

Precise age and biostratigraphic significance of the Kinney Brick Quarry Lagerstätte, Pennsylvanian of New Mexico, USA

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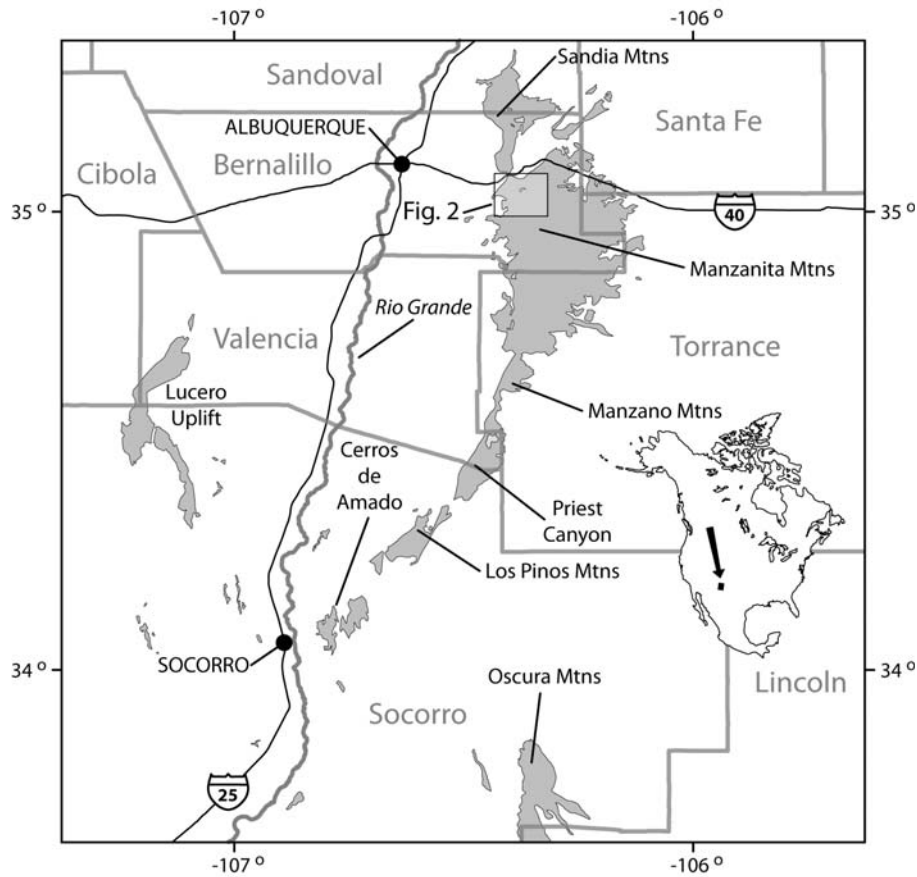
ABSTRACT: The Kinney Brick Quarry is a world famous Late Pennsylvanian fossil Lagerstätte in central New Mexico, USA. The age assigned to the Kinney Brick Quarry (early-middle Virgilian) has long been based more on its inferred lithostratigraphic position than on biostratigraphic indicators at the quarry. We have developed three datasets — stratigraphic position, fusulinids and conodonts — that indicate the Kinney Brick Quarry is older, of middle Missourian (Kasimovian) age. Our detailed local lithostratigraphic studies coupled with regional stratigraphic investigations indicate the Kinney Brick Quarry is in the Tinajas Member of the Atlasado Formation, so it is stratigraphically lower than suggested by previously published maps. A laterally extensive fusulinid-bearing limestone a few meters below the level of the Kinney Brick Quarry yields an early-middle Missourian fusulinid assemblage consisting of *Tumulotrinitites* cf. *T. tumidus* and species of *Triticites*: *T. cf. T. planus*, *T. cf. T. myersi* and *T. ex gr. T. ohioensis*. The Kinney conodont fauna 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). Nonmarine biostratigraphic indicators at the Kinney Brick Quarry indicate either an imprecise age (Late Pennsylvanian: megaflora) or a slightly younger age (late Kasimovian-early Gzhelian: blattids) than do stratigraphic position and marine microfossils. The well-established age of Kinney on the marine timescale thus can be used to better calibrate the nonmarine biostratigraphy. So, the insect biozonation of the Euramerican continental basins, which was calibrated to the so-called regional West European Carboniferous stages by macrofloras and to the global marine scale by sparse, ambiguous isotopic ages, can now be linked directly to the marine conodont zonation.

INTRODUCTION

The Kinney Brick Quarry in the Manzanita Mountains of central New Mexico is a world-famous locality for Late Pennsylvanian fossil plants, invertebrates and vertebrates located ~ 12km south-southeast of Tijeras, New Mexico in sec. 18, T9N, R6E, Bernalillo County, New Mexico (text-figs. 1-3). The quarry is actively mined for clay utilized to manufacture bricks by the Kinney Brick Company in Albuquerque, New Mexico.

A classic Konservat Lagerstätte, Kinney preserves soft tissues and other delicate structures of plants and animals not well

known from correlative deposits (Lucas and Huber 1991; Kues and Lucas 1992). Fossils documented from the Kinney Brick Quarry are palynomorphs (Willard 1992), a diverse, conifer-rich megaflora (Mamay 1981, 1990; Ash and Tidwell 1982; Mamay and Mapes 1992), a shelly marine invertebrate assemblage that includes a few ammonoids but is dominated by brachiopods and the pectinacean bivalve *Dunbarella* (Clark 1978; Archer and Clark 1992; Kues 1992a, b; Mapes and Boardman 1992), syncarid and hoplocarid crustaceans (Schram and Schram 1979), eurypterids (Kues 1985), conchostracans (Kozur et al. 1992), ostracods (Kietzke and Kaesler 1992), ter-



TEXT-FIGURE 1
Map of central New Mexico showing location of Pennsylvanian outcrops (shaded) Kinney Brick Quarry and other important localities mentioned in the text.

restrial arthropods, mostly diplopods and insects (Carpenter, 1970; Shear et al. 1992), conodonts (Krukowski 1992), a diverse assemblage of fishes, mostly acanthodians and palaeoniscoids (Zidek 1975, 1992b; Gottfried 1987a, b 1992; Bardack 1992; Huber 1992; Schultze 1992) and amphibians (Berman 1973; Hunt et al. 1992, 1996; Werneburg and Lucas, 2007), as well as coprolites (Hunt 1992) and “fish eggs” (Mamay 1994). The depositional setting of Kinney is interpreted to be that of an estuary fed by a river delta (Feldman et al. 1992; Lorenz et al. 1992).

The Kinney Brick Quarry is located in the Atrasado Formation, a lithostratigraphic unit of well-established Late Pennsylvanian age. However, the precise age of the Kinney Brick Quarry fossils has been difficult to determine, given that most of the fossils from the quarry are not precise age indicators. Indeed, the precise age long assigned to the Kinney Brick Quarry fossils—early-middle Virgilian—is based more on its previously inferred lithostratigraphic position than on any age indicators found at the quarry. Here, we present new data that not only alter the long-accepted lithostratigraphic position of the Kinney Brick Quarry fossils, but we also provide direct age determination of the Kinney fossil assemblage based on fusulinids and conodonts. These data indicate that the Kinney fossils are of middle Missourian age, substantially older than previously thought. This newly determined age on the marine timescale can be used to better calibrate nonmarine biostratigraphic indi-

cators from Kinney (plants and blattid insects) and may well explain the resemblance of Kinney to some other Pennsylvanian Lagerstätten.

PREVIOUS AGE DETERMINATIONS

Lucas and Huber (1991) and Kues and Lucas (1992) provided a detailed review of paleontological studies of the Kinney Brick Quarry Lagerstätte (KBQL) through 1992, when a comprehensive, edited volume brought together the state-of-the-art of knowledge of KBQL paleontology (Zidek 1992a). Little has appeared in print on Kinney paleontology since that volume (e.g., Mamay 1994; Hunt et al. 1996; Lucas et al. 1999; Werneburg and Lucas 2007). Here, we focus on the history of the study of the stratigraphic position and age determinations of the KBQL, which can be divided into three phases (text-fig. 4).

Students at the University of New Mexico initiated the first phase when they discovered the fossils at the KBQL in the early 1960s. Stukey (1967, p. 48-52) first determined the lithostratigraphic position of the KBQL as about 122m below the base of the Abo Formation in what he termed interval “S-1,” which is in the lower part of the “arkosic limestone member of the Madera limestone.” Based on fossil fishes (especially *Acanthodes*) and plants (especially *Callipteris*) from the KBQL, Stukey (1967) suggested a possible Permian age for the KBQL (text-fig. 4). Kelley and Northrop (1975, p. 47-49) essentially repeated this conclusion, but were more tentative about the

Permian age. They noted that the early report of *Callipteris* from the KBQL was not verifiable, but still considered it possible that the KBQL strata may be an equivalent of the lower Wolfcampian Bursum Formation.

During the 1960s, D. A. Myers of the U. S. Geological Survey began the second phase of study relevant to the age of the KBQL when he undertook an extensive two-decade-long study of the lithostratigraphy and fusulinid biostratigraphy of Pennsylvanian strata in the Manzano and Manzanita Mountains. This work appeared as a series of geologic maps (Myers 1966, 1967, 1969, 1977; Myers and McKay 1970, 1971, 1972, 1974, 1976; Myers et al. 1986) and reports (Myers 1973, 1982, 1988). Particularly significant is that Myers established a formal scheme of Pennsylvanian lithostratigraphy correlated by fusulinid biostratigraphy (text-fig. 4). In that scheme, Myers named strata formerly referred to as the “arkosic limestone member of the Madera limestone” the Wild Cow Formation, and established its age as Missourian-Virgilian based on fusulinids. Myers made no specific reference to the KBQL in his published work; only his geologic map of the area that encompasses the Kinney Brick quarry (Myers and McKay 1976) provided its stratigraphic position and age. Thus, Myers and McKay (1976) mapped the KBQL in the approximate middle of the Pine Shadow Member of the Wild Cow Formation, ~ 30m below the base of the La Casa Member (text-fig. 4). Myers (1988) reported no fusulinids from the area of the KBQL, but at Cedro Peak, ~ 6km to the north (text-fig. 2), he reported the fusulinids *Oketaella* sp., *Triticites* sp. and *T. cf. T. bensonensis* Ross and Tyrrell in strata he identified as the middle and upper parts of the Pine Shadow Member. This is an assemblage of early-middle Virgilian age, and subsequent workers (see the articles in Zidek 1992a) thus assigned an early-middle Virgilian age to the KBQL.

