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Silurian to basal Devonian conodonts from the Broken River Crossing, northern Australia

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Abstract – Stratigraphy and conodont biostratigraphy of the Graveyard Creek Group, particularly the Jack Formation, near the Broken River Crossing, northwest of Charters Towers, are described. A minor lenticular limestone within pelitic lithologies near the Crossing, yielded a late Llandovery C_5 fauna, consistent with evidence from graptolites. Diagnostic conodonts were obtained from two limestone units in the overlying Jack Formation. The lowest 72 m of the lower of these units is referred to the Ludlow (but not latest Ludlow) *ploeckensis* and *siluricus* zones, and correlates broadly with the interval Silverdale Formation to lower Hume Limestone of the Yass Basin, southeastern Australia. The upper unit yielded *Icriodus woschmidti hesperius* from two localities, which indicates a latest Pridoli-early Lochkov age and provides the possibility of recognising the Silurian-Devonian boundary within the sequence.

INTRODUCTION

The Graveyard Creek Group crops out in northern Queensland in the Broken River Province (White 1959; Arnold and Henderson 1976) west of Townsville. The outcrops investigated in this study (Figures 1 and 2) are adjacent to the Wandovale-Pandanus Creek road where it crosses the Broken River approximately 230 km northwest of Charters Towers.

Pioneer investigations of the geology of the Broken River area have been chronicled by White (1965) and Jell (1967). White (1959) defined the Graveyard Creek Formation and differentiated, in parts of the formation, two members: the Jack Limestone Member at the top of the sequence in the south, and a basal unit, the Crooked Creek Conglomerate Member. White (1961, 1962, 1965) produced the first synthesis of the geological history of the region. Since White's time there has been increased awareness of a major time break between his Jack Limestone Member and underlying strata equated, though with some uncertainty (Jell pers. comm.), with the Graveyard Creek Formation developed typically in the Pandanus Creek area 35 km to the north.

Arnold and Henderson (1976) re-interpreted the pre-Devonian stratigraphy of the region, including the area about the Broken River Crossing. The Geological Survey of Queensland completed field work in the Clarke River 1:250,000 sheet area in 1987 and accorded the Graveyard Creek Formation group status and the Jack Limestone Member formation status (Withnall *et al.* 1988). Additional data on the Silurian of the region have been presented by Jell and Talent (1989). Strata younger than the Graveyard Creek Group have been described by Wyatt and Jell (1980). Models for the geological evolution of the Broken River and Hodgkinson Provinces have been presented by Arnold and Fawkner (1980) and Withnall *et al.* (1988).

Previous work on the Graveyard Creek Group has focused mainly on broad scale regional mapping, based largely on air-photo interpretation. The only prior age data come from a few rare graptolite occurrences (middle to late Llandovery; Thomas 1960), and from spot sampling of rugose and tabulate coral faunas (Hill in White 1959, 1965). This latter work provided field parties with generalised ages for the numerous Silurian and Devonian carbonates of the region but did not allow for age determinations and correlations of high resolution. The only previous study of Silurian conodonts from the region was incidental to a study of the Devonian faunas of the Broken River Formation by Telford (1975). Of the succession of eight faunas discriminated by Telford (1975), only the oldest, from two localities in the Jack Formation, was referred to the Pridoli (latest Silurian). More recent work (Simpson 1999) documents Early Silurian conodonts from allochthonous carbonates in the Graveyard Creek Group.

There are three major studies of Australian Silurian conodont faunas to date. They are the late Silurian faunas of the Yass Basin (Link and Druce 1972), the early and middle Silurian faunas from midwestern New South Wales (Bischoff 1986) and the early to late Silurian faunas of the Limestone Creek region (Simpson and Talent 1995).

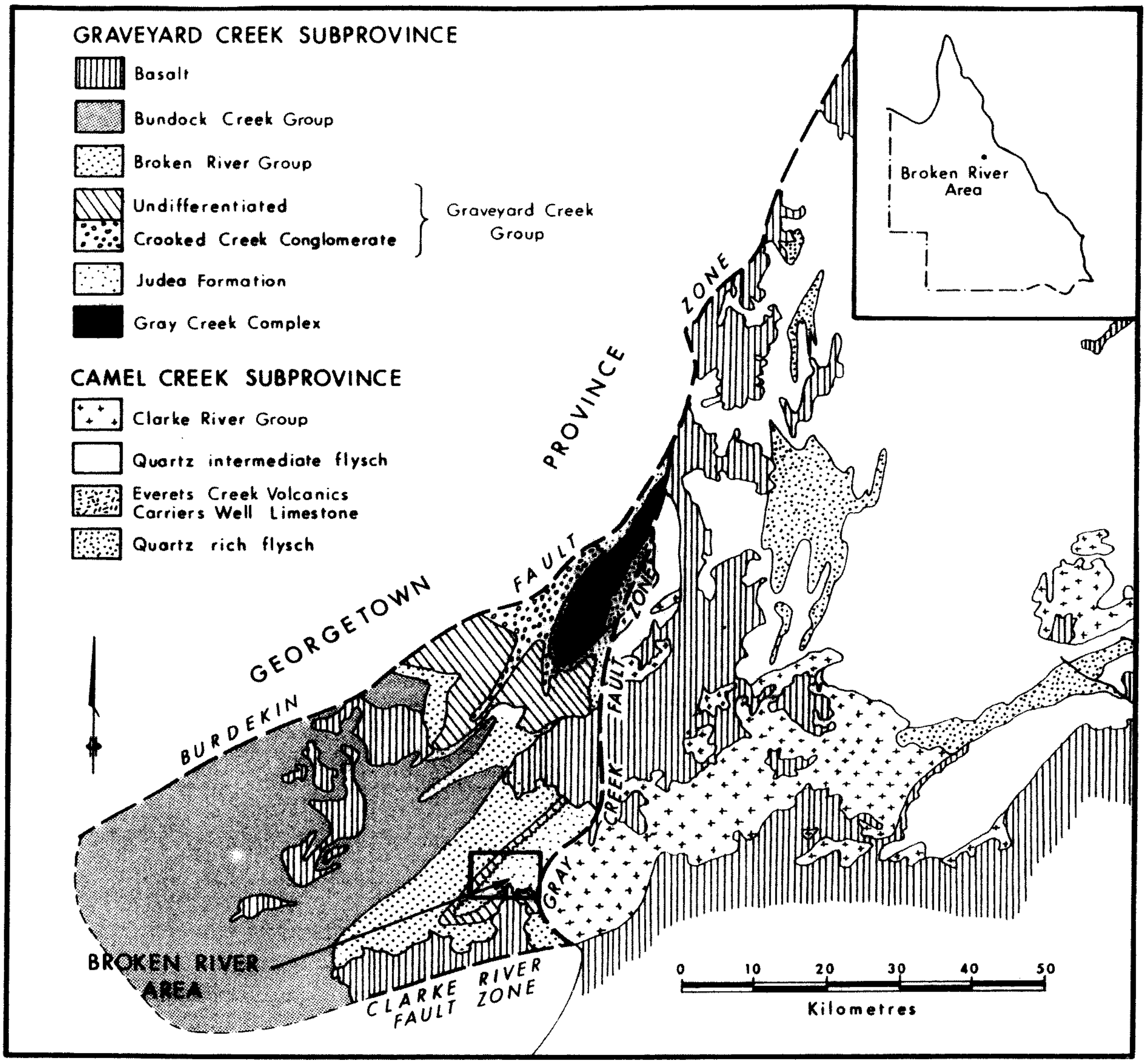


Figure 1 Geology of the Broken River Province, north Queensland, Australia, after Arnold and Henderson (1976) and Arnold and Fawkner (1980).

