

Improved conodont biostratigraphic constraint of the Carboniferous/Permian boundary in south-central New Mexico, USA

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ABSTRACT: Recovery of P₁ elements of *Streptognathodus isolatus* and associated nodose streptognathodids from the Laborcita Member of the Bursum Formation near Tularosa, New Mexico clarifies placement of the Carboniferous/Permian boundary in the northern Sacramento Mountains. Conodont elements, fish teeth, and dermal plates are abundant in a thin (4.8 m) highstand carbonate succession located approximately 70 m above the base of the 130 m-thick Laborcita Member. The fauna represents the oldest Permian conodonts discovered thus far in New Mexico and in a basin associated with the Ancestral Rocky Mountains orogen. The occurrence of *S. isolatus* in this tectonic and geographic setting further demonstrates its utility in defining and correlating the base of the Permian System on a global scale. Occurring with *S. isolatus* in earliest Asselian strata is *S. barricki* n. sp., which is described herein.

INTRODUCTION

The GSSP for the base of the Permian System was established at the Aidaralash Creek section in northern Kazakhstan (Davydov et al. 1998) at the level of the first occurrence of the conodont *Streptognathodus isolatus* Chernykh, Ritter, and Wardlaw 1997. This species has been found in several Carboniferous/Permian (C/P) boundary sections globally since that time (see below). This biostratigraphic boundary has been elusive, however, in mixed carbonate-siliciclastic intervals in the domain of the Ancestral Rocky Mountains (ARM) orogen of the west-central United States, where tectonically derived non-marine and paralic sediments dominate most boundary sections. Sparse to abundant conodont faunas derived from thin, highstand carbonates and shales interbedded with non-marine strata permit approximate placement of the C/P in the Paradox Basin of southeastern Utah-southwestern Colorado (Ritter et al. 2002; Scott 2013), the Lucero Basin of north-central New Mexico (Orchard et al. 2004; Lucas et al. 2013a, b and 2016a, b), and the Orogrande Basin of south-central New Mexico (Frederick et al. 2018). The purpose of this paper is to describe an abundant conodont fauna from the Laborcita Member of the Bursum Formation in the northern Sacramento Mountains of New Mexico that permits the precise placement of the C/P boundary on the eastern shelf of the ARM-related Orogrande Basin.

LITHOSTRATIGRAPHIC AND BIOSTRATIGRAPHIC SETTING

Carboniferous-Permian boundary strata in the Sacramento Mountains of southern New Mexico were assigned to the Laborcita Formation by Otte (1959). The Laborcita was subsequently designated a formal member of the Bursum Formation by Krainer and Lucas (2009). The member is comprised of interbedded, lowstand fluvial-deltaic arkoses and fanglomerates and thin, highstand marine carbonates that were deposited on the narrow eastern shelf of the Orogrande Basin (Krainer et al.

2003) during late Pennsylvanian and early Permian time. The member is 130 m thick at its type section in Laborcita Canyon located approximately 14 km south of the current study area. East of Tularosa, the lower 60+ meters have been cut out by range-bounding normal faults or are covered by Quaternary alluvium (Frederick et al. 2018). Age-diagnostic ammonoids (Bose 1920; Miller 1932), fusulinids (Otte 1959; Steiner and Williams 1968), and conodonts (Frederick et al. 2018) collected from the lower half of the Laborcita Member indicate a late Virgilian age (late Gzhelian; i.e., Pennsylvanian). The age of the upper ~70 m of the Laborcita Member exposed east of Tularosa remains largely undocumented, in spite of extensive work by Toomey and Cys (1977, 1979), Mazzulo and Cys (1979), Cross and Klosterman (1981a, 1981b), Shinn et al. (1983), Toomey (1983a, 1983b), and Cox, (1998) on algal-microbial and phylloid-algal bioherms that occur in the upper part. The only age-diagnostic fossil noted by these workers was the reported occurrence (Toomey 1983b) of *Schwagerina longissimoidea* (Beede 1916) associated with phylloid-algal mounds that comprise Otte's (1959) unit 33. This species ranges from the late Virgilian (late Gzhelian) Hughes Creek Shale Member to the early Wolfcampian (early Asselian) Neva Limestone Member in the American Midcontinent (Wahlman 2013) therein limiting the species utility in precise identification of the system boundary.

The highest well-documented Pennsylvanian (late Virgilian) fossils described to-date were collected from the Tularosa Clay Pit (TCP) located south of US Highway 70 immediately east of Tularosa (text-fig. 1). A thin, 20-30 cm-thick limestone bed near the base of the west-facing quarry wall (sample TCP 14-19 on text-fig. 2A; text-fig. 3B) hosts one of the few Late Paleozoic ammonoid faunas known from southern New Mexico. This fauna has been the focus of several studies (Miller 1932; Furnish and Glenister 1971; Tharalson 1984) dating back to Bose (1920). A superjacent 10 cm-thick limestone and the basal few cm of the overlying black shale (respective samples TCP-16-19

and TCP-17-19 on text-fig. 2A) yielded moderately abundant conodont faunas reported by Frederick et al. (2018). These ammonoids and conodonts indicate a latest Virgilian (latest Gzhelian) age for and permit correlation to the fifth-order lower Hughes Creek sequence of the Midcontinent stratigraphic succession (see text-fig. 4; Boardman et al. 2009). The Hughes Creek sequence is located immediately below the Red Eagle sequence (which contains the base of the Permian System) in the American Midcontinent (Sawin et al. 2006).

CONODONT FAUNAS AND AGES

The report of conodonts from TCP beds (Frederick et al. 2018) prompted the author to re-sample the quarry in addition to several meters of the overlying Laborcita Member from two nearby sections in an attempt to more precisely locate the C-P boundary. During July 2019, a total of 16 samples were collected from the middle to upper part of the Laborcita Member: two from black shales and 14 from carbonate horizons (text-fig. 2). The lowermost three collections represent a re-sampling of units 14, 16, and the basal 20 cm of unit 17 of Frederick et al.'s (2018) TCP section (text-fig. 3B). Twelve of the remaining 13 samples were collected on the west side of the low hills at the east end of NE Bookout Road (Mound Gulley section) and the thirteenth sample from the middle of the Laborcita Member in the Coyote Hills (CH) located 4 km north of Tularosa (text-fig. 1). The low hills due east of the Mound Gulley (MG) section are conspicuously capped by phylloid algal mounds (text-fig. 3A) described by Cross and Klosterman (1981a, 1981b) and referred to as Scorpion Mound by Shinn et al. (1983), Toomey (1983b), and Mazzullo (1998). Correlation of the TCP, MG, and CH sections (text-fig. 1) was accomplished by tracing key stratigraphic intervals as observed in Google Earth and in the field. These sections and their constituent conodont faunas are described below.

Tularosa Clay Pit Section

The basal few meters of the TCP exposure are comprised mostly of gently eastward-dipping black, laminated calcareous shale (text-fig. 3B). Two thin clayey skeletal wackestone beds form ledges that continue along strike for several tens of meters just above the quarry floor. The lower of these limestone beds (unit 14) ranges from 15 to 25 cm in thickness and contains ammonoids (described by several authors noted above), gastropods (Kues 1991a), scaphopods (Kues 1991b), and brachiopods. The upper skeletal wackestone bed (unit 15) is 10-15 cm thick and forms a discontinuous ledge. This bed contains skeletal fragments of various invertebrate groups and conodont elements (Frederick et al. 2018). During the course of the current study, these two limestone beds and the overlying 20 cm of black shale (lower part of unit 17) were sampled for conodont elements (text-fig. 2A). Each of the three samples (TCP-14-19, TCP-16-19, and TCP-17-19) yielded sparse conodont faunas (3 to 10 elements/kg) dominated by P_1 elements of *Streptognathodus*. Frederick et al. (2018) reported the following four species from units 16 and 17: *S. elongatus* Gunnell 1933, *S. wabaunsensis* Gunnell 1933, *S. farmeri* Gunnell 1933, and *S. conjunctus* Barskov, Isakova, and Schastlivceva 1981. Re-sampled unit 16 yielded an additional species, *S. tenuialveus* Chernykh and Ritter 1997, reported initially from late Gzhelian strata in northern Kazakhstan (Chernykh and Ritter 1997). As discussed by Frederick et al. (2018), this species association indicates a latest Virgilian (latest Gzhelian) age for these strata.

