, and associated deposits. Unit 15 is a shale that shows marine influence indicated by the presence of *Lingula* and *Myalina*. This unit, and the overlying fluvial sandstone/conglomerate, may be the base of another transgressive sequence. Thus, the stratigraphic sequence at the Kinney Brick Quarry mostly reflects shoreline progradation, created by the progressive construction (progradation) of a clastic delta (Fig. 7). Lateral shifts in the accumulation of sediments from the delta probably fringed an embayment, isolated from normal marine conditions as the clastic wedge developed and extended seaward. Clastic input in the embayment was initially restricted to clay-size particles. Eventually, the embayment was filled by silty shales from an advancing delta plain on which sand was later deposited. The onset of a subsequent transgression is documented by the highest strata in the quarry section.

PALEONTOLOGY

Introduction

Fossils documented from the Kinney Brick Quarry are palynomorphs, a diverse, macroflora consisting of plants typical of a range of substrate moisture, a shelly marine invertebrate assemblage that includes a few ammonoids but is dominated by brachiopods and the pectinacean bivalve *Dunbarella*, syncarid and hoplocarid crustaceans, conchostracans, ostracods, eurypterids, trilobites, terrestrial arthropods (mostly diplopods and insects), arachnids, conodonts, a diverse assemblage of fishes (mostly acanthodians and palaeoniscoids) and amphibians, as well as microbially induced sedimentary structures (MISS), insect and pathogen damage to vegetation and bromalites (mostly regurgitalites and coprolites). Most of the documentation of these fossils is published in Zidek (1992a) and this volume.

Palynomorphs

Willard (1991, 1992) presented the only published work on palynomorphs from Kinney. She recovered abundant assemblages of cordaitalean conifer and pteridosperm pollen as well as a diversity of spores and identified distinct palynomorph assemblages from two different, spatially separate collections made at the quarry. Thus, the collections made by Mamay at the northern end of the clay pit (Fig. 3) indicate a local macroflora composed mostly of cordaitaleans and conifers. To the south, at the site of the collections made by Huber (Fig. 3), the assemblage is dominated by spores of pteridophytes, primarily fern spores, with a background of conifers, cordaitaleans, and a spectrum of typically wet-substrate taxa (pteridosperms, sphenopsids, lycopsids, and marattialean tree ferns). Willard (1992) interpreted the assemblage from the Huber site to be drawn from a wetter habitat than that of the Mamay site, and suggested that this may reflect different distances from the fluvial source. However, the differences also may reflect sampling of different temporal-stratigraphic horizons in the Kinney strata.

Charophyta

Kietzke and Kaesler (1992, fig. 6A-C) illustrated two charophyte gyrogonites from Kinney but did not identify them. These gyrogonites display characteristic features of *Palaeochara*, including their oblate spheroidal shape, the presence of six, sinistrally spiralled cells, a round and not protruding base and a small apical beak (cf. Lucas and Johnson, 2016). *Palaeochara* is a well-known charophyte that has a stratigraphic range of Mississippian-early Permian (Lucas and Johnson, 2016; Lucas, 2018). Generally freshwater denizens, these gyrogonites were likely washed into the Kinney deposit.

Macroflora

Among the most abundant and striking fossils from Kinney are those of the macroflora, which has been the subject of several