Reconnaissance sampling, yielding some age-diagnostic conodonts, was undertaken prior to this project by a number of field workers. A full record of faunas recovered from this earlier sampling was not available and the precise stratigraphic position of individual samples was unclear (see explanation of Figure 3).

The area in the vicinity of the Broken River Crossing was subsequently mapped and three stratigraphic sections were measured; two in the Bullock Creek valley and a third along the axis of the major syncline close to the road crossing (Figure 2). Another short section on the eastern limb of the syncline was measured by J.A. Talent and colleagues in 1983. These sections were sampled at 2–5 m intervals in lithologies such as thin, interbedded limestone and siltstone from which rich coral faunas have been documented (Munson 1987), but at 5–30 m intervals in the lithologically monotonous, thickly bedded and massive limestones. A small number of limestone clasts were collected from calcirudites and acid-leached independently to determine if there might be detectable divergence in age between them and the associated, presumably indigenous matrix. No such disharmony was proved. A total of 93 samples of limestone and other carbonates was collected from the Bullock Creek-Broken River Crossing area.

Basal samples of each section are designated 00; sample numbers increase up-section. Specimens were photographed with the Jeol scanning electron microscope housed in the School of Biological Sciences at Macquarie University.

STRATIGRAPHY

Graveyard Creek Group

This group consists primarily of shales, siltstones,

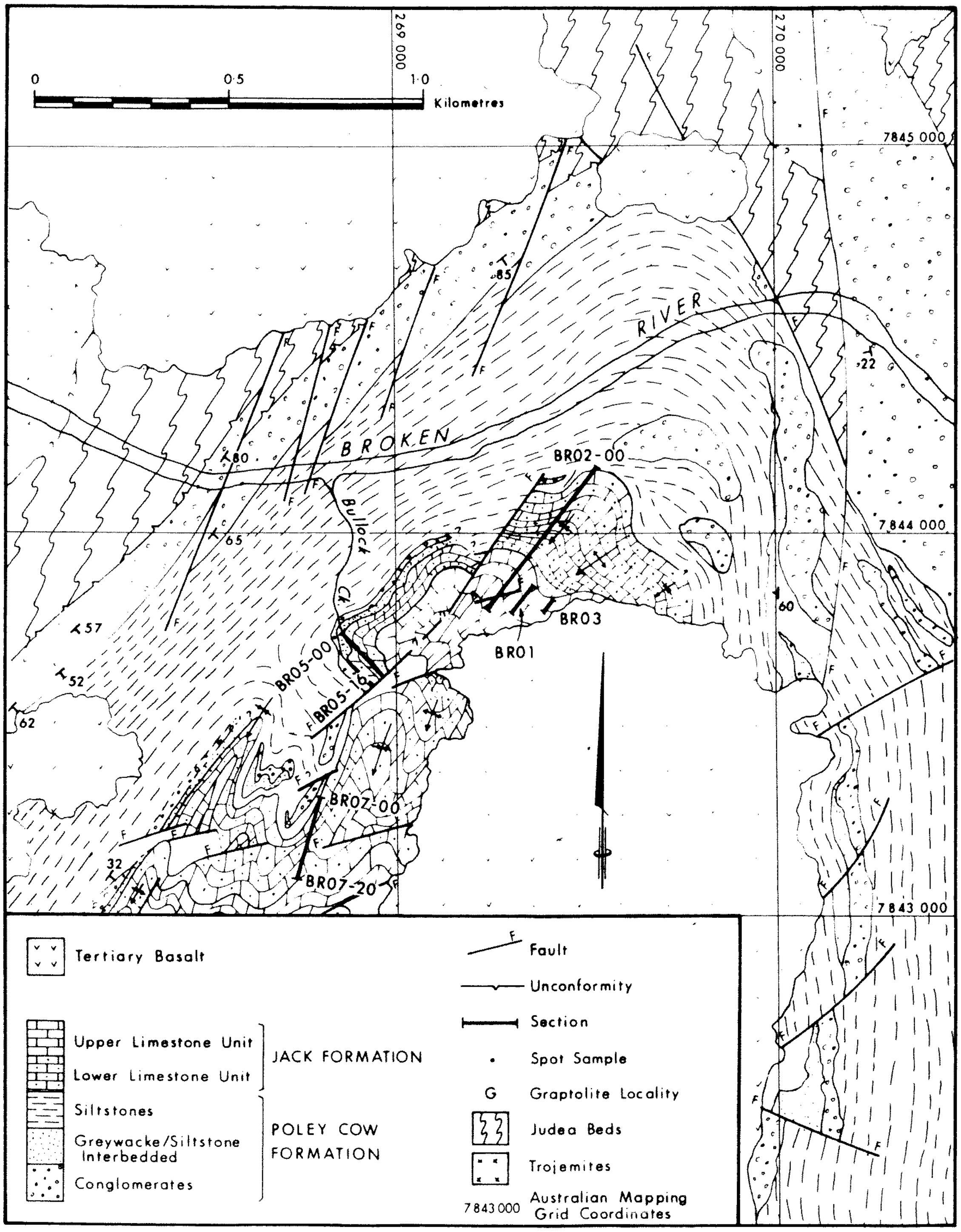


Figure 2 Geology of the Broken River Crossing area showing locations of sections through the Jack Formation.

and greywackes with conglomeratic and minor carbonate lenses. Typical sequences occur about 35 km north of the Broken River in the watershed of Gray Creek and its tributaries. Withnall *et al.* (1988) defined the Poley Cow and Quinton formations within the Graveyard Creek Group. The latter crops out in the north of the Graveyard Creek Subprovince and the former underlies the shelf carbonates of the Jack Formation in the south. Sloan *et al.* (1995) have argued that the two represent the same sedimentary tract. Simpson (1999) has argued that only one name, the Quinton Formation be retained for this sedimentary tract.