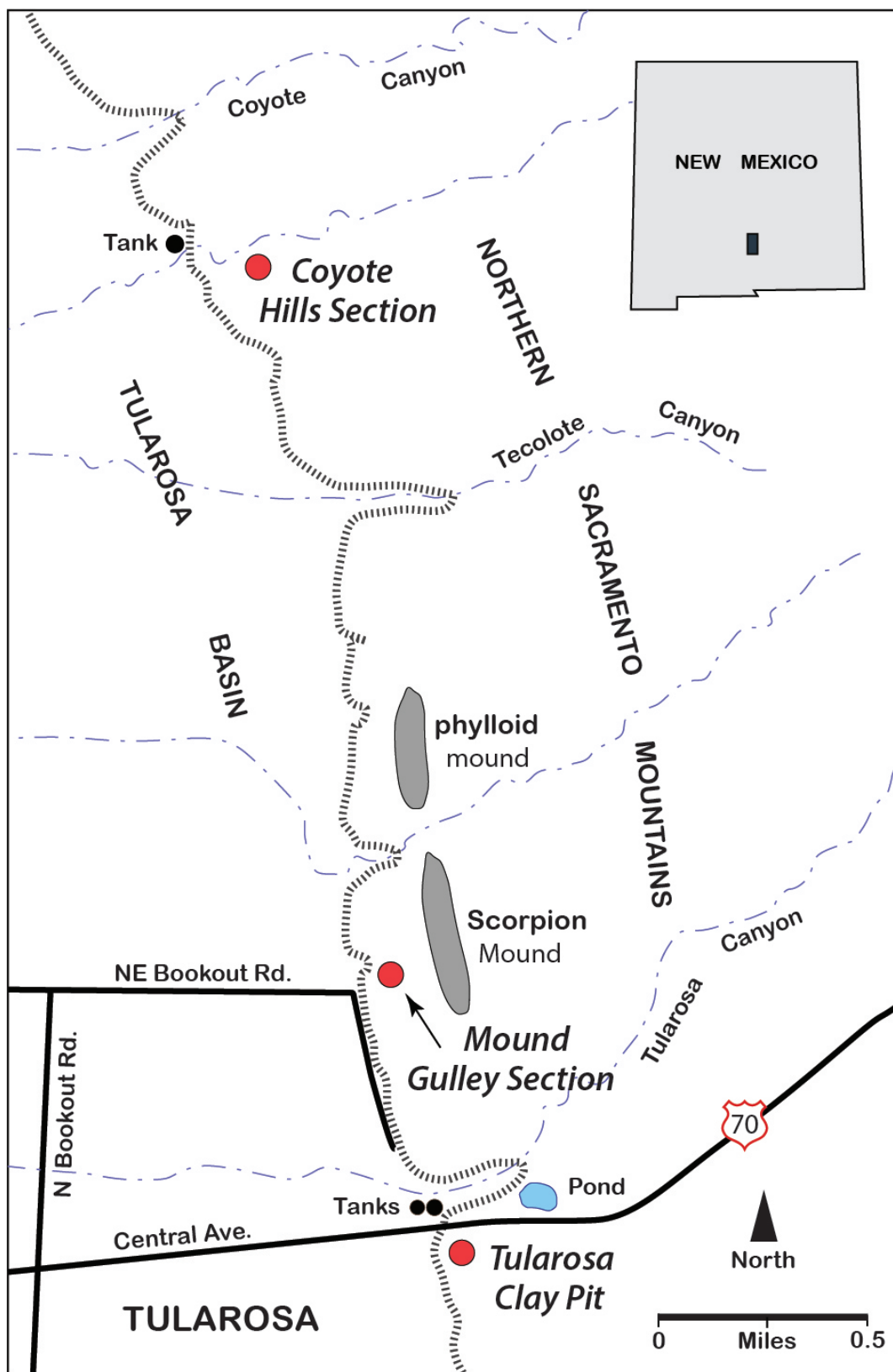
Mound Gulley Section

The MG section corresponds to units 1 through 26 of Otte's (1959) section 29 (text-fig. 2B, 2C). The section begins immediately east of the sharp turn in NE Bookout Road (text-fig. 1) and continues up the west-facing slope, ending several meters below the phylloid-algal mounds that cap the hill. The section is dominated by green, brown, and red siltstone, feldspathic/lithic wacke, and clast-supported fanglomerate (text-fig. 3D and F). These rocks are texturally and compositionally immature reflecting deposition in close proximity to the Pederal Uplift. A single specimen of the conodont *Bispathodus* sp. (Plate 1, fig. 14) was recovered from sample MG-9k-19. This specimen was likely eroded from upper Devonian or lower Mississippian strata exposed on the emerging highland. The MG section contains seven thin limestone bands that reflect intermittent highstand flooding of the narrow eastern Orogrande Shelf.

The lowest outcropping limestones in the MG section correspond to Otte's (1959) stratigraphic unit 4. This unit is composed of approximately 1.0 m of brown, slope-forming shale and siltstone sandwiched between two thin (10 cm) skeletal, mud-dominated packstone beds that form discontinuous ledges. These packstone beds are shaly and contain abundant brachiopod shells as well as the remains of echinoderms and bryozoans. Samples from the lower bed did not yield conodont elements. The upper limestone, however yielded a few juvenile P_1 elements of *Streptognathodus elongatus* (sample MG4b-19). This species occurs in both uppermost Pennsylvanian and earliest Permian strata (Ritter 1995; Boardman et al. 2009; Frederick et al. 2018). Stratigraphic unit 4 is deemed to be latest Virgilian (latest Gzhelian) in age because it does not appear to represent a significant sea-level highstand that could be correlated with the Red Eagle major cycle of the Midcontinent and because the first occurrence *S. isolatus* and other boundary indicators are at a chronostratigraphic position above this interval.

The overlying limestone-bearing interval is Otte's (1959) stratigraphic unit 9. This unit was sampled in the bottom of a north-west-southeast-oriented gully located approximately 190 m northeast of the sharp bend in NE Bookout Road (text-fig. 1). This heterolithic unit is approximately 3 m thick and contains nine individual limestone horizons separated by siliciclastic beds (text-fig. 2C). Exposure surfaces capping three of the nine limestones, suggest an element of eustatic control on deposition of the limestone beds, although tectonics may also account for introduction of the interbedded siliciclastic sediment into the area. For purposes of stratigraphic precision, Otte's (1959) bed 9 is herein subdivided into 12 subunits designated 9a through 9l. Unit 9a is a 30 cm-thick, ledge-forming, sparse skeletal wackestone. Phylloid-algal fragments are the most common skeletal grains. The bed is grayish-yellow in color and is best exposed in the bottom of the gully. A thin exposure breccia occurs on top of the bed. Unit 9b is a covered slope. Like 9a, unit 9c is a ledge-forming, skeletal wackestone (70 cm) that is also capped by a thin exposure breccia. Unit 9d is covered. Unit 9e is a limestone pebble conglomerate with a sandy carbonate mudstone matrix. It is overlain by a thin, quartz-granule conglomerate representing a third exposure surface within Otte's (1959) unit 9. Wackestone units 9h and 9i are interbedded with green shaly siltstone.

The most abundant and stratigraphically significant conodont faunas were obtained from the maximum-flooding interval spanning units 9j through 10b, specifically from samples



TEXT-FIGURE 1
Index map showing location of stratigraphic sections (circles) in the Northern Sacramento Mountains east and northeast of Tularosa, New Mexico.

MG-9k-19 and MG-9l-19 (text-fig. 2C). Sub-unit 9j is a 10 cm-thick, light gray transgressive limestone that formed a substrate for development of a small patch reef community (text-fig. 3C) constructed by microbes, algae, and sponges (Toomey and Cys 1979). The mound horizon can be traced for at least 5.5 km along depositional strike. Individual mounds are a few tens of centimeters high and approximately 1 to 1.5 meters in diameter. Mound cores have a mottled fabric referred to as “leopard rock” by Toomey and Cys (1979) and subsequent authors. Intermound and mound-flanking beds are comprised of skeletal packstone that is locally rich in phosphatic nodules, brachiopod shells, fish remains, and conodont elements. The upper part of unit 9k is oncoidal wackestone and packstone that fills the relief between mounds. The weathered surface is littered with dark-colored, red-algal oncoids (rhodoids) that range from a few to 10 cm in diameter (text-fig. 3E). The coated grains are composed of concentric thalli of the red alga *Archaeolithophyllum lamellosum* Wray 1964 and were interpreted to have formed in a lagoon that developed on the eastern Orogrande Shelf (Toomey 1983a and 1983b). The rhodoid bed (unit 9k) becomes shaly near the top and is capped by a thin (5 cm) gray skeletal limestone (unit 9l) that contains remains of brachiopods, bryozoans, echinoderms, and conodonts. The transition from reefal limestone to lowstand/tectonic arkose is reflected in the transition from black shale and limestone of units 10a and 10b to greenish arkose of unit 10c (text-fig. 2B and C).