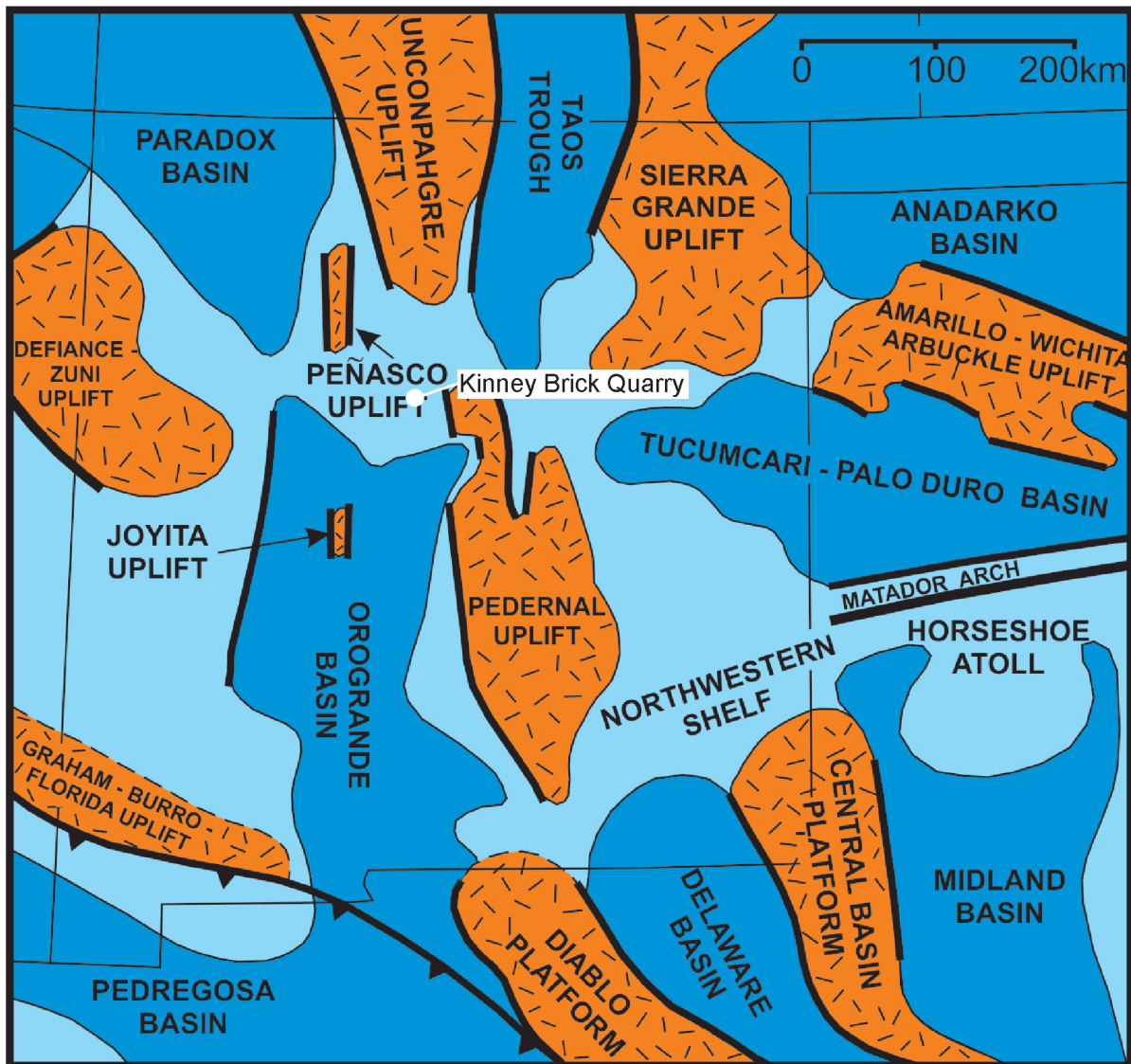


FIGURE 6. Paleotectonic map of late Paleozoic New Mexico showing basins and uplifts of the Ancestral Rocky Mountain orogeny and the location of the Kinney Brick Quarry.

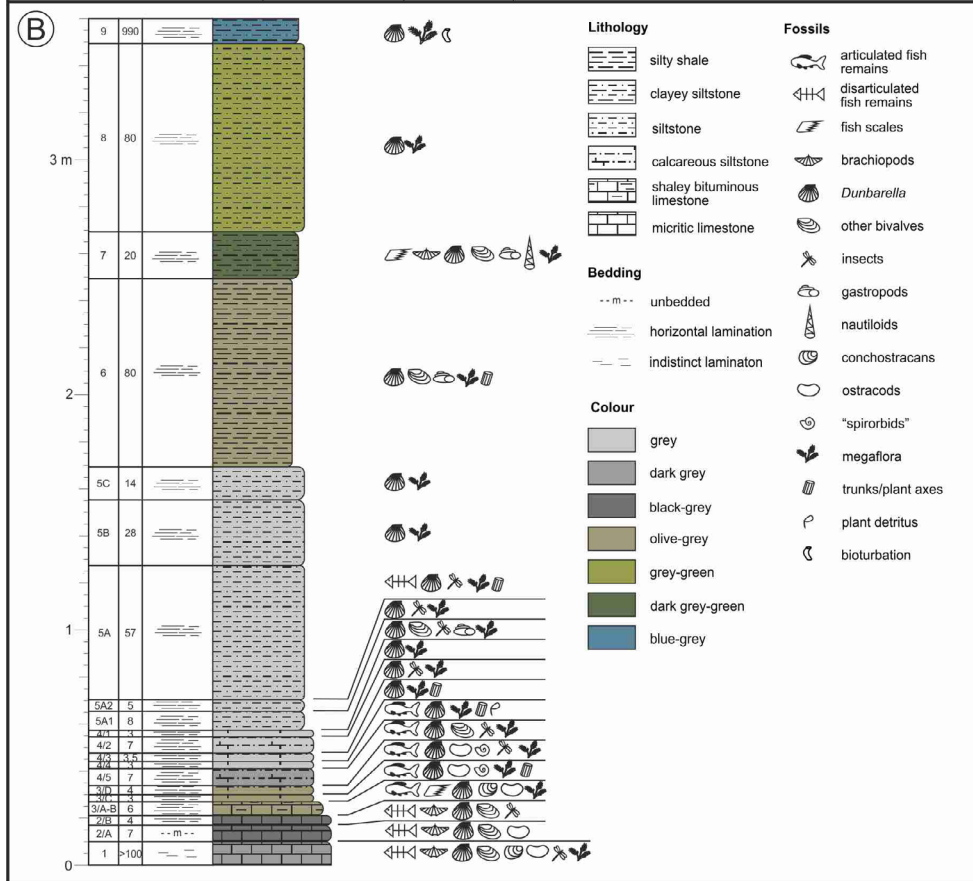
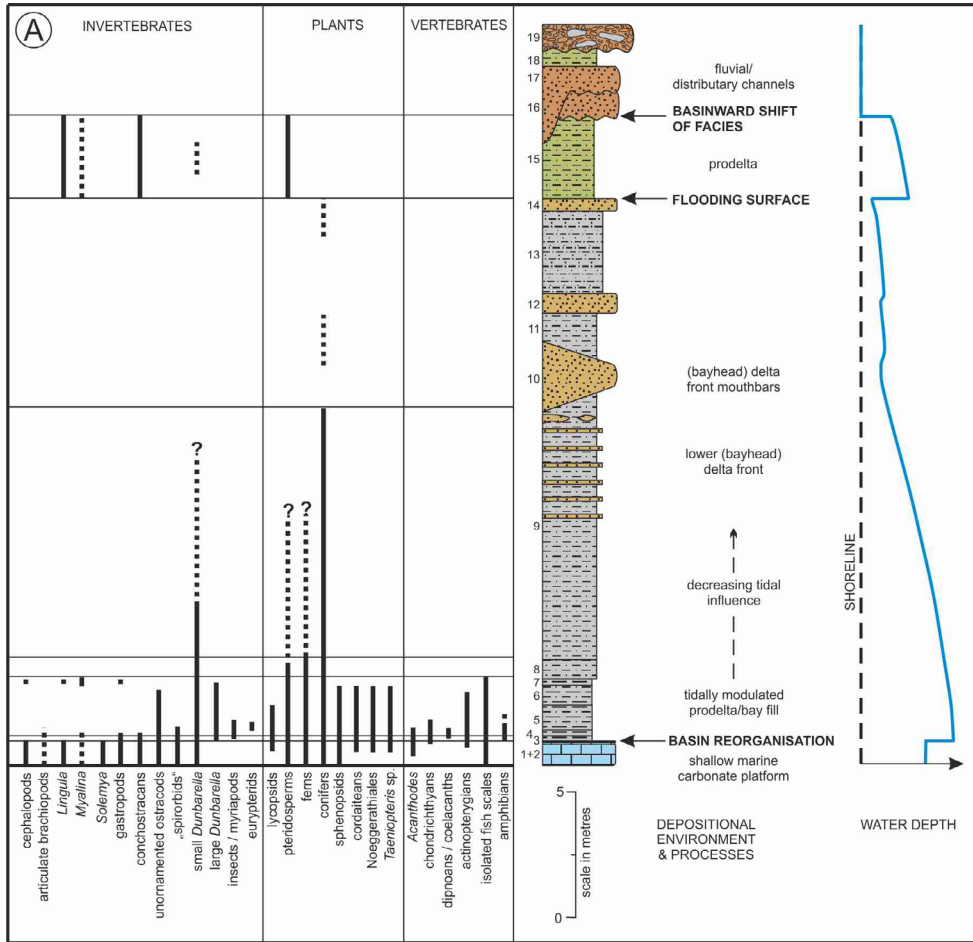
publications (Mamay, 1981, 1990, 1992; Mamay and Mapes, 1991, 1992; DiMichele et al., 2013). A list of Kinney plant taxa (Table 1) is taken from DiMichele et al. (2013). In this volume, DiMichele et al., present an analysis of the taphonomy of the Kinney plants. The flora, sorted by individual fossiliferous beds, corresponding to the controlled excavation, is illustrated by Donovan et al. A particularly large walchian conifer branch found in one of the beds of the excavation is described and illustrated by Looy and Duijnsteet.