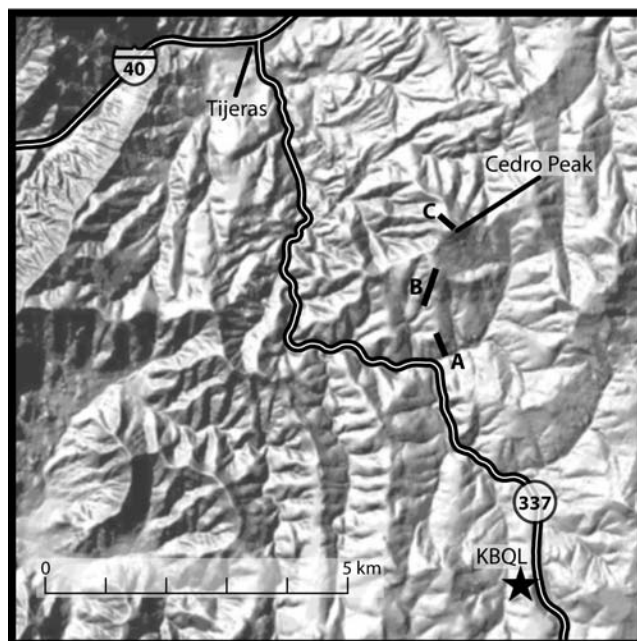
Phase three of the study of the stratigraphic position and age of the KBQL is the research reported here (text-fig. 4) and detailed below.

AGE OF THE KINNEY BRICK QUARRY LAGERSTÄTTE

Three lines of evidence can be used to determine the precise age of the KBQL: (1) lithostratigraphic position and, thereby, lithostratigraphic correlation with nearby, well-dated Pennsylvanian sections; (2) fusulinid biostratigraphy, based primarily on fusulinids newly discovered only a few meters below the stratigraphic level of the KBQL; and (3) conodont biostratigraphy, based on conodonts newly recovered from the basal fossiliferous beds of the KBQL. Here, we review these age data to show they all concur that the KBQL is of middle Missourian age.

Lithostratigraphic position

The Kinney Brick Quarry is developed in clastic strata that were originally assigned to the “arkosic limestone member of the Madera Formation” by Stukey (1967), who first studied the lithostratigraphic position of the quarry (also see Kelley and Northrop 1975, text-fig. 4). Stukey’s lithostratigraphic terminology was part of a generalized formation- and group-rank nomenclature developed during the first half of the 20th century for Pennsylvanian strata in central New Mexico, principally by workers of the U. S. Geological Survey (e.g., Herrick 1900; Gordon 1907; Darton 1922, 1928; Wilpolt et al. 1946; Read and Wood 1947).

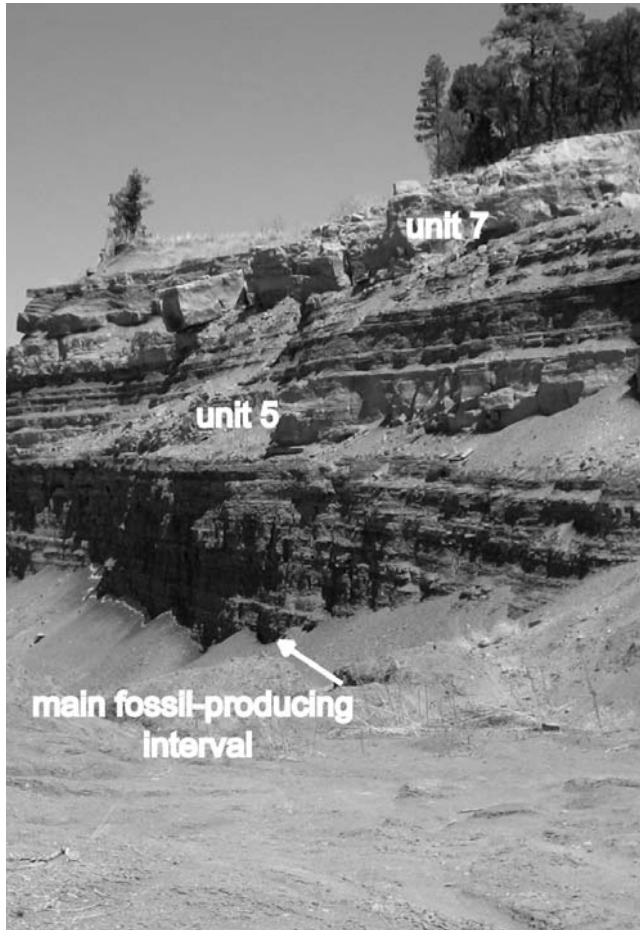


TEXT-FIGURE 2

Digital elevation map of part of the Manzanita Mountains (see text-fig. 1) showing location of Kinney Brick Quarry, Cedro Peak and the measured stratigraphic sections at Cedro Peak.

All workers apply the term Sandia Formation to the lowest Pennsylvanian formation-rank stratigraphic unit in the Manzano-Manzanita Mountains (text-fig. 4)—a succession of siliciclastics (notably quartz sandstone and conglomerate) and carbonates (especially coarse-grained bioclastic wackestone) that yields fusulinids of Atokan age (Myers 1988). Similarly, all workers use the term Bursum Formation for the stratigraphically highest Pennsylvanian strata in the section (text-fig. 4)—a mixed succession of red-bed clastics and marine limestones (the Bursum was long regarded to be of earliest Permian age, but is now assigned to the latest Pennsylvanian) (e.g., Lucas and Krainer 2004; Krainer and Lucas 2009).

During the last decade, the terms Gray Mesa and Atrasado formations have been used for the strata in central New Mexico that had previously been termed Madera limestone (Formation or Group) by many workers (Kues 2001; Krainer and Lucas 2004; Lucas et al. 2009). Gray Mesa and Atrasado are the oldest mappable formation rank unit names formally proposed for these units (Kelley and Wood 1946; Krainer and Lucas 2004) and apply to mappable lithosomes across much of central New Mexico, from the Oscura Mountains through the Cerros de Amado, the Los Pinos, Manzano, Manzanita and Sandia Mountains and Lucero Mesa (text-fig. 1). They are formal terms for the lower gray limestone and upper arkosic limestone members, respectively, of the Madera limestone mapped by Wilpolt et al. (1946) and Wilpolt and Wanek (1951), among others, and first explicitly applied by Stukey (1967) to the strata exposed at the KBQL. The formation names Myers (1973) introduced for what he termed the Madera Group in the Manzano Mountains—Los Moyos and Wild Cow formations—are, as Kues (2001) first noted, obviously synonyms of the Gray Mesa and Atrasado formations of Kelley and Wood (1946). The names Los Moyos



TEXT-FIGURE 3
Photograph of part of Kinney Brick Quarry. Unit numbers refer to measured stratigraphic section in text-figure 5.

Formation and Wild Cow Formation thus have been abandoned and replaced by Gray Mesa Formation and Atlasado Formation, respectively (text-fig. 4).

Renewed mapping in the Manzanita Mountains beginning in the 1990s as part of the U.S. STATEMAP Program necessitated a re-evaluation of Myers's work. Most of the geologists involved in this mapping effort (e.g., Karlstrom et al. 1994; Chamberlin et al. 1997; Read et al. 1998), working in areas previously mapped by Myers and McKay, found it difficult to apply Myers's stratigraphic nomenclature, especially with respect to Myers's member-level units of the Atlasado Formation (Sol se Mete, Pine Shadow, and La Casa members of Myers's Wild Cow Formation). Further confusion arose from Myers's (1988) statement that the Bursum Formation was not present in the Manzanita Mountains, despite the fact that the Bursum lithosome is well-exposed in outcrops near Interstate 40 east of Albuquerque (text-fig. 1). Myers and McKay (1976) included these strata in the La Casa Member of the Wild Cow Formation in their map of the area. STATEMAP mappers placed these strata in the Permian Abo Formation, but they are readily assigned to the Bursum Formation based on lithology.

The result of this renewed mapping effort was that, for the most part, Myers's formal stratigraphic divisions were abandoned,

and map-unit designations utilized by most STATEMAP mappers reverted to the mid-20th century nomenclature of the U.S. Geological Survey (i.e., "lower gray limestone" and "upper arkosic limestone" members of the "Madera Formation:" text-fig. 4).

As part of the STATEMAP effort, one of us (BDA) attempted to retain Myers's formation- and member-rank nomenclature (e.g., Allen 2002), recognizing that it was indeed possible to consistently divide the Atlasado Formation into three map-scale units based on the presence of two, relatively thick and laterally extensive limestone beds separated by siliciclastic (abundant shale and sandstone) intervals. We now assign these two limestone beds to the Amado and overlying Council Springs members of the Atlasado Formation (text-fig. 4; these units are discussed below). Thus, Allen assigned the Bartolo and Amado members of the Atlasado Formation to Myers's Sol se Mete Member of the Wild Cow Formation, the overlying Tinajas and Council Springs members to Myers's Pine Shadow Member, and all the overlying strata between the Council Springs Member and the Bursum Formation to Myers's La Casa Member.

The primary reason for the mistaken stratigraphic position (and therefore the incorrect age) of the KBQL is the fact that Myers's maps of the area are, in many places, incompatible with his own stratigraphy. A good example is on Cedro Peak just to the north of the KBQL, where Myers and McKay (1976) placed the contact between the Gray Mesa and Atlasado formations (their Los Moyos and Wild Cow formations) far up in the Atlasado Formation (near the top of the Amado Member). The reason for this may be that the Amado is a relatively thick, cherty, cliff-forming limestone, similar to the underlying Gray Mesa Formation in many respects. Nonetheless, our re-examination of Cedro Peak shows that the stratigraphic sequence there, despite subtle structural modifications (faults and landslides), is rather clear and incompatible with the mapping of Myers and McKay (1976).

In the immediate vicinity of the KBQL, Myers and McKay (1976) mapped the quarry as just below the base of their La Casa Member of the Wild Cow Formation. We now know that the quarry is in the lower part of the Tinajas Member of the Atlasado Formation, corresponding in reality to what we surmise they considered to be upper Sol se Mete or lower Pine Shadow in other parts of the mountain range. In short, it seems clear that the disconnect between Myers's fusulinid-based, biostratigraphic units, actual mappable lithostratigraphic units, and what he and his colleagues mapped on the ground is so great in some areas that Myers's member-rank nomenclature for the Atlasado Formation has to be abandoned (and much of the mapping redone). This is unfortunate, considering the large amount of good work that was done during Myers's nearly two-decade long efforts in the Manzanos.

Thompson (1942) proposed a very detailed lithostratigraphic nomenclature for Pennsylvanian strata in central and southern New Mexico, and much of it has been used by those who have subsequently studied and/or mapped the Pennsylvanian rocks in Socorro and Valencia Counties, just to the south of the Manzano-Manzanita Mountains (e.g., Hambleton 1959, 1962; Kottlowski 1960; Rejas 1965; Maulsby 1981; Bauch 1982; Brown 1987; Cather and Colpitts 2005; Lucas and Krainer 2009; Lucas et al. 2009). Our recent work indicates that much of

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

■ = stratigraphic position of the Kinney Brick Quarry

TEXT-FIGURE 4
Development of lithostratigraphic nomenclature and age assignments for the Kinney Brick Quarry.

this nomenclature can be applied to the Pennsylvanian section in the Manzano-Manzanita Mountains (Lucas and Krainer 2010), so that an older, member-level nomenclature exists that predates the terminology introduced by Myers (1973). We will present a more detailed treatment of Pennsylvanian lithostratigraphy in the Manzano-Manzanita Mountains elsewhere, but here we employ the member-level nomenclature of Thompson (1942) and Rejas (1965), as used by Lucas et al. (2009) in the Cerros de Amado of Socorro County, and correlate it with the member-level nomenclature of Myers (1973) (text-fig. 4).