Conodont elements were recovered only from beds 9k and 9l in Otte’s (1959) unit 9. Specimens from bed 9k (40 elements/kg) were more abundant and better preserved than those from unit 9l (15 elements/kg), but otherwise yielded a similar association of earliest Permian species that includes *Streptognathodus acuminatus* Gunnell 1933, *S. farmeri* Gunnell 1933, *S. fuchengensis* Zhao 1982, *S. invaginatus* Reshetkova and Chernykh 1986, *S. nodulinear* Reshetkova and Chernykh 1986, *S. isolatus* Chernykh Ritter, and Wardlaw 1997, *S. distortum* Chernykh 2005, and *S. barricki* n. sp. A few specimens of *S. flangulatus* Gunnell 1933 were recovered from bed 9k that were not found in bed 9l. Early Permian representatives of Late Pennsylvanian to Early Permian *S. elongatus* Gunnell 1933 are also present in these faunas. In addition to conodont elements, sample MG-9k-19 produced an abundance of other phosphatic remains (>100 specimens/kg), principally fish teeth and dermal plates.

Two additional limestone intervals were sampled during the course of this study. These correspond to units 15 and 22 of Otte’s (1959) section 29 (text-fig. 2B). Unit 15 forms a discontinuous, 1.5 m-high ledge comprised of argillaceous wackestone. Samples were collected from three different levels, but none yielded conodont elements. Unit 22 constitutes the highest sampled horizon in this study. This unit is approximately 2 m thick and is comprised of a basal transgressive skeletal limestone overlain by a complex of algal-sponge mounds and intermound deposits. These small patch reefs were the subject of papers by Toomey (1983a and 1983b). Two horizons were sampled: the mound substrate and the intermound skeletal packstones. Neither sample was productive of conodont elements. The intermound packstone sample, however, yielded abundant inarticulate brachiopod fragments and some fish debris.

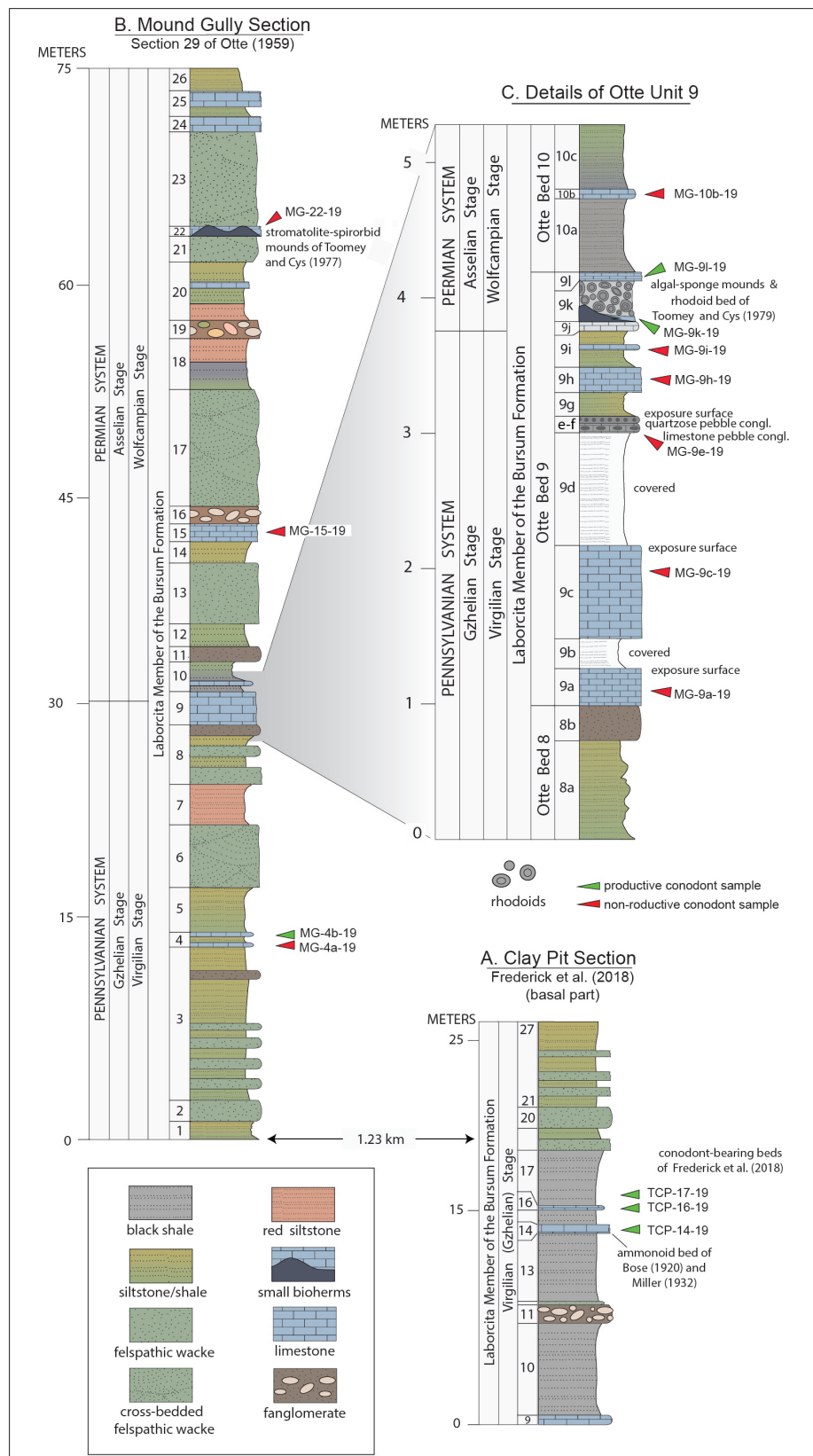
Coyote Hills Section

No detailed section was measured in the Coyote Hills, but several beds were traced northward from the TCP and MG sections. Two key intervals that provided precise correlation between the sections include the black shale-dominated succession exposed in the TCP section and the microbial-sponge mound/rhodoid bed that yielded abundant conodont elements and fish debris in the MG section. Each of these was sampled for conodonts. The author was unable to confidently locate the TCP ammonoid bed from among several thin wackestone beds in the upper part of the black shale unit (TCP unit 17 equivalent), so the uppermost skeletal wackestone bed was arbitrarily collected. No conodont elements or fish remains were recovered from this sample. However, the skeletal packstone bed collected between the algal-sponge bioherms and beneath the rhodoid-bearing horizon did yield a moderately abundant fauna of conodont elements and fish material. The conodont fauna is identical in species composition to the fauna from laterally equivalent sample MG-9k-19, but with a far lower element yield. This reconnaissance sampling demonstrates that the *S. isolatus*-bearing C-P boundary bed is laterally continuous and readily traceable over a distance of several kilometers within the northern Sacramento Mountains. The lateral continuity of this carbonate succession suggests that it was deposited in response to a regionally extensive highstand of sea level, an event that most reasonably correlates with the Red Eagle 4th-order cycle of the Midcontinent (Boardman et al. 2009).

THE CARBONIFEROUS/PERMIAN BOUNDARY

The Eurasian GSSP

The Global Section Stratotype and Point (GSSP) for the base of the Permian System (and base of the Asselian Stage) is located at Aidaralash Creek, a few tens of kilometers south of Aktubinsk, northern Kazakhstan (Davydov et al. 1998). The C/P boundary is defined by the first occurrence of the conodont *Streptognathodus isolatus*, characterized by development of an isolated node field within the *S. wabaunsensis* (renamed the *S. acuminatus* herein, by priority) chronocline (Chernykh and Ritter 1997; Chernykh et al. 1997). Additional morphotypes of nodose streptognathodids (*S. nodulinear*, *S. invaginatus*, *S. fuchengensis*) closely coincide with the first occurrence of *S. isolatus* and can be used as additional or proxy indicators of the system boundary (Davydov et al. 1998; Wardlaw et al. 2004). Evolving species concepts, taxonomic priority, and possible diachroneity of first occurrences within this group led Lucas (2013a) to call for reconsideration of *S. isolatus* and Aidaralash as the GSSP for the base of the Permian System. He also noted limited global occurrence of *S. isolatus* as a point of concern. With respect to evolving species concepts and priority, the original definition of *S. isolatus* focused upon the separation of the caudal lobe from the caudal adcarinal ridge and margin of the P₁ element. Chernykh et al. (1997) unintentionally illustrated specimens of previously named streptognathodids with reduced or linear isolated node fields (*S. invaginatus* and *S. nodulinear*, respectively) as *S. isolatus*. Boardman et al. (2009) in their study of the Midcontinent conodonts clarified the taxonomy and local stratigraphic ranges of the nodose *Streptognathodus* group. Their amended species diagnoses (summarized under the heading of Taxonomic Considerations below) should preclude further taxonomic confusion. The issue of the diachronous appearance of *S. isolatus* relative to the first occurrence of “inflated schwagerinid” fusulinids was addressed



TEXT-FIGURE 2

Stratigraphic column of Laborcita strata exposed in the Mound Gully and Tularosa Clay Pit sections. The clay pit section (A) is the lower part of the section reported by Frederick et al. (2018). The Mound Gully section (B) is equivalent to the lower part of Otte's (1959) section 29. C. Details of Otte's (1959) stratigraphic unit 9 showing subunits delineated herein. Sampled horizons are indicated by arrows: green arrows indicate samples that produced conodont elements while red arrows indicate samples that did not yield conodont elements.

and rejected by Davydov (2013). With respect to Lucas's (2013a, b) conclusion that well documented and published records of *S. isolatus* are few, subsequent work has demonstrated that this is no longer the case. *Streptognathodus isolatus* and associated species have now been reported from China (Wang 2000; Wang and Qi 2002), Uzbekistan (Iskandarov and Bensch 2000), the Canadian Arctic (Mei and Henderson 2001) southern Russia (Forke 2002; Chernykh 2005), Central Iran (Sohrabi 2010), South Korea (Wang et al. 2017), and from within the U.S.A. in Kansas (Chernykh et al. 1997; Sawin et al. 2006), West Texas (Wardlaw and Nestell 2014), and now New Mexico (Lucas et al. 2013a,b).