The Kinney Quarry flora is a characteristic “mixed” assemblage, typical of a type that characterized the Late Pennsylvanian and early Permian of western Pangea. By “mixed” is meant that it includes elements typically characterized as hygromorphic, mesomorphic, and xeromorphic, intimately associated within the host strata and each other. Presumably, the parent plants from which the fossil remains were drawn lived in environmentally distinct microhabitats in a heterogeneous landscape. On average, medullosan pteridosperms are conspicuous, particularly *Neuropteris ovata*, a widespread and well characterized species, and a prominent component through

the entire plant-bearing interval. Other important elements include the calamitaleean sphenopsid *Phyllothea*, and a variety of other calamitaleean remains, the coniferophytes *Walchia* and *Dicranophyllum*, the likely pteridosperm *Sphenopteridium manzanitanum* (*Sphenopteris germanica*), and the pteridosperm *Mixoneura* (*Odontopteris*) *subcrenulata*. Marattialeean fern foliage of various forms also is occasionally abundant at some horizons and locations in the quarry.

Plant fossils were collected from six separate horizons. In all instances, the remains are allochthonous, which may have allowed for the mixing of plant remains, drawn from parent plants growing in close proximity, but in different microhabitats within the shoreline landscape. Some trends were noted in both composition and preservation from the lowest to the highest plant-bearing beds. First, plant-fragment size increases from the bottom to the top of the deposit, within the nearshore depositional environment (Beds 2 through 5). In fact, in Bed 5, some very large, complete representatives of walchian conifer branch systems were found (see Looy and Duijnsteet), as well as the *Sphenopteris germanica* plant. This finding is concordant

FIGURE 7. (facing page) Summary diagram of the paleontology, stratigraphy, depositional environments and sea-level changes at the Kinney Brick Quarry (from Schneider et al. in this volume).



with the sedimentological model, in which the sediments were formed in progressively more proximal environments. Second, there is no significant size sorting by taxonomic group within any one of the sampling levels, nor are there any obvious differences in the quality of preservation. Additionally, the fossil plant components are thoroughly intermixed, regardless of inferred microhabitat preferences of the parents. Third, the flora of Beds 2 and 3 differs in its pattern of dominance from the flora of Beds 4 and 5. The lower beds were dominated by or greatly enriched in *Neuropteris ovata*, *Phyllothea* sp., *Walchia* sp., and, to a lesser extent, *Dicranophyllum* sp., and marattialean foliage. This is a mixed assemblage with hygromorphic to mesomorphic taxa as the most abundant elements. Beds 4 and 5, in contrast, are characterized by abundant *Sphenopteridium manzanitanum* (*Sphenopteris germanica*), *Walchia* sp., *Dicranophyllum*, and a continuing significant presence of *Neuropteris ovata*, with a noticeable component of marattialean fern foliage. This represents a subtle change to a more xeromorphic flora. Bed 6 continues this trend to a more xeromorphic fossil assemblage, and is dominated by walchian conifers.

In this volume, Looy and Dujinstee describe a foliated walchian conifer branch system from the Kinney deposits. The specimen's large size (101 cm) and three orders of branching are unique among specimens of late Paleozoic, Euramerican walchian conifers. Analysis of the morphological characteristics of the specimen's leaves indicates that it does not fit well within existing taxonomic categories for Pennsylvanian walchians. There seems to be a strong relationship between leaf-morphological characteristics and position within the branch system, and leaf measurements produce a suite of allometric relationships that govern the observed variation in leaf shape. These allometric relationships are significant as a new type of gross-morphology-based taxonomic characteristic, potentially of much greater diagnostic value than the highly variable leaf-measurement ranges commonly employed in walchian taxonomy.

Crustacea

Conchostraca

Kozur et al. (1992) presented a preliminary report on the conchostracans from Kinney. They assigned them to *Pseudestheria* sp. Given that conchostracans are primarily freshwater organisms, Kozur et al. (1992) suggested that some accumulations of conchostracans on selected bedding planes at Kinney are mass death assemblages that reflect a rise in salinity that killed the crustaceans.