Only about 55-60m of strata are well-exposed at the KBQL, and these clastic-dominated strata are certainly in the Atrasado Formation. Their precise lithostratigraphic position can be established by correlation with the section at Cedro Peak, where a

complete section of the Atrasado Formation is exposed between the Gray Mesa Formation (below) and the Bursum Formation (above) (text-figs. 5-6) (Kelley and Northrop 1975; Myers and McKay 1976; Read et al. 1998). Our measured section of the Atrasado Formation at Cedro Peak consists of three overlapping segments that indicate total Atrasado thickness is ~ 200 m (text-fig. 5). We can divide this Atrasado Formation section into eight members (text-fig. 5):

1. The lower 40m of the Atrasado Formation is the Bartolo Member and consists of olive-gray micaceous sandy shale at the base, various limestones and a quartz-rich, crossbedded pebbly sandstone in the middle. Limestone ledges are 0.2-1.9m thick and include thin- to thick-bedded, locally cherty lime mudstone, crinoidal packstone and thin-bedded algal limestone near the top. Covered slopes, presumably shale, are up to 13.3m thick.

2. The overlying Amado Member is 14m thick and composed of limestone intervals 0.3-2.1m thick separated by shale (0.1-m-thick) or thicker covered intervals up to 0.8m thick. The limestone types are mostly thin- to thick-bedded lime mudstone that locally contain large chert nodules, cherty bioclastic wackestone containing brachiopods, and algal wackestone.

3. The Tinajas Member is 61m thick and begins with olive-gray, sandy micaceous shale, overlain by coarse-grained, crossbedded arkosic sandstone, followed by 0.2-0.4-m-thick limestone beds (calcarenite and fusulinid wackestone). The thin limestone beds are separated by 1-5m thick covered intervals. In the middle of the section, green, laminated micaceous sandstone 0.2-2.1m thick alternates with mostly covered shale. The upper part consists of limestone ledges 0.3-1.9m thick, and three sandstone horizons 0.4-1.1m thick. The limestone ledges consist of lime mudstone and thin- to medium-bedded algal wackestone with brachiopods, locally containing some chert. The lowermost sandstone is massive, coarse grained and arkosic in composition. The middle sandstone is red, laminated and very micaceous. The uppermost sandstone is a massive, coarse-grained carbonate sandstone.

4. The Council Spring Member is about 7m thick and composed of algal limestone (wackestone), which is locally bioturbated and contains brachiopods and fusulinids near the base. This basal limestone is overlain by a 3-m thick covered interval, followed by two limestone ledges, 1.8 and 0.6m thick. Both ledges are composed of algal wackestone and separated by a thin shale notch.

5. The Burrego Member is 47m thick and composed of four, fining-upward cycles. The basal 2.1m are not exposed and are overlain by cycle 1, which begins with 5.7m of pebbly, crossbedded sandstone containing hematized plant stems, overlain by fine-grained, micaceous sandstone with horizontal lamination and ripple lamination, followed by siltstone and olive-green shale. Cycle 2 starts with horizontal laminated and crossbedded sandstone, overlain by covered (shale) interval and green, thin-bedded micaceous sandstone with ripple lamination, followed by a thin algal limestone bed and a covered interval. Cycle 3 starts with coarse-grained, pebbly arkosic sandstone, followed by covered slope and a thin limestone bed (algal wackestone with brachiopods). Cycle 4 has a coarse, crossbedded arkosic sandstone at the base, overlain by covered slope and fine-grained micaceous sandstone with ripple lamination, followed by crinoidal and algal limestone with covered intervals.

6. The Story Member is 10.2m thick and consists of a lower (2 m), middle (1.8 m) and upper limestone interval (3.1 m) separated by covered intervals (1.5 and 1.8m thick). The lower limestone is a fusulinid packstone at the base overlain by bioclastic wackestone containing bryozoans, fusulinids, brachiopods and oncolids. The middle limestone is cherty, bedded and contains crinoidal debris and brachiopods. The upper limestone is thick-bedded crinoidal wackestone containing brachiopods and algae.

7. The thickness of the Del Cuerto Member is 8.8m. In the lower part, a thin, fine-grained sandstone is exposed, within a covered slope and followed by shale with limestone nodules and nodular limestone containing brachiopods.

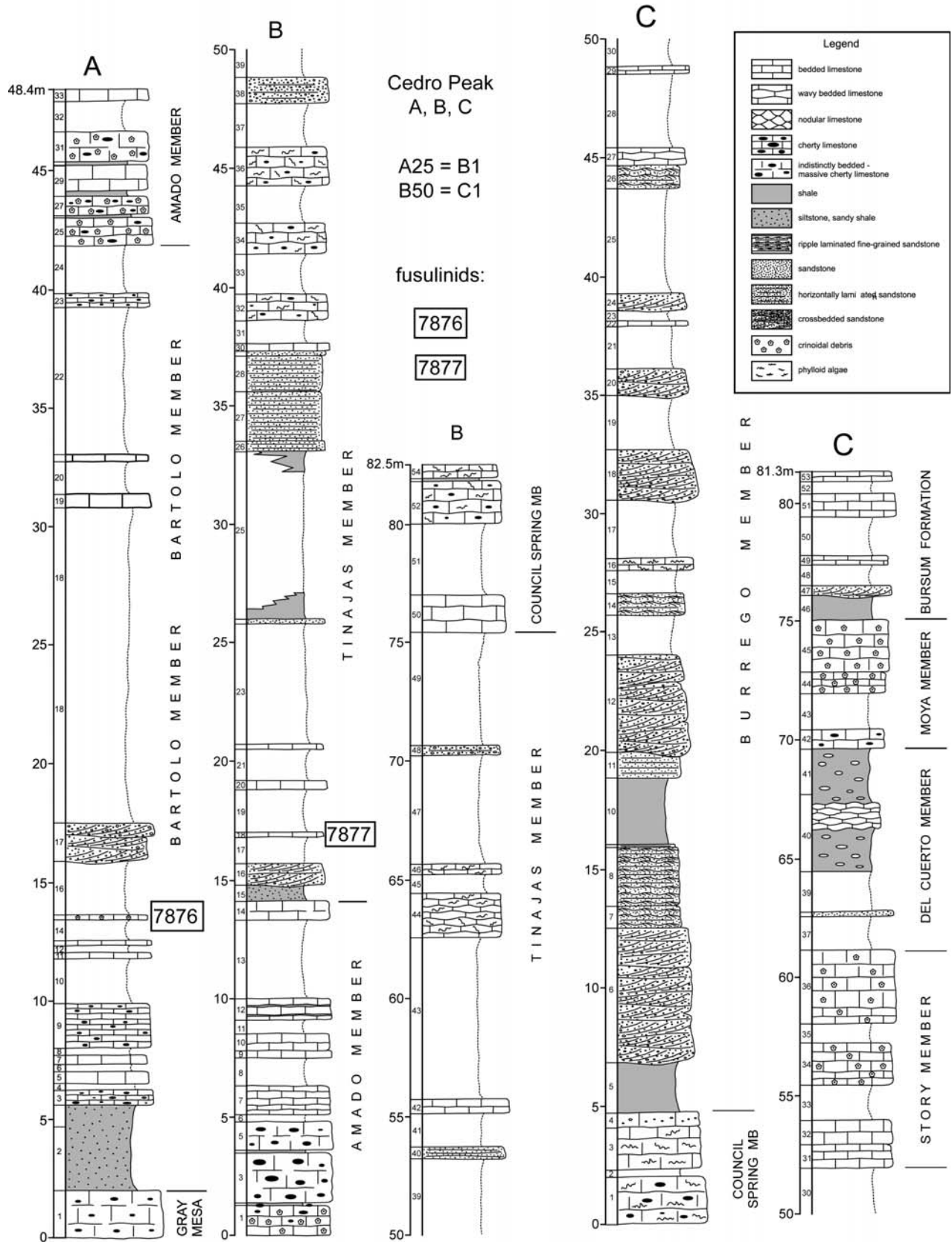
8. The Moya Member is about 4.9m of limestone ledges that are 0.3-1m thick, separated by covered intervals. Limestones consists of crinoidal wackestone and algal limestone containing large *Triticites*.

The stratigraphic section we measured at the KBQL is 56m thick and can be correlated with most of the Tinajas Member at Cedro Peak (text-fig. 6). Thick-bedded cherty limestone of the Amado Member is at the base of the KBQL section. The lower part of the overlying section is poorly exposed with thick covered intervals (shale), and one crossbedded sandstone bed near the base with a thin limestone bed composed of fusulinid wackestone on top. The fusulinid wackestone contains abundant fusulinid tests and rare larger shell fragments that float in fine bioclastic matrix. The matrix also contains abundant calcivertellid foraminifers, subordinate ostracods, echinoderms, shell debris, rare brachiopod spines, *Tuberitina*, and peloids.