New Mexico and the Ancestral Rockies Region

The Carboniferous/Permian boundary has been elusive in mixed carbonate-siliciclastic successions associated with the Ancestral Rocky Mountains (ARM) orogen of the west-central United States, where tectonically derived non-marine and paralic sediments dominate most boundary sections. Sparse to abundant conodont faunas derived from thin, highstand carbonates and shales interbedded with non-marine strata permit approximate placement of the C/P boundary in the Paradox Basin of Utah (Ritter et al. 2002; Scott 2013), the Lucero Basin of north-central New Mexico (Orchard et al. 2004; Lucas et al. 2013b), and the Orogrande Basin of south-central New Mexico (Frederick et al. 2018).

The C/P boundary in the western Paradox Basin of southeastern Utah is established within the Halgaito Formation, a largely fine-grained redbed succession that occurs in the Four Corners area. Scott (2013) placed the boundary within the basal 10 m of the Halgaito Formation immediately underlying the well documented first occurrence of the xanacanth shark *Orthacanthus texensis* (Cope 1888) located 10 m above the Virgilian (Gzhelian) Shafer Limestone (top of the Paradox Formation). The author (manuscript in preparation) has recently recovered P₁ elements of middle Virgilian (middle Gzhelian) *Streptognathodus vitali* Chernykh 2002 from overlying strata, indicating that the C/P boundary occurs somewhat higher in the Halgaito Formation than proposed by Scott (2013). The chronostratigraphically highest conodont fauna thus far recovered from the eastern margin of the Paradox Basin yielded early Missourian (Kasimovian) elements of *Idiognathodus biliratus* Gunnell 1933 and *I. heckeli* Rosscoe and Barrick 2013 (manuscript in preparation). Based upon these observations, it appears that siliciclastic influx curtailed carbonate deposition during Missourian time in areas adjacent to the Uncompahgre source area while marine sedimentation continued well into the Virgilian (Gzhelian) in more distal parts of the basin. In the Lucero Basin of north-central New Mexico, the C/P boundary is bracketed within the Red Tanks Member of the Bursum Formation based upon the occurrence of *S. isolatus* and younger Wolfcampian (Asselian) streptognathodids in overlying strata (i.e., unit 32 of the Carrizzo Arroyo section; Orchard et al. 2004; Lucas et al. 2013a and 2013b). On the western margin of the Orogrande Basin in the Robledo Mountains, Krainer et al. (2015) reported the occurrence of latest Virgilian *S. conjunctus*, *S. elongatus*, and possibly *S. wabaunsensis* in the upper part of Member E of the Horquilla Formation. A coeval latest Virgilian fauna was also described on the eastern shelf of the basin, from just above the ammonoid-bearing horizon of the TCP section (Frederick et al. 2018). The conodont fauna reported herein permits precise placement of the C/P boundary in the middle of the Laborcita Member in the upper part of Otte's (1959) unit 9 and

correlation to the Red Eagle major cycle in the American Midcontinent (text-fig. 4).

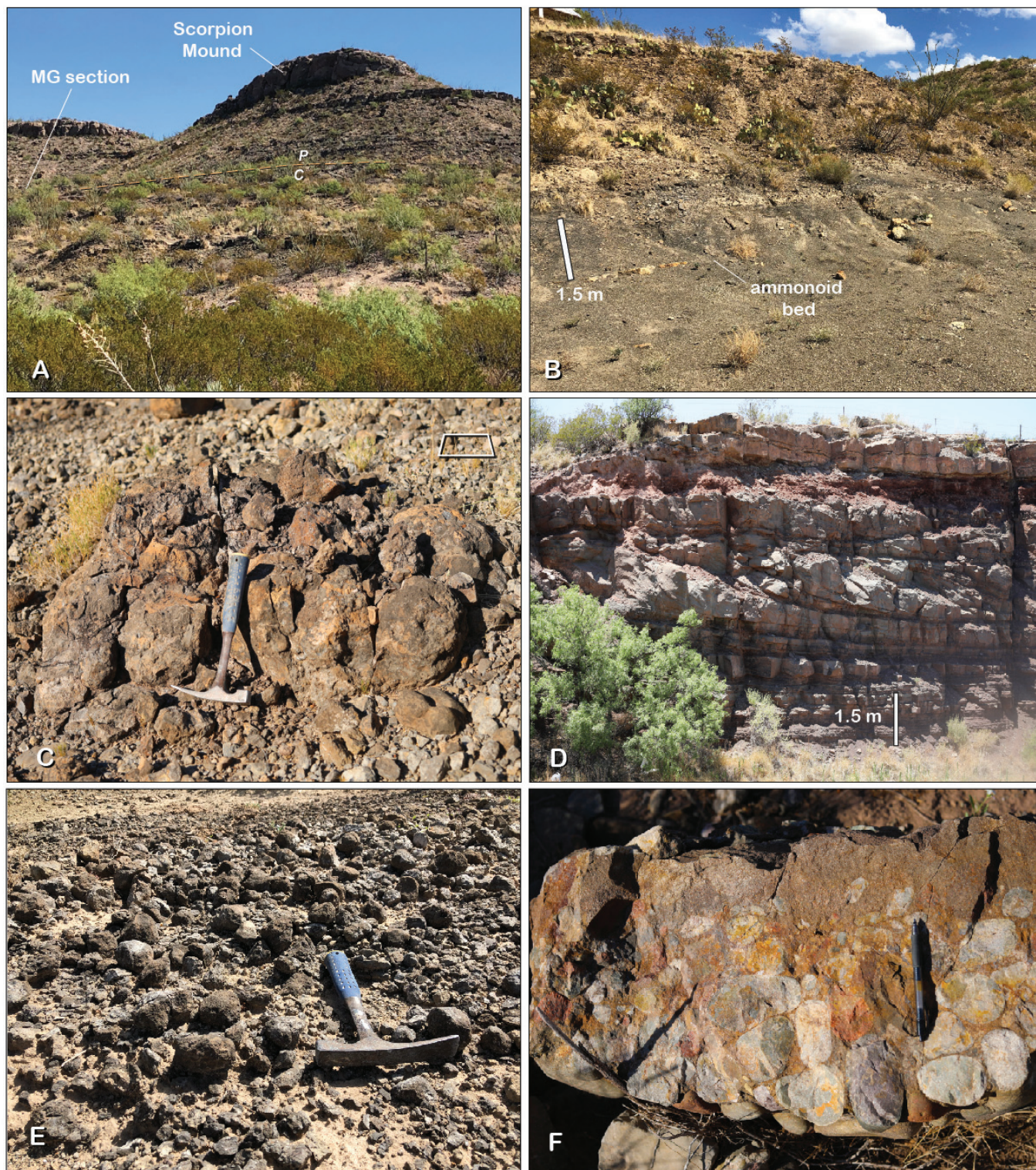
TAXONOMIC CONSIDERATIONS

Introduction

The conodont genus *Streptognathodus* was established nearly 90 years ago by Stauffer and Plummer (1932); based upon the type species *S. excelsus* and three other species from Upper Pennsylvanian strata in north-central Texas, U.S.A. In the following year, Harris and Hollingworth (1933) named an additional species from the Pawhuska Formation of Oklahoma while Gunnell (1933) established 22 new species from five Upper Pennsylvanian horizons in Missouri and Kansas. Ellison (1941) later performed the first stratigraphically comprehensive synthesis of Pennsylvanian conodonts through systematic sampling of cyclothems in the American Midcontinent. He concluded that only seven of the 27 previously defined species were valid and that most had relatively long stratigraphic ranges. At the same time, he defined three new streptognathodid species. As conodont workers began to study Pennsylvanian and early Permian strata in Europe, Asia, and South America, several new species of *Streptognathodus* were established. Many of the newly named species were valid, but many were junior synonyms of pre-existing or incorrectly revised species. Perpetuation of invalid species concepts was exacerbated by language barriers and endemism of conodont workers. International cooperation and collaboration was required to define the morphologic, stratigraphic, and geographic ranges of competing species. This collaboration was in its infancy when we defined *Streptognathodus isolatus* (Chernykh et al. 1997) and when our proposal for the Aidaralash GSSP was ratified in 1999. Lucas (2013a, b) and Lucas et al. (2013b) are correct in asserting that the taxonomy and phylogeny of *S. isolatus* and closely allied species was originally unclear and that additional study was needed. Subsequent work in the American Midcontinent (Sawin et al. 2006; Boardman et al. 2009) and in the southern Ural Mountains (Chernykh 2005, 2006) permitted a meaningful clarification of the morphology and ranges of C-P boundary species without requiring redefinition of the GSSP. Diagnostic features and stratigraphic ranges of key species are summarized below.