In the vicinity of Broken River Crossing, the underlying clastic unit (Poley Cow Formation *sensu* Withnall *et al.* 1988; Quinton Formation *sensu* Simpson 1999) consists almost entirely of conglomerates, greywackes and pelites. The conglomerates vary greatly in lithology (Arnold and Henderson 1976). Graptolites of middle to late Llandovery age (White and Stewart 1959; Thomas 1960; Jell and Talent 1989) have been recovered from pelitic rocks near the Broken River Crossing. One small isolated limestone body from within siltstones was sampled and yielded conodonts of comparable age (Sample BR12-08). Apart from mapping and sampling of such rare carbonates, this investigation has not focused on this unit.

Jack Formation

Extensive outcrops of the Jack Formation occur in the Jack Hills region and about the Broken River Crossing. In the latter area they form the core of a broad southwest-plunging syncline on which secondary and tertiary folding has been developed as well as complications from extensive minor faulting (Figure 2). Two units within the Jack Formation can be discriminated.

The first is a lower limestone unit consisting of a sequence of thinly interbedded nodular limestones and siltstones. The unit is highly fossiliferous and contains abundant corals and stromatoporoids in growth position. It has been colloquially known as the "coral gardens" by field geologists for many years and is informally referred to as the "coral gardens" unit in this study. Skeletal allochems, which may make up 50 percent of the limestone, include coral fragments, brachiopods, medium- and high-spired gastropods, crinoid ossicles, including calical plates, bryozoans, and ostracodes. The thickness of interbeds varies, but most carbonate and pelitic beds are less than 10 cm thick. There is a tendency for the percentage of siltstone to increase up-section. Lenticular beds of calcirudite, up to 4 m thick, also crop out within the regularly interbedded sediments. All sections of this lower limestone (coral gardens unit) show a marked decrease in microfossil abundances up-section.

The second, an upper limestone unit, consists of thickly bedded and massive bluff-forming limestone seemingly equivalent to the massive limestone unit at the Jack Hills gorge. At Broken River Crossing it occupies the core of a southwesterly plunging syncline, and its thickness is not readily determinable because extensive faulting causes repetition of the sequence. The limestone is composed of recrystallized micrite, biomicrite, and pelmicrite. Bedding can be defined by rare layers of skeletal detritus, stromatoporoids in growth position, and a few oolitic beds. The basal 7 m of this limestone is in places characterized by crinoid stems, bryozoans, and brachiopods, some of which have thin algal envelopes. Stratigraphically higher limestones are generally poorer in microfossils. This correlates with an increase in dolomitic interbeds.

BIOSTRATIGRAPHY

Conodonts from the underlying clastic unit

BR12-08, a small isolated limestone lens within the pelitic lithologies yielded elements of *Distomodus staurognathoides* and a number of fragments of ?*Astropentagnathus irregularis* (Mostler). Mostler (1967) considered *Astropentagnathus* as characteristic of the early *celloni* Zone, whereas Aldridge (1972, 1975) indicated a range equivalent to the late *celloni* Zone (British C_5 division).

In Australia, *Astropentagnathus irregularis* is known from the Burly Jack Sandstone Member of the Glendalough Formation and the Liscombe Pools Limestone of New South Wales, which have been correlated with the *griestoniensis* and *crispus* graptolite Biozones (Bischoff 1986: 161–162). There is no discordance in age between the limestone lens BR12-08 and surrounding pelites already known from graptolitic evidence to be no younger than the *griestoniensis* Zone. Strata of unequivocal Wenlock age have not been discriminated in the area around Broken River Crossing. Present evidence thus accords with a significant hiatus between the underlying clastic unit and the basal beds of the overlying Jack Limestone. There is no obvious lithological evidence for a time break, it is more likely to be represented by an extended period of very slow deposition of fine-grained clastics possibly punctuated by small periods of non-deposition.

Conodonts from the "coral gardens" unit, Jack Formation.

Representatives of the Pa element of *Ancoradella ploeckensis*, used by Walliser (1964) to delineate an early Ludlow zone, were recovered from the basal sample (BR07-00) through to sample (BR07-18) of the lower unit of the Jack Formation in the Upper Bullock Creek section. In this section *A. ploeckensis* occurs through a section interval of 95 m.

Polygnathoides siluricus was recovered in small numbers from two samples (BR05-12 Lower Bullock Creek and BR07-14 Upper Bullock Creek) high within the stratigraphic range of *A. ploeckensis*. This matches the approximate level of recovery of this taxon from earlier sampling and indicates a possible stratigraphic interval of 17 m in the Upper Bullock Creek section and 16 m in the Lower Bullock Creek section. Earlier sampling (BR06-06), inferred to lie just above the *P. siluricus* interval, yielded a possible fragment of another of Walliser's (1964) Ludlow index species, *Pedavis latialata*.

Therefore, the *Polygnathoides siluricus* Zone in the "coral gardens unit" of the Jack Formation is a narrow interval occurring at approximately equivalent stratigraphic positions in both measured sections (Figure 3).