In this volume, Scholze et al. present a more detailed analysis of the Kinney conchostracans. The conchostracans from Kinney are assigned to *Pseudestheria* sp. aff. *Pseudestheria limbata*. At Kinney, the occurrence of conchostracans in the marine to brackish-marine beds is regarded as allochthonous. Thus, Scholze et al. conclude that the conchostracans were, together with other freshwater organisms, such as smooth shelled ostracods, syncarid shrimps, temnospondyl amphibians, and, of course, the remains of terrestrial plants, most likely washed in from nearshore freshwater and terrestrial habitats during flood events caused by heavy rainfalls under a seasonal climate.

Ostracoda

Kietzke and Kaesler (1992) documented a low diversity of ostracods from Kinney that they grouped into three assemblages: (1) a marine assemblage dominated by *Paraparchites* from basal strata at the quarry; (2) an overlying assemblage characterized by *Geisina* and judged to represent brackish water; and (3) a stratigraphically higher freshwater/brackish water assemblage dominated by *Darwinula* and *Carbonita*?. Freshwater forms also were documented at Kinney by Werneburg et al. (2013) as gut contents of the amphibian *Milnerpeton huberi*.

Schultze (2013) suggested that the Kinney amphibians were salinity tolerant, perhaps marine tetrapods. However, Werneburg et al. (2013) documented freshwater ostracods as the gut contents (consumulite) of the holotype of the Kinney amphibian *Milnerpeton huberi*. This does not support a marine habitus for this amphibian.

Syncarida

Schram and Schram (1979) documented two new shrimp species from Kinney, the syncarid *Uronectes kinniensis* and the hoplocarid *Aenigmacaris minima*. They judged these taxa to be indicative of a lagoonal environment.

In this volume, Lerner and Lucas re-evaluate the Kinney syncarid fossils and a better preserved collection of syncarids from the Tinajas Member in the Cerros de Amado of Socorro County, New Mexico (cf. Lerner et al., 2009). They assign the Socorro County syncarids to *Palaeocaris secretanae*, which is the first report of *P. secretanae* from North America. *Uronectes kinniensis* is endemic to the Kinney Lagerstätte, and Lerner and Lucas add 14 recently collected topotypes to the sparse record of this species.

Arthropoda

Diplopoda and Myriapoda

Shear et al. (1991, 1992) documented a few diplopod (millipede) specimens from Kinney but judged them to be too incomplete to be identified precisely. They also documented a myriapod specimen from Kinney, and considered it to be a possible centipede.

Insecta

Most of the insect fossils from Kinney are of blattoids (cockroaches). Shear et al. (1992) illustrated a single blattoid wing. Other insects are much less common at Kinney, but some have been described by Carpenter (1970) and Shear et al. (1992). These include the lycocercid *Madera mamayi*, the caloneurod *Pseudobiella fasciata* and an indeterminate monuran described by Carpenter (1970), and a possible brodiid megasecopteran illustrated by Lucas and Huber (1991, fig. 5D) and Shear et al. (1992, figs. 4A-B, 5A). Much more research remains to be undertaken on the non-blattoid insects from Kinney.

In this volume, Schneider et al. present a study of about 41 blattoid fossils from Kinney. The family Phylloblattidae is represented by *Phylloblatta occidentalis* and the *Anthracoblattina ensifera-gigantea* group. Only one specimen belonging to the Family Necmylacridae is present, and it is identified as the large-winged *Necmylacriscus scudderi*. Members of the Mylacridae are rare; *Opsiomylacriscus thevenini* is represented by one specimen, and three specimens are identified as *Neorthroblattina germari*. Representatives of the family Spiloblattinidae are more common and pertain to the species *Syscioblatta allegheniensis*, *Sysciophlebia* sp. form KBQ, and a new taxon that Schneider et al. name *Kinneyblatta huberi* gen. et sp. nov.

The Kinney Brick Quarry insect fauna is of typical Euramerican composition, but an unusually high number of specimens, 23 out of 41, which is 56% of the blattoid insect remains, are represented by articulated specimens. This contrasts with the coal-seam roof-shale entomofaunas from Europe, and may be explained by the taphonomic conditions at Kinney. Dysoxic to anoxic conditions in the sediment and in the bottom waters prevented the oxidation of organic remains, as well as preventing bioturbation and the existence of benthic scavengers. Nectic predators and necrophageous animals such as fishes and the nectobenthic eurypterids were extremely rare. A high sedimentation rate caused by sediment plumes during seasonal river floods resulted in fast burial. Because of the extreme rarity of terrestrial arthropods, the lack of freshwater aquatic insects, and the dominance of flying adult insects, river transport seems

TABLE 1. List of Kinney plant taxa (from DiMichele et al., 2013).

Lycopsids

- Sigillaria brardii* (stem)
- Unidentified small lycopsid (stem)

Sphenopsids

- Calamites* spp. (stem)
- Palaeostachya thuringiaca* (reproductive organ)
- Palaeostachya* sp. (reproductive organ)
- Calamostachys spicata* (reproductive organ)
- Annularia spicata* (foliage)
- Annularia spinulosa* (foliage)
- Annularia carinata* (foliage)
- Annularia sphenophylloides* (foliage)

Ferns

- Nemejcopteris feminaeformis* (foliage)
- Danaeites emersonii* (foliage)
- Pecopteris potoniei* (foliage)
- Pecopteris* cf. *oreopteridia* (foliage)
- Pecopteris* cf. *monyi* (foliage)
- Pecopteris* spp. (foliage)
- Remia pinnatifida* (foliage)
- cf. *Sphenopteris* (*Discopteris*?) *hadrophylla* (foliage)

Pteridosperms

- Macroneuropteris scheuchzeri* (foliage)
- Neuropteris ovata* (foliage)
- Neuropteris cordata* (foliage)
- Alethopteris schneideri* (foliage)
- cf. *Blanziopteris praedenta* (foliage)
- Mixoneura subcrenulata* (foliage)
- Mixoneura* cf. *gimmii* (foliage)
- Neurodopteris auriculata* (foliage)
- Neurocallipteris planchardii* (foliage)
- Pseudomariopteris cordato-ovata* (foliage)
- Sphenopteridium manzanitanum* (foliage)

Coniferophytes

- Walchia piniformis* (stems, foliage)
- ?*Hermitia schneideri* (stems, foliage)
- Culmitzschia* cf. *C. speciosa* or *C. laxifolia* (stems, foliage)
- Ernestiodendron filiciforme* (stems, foliage)
- Dicranophyllum readii* (foliage)
- Gomphostrobus* sp. (reproductive organ)
- Cordaites* spp. (foliage)
- Cordaianthus* sp. (reproductive organ)
- cf. *Podozamites* sp. (stem, foliage)

Noeggerathiales

- Plagiozamites rochei* (foliage)
- Charliea manzanitana* (foliage)

Cycadopsids?