Genus *Streptognathodus*

Streptognathodus, like most other genera of the Family Idiognathodontidae had a multimembrate apparatus comprised of pectiniform and ramiform elements. Carminiscaphate P₁ elements are overrepresented in most collections and all species are based upon the morphology of these elements. Ramiform and angulate pectiniform elements are less diagnostic and are often missing. P₁ elements generally occur in asymmetric pairs in which the sinistral element is relatively narrower and less ornamented (less nodose) than the more robust dextral counterpart. Key features that characterize P₁ elements and permit recognition of species include platform shape, nature of the dorsal tip, depth and shape of the median trough, number and length of transverse ridges, morphology of the caudal and rostral margins, length and orientation of adcarinal ridges, presence or absence of accessory lobes, and number and arrangements of nodes comprising the accessory lobes. Character states of one or a combination of features have been used alternately to split P₁ element faunas into narrowly defined species with small-scale variation (e.g. Gunnell 1933) or group them into broad species categories with high variability (e.g. Ellison 1941); often without explaining why taxonomic primacy is



TEXT-FIGURE 3

Outcrop photographs of the Laborcita Member of the Bursum Formation in the northern Sacramento Mountains. A. Scorpion Mound located above the Mound Gulley section (arrow). Orange dashed line indicates location of the Carboniferous/Permian boundary. B. Tularosa Clay Pit. Arrow points to the ammonoid-bearing bed first described by Bose (1920). C. Sponge-microbial mound in the Mound Gulley section. Area in white box indicates relative position of the conodont-bearing intermound skeletal packstone facies. D. Cross-bedded deltaic arkoses and shales exposed in roadcut on south side of highway 71, north of the Tularosa Clay Pit. These are equivalent to units 20 through 27 of Frederick et al.'s (2018) measured section. These lowstand siliciclastics were deposited between the highstands represented by the black shale succession exposed in the Tularosa Clay Pit and in the Coyote Hills and the highstand represented by carbonate strata comprising unit 9 of Otte (1959). E. Rhodoid bed exposed in the Coyote Hills section. F. Coarse fanglomerate exposed on slope below Scorpion Mound. Bed 19 of Otte's (1959) section 29.

granted to one character over another. Rosscoe and Barrick (2009) used a “functional” model to revise species-level taxonomy of late Desmoinesian to early Missourian representatives of the closely related genus *Idiognathodus*, focusing on the food-grinding and crushing function of the oral platform surface and accessory nodes as first interpreted by Donoghue and Purnell (1999). The functional model is adopted to justify the taxonomy of earliest Asselian streptognathodids described herein.

Taxonomic primacy is given to the nature of the oral platform surface and secondarily to the arrangement of nodes (denticles) comprising the caudal accessory lobe. These features affected the P₁ element pairs’ ability to process food. The nature of the oral platform surface is determined by two characteristics: the platform shape and the topography of the oral platform surface. Shape (length-to-width ratio of the dorsal platform) ranges from narrow and elongate to broad or robust. Sinistral elements are typically narrower than their dextral counterparts. Surface topography is a function of the depth and shape of the median trough, the length of the transverse ridges, and the nature and arrangement of accessory nodes. Three platform configurations predominate in the Laborcita faunas: unornamented narrow forms with a shallow U- to V-shaped trough, nodose forms with a relatively deep trough ventrally and shallower trough dorsally, and forms with a constricted ventral trough that generally lack accessory nodes.

Narrow forms

As the name implies, the chief distinguishing character of *Streptognathodus elongatus* is the narrow, elongate shape of the platform. This species was established on the basis of material from the Americus Limestone Member of the Foraker Limestone (latest Virgilian) by Gunnell (1933). Sinistral and dextral elements are both narrow. The trough ranges from shallow and U-shaped with abbreviated transverse ridges to shallow and V-shaped with more continuous transverse ridges. The latter end-member morphotype was named *S. simplex* by Gunnell (1933), but most authors, beginning with Ellison (1941) have treated *S. simplex* as a junior synonym of *S. elongatus*. This species is present in all three of the productive Laborcita samples. Sinistral and dextral elements are well represented. This species is common in latest Virgilian (latest Gzhelian) through earliest Wolfcampian (earliest Asselian) conodont faunas worldwide.

Nodose forms with a variable trough

The majority of P₁ elements from the Laborcita Member bear accessory nodes and are characterized by a median trough that changes in depth longitudinally. The trough is deepest and widest (often U-shaped) adjacent to the dorsal termination of the carina, becoming shallower and more V-shaped (with more continuous transverse ridges) dorsally. Great variability in trough morphology characterizes this group. In some cases, the trough is wide and U-shaped ventrally with abbreviated transverse ridges that do not extend onto the floor of the trough. On the other end of the morphological spectrum are specimens in which the ventral portion of the trough is more V-shaped with longer transverse ridges. In each case the trough is deeper ventrally than it is dorsally. Additionally, the caudal platform margin may be higher with longer transverse ridges than the relatively lower and narrower rostral parapet. Sinistral forms are typically narrower than dextral forms. This upper platform configuration (deeper ventral trough) first becomes common in the Americus Limestone Member of the Foraker Limestone of

Kansas (Gunnell 1933; Ritter 1995; Boardman et al. 2009) and ranges upward into lower Permian faunas, the group having descended from *S. bellus* Chernykh and Ritter 1997 (Boardman et al. 2009). By priority, species with this platform configuration are assigned herein to the *S. acuminatus* group (instead of *S. wabaunsensis* of authors) based upon Gunnell’s (1933) species of that same name. Species in this group are distinguished from one another chiefly by the number and arrangement of accessory nodes on the platform. Species of the *S. acuminatus* group are discussed here in order of priority. The name bearer for the group (and first name by publication priority) was described by Gunnell (1933) based upon late Virgilian specimens that possessed a deep, medial to dorsal ventral trough and a break or rupture between the dorsal end of the caudal adcarinal ridge and the ventral end of the caudal platform margin. The species was made a junior synonym of *S. wabaunsensis*, with which it co-occurs in the Americus Limestone, by Ellison (1941). It was reinstated as a valid species by Ritter (1995), but ignored by subsequent workers. As a result, Barskov and Reimers (1996) described Uralian streptognathodids with the “peculiar rupture of the parapet on the inner side of the platform” to a new species, *S. minacutus*. Boardman et al. (2009) incorrectly perpetuated usage of this Russian species name (deemed here to be a junior synonym of *S. acuminatus*) in their study of Pennsylvanian-early Permian conodonts of the American Midcontinent. They did, however, clarify the dextral-sinistral morphology of *S. acuminatus* (their *S. minacutus*), demonstrating that the diagnostic rupture is confined to the dextral P₁ element and that the broader dextral element bears accessory nodes interior to the fused or partially fused caudal margin. A few sinistral elements with the characteristic rupture between the adcarinal parapet and caudal margin are present in sample MG-9k-19 and MG-9l-19. It is difficult to distinguish nodose dextral forms of this species, as redefined by Boardman et al. (2009), from dextral elements of *S. isolatus* in current collections.

Two of Gunnell’s (1933) other Americus species that were deemed junior synonyms of *S. wabaunsensis* by Ellison (1941) have re-emerged as valid species: *S. farmeri* and *S. flangulatus*. Boardman et al. (2009) resurrected the concept of *S. farmeri* for streptognathodids in which the dorsal end of the carina either merges with a rostral transverse ridge or is noticeably deflected toward the rostral margin. Although the functional significance of this character is not clear, the amended diagnosis is tentatively accepted because the carinal deflection is readily diagnosed and morphologically distinctive. Specimens with the deflected carina occur only in lower Permian sample MG-9k-19 where they comprise a small percentage of the P₁ element fauna. The occurrence of *S. farmeri* in this sample extends the range of the species upward from the uppermost Virgilian to lowest Permian. *Streptognathodus flangulatus* also became a junior synonym of *S. wabaunsensis* as part of Ellison’s (1941) revision. The holotype differs from that of *S. wabaunsensis* in possessing accessory nodes on the rostral as well as caudal side of the platform leading Ritter (1995) to recognize it as a valid species. Likewise, the author assigns streptognathodids with accessory nodes on both sides of the platform in Laborcita faunas to *S. flangulatus*. It is likely that the Russian species *S. russo-flangulatus* named by Chernykh (2005) is a junior synonym of *S. flangulatus*. Further work is needed to clarify this relationship.