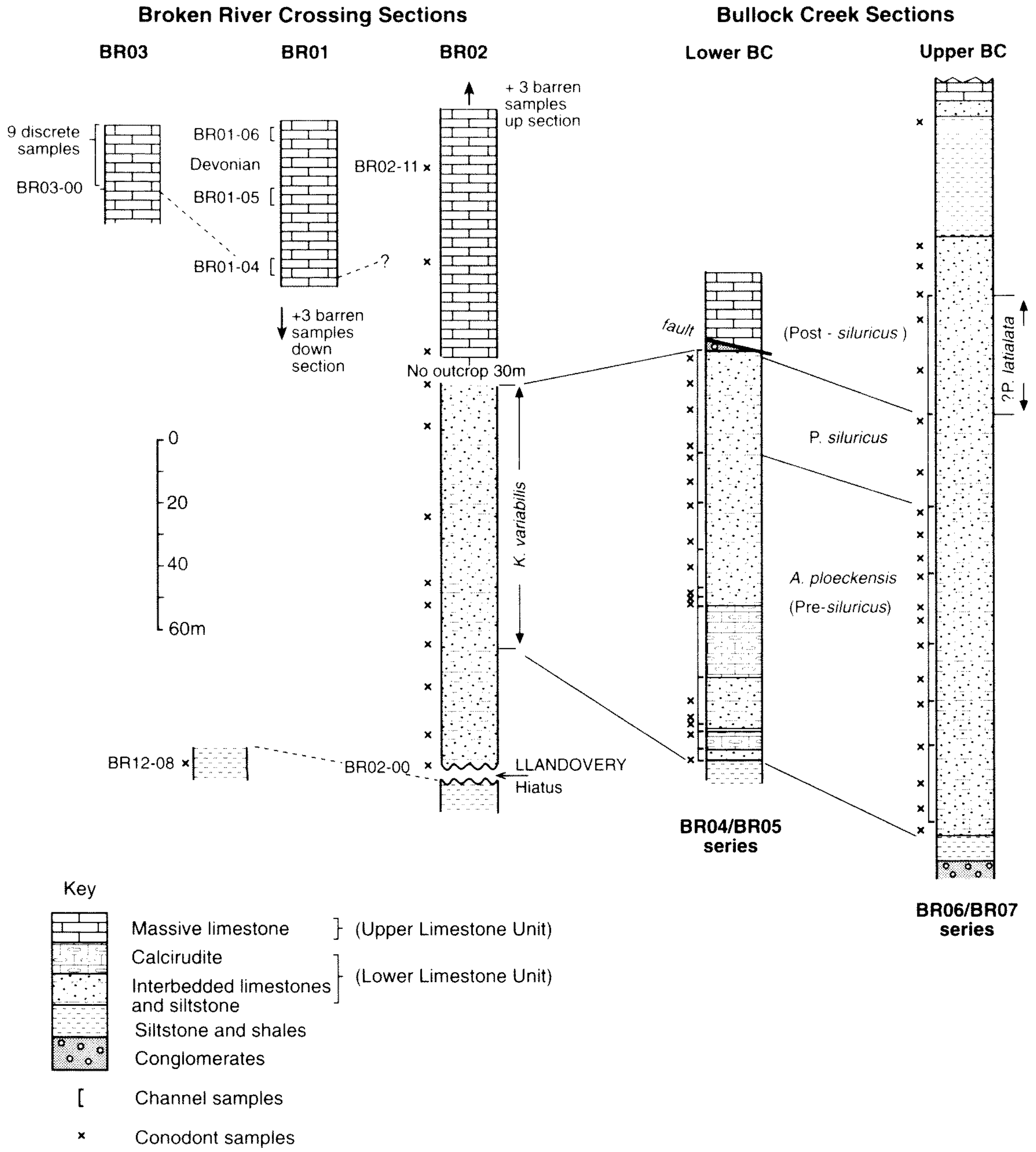


Figure 3 Correlation of Broken River Crossing and Bullock Creek sections showing ranges of diagnostic conodont occurrences. Sections BR01 (Broken River Crossing), BR04 (Lower Bullock Creek) and BR06 (Upper Bullock Creek) are depicted as channel samples. These sections consist of earlier reconnaissance sampling and the exact location of individual samples cannot be precisely determined, their relative positions are therefore shown over a stratigraphic interval as best inferred from early field notes of other workers.

The partial overlap of the *ploeckensis* and *siluricus* zones is well established. Walliser (1964: 97) first noted the overlap in the basal sample of the *P. siluricus* Zone at Cellon (sample 21, Table 2, part II). It was also discussed by Klapper and Murphy (1975: 12) as demonstrated in the Pete Hanson Creek, section IIE (figure 7, table 7). Uyeno (1981, figure 16) noted the two co-occur through 90 m of section in the Douro Formation on Cornwallis Island. Furthermore, Uyeno (1990: 50) suggested that in one area of the Douro Formation (section 3C, northwest of Ptarmigan Lake, Devon Island), the overlap occurs throughout the entire *P. siluricus* Zone.

On the available data for the Jack Formation, *A. ploeckensis* ranges through the *siluricus* Zone and into younger strata yielding ?*Pedavis latialata*. More intense sampling is required to establish the precise relationship between these Ludlow index zones in the Jack Formation.

The only other Australian record of the relationship between the *ploeckensis* and *siluricus* zones is from the Silverdale Formation of the Yass Basin (Link and Druce 1972). They reported *Ancoradella ploeckensis* as being long-ranging and extending through the Yass sequence from the Silverdale Formation into the lower Hume Limestone. *Polygnathoides siluricus* was reported from only the Hume Limestone through an interval of 4.5 m, and *Ancoradella ploeckensis* co-occured in three samples. Thus, the lowermost 72 m of the limestones near the Broken River Crossing may be broadly correlated with the Bowspring Limestone and Barrandella Shale Members in the Yass Basin and the Hume Limestone Member can be correlated with the *P. siluricus* interval in the Jack Limestone. In the Limestone Creek area in southeastern Australia, unit three of the Claire Creek Limestone and the undifferentiated Cowombat Formation directly overlying the Claire Creek Limestone also yielded *A. ploeckensis* (Simpson and Talent 1995). The lowermost 72 m of Jack Formation limestone can also be correlated with this interval.

The long-ranging species *Kockelella variablis* is more widely distributed than *Ancoradella ploeckensis* in the Broken River region. It is known from numerous localities elsewhere in the world (see Klapper in Ziegler 1981: 181–182) and ranges from the *crassa* Zone to the middle Ludlow *siluricus* zone. Elements were recovered in both Bullock Creek sections and in the Broken River Crossing section (BR02 series), in the latter over a stratigraphic interval of 86 m.

Although a number of Ludlow biozones can be recognized, identification of younger Silurian strata is problematic. The uppermost sections of the unit are dominated by pelitic intervals and there is an overall decrease in the number of microfossils in limestone samples upsection. These uppermost beds are interpreted as probably Pridoli in age because of their stratigraphic position above strata of unequivocal Ludlow age and below strata of latest Pridoli to Early Devonian age low in the overlying unit.

At the base of the Pridoli Series, the first appearance of *Monograptus parultimus* coincides with the last appearance of *Ozarkodina crispa* (Schönlaub *in* Kríz *et al.* 1983). In the Jack Formation, the late Ludlow zonal conodont *Pedavis latialata* has been recovered as only a single fragment and *O. crispa* has not been found; it is therefore impossible on available data to accurately delineate a Pridoli interval in the Broken River Crossing sequence.

The extended range of *Ancoradella ploeckensis*, and the lack of diagnostic conodonts in higher horizons of the "coral gardens unit", therefore, permit only a three-fold subdivision of this part of the sequence. An uppermost post *siluricus* interval (late Ludlow–Pridoli), a middle *siluricus* interval and a lowermost *ploeckensis* (pre-*siluricus*) interval can be identified.

Conodonts from the upper limestone unit, Jack Formation.

Specimens of *Icriodus woschmidti hesperius* Klapper and Murphy were recovered from two samples, both in the vicinity of Broken River Crossing. One (BR01-04), was a spot sample and the other (BR03-01) a channel sample from a measured section 110m east-northeast of BR01-04 through an interval of 1.5–4.5 m above the base of the section. *Icriodus woschmidti* is the nominate zonal species for the latest Silurian and earliest Devonian strata. Therefore, in the absence of graptolites, the primary group by which the base of the Devonian can be recognised (specifically the incoming of *Monograptus uniformis*), the base of the Devonian is taken to occur probably somewhere low in the upper unit of the Jack Limestone and certainly not much higher than BR03-01.

Icriodus woschmidti hesperius has been reported from three localities in North America (Klapper and Murphy 1975; Uyeno 1990), and one in the former U.S.S.R. (Drygant 1984). Klapper and Johnson (1980) regarded a form described as *I. woschmidti* by Link and Druce (1972) from the Elmside Formation in the Yass district of southeastern Australia as referable to this subspecies.