- Taeniopteris* sp. (foliage)

to have played a small role in the input of insects into the Kinney embayment. Hence, Schneider et al. posit a mainly wind-driven origin for the very high percentage of nearly complete insect body fossils at Kinney.

Eurypterida

Kues (1985) documented two eurypterids found at Kinney and identified them as *Adelophthalmus luceroensis*, a species originally described from late Virgilian strata of the Red Tanks Member of the Bursum Formation at Carrizo Arroyo in Valencia County, central New Mexico.

Trilobita

During the 2014 controlled excavation, a single trilobite pygidium was found in the fish bed (bed 3) at Kinney.

Arachnida

Dunlop et al. (2014) described a new species of spider-like trigonotarbid, *Pleophrynus hawesi*, from Kinney. In this volume, Selden, in the broader context of a review of Paleozoic spiders, describes a new specimen of fossil spider from the Kinney Brick Quarry as *Protolycosa suazoi* n. sp., in the family Arthrolycosidae.

Vermiform Fossils

Vermiform fossils of uncertain affinity, possibly annelid worms or onychophorans, have been reported from Kinney by Hannibal (1992) and Lerner et al. (2004). They merit further study.

Conodonta

Kelley and Northrop (1975) mentioned an unpublished undergraduate study by Burton, who, in 1964, and again later, extracted about 500 conodonts from the Kinney quarry and considered them to be of Virgilian age. Krukowski (1992) identified some conodonts from Kinney as *Adetognathus lautus* and *Idiognathodus delicatus*. He judged the sample inadequate for an age assignment.

Barrick (in Lucas et al., 2011) documented conodonts from the “fish bed” (bed 3) at Kinney. The Kinney conodont fauna they reported is characterized by *Idiognathodus corrugatus* and *I. cherryvalensis*, which suggest an assignment to the *Idiognathodus confragus* Zone of the North America Midcontinent region (Dennis cyclothem; middle Missourian).

In this volume, Rosscoe and Barrick re-evaluate the Kinney conodont fauna based on a much larger sample than was previously available. Two conodont faunas were recovered; one from the fish bed in the Kinney Brick Quarry and one from a stratigraphically lower fusulinid marker bed from nearby outcrops. Both faunas are characteristic of the lower part of the Missourian Stage (Kasimovian). The fusulinid marker bed conodont fauna correlates with the diverse fauna of the Hushpuckney Shale from the Swope cyclothem in the Midcontinent Basin (*Idiognathodus cancellosus* Zone). Species of the fusulinid genus *Triticites* occur with the Swope-equivalent conodonts in the fusulinid marker bed, indicating that *Triticites* appeared in New Mexico very early in Missourian time. The Kinney Brick Quarry fish-bed conodont fauna correlates with the low diversity fauna of the younger minor Mound Valley cyclothem (base of *I. confragus* Zone).

Brachiopoda

Kues (1992a) documented the fossil assemblage from the basal limestone at the Kinney Quarry that includes the brachiopods *Lingula* (very abundant) and a few specimens of *Chonetinella*, *Linoproductus*, *Composita* and *Derbya*. He inferred that these were brachiopods that lived in an environment of fluctuating salinity and restricted circulation.

Mollusca

Bivalvia

From the basal limestone bed at Kinney, Kues (1992a) documented bivalves that are common fossils of *Solemya*, *Myalina* and *Dunbarella* and rare fossils of *Streblochondria*?, *Clinopisthia*, *Leptodesma* and *Parallelodon*? Some living *Solemya* prefer low oxygen settings with large amounts of dissolved organic matter (Pojeta, 1988), and *Myalina* and *Dunbarella* are well known to have been euryhaline. This fits the interpretation of the basal limestone at Kinney having been deposited in an oxygen depleted environment with poor

circulation. *Myalina* is also present in the shale immediately above the basal limestone at Kinney.

Dunbarella is a well known pectinacean bivalve found in a range of fully marine, brackish and freshwater settings (e. g., Johnson, 1962; Murphy, 1967). It is the most obvious and most abundant animal fossil at the Kinney Brick Quarry, particularly in shale beds in the quarry section. Clark (1978) first drew attention to the close association of many *Dunbarella* shells with plant matter at Kinney, and the fact that some *Dunbarella* were evidently attached to plant stems (also see Mamay, 1981, 1990; Lucas and Huber, 1991). Kues (1992b) presented a detailed study of the Kinney *Dunbarella* and concluded that they were r-strategists that proliferated rapidly to achieve large size and extensive numbers, and experienced seasonal mortality due to fluctuations in salinity and sediment influx.

Gastropoda

From the basal limestone, Kues (1992a) reported a few poorly preserved gastropods that he assigned to *Euphemites*, *Glabrocingulum* (most common) and an unidentified form. This included an undetermined taxon of high-spined gastropod, also found in the overlying fish bed.

Kietzke and Kaesler (1992, fig. 6H-L) illustrated two specimens they identified as *Spirorbis* sp., but such fossils are now correctly identified as those of microconchiod gastropods. Microconchids may indicate some degree of brackish water, although that is subject to debate (Gierlowski-Kordesch and Cassle, 2015; Gierlowski-Kordesch et al., 2016; Zatoń et al., 2016). The mixed marine, brackish and freshwater nature of the Kinney deposits means that the salinity preferences of the Kinney microconchids cannot be readily resolved.