Streptognathodus fuchengensis Zhao 1982 was diagnosed as a species of *Streptognathodus* with a wide, slightly to strongly

CHRONO.		MIDCONTINENT LITHOSTRATIGRAPHY			4TH SEQ.	MIDCONTINENT CONODONT RANGES		SACRAMENTO MOUNTAINS		
PENNSYLVANIAN		PERMIAN		WOLFCAMPIAN						
GZHELIAN		ASSELIAN								
VIRGILIAN										
		Council		Grove	Group					
		Foraker Limestone		Red Eagle Fm.	Grenola Fm.					
		Americus Ls. Mbr.		Johnson Sh. Mbr.	Bennett Sh. Mbr.					
		Hughes Creek Sh. Mbr.		Johnson Sh. Mbr.	Howe Ls. Mbr.					
		Long Creek Ls. Mbr.		Johnson Sh. Mbr.	Roca Sh. Mbr.					
				Johnson Sh. Mbr.	Salyards Ls. Mbr.					
				Johnson Sh. Mbr.	Legion Sh. Mbr.					
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TEXT-FIGURE 4

Chart of latest Pennsylvanian and earliest Permian strata in the American Midcontinent showing correlation of the level of the Tularosa Clay Pit and Mound Gulley faunas. Midcontinent stratigraphy and conodont ranges from Ritter (1995) and Boardman et al. (2009). Chrono. = Chronostratigraphy; Sh. = Shale; Fm. = Formation; Mbr. = Member; Ls. = Limestone; S. = *Streptognathodus*; 4TH SEQ = Fourth-order Midcontinent sequences of Boardman et al. (2009). The red star indicates the occurrence of *Streptognathodus farmeri* in Permian strata of the northern Sacramento Mountains (compared to Upper Pennsylvanian range in the Midcontinent).

asymmetric platform with elongate, relatively straight transverse ridges and one to four accessory nodes. Platform asymmetry results from widening of the ventral part of the rostral margin, with concomitant lengthening of the ventral-most transverse ridges adjacent to the termination of median carina. This produces a somewhat distinct “shoulder” on the rostral margin. Some specimens possess a relatively deeper trough ventrally indicating kinship with the *S. acuminatus* group. Named by Zhao (1982) on the basis of specimens from the Quinshu Basin of China, this species ranges from the Bennett Shale Member of the Red Eagle Limestone to the Neva Limestone Member of the Grenola Limestone in the American Midcontinent (Boardman et al. 2009) and is a common component of faunas from beds MG-9k-19 and MG-9l-19 in the Laborcita Member.

Streptognathodus invaginatus was named by Reshetkova and Chernykh (1986) for early Permian streptognathodids with a pronounced invagination or inward deflection of the caudal margin at the platform midpoint. The area defined by the inward deflection hosts accessory nodes or denticles that are isolated from the platform by a narrow trough. To distinguish this species from later-named *S. isolatus* (Chernykh et al. 1997), which also has an isolated accessory lobe and variably deflected caudal margin, Boardman et al. (2009) amended the diagnosis of *S. invaginatus* to include specimens with three or fewer accessory nodes, of which one is generally larger than the others. This amended diagnosis is followed herein. At the same time, Reshetkova and Chernykh (1986) erected an additional species, *S. nodulinearis*, for streptognathodids in which the caudal accessory nodes are aligned in a row that roughly parallels the caudal parapet.

Sinistral and dextral elements with the linear arrangement of nodes are present, but rare in the current collections. *S. isolatus* was named by Chernykh et al. (1997) for nodose species with an isolated node field that represented an easily recognizable stage of node development within the streptognathodid lineage. The original diagnosis stated that the P₁ element possessed a nodose inner accessory lobe separated from the continuous and perhaps deflected caudal margin by a shallow trough. As noted above, Boardman et al. (2009) amended the definition to include only those specimens with more than three accessory denticles. This revision is accepted herein and permits unambiguous distinction between the two closely related species: *S. isolatus* and *S. invaginatus*. *S. isolatus* bore an asymmetrical pair of P₁ elements in which the sinistral form is narrower than the dextral element. Dextral and sinistral elements have well defined caudal accessory nodes and both are well represented in Laborcita samples MG-9k-19 and MG-9l-19.

Forms with a constricted ventral trough

Two species with a constricted ventral trough are also present in samples MG-9k-19 and MG-9l-19. Several of these specimens conform to the concept of *S. distortum* Chernykh 2006 which is

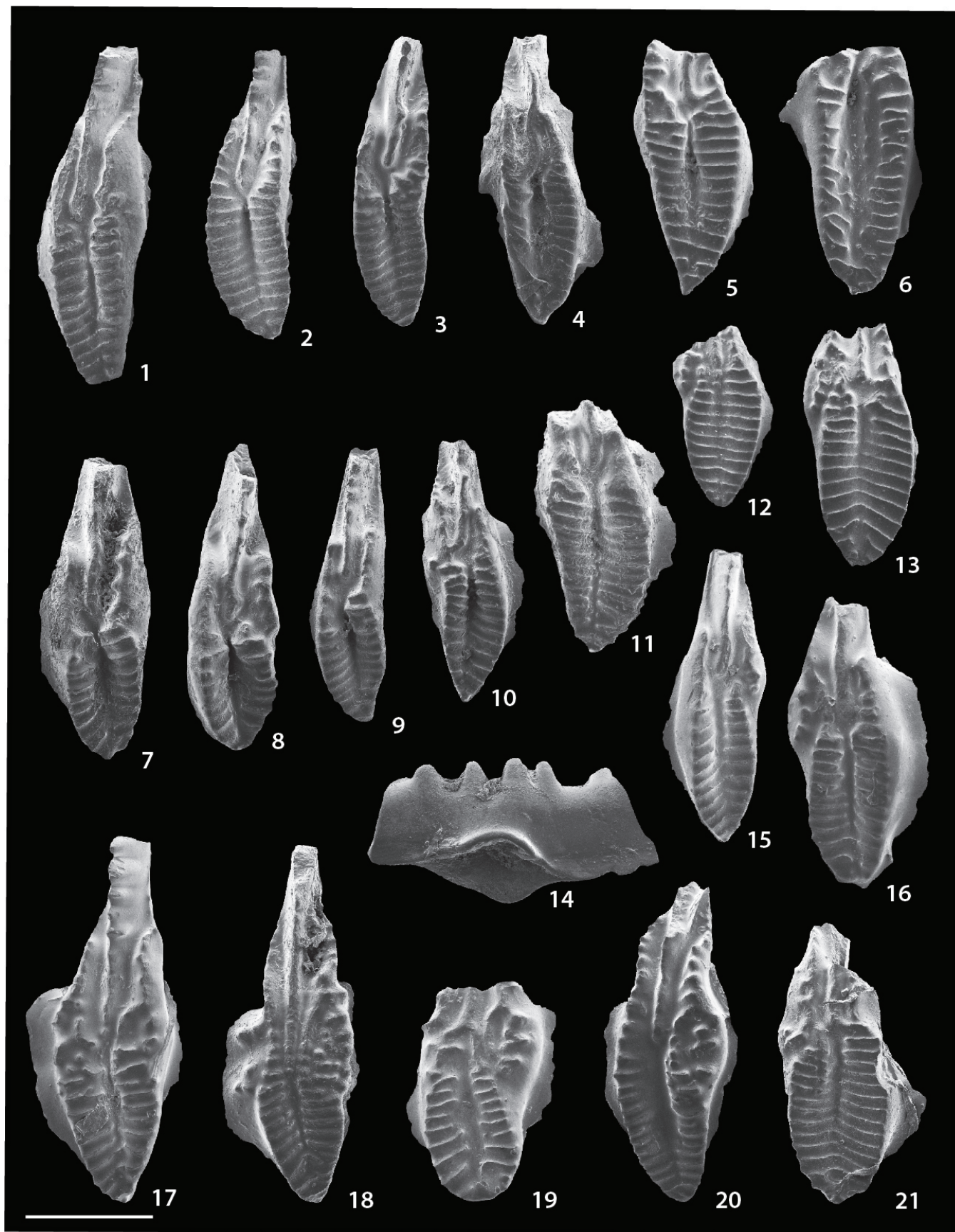
characterized by a distinctive constriction of the median trough adjacent to the dorsal termination of the carina. In these forms, the ventral-most one-fourth of the median trough is reduced to a vertical slit. From this slit, the trough broadens ventrally toward the pointed ventral termination. The constriction is formed largely by widening of the rostral parapet which bulges into the median trough. Caudal and rostral parapets are ornamented with fine, nearly parallel transverse ridges as are the adcarinal ridges. Accessory nodes are absent. The original types were described from basal-most Asselian strata (sample 16/3) in the Usolka River section of the southern Ural Mountains of Russia (Chernykh 2006). *S. distortum* differs from the slightly younger species *S. glenisteri* Chernykh and Ritter 1997 only in the absence of accessory nodes.