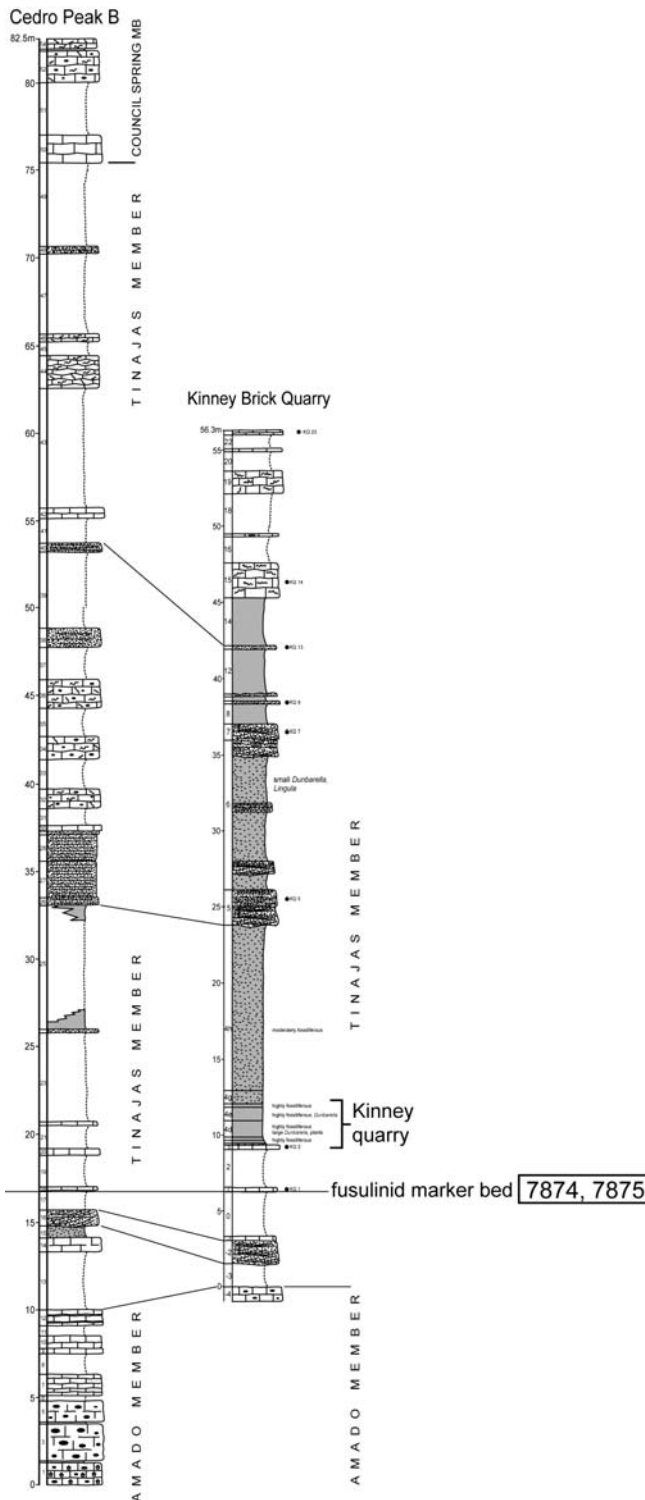
Above another covered interval, two thin limestone beds are exposed, separated by a covered interval. Each limestone bed is 0.3m thick. The lower bed is a fusulinid wackestone (the fusulinid marker bed in text-fig. 6), and the upper limestone contains many brachiopods and is unit 1 of the Kinney section of Kues and Lucas (1992, fig. 5). The upper limestone is a bioclastic wackestone, bioturbated and fine-grained with a few large skeletons. The fossil assemblage is composed of brachiopod shell fragments, many brachiopod spines, algae (?*Anthracoportella*), echinoderm fragments, bryozoans, ostracods, gastropods, a few smaller foraminifers (calcivertellids, *Globivalvulina*, *Bradyina*), and recrystallized phylloid algae. The matrix is peloidal micrite, and locally the wackestone grades into packstone. The KBQL is in the shale immediately above this limestone, in the lower part of unit 4 of our measured section (text-fig. 6).

The overlying part of the Tinajas Member is very well exposed in the KBQL and is composed of greenish-gray shale with intercalated sandstone units (text-fig. 3). The lowermost sandstone unit (unit 5 of our measured section in text-fig. 6, which is unit 10 of the Kues and Lucas 1992 Kinney section) is 2.8m thick, displays crossbedding in the lower part, and horizontal and ripple lamination in the upper part. Fine-grained sandstone (0.1-0.2mm) is moderately sorted and indistinctly laminated by micas oriented parallel to lamination. Medium-grained sandstone (0.2-0.5mm, rarely up to 2mm) is poorly sorted. The most common grain type is monocrystalline quartz (13-24%), and there is subordinate polycrystalline quartz (12-20%). Detrital feldspar is abundant (10-17%) and is partially altered (untwinned K-Fsp, many polysynthetic feldspars). Rare fine-grained rock fragments composed of quartz and mica (metamorphic, < 1 %) and rock fragments of quartz and feldspar (granitic, 6-18%) are present. Mica is common (1-10%), and is mostly biotite, with rare muscovite and chlorite. A few recrystallized detrital carbonate grains are present. Some quartz grains display authigenic overgrowths. The sandstone contains small amounts of matrix (4-7%), and locally coarse blocky calcite cement is present (up to 18%) replacing quartz and feldspars. Fossils include shell debris, echinoderms, echinoid spines, fusulinids, brachiopod spines and brachiopod shells.

Sandstone unit 7 (text-fig. 6) is crossbedded and is unit 17 of the Kues and Lucas (1992) Kinney section. Very coarse-grained sandstone is poorly sorted and composed of mono- (17-34%) and many polycrystalline quartz grains (20-47%), granitic rock



TEXT-FIGURE 5
Composite measured stratigraphic section of Atrasado Formation at Cedro Peak.



TEXT-FIGURE 6
Measured stratigraphic section at Kinney Brick Quarry correlated with interval B of the Cedro Peak section shown in text-figure 5. For legend see text-figure 5.

fragments (quartz and feldspar; 10-14%), sedimentary rock fragments (recrystallized micritic carbonate grains, < 2%) and rare stretched metamorphic rock fragments (< 1%). Detrital feldspars are common (7-20%) and occur as large grains that are partly altered. Most feldspars are untwinned potassium feldspars; perthitic feldspars are subordinate, and polysynthetic twinned feldspar grains are very rare. Some of the feldspars are almost completely replaced by calcite. Detrital muscovite is rare (< 2%). A few fossils are present, mostly echinoderms and shell fragments, rare fusulinids, and bryozoans. Very rare reworked caliche carbonate grains are also present. Quartz grains display authigenic overgrowths. The grains are cemented by coarse, blocky calcite (6-11%), and some dark brown carbonate cement is also present.

This distinctive sandstone horizon is overlain by olive-gray shale with three micaceous sandstone beds intercalated (text-fig. 6, units 8-14). Each sandstone bed is 0.2m thick. The lower and upper bed are massive, and the middle bed displays ripple lamination and is mixed siliciclastic-carbonate, poorly sorted, and composed of mostly subangular to subrounded grains. The most abundant grain type is monocrystalline quartz (14-18%), and polycrystalline quartz is subordinate (4-11%). The sandstone contains many detrital feldspars (mostly potassium feldspars, 4-12%), which are partly altered. Some plagioclase grains are present. The sandstone also contains detrital muscovite (up to 4%), rare rock fragments of quartz and feldspar (up to 2%), and a few micritic carbonate grains (up to 3%). The sandstone contains many fossils, mostly phosphatic fish fragments (locally up to 21%), and other fossils (up to 17%), including shell fragments (brachiopods, mollusks), echinoderms, echinoid spines, bryozoans, smaller foraminifers (*Globivalvulina*, *Climacammina*, *Hedraites?*), brachiopod spines, ostracods, and gastropods. Recrystallized micritic matrix constitutes 28-38%, and carbonate cement is up to 17% of the sandstone.

The upper 11m of the KBQL section (text-fig. 6) is gray, bedded limestone horizons 0.2-2.3m thick, separated by covered intervals 0.9-2.6m thick. Limestone is mostly bioclastic wackestone composed of abundant broken fragments of recrystallized phylloid algae, mollusk shells, gastropods, brachiopod shells, echinoderms, bryozoans, many brachiopod spines and ostracods. Small skeletons include bryozoans, ostracods, echinoderms, smaller foraminifers (*Endothyra*, *Bradyina*, *Climacammina*, *Eotuberitina*, *Tetrataxis*, *Tuberitina*, *Spireitlina*, *Syzrania*, calcivertellids), brachiopod spines, rare *Tubiphytes* (partly encrusting skeletons) and gastropods. A few skeletons are encrusted by cyanobacteria and calcivertellids. The matrix is recrystallized micrite. Phylloid algal floatstone is subordinate, grading into bioclastic wackestone/packstone.

The floatstone contains completely recrystallized fragmented thalli of phylloid algae up to 2 cm long. Skeletons of bryozoans, brachiopods, echinoderms, ostracods and very small *Tubiphytes* are rare and float in peloidal micrite.

Both sections, Cedro Peak and the KBQL, can be correlated primarily on a 0.3-m-thick fusulinid limestone that can be traced from the KBQL to Cedro Peak (text-fig. 6) and which produces a distinctive Missourian fusulinid assemblage described here (Appendix 2). Strata above and below this fusulinid bed include some beds that can be reasonably matched by lithostratigraphic correlation. Particularly significant is that the clastic-dominated

section at the KBQL closely resembles the clastic-dominated Tinajas Member section at Cedro Peak, especially the various beds of micaceous sandstone, which are very similar petrographically at both sections.

The correlation indicates that the KBQL is stratigraphically low in the Tinajas Member of the Atrasado Formation, about 10m above the local base of the member. In the regional stratigraphy (see above and Lucas and Krainer 2010), the lower part of the Tinajas Member is equivalent to the upper part of the Sol se Mete Member of the Wild Cow Formation of Myers (1973), so the KBQL is stratigraphically much lower than the mapping of Myers and McKay (1976) indicates (text-fig. 4). Indeed, our placement of the KBQL in the local Pennsylvanian section is the same as that of Stukey (1967), that is, stratigraphically low in the Atrasado Formation.

Myers (1988) fusulinid biostratigraphy in the Manzano-Manzanita Mountains assigns his upper part of the Sol se Mete Member to the *Triticites ohioensis* zone of “late Missourian” age. However, Douglas (1987) indicated that *T. ohioensis* and related species characterize the Brush Creek and Cambridge Members of the lower Conemough Formation in the Appalachian region. These units correlate with the middle Missourian Swope through Dewey cyclothem in the Midcontinent region on the basis of conodont faunas (Heckel and Weibel 1991; Heckel et al. 2007). Farther south in New Mexico, in Socorro County, conodonts indicate a somewhat later Missourian age (Stanton cyclothem; Heckel et al. 2007) for the middle to upper part of the Tinajas Member (Lucas et al. 2009). Thus, the revised lithostratigraphic position of the KBQL combined with regional biostratigraphy suggest it is of middle Missourian age.

Fusulinid biostratigraphy

About 3m below the stratigraphic level of the KBQL, one of us (BDA) discovered a 0.3-m-thick fusulinid wackestone (text-fig. 6). This fusulinid-rich marker bed provided New Mexico Museum of Natural History (NMMNH) fossil localities 7874, 7875 and 7877 (Appendix 1) and can be traced from the area of the KBQL to Cedro Peak (text-figs. 5-6). In Appendix 2 to this article, we present a systematic paleontology of the fusulinids relevant to the age of the KBQL (text-fig. 7). The assemblage consists of: *Tumulotriticites* cf. *T. tumidus* Wilde 2006 (text-fig. 7.1-2); *Triticites* (*Schwageriniformis*) cf. *T. planus* Thompson and Thomas 1953 (text-fig. 7.3-5), *T. (S.)* aff. *T. planus* (text-fig. 7.6); *Triticites* (*Triticites*) cf. *T. myersi* Wilde 2006 (text-fig. 7.7-8); and *T. (T.)* ex gr. *T. ohioensis* Thompson 1936 (text-fig. 7.9-10).

Based on comparison to Myers (1988, pls. 1-3) and Wilde (2006), the age of the assemblage is early to middle Missourian. The fusulinid assemblage from stratigraphically below the KBQL corresponds well to what Myers (1988) called his “assemblage subzone of *Triticites ohioensis*” from the Atrasado Formation elsewhere in the Manzano Mountains. Myers (1988) correlated this assemblage primarily with rocks of the Dennis cycle in the midcontinent, but the presence of *Tumulotriticites* suggests a possibly older age, perhaps as old as the Swope cycle (compare Wilde 2006).