Cephalopoda

The basallimestone at the Kinney quarry contains ammonoids and a few straight and coiled nautiloids (Mapes, 1991; Mapes and Boardman, 1992; Kues, 1992a). All of the ammonoids were assigned to *Prothalassoceras kingorum* Miller, and one of the straight nautiloids was identified as *Pseudorthoceras knoxense* (McChesney) by Mapes and Boardman (1992). One of the ammonoid specimens shows exceptional preservation of a thick carbon film inferred to represent the mandibles (aptychi) and stomach contents. Mapes and Boardman (1992) considered the ammonoids to have lived in a “restricted environment” (not a normal marine environment) in the Kinney embayment.

Fishes

The Kinney deposit yields a diverse assemblage of fishes, many complete and superbly preserved. As Hodnett and Lucas (2015) noted, this is one of the best preserved and most diverse Pennsylvanian fish assemblages in the American Southwest. The taxa recognized can be divided into acanthodians, chondrichthyans, actinopterygians and sarcopterygians. In this volume, Hodnett and Lucas review the Kinney fish fauna to identify 31 distinct fish taxa, including the first records of a new ctenacanthiform shark, two hybodontiforms, two holocephalans, three actinopterygians, and a megalichthyoform sarcopterygian (Table 2). This is a mixed salinity fish assemblage found almost exclusively in bed 3 at the Kinney Quarry.

Acanthodii

Zidek (1975) first described acanthodians from Kinney, and later (Zidek, 1992b) named *A. jurgenai*, the single species of acanthodian found at the Kinney Quarry. As Williams and Lucas (2013) noted, *A. kinneyi* is the second most common fish at Kinney, typically found as incomplete skeletons of young individuals of various ontogenetic stages.

Chondrichthyes

Zidek (1975, 1992b) first published on the shark fossils from

Kinney, which were few in number and mostly isolated teeth and a dermal spine. He assigned them to five taxa: *Peripristus* aff. *P. semicircularis*, *Symmorium reniforme*, ?*Listracanthus*, *Orthacanthus huberi* (named by Zidek, 1992b) and *Cobelodus aculeatus*. Hodnett and Lucas (2015) questioned some of these identifications but only revised one, changing *Symmorium* to *Glikmanius*. Of these sharks, the best known is the symmoriid “*Cobelodus*,” including a remarkably complete specimen that contains a well-preserved cololite. Williams and Lucas (2013) regarded the sharks as known from fossils allochthonous to the Kinney embayment or representing occasional marine visitors to the embayment.

Collecting at Kinney since 2013 has substantially augmented the record of chondrichthyans from Kinney so that Hodnett and Lucas (2015, and in this volume) listed 11 species of chondrichthyans, several of which are new and yet unnamed taxa (Table 2). This increased diversity and the presence of complete specimens may necessitate a reassessment of the conclusion that none of the shark fossils represent fishes that lived in the Kinney estuary.

Particularly significant is a 2.5-meter long skeleton of a new ctenacanth that Hodnett et al. in this volume name *Dracoprists hoffmanorum* gen. et sp. nov. It represents the most complete ctenacanth found in North America. The morphology of *Dracoprists* suggests it specialized in the benthic environment as a slow moving ambush predator in the marine embayment at Kinney.

Actinopterygii

Actinopterygian fishes from the Kinney quarry are a diverse group of about 16 taxa (Table 2). Most common is the deep-bodied “*Platysomus*” *schultzei* (Zidek, 1992b). Another well known, deep-bodied fish from Kinney is “*Amphicentrum*” *jurgenai*. Other well-described taxa are *Schizolepis manzanitaensis*, *Tanyrhynchichthys mcallesteri*, *Pyritocephalus lowneyae* and an aduelliform, cf. *Bourbonella* (Gottfried, 1987a, b, 1992; Huber, 1992; Williams and Lucas, 2013; Hodnett and Lucas, 2015; Stack et al., 2021). Less studied are various “paleoniscoids” that Bardack (1992) reviewed and assigned to six morphotypes. These fishes are abundant at Kinney and in need of further study.

Sarcopterygii

A single lungfish toothplate assigned to *Sagenodus hlavini* (Zidek, 1975; Kemp, 1996), a rhizodont and an undescribed coelacanth species are the sarcopterygian record from Kinney (Schultze, 1992; Hodnett and Lucas, 2015).

Tetrapoda

Tetrapods from Kinney are a small assemblage of amphibians: the lepospondyl *Brachydectes*?, the “amphibamid” *Milnerpeton*, the trimerorhachid *Lafonius* and a new dvinosaurian named by Werneburg et al. in this volume (Berman, 1973; Hunt et al., 1992, 1996; Werneburg et al., 2013). This is an assemblage of primarily aquatic tetrapods.

In this volume, Werneburg et al. make two separate contributions to knowledge of the Kinney amphibians. In one, a new early adult specimen of *Milnerpeton huberi* brings new insights to the ontogenetic development of the Amphibamiformes.

Werneburg et al. in their second contribution name the new dvinosaurian *Bermanerpeton kinneyi*. Nine unique characters diagnose *Bermanerpeton kinneyi*, many shared with branchiosaurids and larval “amphibamids.” Otherwise, *Bermanerpeton* is clearly a dvinosaurian. The recorded prey in the intestines and stomach of *Bermanerpeton* consists of different arthropods, fishes and amphibians. In the consumulite, ostracods with smooth shells belong to the freshwater/brackish water ostracod ?*Carbonita*. *Bermanerpeton* was thus not marine adapted, but rather a freshwater animal, either washed into the

TABLE 2. The fish assemblage of the Kinney Brick Quarry (from Hodnett and Lucas in this volume).