Samples MG-9k-19 and MG-9l-19 also produced a modest number of P₁ elements with a constricted ventral trough that cannot be assigned to *S. distortum*. These differ in having a distinctly more U-shaped trough and much shorter transverse ridges. The adcarinal ridges are also more disrupted than those of *S. distortum*. The author assigns these morphotypes to *S. barricki* n. sp., which is described more completely in the following section.

PLATE 1

Conodonts from sample MG-9k-19 of the Laborcita Member of the Bursum Formation, section MG.
All figures are upper views of P₁ elements except 14 which is a lateral view of a P₁ element of *Bispathodus* sp.
Specimens are repositated at the Museum of Paleontology, Brigham Young University.
Scale bar = 0.50 mm.

- 1 *Streptognathodus distortum* Chernykh 2006, BYU-2314-24000.
- 2 *Streptognathodus distortum* Chernykh 2006, BYU-2314-24001
- 3 *Streptognathodus distortum* Chernykh 2006, transitional to *S. barricki* n. sp. BYU-2314-24002
- 4 *Streptognathodus barricki* n. sp., BYU-2314-24003.
- 5 *Streptognathodus distortum* Chernykh 2006, BYU-2314-24004.
- 6 *Streptognathodus barricki* n. sp., BYU-2314-24005
- 7 *Streptognathodus barricki* n. sp., BYU-2314-24006, holotype specimen.
- 8 *Streptognathodus barricki* n. sp., BYU-2314-24007.
- 9 *Streptognathodus barricki* n. sp., BYU-2314-24008.
- 10 *Streptognathodus barricki* n. sp., 2006, BYU-2314-24009.
- 11 *Streptognathodus distortum* Chernykh 2006, BYU-2314-24010.
- 12 *Streptognathodus acuminatus* Gunnell 1933, BYU-2314-24011.
- 13 *Streptognathodus acuminatus* Gunnell 1933, BYU-2314-24012.
- 14 *Bispathodus* sp., BYU-2314-24013.
- 15 *Streptognathodus acuminatus* Gunnell 1933, BYU-2314-24014.
- 16 *Streptognathodus acuminatus* Gunnell 1933, BYU-2314-24015.
- 17 *Streptognathodus flangulatus* Gunnell 1933, BYU-2314-24016.
- 18 *Streptognathodus flangulatus* Gunnell 1933, BYU-2314-24017.
- 19 *Streptognathodus flangulatus* Gunnell 1933, BYU-2314-24018.
- 20 *Streptognathodus isolatus* Chernykh, Ritter, and Wardlaw 1997, BYU-2314-24019.
- 21 *Streptognathodus acuminatus* Gunnell 1933, BYU-2314-24020.



SYSTEMATIC PALEONTOLOGY

Class CONODONTI Branson 1938

Order OZARKODINIDA Dzik 1976

Superfamily POLYGNATHACEA Bassler 1925

Family IDIOGNATHODONTIDAE Harris and Hollingsworth 1933

Genus *Streptognathodus* Stauffer and Plummer 1932

Streptognathodus barricki n. sp.

Plate 1, figures 4, 6-10

Diagnosis: A species of *Streptognathodus* distinguished by severe constriction of the ventral one-fourth of the trough, oblique deflection of the caudal margin, and poorly organized adcarinal ridges.

Description: Representative P₁ elements of *Streptognathodus barricki* possess a moderately high free blade that joins the platform in a median position. Fused, ridge-like carina occupies 40

to 50% of the platform. Dorsal end of carina may be offset or deflected slightly in caudal or rostral direction. Caudal adcarinal ridge slightly longer than rostral counterpart. Adcarinal ridges poorly organized, comprised of an adenticulate ridge rostrally or irregularly nodose ridge caudally. Adcarinal troughs moderately deep. Median trough deepest ventrally with severe constriction at midpoint of platform. Constriction results from inward deflection and slight thickening of caudal platform. Transverse ridges (9 to 12) shorten ventrally becoming more elongate dorsally. Dorsal-most transverse ridges may be oblique to platform axis and/or disrupted. Dorsal termination ranges from rounded to pointed. In lateral view, platform tapers slightly in dorsal direction and the rostral platform margin is taller than the caudal margin. Dextral elements are typically more elongate, with less difference in the height of the rostral and caudal margins, and with a slightly more pointed dorsal tip.

Etymology: This species is named in honor of Dr. James E. Barrick (Emeritus Professor, Texas Tech University) in recogni-

PLATE 2

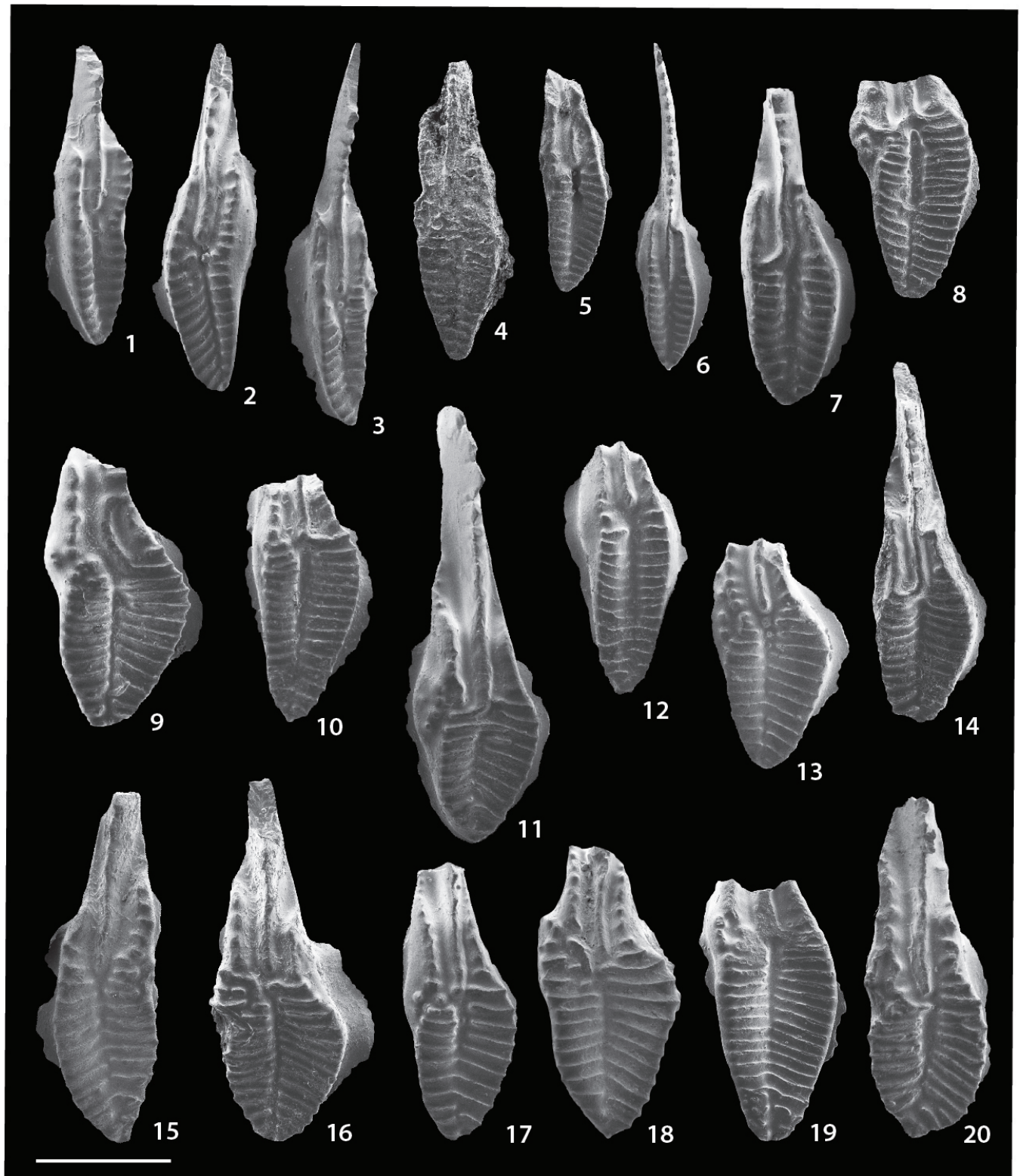
Conodont P₁ elements from sample MG-9k-19 of the MG section and unit 16 of the TCP section.

All figures are upper views of P₁ elements.

Specimens are deposited at the Museum of Paleontology, Brigham Young University.

Scale bar = 0.50 mm.