This discovery of *Tumulotriticites* is also interesting from a paleobiogeographical point of view for intercontinental correlations. *Tumulotriticites* is similar to some advanced *Protriticites* of the Old World (i.e., to those forms with a keriotheca in the last whorls: *Protriticites pramollensis* (Pasini 1963) emend.

TABLE 1

Conodonts recovered from Unit 1, Kinney Brick Quarry. TL – Tom Lehman collection; JB – James Barrick collection; SL – Spencer Lucas collection.

Sample Weight	TL 2.5 kg	JB 2.0 kg	SL 5.8 kg
<i>Idiognathodus corrugatus?</i> P ₁	8	9	11
<i>I. cherryvalensis?</i> P ₁	1	6	6
<i>I. confragus?</i> P ₁	2	2	10
<i>I. sp. aff. I. biliratus</i> P ₁	1	1	1

Forke and Samankassou 2000; *Montiparus priscus* Villa and Martínez-García 1989; *Protriticites robustus* Ueno 1991) and allows a correlation of the early/middle Missourian with the upper part of the early Kasimovian. Moreover, the first representatives of *Schwageriniformis* appear in the middle Kasimovian (Bensh 1972). Advanced *Protriticites* and *Schwageriniformis* constituted immigrants to North America, and the subsequent triticitids are relatively endemic. For example, true *Triticites* of North America corresponds to *Rauserites* of the Old World. *Kansanella* is somewhat similar to *Ferganites* but different because they belong to two different lineages. Similarly, *Thompsonites* has no real equivalent in the Palaeotethys. The second migration of schwagerinids to North America is represented by *Pseudoschwagerina*, and the third by *Pseudofusulina sensu lato*.

Conodont biostratigraphy

Nearly all the conodonts of the KBQL were recovered from the basal marine limestone, unit 1, exposed in the Kinney Brick Quarry (text-fig 6). Three different sets of samples produced the same fauna, but with different numbers of elements per kilogram processed: (1) T. Lehman (Texas Tech) contributed 2.5 kg of brown limestone that had been obtained during collection of fish fossils; another sample of black limestone (0.9 kg; Unit 2?) produced only six small conodont elements and a small sample of the overlying shale was barren of conodonts; (2) J. Barrick collected 2.0 kg of Unit 1 during the 1991 GSA field trip to the Kinney Quarry; and (3) S. Lucas collected 5.8 kg of Unit 1 and a 2.6 kg sample of the overlying shale that produced no conodonts. Table 1 summarizes the conodont recovery.

Most of the Kinney conodonts can be assigned to the genus *Idiognathodus* (text-fig. 8). The taxonomy of Kasimovian to Gzhelian *Idiognathodus* species is not fully resolved and species ranges are not well known outside of the North American Midcontinent region (Barrick et al. 2004). Rosscoe and Barrick (2009) described the *Idiognathodus* faunas from the latest Moscovian and early Kasimovian (late Desmoinesian-early Missourian) in the Midcontinent region, but did not discuss species above the level of the Hertha cyclothem. Rosscoe (2008) revised the taxonomy of the species as high as the middle Kasimovian Dewey cyclothem, and his revision is followed here for the conodonts from the KBQL. His work emphasized conodonts from the deeper water core shales of cyclothem, and included fewer morphotypes from time equivalent shallower water facies.

Many P₁ elements from the Kinney Quarry samples (text-figs. 8.6, 8.12-8.15) can be identified as possible examples of *Idiognathodus corrugatus* Gunnell 1933 (Rosscoe 2008). This form possesses the typical asymmetrical *Idiognathodus* platform outline, but the rostral lobe is reduced to a single node or is absent (Rosscoe 2008). The carina of the Kinney specimens is

longer than usual for Midcontinent *I. corrugatus*, which may represent a shallow water modification of the element. Krukowski (1992, fig. 1a-b) illustrated this form from the KBQL as *Idiognathodus delicatus*. A number of Kinney specimens are P₁ elements with a long carina (25-50% of platform length), reduced lobes, coarse transverse ridges, and a tendency toward a slight depression on the oral surface (text-figs. 8.2-8.5). The outline of the platform is less asymmetrical than typical species of *Idiognathodus*. P₁ elements with reduced lobes may be best assigned to *I. confragus* Gunnell 1933, as Rosscoe (2008) redescribed the species.

Similar P₁ elements (text-figs. 8.7, 8.10-8.11) that possess a more slender platform outline and in which rostral and caudal lobes are absent can tentatively be assigned to *I. cherryvalensis* Gunnell 1933 (see Rosscoe 2008). The adcarinal ridges extend dorsally past the long carina and form high caudal and rostral margins to the platform, making the platform surface appear slightly depressed. Many of the numerous small P₁ elements from Kinney appear to be juvenile examples of these two species. Only a few examples of another species were recovered from the Kinney Brick Quarry. The overall boat-like shape of the P₁ element, lack of caudal and rostral lobes, and the long carina suggest the late Kasimovian-Gzhelian species *Streptognathodus firmus* Kozitskaya 1978. Barrick, in Mapes and Boardman (1992, p. 113), reported *S. firmus* from the Kinney Brick Quarry based on these forms, and Krukowski (1992, fig. 1c) illustrated a small specimen. The larger specimens from the Kinney Brick Quarry, however, possess a long carina that does not extend to the dorsal margin of the platform in specimens, as is diagnostic of *S. firmus*. The few Kinney specimens (e.g., text-fig. 8.9) resemble the rare form *Idiognathodus biliratus* (Gunnell 1933), as described by Rosscoe (2008), but too few specimens are available for confident species assignment.

The KBQL conodont fauna is early to middle Kasimovian in age, and provisional assignment is made to the *Idiognathodus confragus* Zone of the Midcontinent conodont zonation

(*Streptognathodus confragus* Zone of Barrick et al. 2004). The KBQL fauna can be tentatively correlated with that of the Midcontinent Dennis cyclothem (Heckel et al. 2008). In the Midcontinent succession, *Idiognathodus* morphotypes with a long carina, including *I. confragus* and *I. cherryvalensis*, first appear in and characterize the Dennis cyclothem (Rosscoe 2008). *Idiognathodus confragus* and the rare *I. biliratus* range no higher than the Dennis cyclothem, and *I. cherryvalensis* ranges into the lower part of the *Streptognathodus gracilis* Zone of the overlying minor Hogshooter cyclothem. The other two Kinney species, *I. corrugatus* and *Hindeodus minutus*?, provide no additional constraints on the age of the fauna.

Absent from the Kinney Brick Quarry conodont fauna are representatives of two groups of idiognathodids characteristic of middle Kasimovian to Gzhelian faunas in North America. At the level of the Hogshooter cyclothem, multiple species of the genus *Streptognathodus* (*sensu stricto*; e.g., Barrick et al. 2004; Rosscoe 2008) first appear, possibly evolving from *I. cherryvalensis* (Rosscoe 2008). From the Hogshooter cyclothem through the Gzhelian, *Streptognathodus* species are a common and characteristic part of the conodont faunas. In the late Kasimovian (shale of the Stanton cyclothem), the *I. simulator* lineage appears, which comprises strongly asymmetrically paired P₁ elements that possess a well-defined eccentric groove on the platform surface (Barrick et al. 2008). This distinctive group of species ranges into the early Gzhelian. Note that Barrick (in Mapes and Boardman 1992, p. 113) incorrectly identified specimens of *I. corrugatus* from the Kinney Brick Quarry as the early Gzhelian species *I. simulator*.

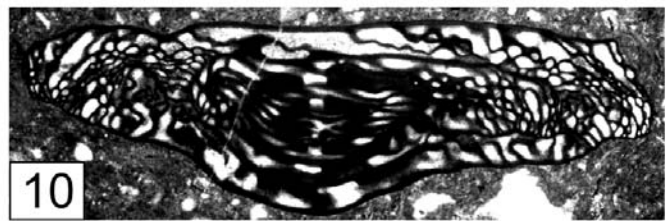
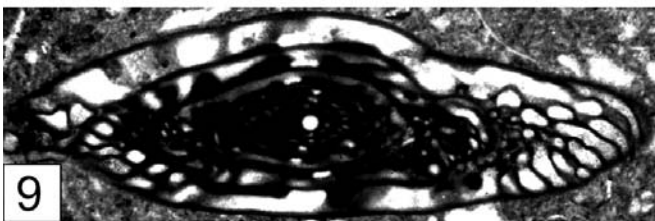
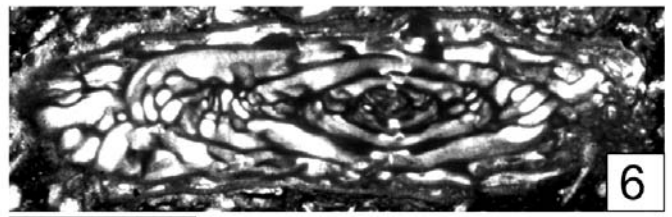
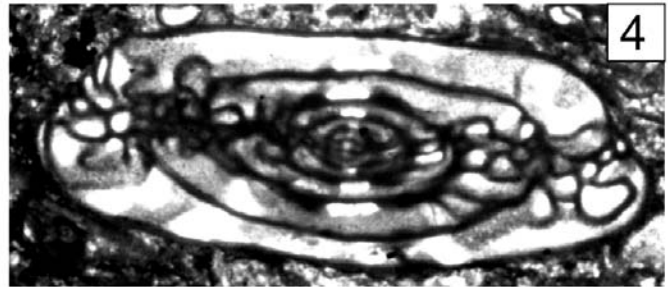
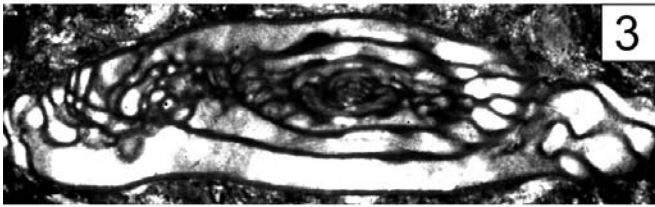
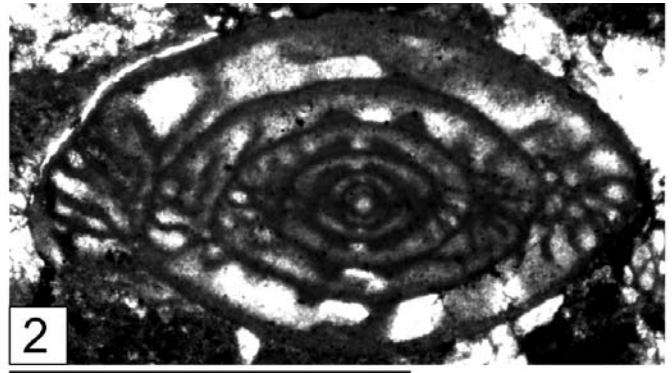
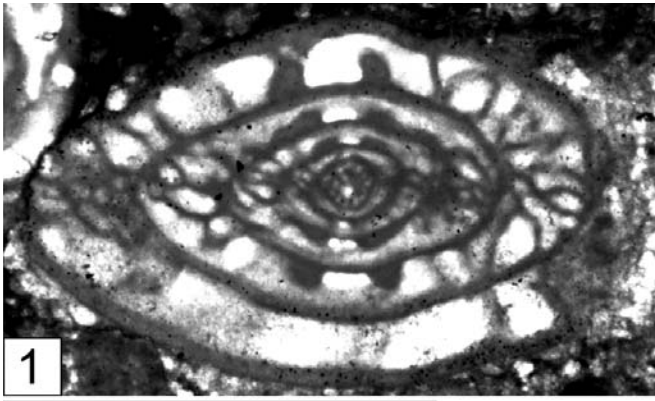
COMPARISON TO NONMARINE BIOSTRATIGRAPHY

Some of the nonmarine fossils from the KBQL, specifically the megafloora and the blattid insects, have been used to determine the age of the deposit. Significantly, these correlations seemed to support the early-middle Virgilian age long assigned to the KBQL. Here, we re-evaluate this nonmarine biostratigraphy to demonstrate that it is imprecise and does not contradict the Missourian age of the KBQL based on marine microfossils.