Although only a small number of elements of *Icriodus woschmidti hesperius* were recovered, these, considered in conjunction with occurrences of other elements, suggest that the upper limestone unit of the Jack Formation at Broken River Crossing may span two or even three Early Devonian conodont zones. An M_2 element of *Pedavis* sp., recovered from BR01-05, has affinities to the M_2 element of *Pedavis* sp. of Murphy and Matti (1982, plate 7, figure 28) from Nevada, and was recovered from stata yielding the *Pedavis breviramis* I element. In Nevada, these strata partially span the *eurekaensis* and *delta* Zones. *Icriodus woschmidti hesperius* is known to range into the *eurekaenensis* Zone (Uyeno 1981); hence co-occurrence of these two elements in the upper limestone unit of the Jack Formation is possible, and the formation may extend through to the *eurekaensis* Zone near Broken River Crossing.

Ozarkodina sp. E of Savage (1976) was recovered from three samples within the upper limestone unit of the Jack Formation (samples BR01-04, BR01-05 and BR01-06). This element has been reported previously from only the Klamath Mountains in northern California in isolated limestone lenses (Savage 1976), and has been interpreted as restricted to the *delta* Zone. The Broken River occurrences therefore suggest extension of the range of Savage's species down to a level in the *eurekaensis–hesperius* interval (BR01-04).

In summary, Jack Formation faunas suggest a conodont biostratigraphy with minor differences from the more thoroughly investigated European and North American Silurian to Early Devonian sequences. The significance of these differences will be clarified only by greater sampling precision and larger collections.

SYSTEMATIC PALAEONTOLOGY

The classification used in this work follows that of Sweet (1988). The specimens are housed in the Department of Earth Sciences, University of Queensland microfossil collection. Specimens in this collection are prefixed with the letter Y.

Order Belodellida Sweet, 1988

Family Belodellidae Khodelevich and Tschernich, 1973

Genus *Belodella* Ethington, 1959

Type species

Belodella devonica Stauffer 1940

Belodella anomalis Cooper, 1974
Figures 4.1–2

Material

Two specimens.

Occurrence

One sample BR06-03, "coral gardens unit" of the Jack Formation, Upper Bullock Creek section.

Remarks

For synonymy of this species see Simpson and Talent (1995: 124). Jack Formation elements are similar to those described and illustrated by Cooper (1974, text-figure 1). Cooper's specimens show development of denticulation on upper and lower margins. As both Jack Limestone specimens are small, it is suggested that the secondary denticulation may be an ontogenetic characteristic.

Order Ozarkodina Dzik, 1976

Family Kockelellidae Klapper, 1981

Genus *Ancoradella* Walliser, 1964

Type species

Ancoradella ploeckensis Walliser 1964

Ancoradella ploeckensis Walliser, 1964
Figures 4.3–9

Material

Eighteen Pa elements.

Occurrence

In the Jack Formation *Ancoradella ploeckensis* spans the entire interval from which *Polygnathoides siluricus* has so far been recovered and also occurs in younger strata. The two occur together in sample BR07-14. *A. ploeckensis* is restricted to the "coral gardens unit" of the Jack Formation through a section thickness of 94 m. The oldest occurrence is at the base of the unit.

Remarks

For synonymy see Simpson and Talent (1995: 131). Although Uyeno (1981, plate 8, figure 19) tentatively identified an M element, Simpson and Talent (1995, plate 5, figure 11) tentatively identified an Sc element, and Männik and Malkowski (1998, plate 2, figures 3, 7 and 9) identified a symmetry transition series as *Ancoradella ploeckensis*, this species is essentially known from its distinctive Pa element.

Jack Formation specimens show some differences from Walliser's (1964) Carnic Alps specimens. In the latter, the carina on the anteroiateral lobe branches in "Y"-shaped fashion from the carina that extends across the posterolateral lobe and meets the fixed blade at a right angle. The outer angle between the carinae and both lateral lobes is thus distinctly less than 180 degrees. In contrast to this, Jack Formation specimens have both carinae on the corresponding lateral lobes that form a continuous nodose ridge, which is slightly curved with the concave side facing outward.

The close phylogenetic relationship between *Ancoradella* and *Kockelella* is well established (Klapper *in* Clark *et al.* 1981). The similar ontogenetic changes in basal cavity morphology of Pa elements led Barrick and Klapper (1976) to suggest that *Ancoradella ploeckensis* might have evolved from *Kockelella patula* (Walliser 1964).

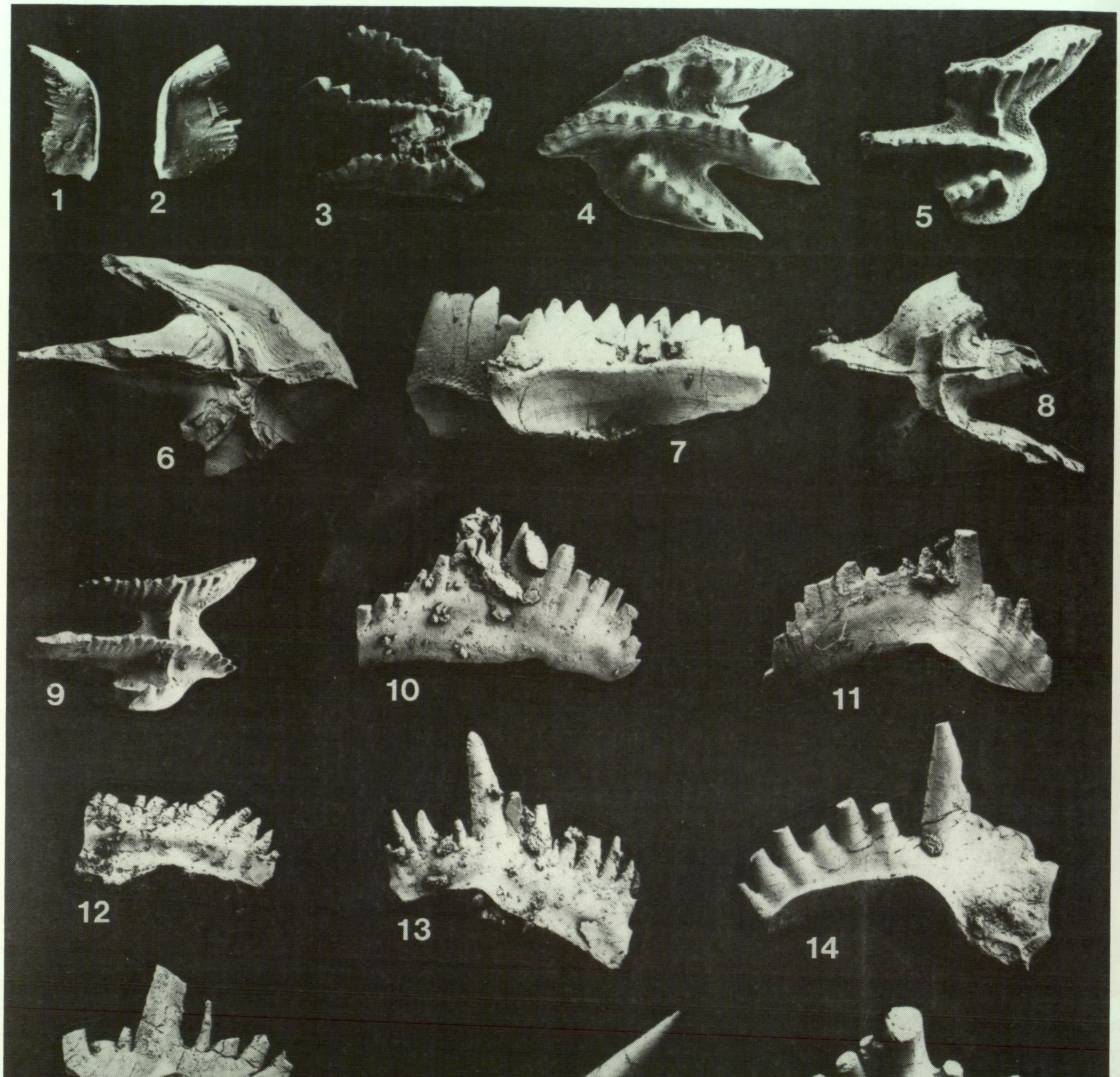
The range of *Ancoradella ploeckensis* in this study coincides with the recurrence of ramiform elements in these samples, which are herein grouped in *Kockelella*. On phyletic grounds *Ancoradella ploeckensis* most probably has symmetry transition and M elements closely related to those of *Kockelella*. A recent reconstruction, however, includes symmetry transition elements that appear mophologically similar to those of *Ozarkodina* (Männik and Malkowski 1998, plate 2, figures 3, 7 and 9).