Acanthodii	
Acanthodiformes	Eurynotiformes
Acanthodidae	Amphicentridae
<i>Acanthodes kinneyi</i>	“ <i>Amphicentrum</i> ” <i>jurgenei</i>
Chondrichthyes	Aeduelliformes
Symmoriiformes	Aeduellidae
Symmoriidae	cf. <i>Bourbonnella</i> sp.
“ <i>Cobelodus</i> sp.”	Sarcopterygii
Xenacanthiformes	Actinistia
Diplodoselachidae	Rhabdodermidae
<i>Orthacanthus</i> sp.	Gen. et. sp. indet
Ctenacanthiformes	Dipnoi
Family Indeterminate	Ceratodontidae
<i>Glikmanius occidentalis</i>	<i>Sagenodus hlavini</i>
<i>Dracopristis hoffmanorum</i>	Osteolepiformes
Euselachii	Family Indeterminate
Hybodontiformes	Indeterminate Megalichthyid
Family Indeterminate	
Hybodontiform indeterminate 1.	
Hybodontiform indeterminate 2.	
Euchondrocephali	
Petalodontiformes	
Pristodontidae	
<i>Peripristis</i> sp.	
Holocephali	
Chondrenchelyiformes	
Family Chondrechelyidae	
Chondrechelyid indeterminate	
Chimaeriformes	
?Family Myriacanthidae	
?Myriacanthid indeterminate	
Subclass Indeterminate	
Order Indeterminate	
Family Listracanthidae	
<i>Ancanthorhachis</i> sp.	
Family indeterminate	
Indeterminate Chondrichthyan	
Osteichthyes	
Actinopterygii	
“Palaeonisciformes”	
Rhadinichthyidae	
Rhadinichthyid indeterminate (Bardack’s type 3)	
Elonichthyidae	
Elonichthyid indeterminate 1	
(Bardack’s type 5)	
Elonichthyid indeterminate 2	
Haplolepidae	
<i>Pyritocephalus lowneyae</i>	
Family Indeterminate	
<i>Schizolepis manzanitaensis</i>	
<i>Tanyrhinichthys mcallisteri</i>	
“Palaeoniscoid” indeterminate 1	
“Palaeoniscoid” indeterminate 2	
“Palaeoniscoid” indeterminate 3	
“Palaeoniscoid” indeterminate 4	
“Palaeoniscoid” indeterminate 5	
“Palaeoniscoid” indeterminate 6	
Bobasatraniiformes	
Platysomidae	
“ <i>Platysomus</i> ” <i>schultzei</i>	
Platysomid indet.	

AGE		Lagerstätte
PENNSYLVANIAN	Virgilian	Montceau-les-Mines
		Robinson
		Hamilton
	Missourian	Garnett
		Kinney
	Desmoinesian	Linton, Nyrary Mazon Creek
Atokan		
Morrowan		

FIGURE 8. Pennsylvanian Lagerstätten (after Schultze and Maples, 1992).

Kinney embayment or living there when freshwater conditions prevailed.

Trace Fossils

Microbially-induced sedimentary structures

Microbially-induced sedimentary structures (MISS) reflect the influence of microbial biofilms and mats on sedimentation (e.g., Noffke, 2010). Little studied before the 2000s, MISS is now recognized as an important ichnological aspect of the sedimentary record.

Recognition of MISS at Kinney only began in 2019 when one of us (SGL) identified what are possible syneresis fractures mediated by microbial activity on some bedding planes in the quarry strata. In this volume, Schneider et al. discuss this MISS, interpreting the polygonal networks as subaqueous MISS generated by growth and expansion of microbial mats.

Arthropod herbivory

Like MISS, the study of arthropod damage on fossilized vegetation is of recent vintage, having really begun during the 1990s (Lucas, 2016). In this volume, Donovan and Lucas document damage on Kinney plant fossils due to arthropod herbivory (these are considered trace fossils) and by pathogens (these are not generally considered trace fossils: Bertling et al., 2006). The highest diversity of damage is on medullosan pteridosperms. Donovan and Lucas record insect and pathogen damage on 2254 fossil plant foliage specimens, describe all damage by host plant, and analyzed damage diversity and frequency. They find low damage diversity, with nine damage types in two functional feeding groups, including external foliage feeding (hole feeding, margin feeding, surface feeding), piercing and sucking, as well as oviposition and pathogen damage. Insect damage was associated with both drought-tolerant and wetland components of the flora, suggesting herbivorous insects had colonized multiple microhabitats across the landscape. Medullosan pteridosperms, including *Neurodontopteris auriculata*, *Neuropteris ovata*, and *Mixoneura subcrenulata*, are

associated with the highest damage diversity at Kinney, which provides further evidence for a general preference for seed plants during the early proliferation of insect herbivory.

Eggs

Eggs are not generally considered trace fossils (Bertling et al., 2006), but we discuss them here for convenience. Mamay (1994) identified small (up to 2 mm diameter) compressed, spherical bodies attached to pteridosperm foliage at Kinney as fish eggs. In this volume, Lucas et al. re-evaluate these fossils as gastropod eggs. They are spherical rings of carbon around host-sediment-filled cavities, or carbon-film-coated spheres. Attached to pteridosperm foliage, these eggs display definite evidence of desiccation, indicating that they were almost certainly laid subaerially and thus not by fishes. The Kinney eggs are remarkably similar to eggs of Devonian, Jurassic and Cretaceous age attributed to gastropods, and also fit well within the range of modern gastropod egg morphology. Thus, gastropods, not fishes, likely produced the Kinney eggs.

Bromalites

The term bromalite refers to “anally or orally derived ejecta and in situ intestinal matter” including “coprolites, cololites and regurgitalites” (Hunt, 1992, p. 221; also see Hunt and Lucas, 2012). Hunt (1992) coined this widely used term in his first study of coprolites from Kinney. These were about 20 specimens of coprolites and a cololite in the body of the shark *Cobelodus* (also see Zidek, 1992b). These trace fossils were attributed to fish producers.