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| 1 <i>Streptognathodus elongatus</i> Gunnell 1933, BYU-2314-24021. MG-9k-19. | 11 <i>Streptognathodus farmeri</i> Gunnell 1933, BYU-2314-24031. MG-9k-19. |
| 2 <i>Streptognathodus elongatus</i> Gunnell 1933, BYU-2314-24022. MG-9k-19. | 12 <i>Streptognathodus fuchengensis</i> Zhao 1982, BYU-2314-24032. MG-9k-19. |
| 3 <i>Streptognathodus elongatus</i> Gunnell 1933, BYU-2314-24023. MG-9k-19. | 13 <i>Streptognathodus fuchengensis</i> Zhao 1982, BYU-2314-24033. MG-9k-19. |
| 4 <i>Streptognathodus tenuialveus</i> Chernykh and Ritter 1997, BYU-2314-24024. TCP-16-19 | 14 <i>Streptognathodus farmeri</i> Gunnell 1933, BYU-2314-24034. MG-9k-19. |
| 5 <i>Streptognathodus elongatus</i> Gunnell 1933, BYU-2314-24025. MG-9k-19. | 15 <i>Streptognathodus invaginatus</i> Reshetkova and Chernykh 1986, BYU-2314-240351. |
| 6 <i>Streptognathodus elongatus</i> Gunnell 1933, BYU-2314-24026. MG-9k-19. | 16 <i>Streptognathodus fuchengensis</i> Zhao 1982, BYU-2314-24036. MG-9k-19. |
| 7 <i>Streptognathodus farmeri</i> Gunnell 1933, BYU-2314-24027. MG-9k-19. | 17 <i>Streptognathodus fuchengensis</i> Zhao 1982, BYU-2314-24037. MG-9k-19. |
| 8 <i>Streptognathodus fuchengensis</i> Zhao 1982, BYU-2314-24028. MG-9k-19. | 18 <i>Streptognathodus fuchengensis</i> Zhao 1982, BYU-2314-24038. MG-9k-19. |
| 9 <i>Streptognathodus fuchengensis</i> Zhao 1982, BYU-2314-24029. MG-9k-19. | 19 <i>Streptognathodus fuchengensis</i> Zhao 1982, BYU-2314-24039. MG-9k-19. |
| 10 <i>Streptognathodus fuchengensis</i> Zhao 1982, BYU-2314-24030. MG-9k-19. | 20 <i>Streptognathodus invaginatus</i> Reshetkova and Chernykh 1986, BYU-2314-24040. MG-9k-19. |



tion of his invaluable work on the taxonomy and stratigraphy of Pennsylvanian conodonts.

Holotype: Specimen BYU-2314-24006, Plate 1, figure 7.

Repository: The holotype and other figured specimens are deposited at the Brigham Young University Museum of Paleontology (BYU) in Provo, Utah.

Remarks: This species is closely related morphologically to *Streptognathodus distortum*, both of which display the constriction of the ventral portion of the median trough. This new species differs from *S. distortum* in bearing relatively coarser and shorter transverse ridges and in having a more strongly deflected rostral margin. The adcarinal ridges of *S. distortum* are wider with short ribs and nodes whereas the adcarinal ridges of *S. barricki* are irregular. The transition from parapets to adcarinal ridges is much less abrupt in *S. distortum* and the dorsal half of the platform is more elongate with a larger number of transverse ridges. Transitional forms between these two species are present in current collections.

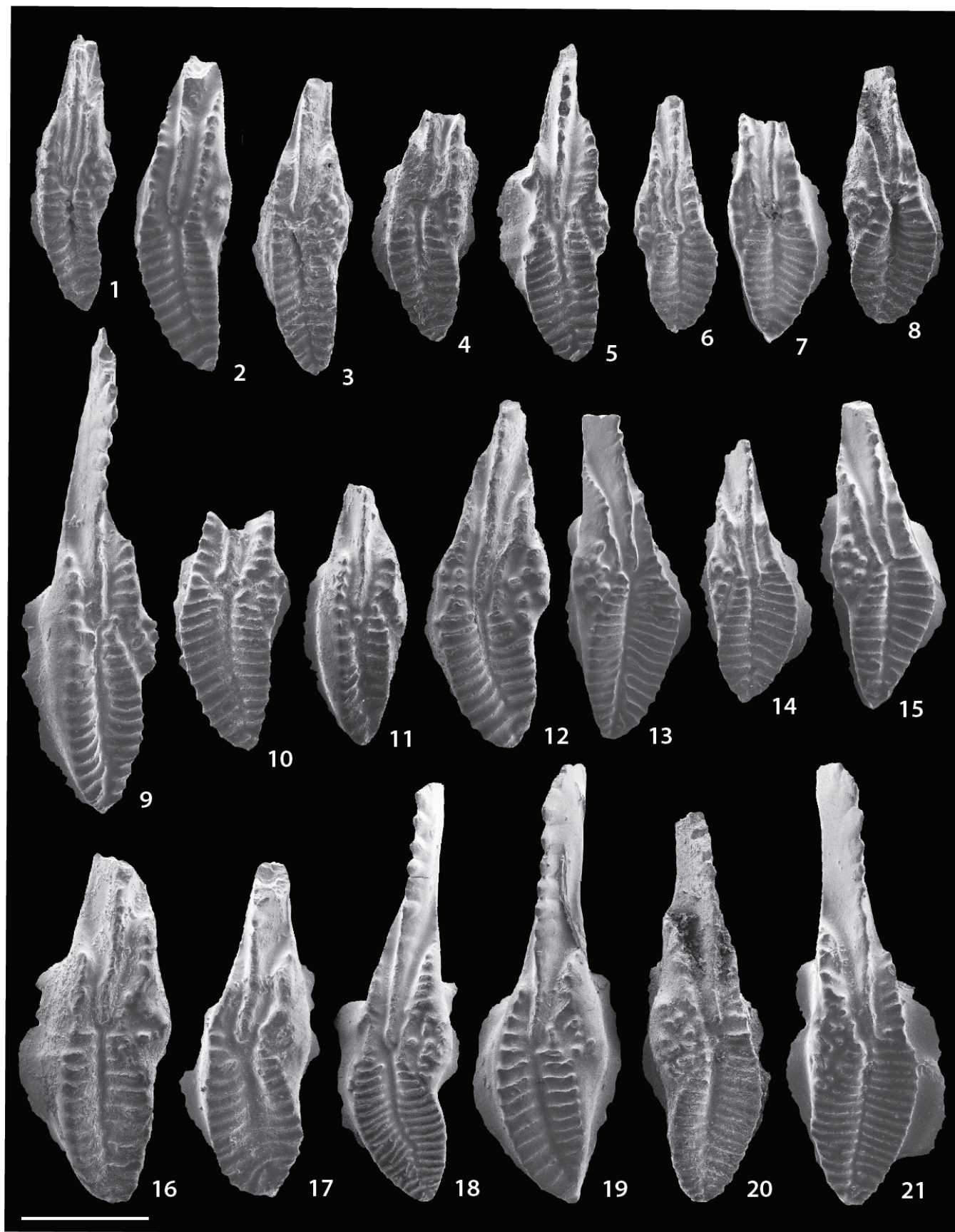
CONCLUSIONS

An abundant and diverse conodont fauna from a thin highstand carbonate unit in the middle of the Laborcita Member of the Bursum Formation in the northern Sacramento Mountains of south-central New Mexico clarifies placement of the Carboniferous/Permian system boundary in this long-studied formation. The occurrence of *Streptognathodus isolatus* and related streptognathodid species indicates the base of the Permian System is located in the upper part of stratigraphic unit 9 of Otte (1959). This critical fauna was recovered from skeletal-rich carbonates associated with small algal-sponge bioherms that formed on the narrow eastern shelf of the ARM-related Orogande Basin during earliest Permian time. The fauna from subunit 9k (sample MG-9k-19) is adequately abundant to permit taxonomic clarification of key boundary taxa that had been incorrectly synonymized or established by earlier authors. A previously unrecognized morphotype characterized by a constriction of the ventral part of the deep median trough is herein assigned to *S. barricki* n. sp.

PLATE 3

Conodonts from sample MG-9k-19 of the Laborcita Member of the Bursum Formation, section MG
All figures are upper views of P₁ elements. Specimens are deposited at the Museum of Paleontology, Brigham Young University.
Scale bar = 0.50 mm.

- 1 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24041.
- 2 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24042.
- 3 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24043.
- 4 *Streptognathodus nodulinear* Reshetkova and Chernykh 1986, BYU-2314-24044.
- 5 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24045.
- 6 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24046.
- 7 *Streptognathodus nodulinear* Reshetkova and Chernykh 1986, BYU-2314-24047.
- 8 *Streptognathodus invaginatus* Reshetkova and Chernykh 1986, BYU-2314-24048.
- 9 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24049.
- 10 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24050.
- 11 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24051.
- 12 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24052.
- 13 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24053.
- 14 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24054.
- 15 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24055.
- 16 *Streptognathodus invaginatus* Reshetkova and Cherykh 1986, BYU-2314-24056.
- 17 *Streptognathodus invaginatus* Reshetkova and Chernykh 1986, BYU-2314-24057.
- 18 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24058.
- 19 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24059.
- 20 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24060.
- 21 *Streptognathodus isolatus* Cherykh, Ritter, and Wardlaw 1997, BYU-2314-24061.



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