Low sample numbers and uncertainty concerning the apparatus architecture preclude any grouping of these "Kockelellan" elements with the Pa element of *Ancoradella ploeckensis* at this stage.

Genus *Kockelella* Walliser, 1957

Type species

Kockelella variabilis Walliser 1957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Kockelella absidata Barrick and Klapper, 1976
Figures 4.10–11

Material
One Pa element and 1 M element.

Occurrence
Upper Bullock Creek section, basal and near basal samples BR07-00 and BR07-02 of the "coral gardens unit" of the Jack Formation.

Remarks
Pa elements of *Kockelella absidata* have a characteristically flared, triangular basal cavity and a narrow groove that extends to the posterior end of the unit (Barrick and Klapper 1976: 73).

One M element, in close proximity to the bed from which the Pa element was recovered, has been tentatively assigned to this species on the basis of basal cavity and lower edge morphology.

Kockelella variabilis Walliser, 1957
Figures 4.12–20; 5.1–11

Material
Seven Pb elements, 3 Sc elements, 4 Sb elements, 7 Sa elements, 6 M elements.

Occurrence
Elements of *Kockelella variabilis* are restricted to the "coral gardens unit" of the Jack Formation. They have been recovered from all three Broken River Crossing sections. This range coincides with that of *Ancoradella ploeckensis* in the Upper Bullock Creek Section.

Remarks
For synonymy see Uyeno (1990: 80). Pb, M and S element of this apparatus were recovered from the Broken River sections.

Sa elements show some variability associated with the degree of flexure of the blade. One specimen (Figure 4.18) is gently arched, whereas other Sa elements (Figures 4.19–20) have a lower edge angle of approximately 90 degrees. Sb elements also display some variability associated with the degree of flexure. One Sb element (Figure 5.2) retains much of its basal filling and has a pluglike structure under the cusp.

Two Pb elements (Figures 4.12–13) have a basal cavity that extends along only the posterior process, as in the form subspecies "*Ozarkodina ziegleri ziegleri*". However, they have a wide process and thin closely packed denticles.

All these features may represent extreme intraspecific variability of the apparatus. No Pa elements were recovered.

Family Spathognathodontidae Hass, 1959

Genus *Ozarkodina* Branson and Mehl, 1933

Type species
Ozarkodina typica Branson and Mehl, 1933.

Ozarkodina excavata excavata (Branson and Mehl 1933)
Figures 5.12–26; 6.1–15

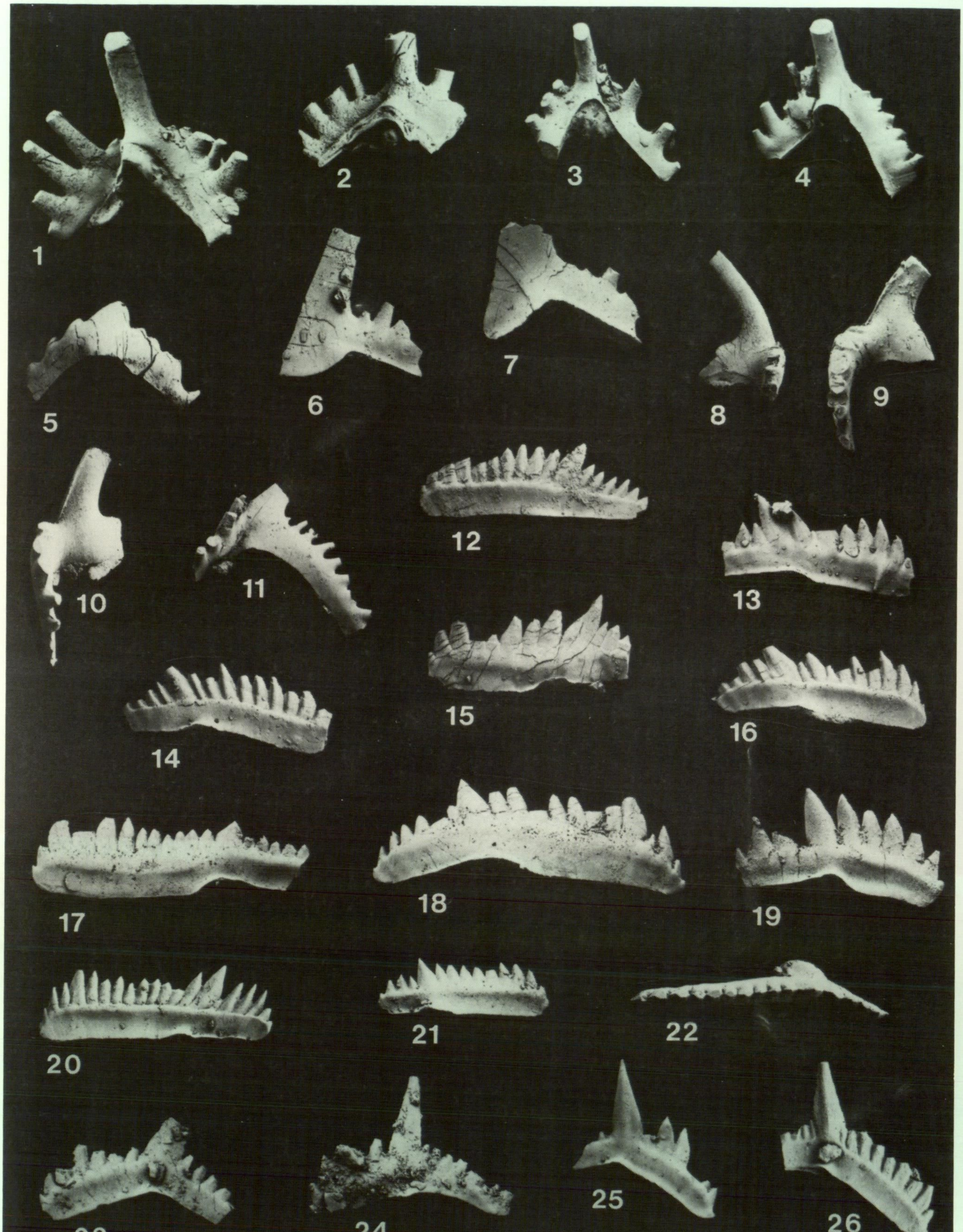
Material
Two hundred and thirty one Pa elements; 111 Pb elements; 118 Sc elements; 32 Sb elements; 41 Sa elements; 44 M elements.