TEXT-FIGURE 7

Missourian fusulinids of the Tinajas Member of the Atrasado Formation at the Kinney Brick Quarry and Cedro Peak (New Mexico). All scale bars = 1mm.

- 1-2 *Tumulotriticites* cf. *tumidus* Wilde 2006. Notice the weak septal folding, the progressive appearance of the primitive keriotheca, and the shape of the chomata 1, Axial section. (NMMNH locality 7876). 2, Axial section (NMMNH locality 7876).
- 3-5 *Triticites* (*Schwageriniformis*) cf. *T. planus* Thompson and Thomas 1953. Elongate fusiform shape, very weak septal folding and low chomata. 3, Subaxial section. (NMMNH locality 7874). 1.1. 4, Axial section. (NMMNH locality 7874). 5, Axial section. (NMMNH locality 7874)
- 6 *T. (S.)* aff. *planus* Subaxial section with the chomata more extended to the poles. (NMMNH locality 7874).
- 7-8 *Triticites* (*Triticites*) cf. *myersi* Wilde 2006 (pl. 1, figs. 7-8). Septal folding a little stronger, characteristic chomata and tunnels. 7, Axial section. (NMMNH locality 7875). 8, Tangential section. (NMMNH locality 7875).
- 9-10 *T. (T.)* ex gr. *ohioensis* Thompson, 1936 Strong chomata in the initial whorls. 9, Axial section. (NMMNH locality 7877). 10, Tangential section (NMMNH locality 7877).



Plant Biostratigraphy

A large megafloral assemblage was collected from the KBQL beginning with U.S. Geological Survey (USGS) geologists Charles B. Read and Sidney Ash in the early 1960s, and followed by Sergius H. Mamay and Arthur Watt in the late 1960s. These USGS collections are housed at the U.S. National Museum of Natural History; other collections are housed at the New Mexico Museum of Natural History and Science and the Carnegie Museum of Natural History. Mamay and Mapes (1992) first described and illustrated the full Kinney flora in detail. We undertake here a re-evaluation of the composition of the Kinney flora based on the USGS collections, and briefly assess the biostratigraphic implications.

Mamay and Mapes (1992) concluded that the KBQL flora was early Virgilian in age (= Late Pennsylvanian, early Gzhelian, Stephanian C, according to Davydov et al. 2010). They described a mixture of seemingly typical Late Pennsylvanian wetland elements and taxa more characteristically found as part of floras from seasonally dry habitats. The plants were collected from at least two different horizons. Palynological analyses at the site indicate considerable differences between samples from lower and higher parts of the exposed succession (Willard, 1992). Because of the sensitivity of plant distribution to climate, we conclude that the different floristic components of the KBQL megafloral assemblage actually represent at least two distinct species pools, probably reflective of some environmental changes during accumulation of the Kinney deposit.

Mamay and Mapes (1992) reported the following elements in the flora. Those typical of seasonally dry habitats are: *Walchia piniformis*, *W. schneideri*, *Gomphostrobus*, *Sphenopteridium manzanitanum*, *Charliea manzanitana*, *Plagiozamites planchardii*, cf. *Podozamites*, cf. *Rhacopteris*, and *Dicranophyllum readii*. Those typical of wet substrate habitats are: *Sigillaria brardii*, *Annularia pseudostellata*, *A. radiata*, *A. asteris*, *A. sphenophylloides*, *Asterophyllites* sp., *As. equisetiformis*, *Calamostachys ludwigii*, *C. pendulata*, *Danaeites emersonii*, *Pecopteris feminaeformis*, *Pecopteris* sp., *Neuropteris ovata*, cf. *N. macrophylla*, cf. *N. heterophylla*, cf. *N. obliqua*, *Macroneuropteris scheuchzeri*, *Odontopteris* sp., and cordaitaleans.

We offer the following additions to the assemblage documented by Mamay and Mapes (1992). Found only in the non-illustrated collection are: *Taeniopteris* sp. (n=1), *Neuropteris pseudoblissii* (n=1), *Alethopteris* sp. cf. *A. schneideri* (n=1), cf. *Neurocallipteris planchardii* (n=2), *Pseudomariopteris cordato-ovata* (n=3), and several small frond fragments with foliage similar to that of an unnamed neuropteroid described by Knaus and Lucas (2004) from Carrizo Arroyo, New Mexico, a Pennsylvanian-Permian boundary deposit. Among the population of larger *Annularia* specimens in the collection, there are several with ovoid, rather than round leaf whorls, with spatulate leaves and mucronate leaf tips. These may be referred to *Annularia carinata* (= *A. mucronata*).

In addition, we suggest the following revisions to the specimens illustrated by Mamay and Mapes (1992):

1. Text-figure 2D: This specimen was identified as *Annularia radiata*, a species typical of Middle Pennsylvanian strata. This material may instead belong to *A. spicata*, which is a characteristic Late Pennsylvanian species (Wagner and

Álvarez-Vázquez 2010), although it is somewhat larger than typical representatives of that species.

2. Text-figure 2F: *Annularia pseudostellata*. Specimens in the collection indicate considerable morphological variation among *Annularia* with larger leaf whorls. Much of this material may belong to a single species, possibly *A. stellata* forma *typica*. *Annularia stellata*, at least as that name has come to be used in the United States, includes forms with spatulate leaves, as well as forms with somewhat more fusiform leaves, as illustrated by Mamay and Mapes (1992). The type form of Wood is fusiform in shape. At present we are inclined to recommend continued recognition of *A. pseudostellata* in this flora.

3. Text-figure 3E: *Odontopteris* sp. There is significantly more material of this taxon in the general collections. Ultimate pinnae are generally short, and are characterized by a large, elongate or linguoid terminal pinnule that can be lobate near the base, ultimately dividing into small pinnules that are partly fused to the ultimate rachis. This taxon appears to be one of a complex of odontopterids that may belong to the fossil genus *Mixoneura* (*sensu* Wagner and Castro 1998). It most resembles *Odontopteris subcrenulata* and *Odontopteris pseudoschlotheimii*, which occur in Upper Pennsylvanian strata of the Saint-Etienne Basin, Massif Central (Doubinger et al. 1995).

4. Text-figure 4A, C-E: The identification of this material as *Neuropteris ovata* is probably correct. The pinnules are somewhat more rounded in overall shape than is typical and not notably auriculate. However, there are specimens with inflated terminal pinnules with fused, subjacent odontopteroid pinnules immediately below the terminal. As others have noted, *N. ovata* may be in need of systematic revision given its long range and extensive geographic coverage.

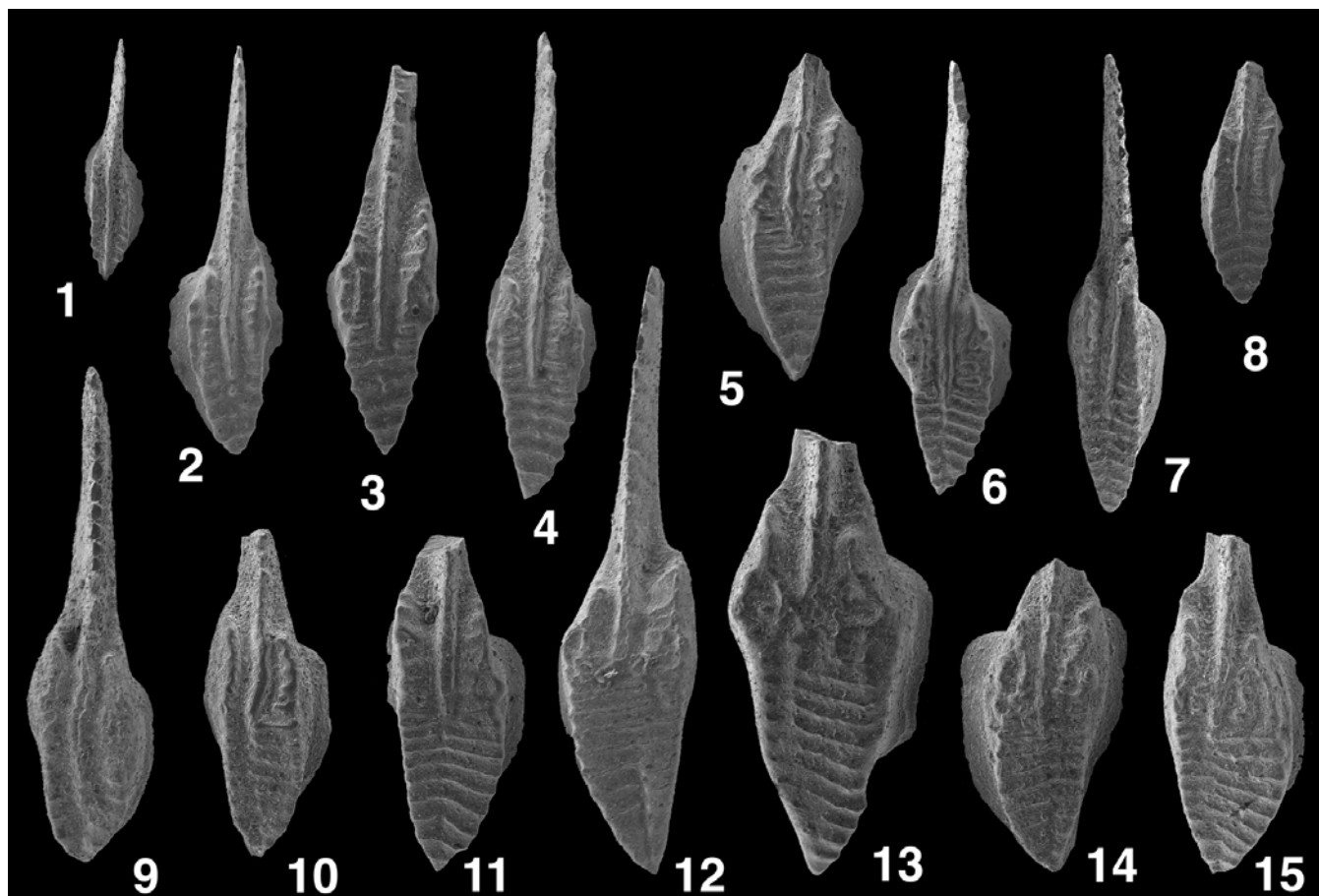
5. Text-figure 4B. This tiny fragment cannot be assigned with confidence to *Neuropteris heterophylla*. It probably belongs to the neuropteroid described by Knaus and Lucas (2004).