Hunt et al. (2012) presented another study of Kinney bromalites based on a larger sample. They assigned the bromalites to seven morphotypes, including one that was the basis of a new ichnotaxon, *Conchobromus kinneyensis*. This ichnotaxon refers to coprolites with a groundmass of conchostracan shells, likely made by acanthodian fishes.

In this volume, Hunt and Lucas review the more than 100 bromalites from Kinney. They name two new ichnogenera and three new ichnospecies of non-evisceralite consumulites: *Werneburgichnus kinneyensis* and *W. varius* from branchiosaur-like amphibians, and *Chondripilula zideki* from chondrichthyans. New ichnogenera and ichnospecies of non-consumulite bromalites named by Hunt and Lucas are *Huberobromus ovatus*, *Maculacoprus ateri*, *Virgacoprus brevis*, and *Kinneybromus jurgenei*. *Conchobromus kinneyensis* is also present, as are various unnamed morphotypes of coprolites. The Kinney bromalite ichnofauna is significant because: (1) it contains the most studied bromalites of any Paleozoic ichnofauna and includes the highest number of named ichnotaxa; (2) its study stimulated the development of a synthetic nomenclature, with the introduction of the terms bromalite and regurgitalite; (3) it includes the first named non-evisceralite consumulite taxa; and (4) the Kinney ichnofauna provides a reference for bromalites in shallow marine embayment paleoenvironments.

SCIENCE EDUCATION

The Kinney Brick Quarry presents classic aspects of sedimentary geology and paleontology that makes it an ideal teaching tool for science educators. To that purpose, in this volume Burton presents a field trip to enhance the learning experience by placing the students in a real-world environment at Kinney. This fieldtrip demonstrates in the field the results of earth-change processes that can only be talked about in the classroom environment. Burton aligns the content of his field guide to the applicable National Next Generation Standards for Public Education.

SIGNIFICANCE OF THE KINNEY LAGERSTÄTTE

The Kinney Lagerstätte is significant in several ways. Perhaps foremost are the many taxa first discovered at Kinney

and the exceptional preservation of many of its fossils that provide unique morphology not known otherwise. Recent work indicates that such discoveries will continue at Kinney, and it will long remain an important source of new morphology and new taxa.

As noted above, and described in associated contributions to this volume, the Kinney flora consists of an intimately intermixed assemblage of plants typical of high soil moisture, tolerant of only short periods of drought, and forms that are considered drought-tolerant. Such a “mixed” assemblage is most likely to be drawn from a landscape characterized by habitat, even microhabitat, heterogeneity. The extremes of heterogeneity indicated by the Kinney flora would be unlikely to be found on a delta plain and associated floodplain under a humid climate, with relatively high rainfall, nearly equably distributed throughout the year. Rather, the regional climate almost certainly was strongly seasonal. The rationale for this interpretation is explained in detail in papers by DiMichele et al. (2020) and Bashforth et al. (2021). Seasonal drought magnifies microhabitat differences that would be masked under a higher volume, more equably distributed rainfall regime. In a nearshore to shoreline setting, like the Kinney Quarry, the opportunity for the close proximity of standing water and better drained microhabitats is great. We suggest, therefore, that the parent plants of the fossil flora populated a complex, spatially and environmentally variable terrestrial environment, and lived within close proximity of one another.

The animal fossils at Kinney are a mixture of taxa that lived in the embayment (most of the invertebrates and fishes), those washed in from terrestrial/freshwater environments (the insects and amphibians) and marine visitors to the estuary (the sharks). If these fossils fully capture the diversity that lived in the Late Pennsylvanian embayment, then that diversity was low compared to modern analogues (e.g., Williams and Lucas, 2013), either a result of taphonomic bias and/or a Pennsylvanian biota of lower diversity than the Modern world.

Schultze and Maples (1992) compared the Kinney Lagerstätte to other Pennsylvanian Lagerstätten (Fig. 8) to conclude that Kinney is most similar to the Lagerstätten at the Garnett, Hamilton and Robinson localities in Kansas (also see Maples and Schultze, 1988). These Lagerstätten were characterized by Schultze and Maples (1992) as nearshore marine fossil assemblages that accumulated along tidally influenced coastlines or in estuaries. Kinney is now known to be older than Hamilton and Robinson, which are both of Virgilian age. Indeed, Kinney fills a temporal gap in the Pennsylvanian Lagerstätten between Desmoinesian localities such as Linton and Mazon Creek and the late Missourian Garnett locality. In contrast, from the perspective of the vegetation, Kinney falls among those floras with an abundance of both drought-tolerant and drought-intolerant taxa. Many so-called mixed floras have been documented in both the Pennsylvanian and early Permian, summarized in some detail in Bashforth et al. (2021). Many of these, especially those with a major tree-fern component, are found well into the early Permian, up into the Leonardian (e.g., Emily Irish – Koll and DiMichele, 2020; Montgomery Ranch - Simon et al., 2018). In contrast, Garnett is heavily dominated by conifers, with few pteridophyte, or even medullosan pteridosperm elements (Winston, 1983), and Hamilton is similarly highly conifer dominated, but with pteridosperms and calamitaleans, but no significant tree-ferns. The Hamilton flora also is composed both of adpressions and anatomically preserved remains in a carbonate matrix (Rothwell and Maples, 1988). These floristic and preservational differences suggest dissimilarities in the various Lagerstätte, perhaps in prevailing climatic conditions.

ACKNOWLEDGMENTS

We are grateful to the owners of the Kinney Brick Quarry, in particular the late Robert Jurgena, and the current owners, Ralph and Jeanette Hoffman, for their willingness to allow collecting and other research at the quarry over many years. Our thanks also to all the contributors to this volume, which was completed during the COVID pandemic of 2020-2021 under conditions that slowed but did not prevent its completion. Adrian Hunt and Joerg Schneider provided helpful reviews of the manuscript.

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