Occurrence
Ozarkodina excavata excavata was recovered from both the upper and lower limestone units of the Jack Formation, but is more abundant in the latter. It is by far the most abundant species recovered in this study.

Remarks
For synonymy see Simpson and Talent (1995: 147–152). Synonymy of the specific names was first undertaken by Jeppsson (1969: 18–19).

Jack Formation elements show minor variations in morphology. Pa and Pb elements show various degrees of ledge development along the blade.

◀ **Figure 4** **1–2**, *Belodella anomalis* Cooper, both are lateral views of elements from BRO6-03, X66. **1**, Y5239. **2**, Y5240. **3–9**, *Ancoradella ploeckensis* Walliser, all Pa elements. **3**, Y5230 from BR06-03, upper view, X33. **4**, Y5231 from BR06-00, upper view, X50. **5**, Y5232 from BR07-01, upper view, X33. **6**, Y5233 from BR07-01, lower view, X50. **7**, Y5234 from BR07-14, lateral view, X50. **8**, Y5235 from BR06-03, lower view, X50. **9**, Y5236 from BR07-14, upper view, X50. **10–11**, *Kockelella absidata* Barrick and Klapper, inner lateral views, X50. **10**, Pa element Y5247 from BR07-00. **11**, M element Y5248 from BR07-02. **12–20**, *Kockelella variabilis* Walliser, all X50 unless otherwise indicated. **12**, Pb element Y5249 from BR05-15, inner lateral view. **13**, Pb element Y5250 from BR05-16, inner lateral view. **14**, Pb element Y5251 from BR07-01, inner lateral view. **15**, Pb element Y5252 from BR07-01, inner lateral view, X66. **16**, Pb element Y5253 from BR07-16, inner lateral view. **17**, Sa element Y5254 from sample BR07-04, anterior view. **18**, Sa element Y5256 from sample BR07-01, anterior view. **19**, Sa element Y5257 from sample BR02-03, anterior view. **20**, Sa element Y5258 from sample BR02-03, anterior view, X66.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Denticles are generally peglike and may be relatively short or tall.

There is a wide range of basal cavity morphology in S elements. The basal cavity margin may be gently rounded (Figure 6.9, Sb element) or more sharply rounded and be extended to a level high on the blade (Figure 6.8). The greatest variation in basal cavity morphology occurs in the lowest parts of the sections (*ploeckensis* Zone). However, this may be due to the overall decrease in the number of elements up-section. Larger numbers of specimens from high in the lower limestone unit and from the upper limestone unit would be needed to establish trends with any certainty.

Ozarkodina sp. A Klapper and Murphy, 1975

Figures 6.16–27; 7.1–8

Ozarkodina sp. nov. A: Klapper and Murphy 1975: 43–44, plate 2, figures 7, 9–12.

Material

Eight Pa elements; 9 Pb elements; 4 Sc elements; 2 Sb elements; 3 Sa elements; 1 M element.

Occurrence

Ozarkodina sp. A occurs sporadically throughout both the "coral gardens unit" and the upper limestone unit of the Jack Formation. Elements were recovered from both Bullock Creek sections.

Remarks

Klapper and Murphy (1975) first indicated a separate species based on the morphology of the Pa element. Six elements from the Jack Formation are tentatively assigned to this apparatus. This reconstruction is tentative because of the small number of specimens, but particularly because of the lack of large Pa and Pb elements from Silurian horizons within the study area.

Pa elements have small, stout, triangular denticles of varying, but subdued height. The basal cavity of these elements is small, posteriorly located, and in most examples, constricted close to the blade. In the larger specimens the basal cavity extends as narrow grooves toward both the anterior and posterior margins (Figures 6.19–20). In all specimens the posterior blade is lower and shorter than the anterior blade.

Pa elements have a blade morphology similar to some northern hemisphere Wenlock and Llandovery forms such as *Ozarkodina hadra* (Nicoll and Rexroad 1968) and *Ozarkodina gulletensis* (Aldridge 1972). Those illustrated by Aldridge (1985, plate 3.3, figure 11 and plate 3.2, figure 9 respectively) both have a narrow and relatively short posterior blade. These Jack Formation elements do not all have a broad cusp and are not arched.

Pb, M and S elements all have slender denticles that are, in many specimens, inclined and crowded near the cusp. Specimens in this study are poorly preserved, but some have similarities with those of *Ozarkodina confluens* (Branson and Mehl), in particular the Sb elements. They are grouped with this apparatus because of their recurrence with the Pa and Pb elements in Silurian and Devonian strata in the study area.

The apparatus is broadly similar to the Wenlock form *Hindeodella gulletensis* illustrated by Jeppsson (1979 figures 72.14–22). Whether this apparatus is related to European Wenlock species can not as yet be established. No Wenlock sequence has been identified in the Broken River Crossing area.

Ozarkodina sp. aff *O. remscheidensis* (Ziegler 1960)

Figures 7.9–11

Material

Three Pa elements.