6. Text-figure 5D-E: These pinnae probably do not represent *Neuropteris macrophylla* (incorrect gross shape, size and venation), but are rather more similar to *Neuroodontopteris auriculata*. There is a considerable amount of this material in the collections. Pinnules are quite variable in size and shape, often with rounded, inflated bases and with dense, often irregular venation.

7. Text-figure 5H: Identified as comparable to *Neuropteris obliqua*, this specimen has very high angle veins, lobed bases, and other *Odontopteris* characteristics. It is likely part of the larger *Odontopteris subcrenulata* population described above. However, it shows some comparison with *Odontopteris brardii* (see Castro 2005, pl. III), whereas text-figure 5F could be the cyclopteroid of the same species (see Castro 2005, pl. IV).

8. Text-figure 9E: Identified as “reminiscent of *Rhacopteris*.” We think that this identification should not be included in the floral list.

None of the newly identified or re-identified specimens are narrowly diagnostic stratigraphically. Plant taxa typical of seasonally dry habitats, in particular, are not good stratigraphic indicators because little is known about the details of their temporal distributions. Where such taxa have been used to infer young ages in the face of older ages inferred from wetland flora,



TEXT-FIGURE 8

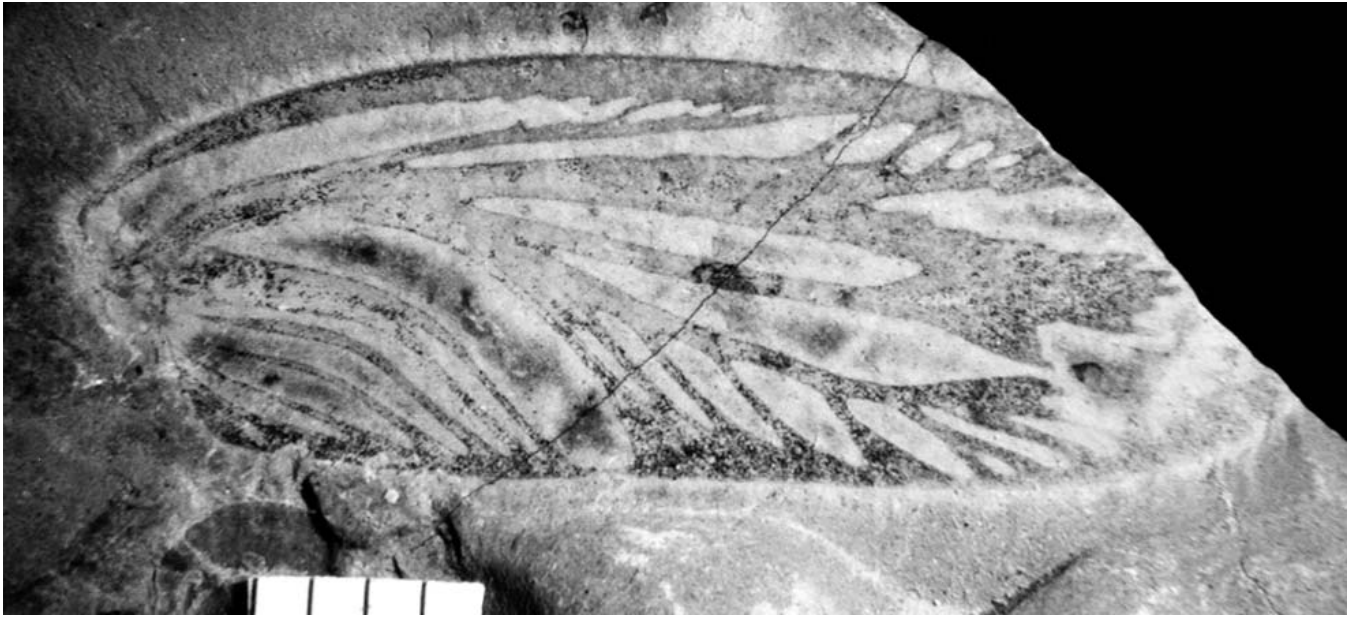
Conodonts of the Tinajas Member of the Atrasado Formation at the Kinney Brick Quarry. All $\times 50$.

- | | | | |
|---------|--|---------|---|
| 1,8 | <i>Idiognathodus</i> sp. indet., juvenile specimens. | 9 | <i>Idiognathodus biliratus</i> (Gunnell 1933)? |
| 2-5 | <i>Idiognathodus confragus</i> Gunnell 1933? | 7,10,11 | <i>Idiognathodus cherryvalensis</i> Gunnell 1933? |
| 6,12-15 | <i>Idiognathodus corrugatus</i> Gunnell 1933? | | |

they invariably occur in paleoenvironmental settings suggestive of seasonally dry climates, and can significantly mislead biostratigraphic conclusions (e.g., Wagner and Lyons 1997; Falcon-Lang et al. 2011). The neuropteroid described by Knaus and Lucas (2004), for example, has been identified at several places in fragmentary preservation, but is rare enough and regionally localized enough not to be able to be used with confidence to specify an age. Overall, the flora is consistent with a Late Pennsylvanian age for the KBQL. It is not inconsistent with the early Virgilian age originally determined by Mamay and Mapes (1992). However, it also is in conformance with a Missourian age, as determined by other means in this paper, and this underscores the inherent imprecision of Late Pennsylvanian plant biostratigraphy.

Insect biostratigraphy

The KBQL has yielded various insect remains of different orders (Carpenter 1970, Shear et al. 1992), including cockroaches of the family Spiloblattinidae, which display distinctive color patterns on their wings (text figs. 9-10). Color patterns on the wings of blattids (cockroaches) show a directed development through time, which has been documented from the beginning of the Stephanian (Missourian) through the Sakmarian (middle Wolfcampian) and provides a basis for nonmarine biostratigraphic correlations in that interval (Schneider 1982; Schneider and Werneburg 2006). Based on these color patterns, three genera have been distinguished, each represented by one chronocone, which are the *Sysciophlebia*, the *Spiloblattina* and the *Syscioblatta* lineages. Each of these lineages is subdivided



TEXT-FIGURE 9
NMMNH P-14342, forewing of the blattid genus *Syscioblatta* from the Kinney Brick Quarry. Scale in mm.

into several zonal species, but increasing data show that they form in reality a continuum or chronocline of successive biospecies in each lineage.

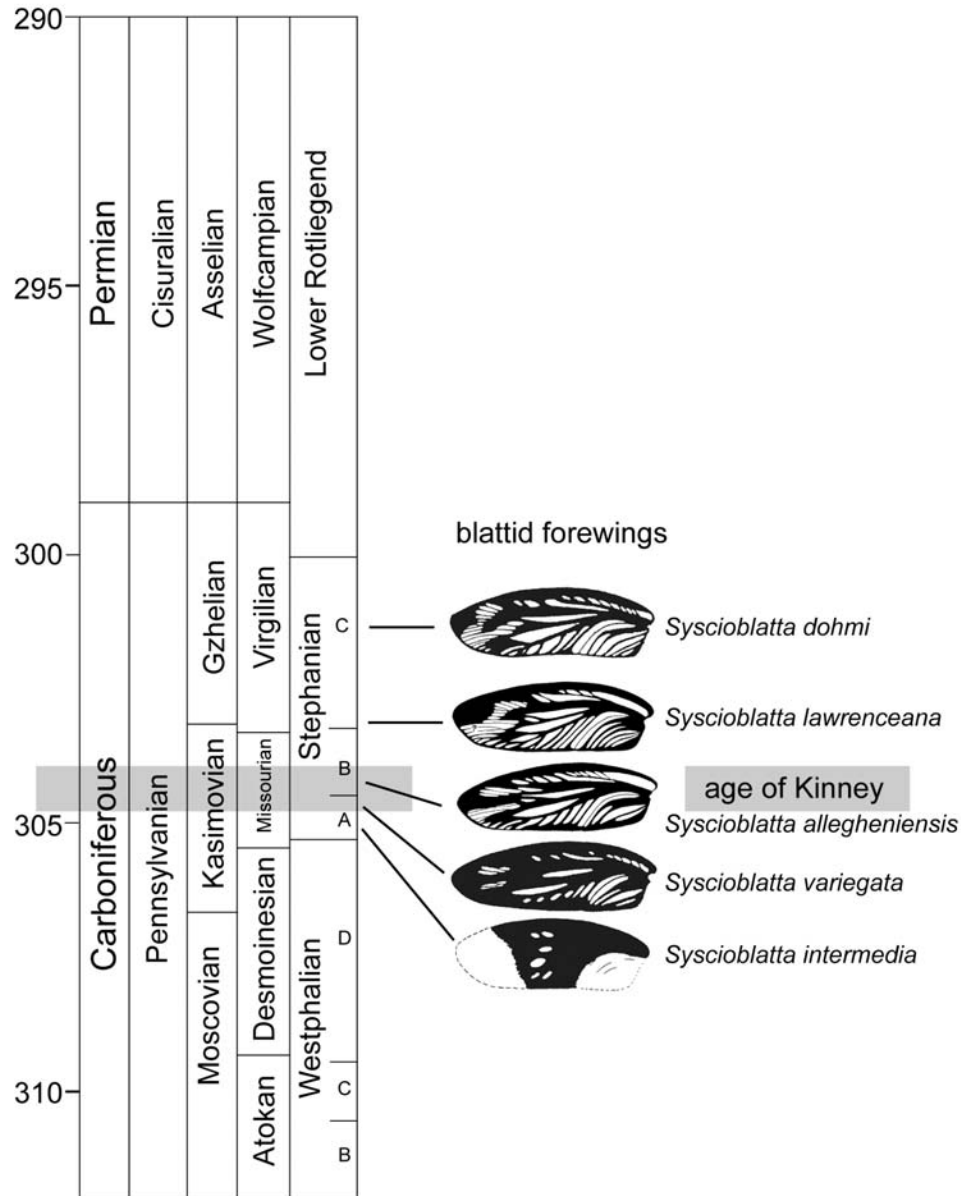
The time resolution of this blattid-based biostratigraphic tool for continental sediments is comparable to that for marine sediments using microfossils and ammonoids (Schneider and Werneburg 2006). However, there is no direct connection of the continental insect biostratigraphy to the marine biostratigraphy, although that will change now with data from the KBQL and from the Red Tanks Member of the Bursum Formation in central New Mexico (Schneider et al. 2004; Schneider and Werneburg 2006). Indeed, the link to marine standard sections, as shown, for example, in the correlation charts of Roscher and Schneider (2005) and Schneider and Werneburg (2006), is based only on some rare and often ambiguous isotopic ages from the latest Stephanian and the Lower Rotliegend (Gzhelian-Asselian) of Germany (Menning et al. 2006; Lützner et al. 2007). For most of the Pennsylvanian, isotopic ages are virtually unknown in either terrestrial or marine deposits (Ogg et al. 2008; Davydov et al. 2010). Therefore, the insect biostratigraphy has thus far mostly been calibrated by plant biostratigraphy. However, macroplant biostratigraphy and palynological biostratigraphy are primarily ecostratigraphy (see above), so time boundaries based on them can be very diachronous as shown, for example, in Hmich et al. (2005, 2006).

At the KBQL, species of the genera *Syscioblatta* and possibly *Sysciophlebia* are present. Best preserved are forewings of the genus *Syscioblatta* (text-fig. 9). Size and distribution of the light-colored areas of the wings are transitional between *S. allegheniensis* and *S. lawrenceana*, possibly a bit closer to the former and therefore designated here as *S. allegheniensis* form K. According to Carpenter (1934), *S. allegheniensis* comes from the Conemaugh Formation at Aspinwall, west side of Allegheny River, Appalachian basin, Pennsylvania. The type hori-

zon is the Duquesne coal zone of the Casselman Formation of the Appalachian basin in Pennsylvania, strata of early Virgilian age (Barrick et al. 2008). The precursor species of *S. allegheniensis* is *S. variegata*. The type horizon of this species is the roof shale of the Ames Limestone (below the Duquesne coal zone) of the Appalachian basin in Ohio. Based on conodonts, the Ames was dated as early Gzhelian by Ritter (1995). Barrick et al. (2008) and Heckel et al. (2008) confirmed this based on the redescribed conodont *Idiognathodus simulator*, as they placed the base of the Gzhelian at the first appearance of *I. simulator*.

Comparing the color pattern and assuming a nearly constant rate of evolution, the time difference between *S. variegata* and *S. allegheniensis* is larger than that between *S. allegheniensis* and the subsequent *S. lawrenceana*. The latter co-occurs together with *Sysciophlebia rubida* in the Plouznice Horizon of the Semily Formation in the Krkonoše-Piedmont basin, Czech Republic, which is dated by macroplants as late Stephanian B, which is about early Gzhelian.

Significantly, at NMMNH locality 4629 in the Cerros de Amado of central New Mexico, the lower part of the Tinajas Member of the Atrasado Formation contains an ~7m thick unit of lacustrine to transitional brackish marine black shales (Lerner et al. 2009). Besides a variety of plants, invertebrate and fish fossils, some remains of *Neorthroblattina* as well as a spiloblattnid forewing fragment are known from this site, which is stratigraphically just below late Missourian conodonts (Lucas et al. 2009). This fragment has been determined by Schneider in Lerner et al. (2009) as *Sysciophlebia* cf. *S. grata*, which is in accordance with the age determination of the KBQL based on *S. allegheniensis* (see above). *Sysciophlebia grata* is known from the Hredle Member of the Slanz-Formation (lower to middle Stephanian B) of the Kladno basin of the Czech Republic (Schneider and Werneburg 2006), as well as from the upper Qued Issene Formation of the Souss basin in Morocco



TEXT-FIGURE 10

Age of the Kinney Brick Quarry Lagerstätte and recalibration of blattid biostratigraphy based on this age assignment. See text for discussion. Timescale modified from Davydov et al. (2010). Correlation of Lower Rotliegend to marine stages from Heckel and Clayton (2006) and Menning et al. (2006).

(Hmich et al. 2005). The *Sysciophlebia grata* zone is regarded as of Kasimovian to Gzhelian in age.

These data indicate a stratigraphic range for the *Syscioblatta* specimens from the KBQL of approximately late Kasimovian to early Gzhelian, which is based on two interpretations (text-fig. 10). First, *S. variegata* is the precursor species of *S. allegheniensis*, and second, and most important, the Ames Limestone is earliest Gzhelian in age based on conodonts (Ritter 1995; Barrick et al. 2008; Heckel et al. 2008). However, the newly determined age of the KBQL presented here is early-middle Kasimovian, which is not completely congruent with the published insect biostratigraphy. Thus, the blattid insect biostratigraphy can now be in part recalibrated to the ma-

rine scale using the age of the KBQL (text-fig. 10). This indicates that at least part of the *Sysciophlebia grata* blattid zone is of early-middle Kasimovian age.

COMPARISON TO OTHER LAGERSTÄTTEN

The Missourian age of the KBQL indicates that it preserves a biota that lived during a time of seasonal moisture limitations (relatively dry) when sea level was low in the western equatorial tropics of Pangea (Bishop et al. 2010). Schultze and Maples (1992) used cluster analysis to compare the KBQL biota to other Pennsylvanian Lagerstätten. They found that Kinney is, overall, most similar to the Garnett, Kansas Lagerstätte, which is also the Lagerstätte closest in age to Kinney (both are Mis-

sourian, though note that Garnett is late Missourian, separated from the KBQL by most of three cyclothems) of the Lagerstätte examined in the analysis. This may indicate that similarity in age, rather than similar paleoenvironment or taphonomy, best explains the similarity of the KBQL to the Garnett Lagerstätte.

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APPENDIX 1

Fossil localities. All localities are in the Tinajas Member of the Atrasado Formation, Bernalillo County, New Mexico (text-figs. 4-5).

NMMNH locality 345 (Kinney Brick Quarry Lagerstätte)

–UTM zone 13, 378414E, 3873814N, NAD 27.

NMMNH locality 7874—UTM zone 13, 377754, 3873789N, NAD 27.

NMMNH locality 7875—UTM zone 13, 378172E, 3873954N, NAD 27

NMMNH locality 7876—UTM zone 13, 376617E, 3877447N, NAD 27.

NMMNH locality 7877—UTM zone 13, 376310E, 3878366N, NAD 27.

APPENDIX 2

Fusulinid identifications.

Genus *Tumulotriticites* Wilde, 2006

Synonyms: ?*Protriticites* (part.); ?*Eotriticites*.

Diagnosis: Test inflated fusiform; first whorls fusulinellin, last whorls schwagerinid; chomata mound-shaped; septa weakly folded; aperture terminal, simple.

Composition: Apparently monospecific.

Occurrence: Early/Middle Missourian of the Big Hatchet Mountains and Manzanita Mountains (New Mexico).

Tumulotriticites cf. *T. tumefactus* Wilde 2006

Text-figure 7.1-2

Discussion: All the characters of the species were observed : shape of test, wall microstructure, shape of tunnel and chomata, and weakness of septal folding. The population is a little smaller in all these parameter measurements than that reported by Wilde (2006): Diameter (D) = 0.840-0.870mm (versus 1.100mm); width (w) = 1.425-1.500mm (versus 2.770mm); w/D = 1.63-1.79 (versus 2.5); proloculus diameter = 0.020-0.030mm (versus 0.073mm); wall thickness at the last whorl = 0.040-0.050mm; number of whorls = 5.5-6 (versus 6). The population may correspond to an immature set of *T. tumefactus*, to a subspecies, or to a microspherical generation (smaller proloculi).

Genus *Triticites*

Subgenus *Schwageriniformis* Bensch in Rauzer-Chernousova et al 1996

Type species: *Triticites schwageriniformis* Rauzer-Chernousova 1938.

Synonym: *Triticites* (part.)

Diagnosis: Subgenus of *Triticites* characterized by plane to almost plane, small proloculus and tight coiling (Leven and Davydov 2001).

Occurrence: Middle Kasimovian of Palaeotethys and Urals; rare in the Early/ Middle Missourian of North America

Triticites (Schwageriniformis) cf. *T. planus* Thompson and Thomas 1953

Text-figure 7.3-5

Triticites planus THOMPSON and THOMAS 1953, p. 31-34, pl. 3, figs. 1-19, pl. 4, figs. 1-10. –KAHLER and KAHLER 1966, p. 512 (not illustrated). –ROZOVSKAYA 1975, p. 158 (not illustrated). –WILDE 1984, p. 545, figs. 4D-E. –LUO and WU 1990, pl. 1, fig. 21.

Discussion: Many characters of the species were observed: elongate fusiform shape of test and relative weakness of septal folding. The population is a little smaller than that reported by Wilde (2006) and measures: Width (w) = 2.140-3.540mm (versus 4.600-7.600mm); Diameter (D) = 0.800-1.150mm (versus 1.400-1.800mm) for less whorls (5-6 versus 6-7); but the w/D ratio is similar: 3.3-4.2 versus 3.5-4.5 = 1.63-1.79 (versus 2.5) as well as the proloculus diameter = 0.060-0.130mm (versus 0.065-0.112mm). The wall thickness at the last whorl is 0.020-0.030mm; and the height of the last whorl, 0.145-0.185mm.

Occurrence: Casper Formation of Wyoming (U.S.A.); Upper Carboniferous of Fujian (China); Missourian of New Mexico.

Triticites (Schwageriniformis) aff. *T. planus* Thompson and Thomas 1953

Text-fig. 7.6

Discussion: The measurements are consistent with *T. planus* and *T. cf. T. planus*: w = 4.000mm ; D = 1.000mm ; w/D = 4.0; proloculus diameter = 0.050mm; number of whorls: 5-6 ; but the chomata are lower and more elongate towards the poles.

Subgenus *Triticites*

Triticites (Triticites) cf. *T. myersi* Wilde 2006

Text-fig. 7.7-8

Discussion: The measurements are consistent with *T. myersi*: w = 4.090-5.000mm ; D = 1.000-1.250mm; w/D = 4.0-4.1; proloculus diameter = 0.045mm; number of whorls: 5-6; but the specimens are a little deformed due to lithoclastic compaction, so exact identification is not possible.

Triticites (T.) ex gr. *T. ohioensis* Thompson, 1936

Text-fig. 7.9-10

?*Triticites* cf. *ohioensis* Thompson. –ROSS AND TYRRELL 1965, p. 632, pl. 77, figs. 19-21.

Discussion: Because of its massive chomata, as noted by Ross and Tyrell (1965), this elongate fusiform species is transitional between *T. ohioensis* and *Kansanella* Thompson, 1957. W = 4.210-5.130mm; D = 1.460-1.580; w/D = 2.9-3.8; number of whorls : 6.

Occurrence: Horquilla Formation of Whetstone Mountains (Arizona); Manzanita Mountains, New Mexico.