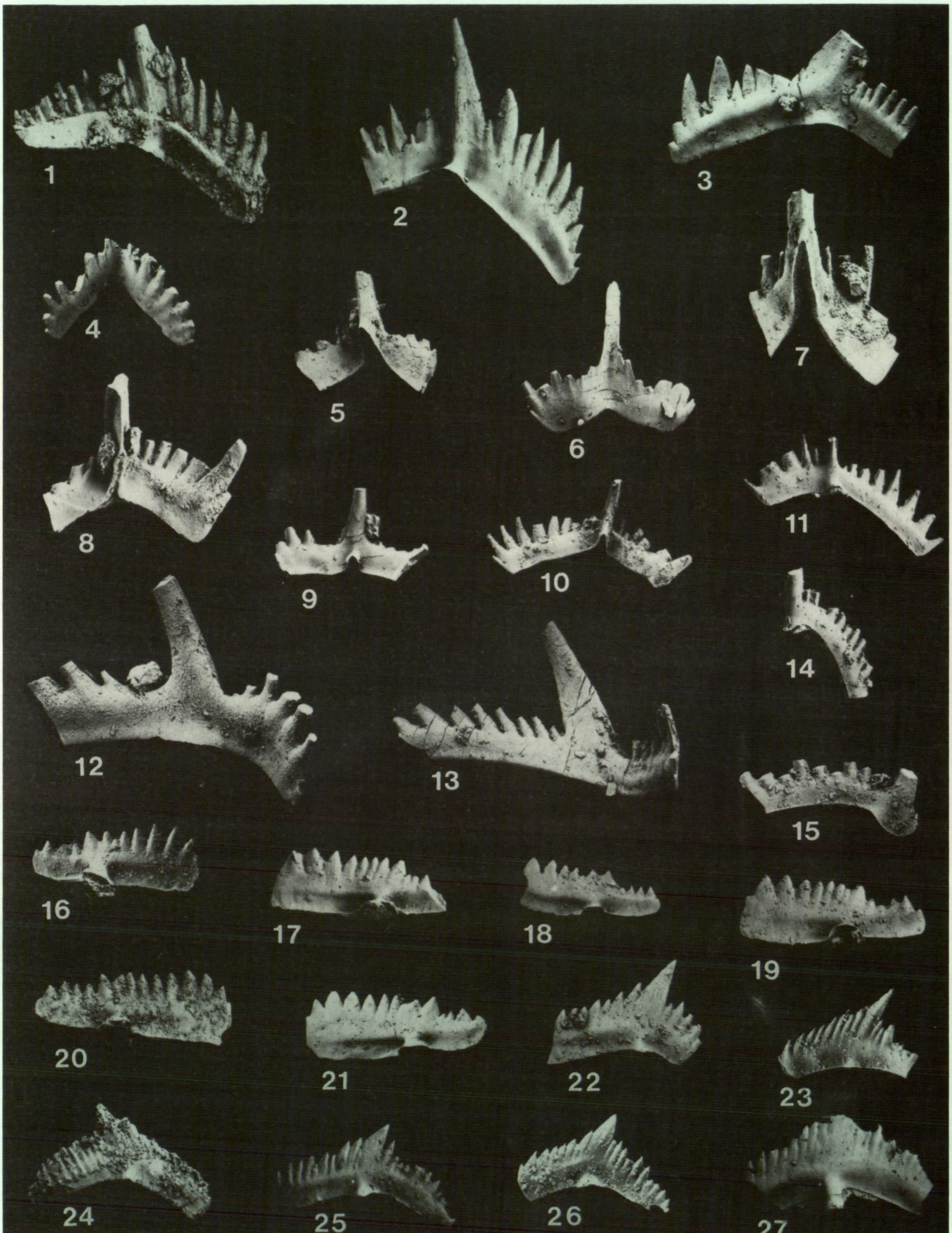
Occurrence

Upper limestone unit of the Jack Formation, sample BR01-04.

Remarks

Three Pa elements have a heart-shaped, posteriorly located basal cavity. The posterior blade

◀ **Figure 5** **1–11**, *Kockelella variabilis* Walliser, all specimens X50. **1**, Sa element Y5255 from BR06-00, anterior view. **2**, Sb element Y5259 from BR07-01, anterior view. **3**, Sb element Y5260 from BR07-02, anterior view. **4**, Sb element Y5261 BR04-10, anterior view. **5**, M element Y5262 from BR07-16, outer lateral view. **6**, M element Y5263 from BR05-12, inner lateral view. **7**, M element Y5264 from BR02-04, inner lateral view. **8**, Sc element Y5265 from BR07-01, lateral view. **9**, Sc element Y5266 from BR06-03, lateral view. **10**, Sc element Y5267 from BR07-01, lateral view. **11**, Sc element Y5268 from BR02-03, lateral view. **12–26**, *Ozarkodina excavata excavata* Branson and Mehl, all specimens lateral views, X50, unless otherwise stated. **12**, Pa element Y5290 from BR06-00. **13**, Pa element Y5291 from BR04-10. **14**, Pa element Y5293 from BR06-00. **15**, Pa element Y5294 from BR04-10. **16**, Pa element Y5296 from BR06-00. **17**, Pa element Y5297 from BR02-03. **18**, Pa element Y5298 from BR02-03. **19**, Pa element Y5302 from BR07-01, X66. **20**, Pa element Y5301 from BR06-03. **21**, Pa element Y5300 from BR05-12. **22**, Pa element Y5299 from BR07-09, upper view showing deflection of blade. **23**, Pb element Y5303 from BR06-03. **24**, Pb element Y5304 from BR06-03. **25**, Pb element Y5307 from BR04-10. **26**, Pb element Y5310 from BR06-00.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is lower and shorter than the anterior blade as with *Ozarkodina* sp. A descibed above. However, the denticulation is irregular, with a high anterior denticle and high denticle directly over the basal cavity, similar to *Ozarkodina remscheidensis* (Ziegler 1960). In the Jack Formation specimens these higher denticles are separated by five smaller ones and five or six are developed on the posterior blade.

Ozarkodina sp. E Savage, 1976
Figures 7.12–15

Spathognathodus fundamentatus (Walliser): Bischoff and Sanneman 1958: 105, plate 13, figure 8; plate 14, figures 1–3.

Spathognathodus steinhornensis steinhornensis (Zeigler): Schulze 1968: 228–229, plate 17, figure 13.

Spathognathodus aff. *transitans* (Bischoff and Sanneman): Bultynck 1971: 31–34, plate 1, figures 1, 2, 4?, 3–18?.

Ozarkodina sp. E: Savage 1976: 1186, plate 2, figures 37–39.

Material
Four Pa elements.

Occurrence
Upper limestone unit of the Jack Formation, Broken River Crossing section, 3 samples: BR01-05, BR01-06, BR12-11 (spot sample upper limestone unit of the Jack Formation). This species has previously been recovered only from the Devonian *delta* Zone (Savage 1976).

Remarks
These Pa elements have a relatively long, slightly flexed anterior blade (approximately two thirds the total length). The denticles are broad, closely spaced and of uniform height. Posterior denticles are similar but shorter and developed on a lower blade. The basal cavity is anterior to the change in blade height and is asymmetrical, with the outer lobe better developed than the inner lobe (Figure 7.15).

In two of the specimens there are clearly two levels of denticle development. However, one specimen has a denticle of intermediate height (Figure 8.15).

Savage (1976: 1186) recorded that some elements have denticle-bearing basal cavity lobes. This is not seen in the Jack Formation specimens.

Genus *Polygnathoides* Branson and Mehl, 1933

Type Species
Polygnathoides siluricus Branson and Mehl 1933.

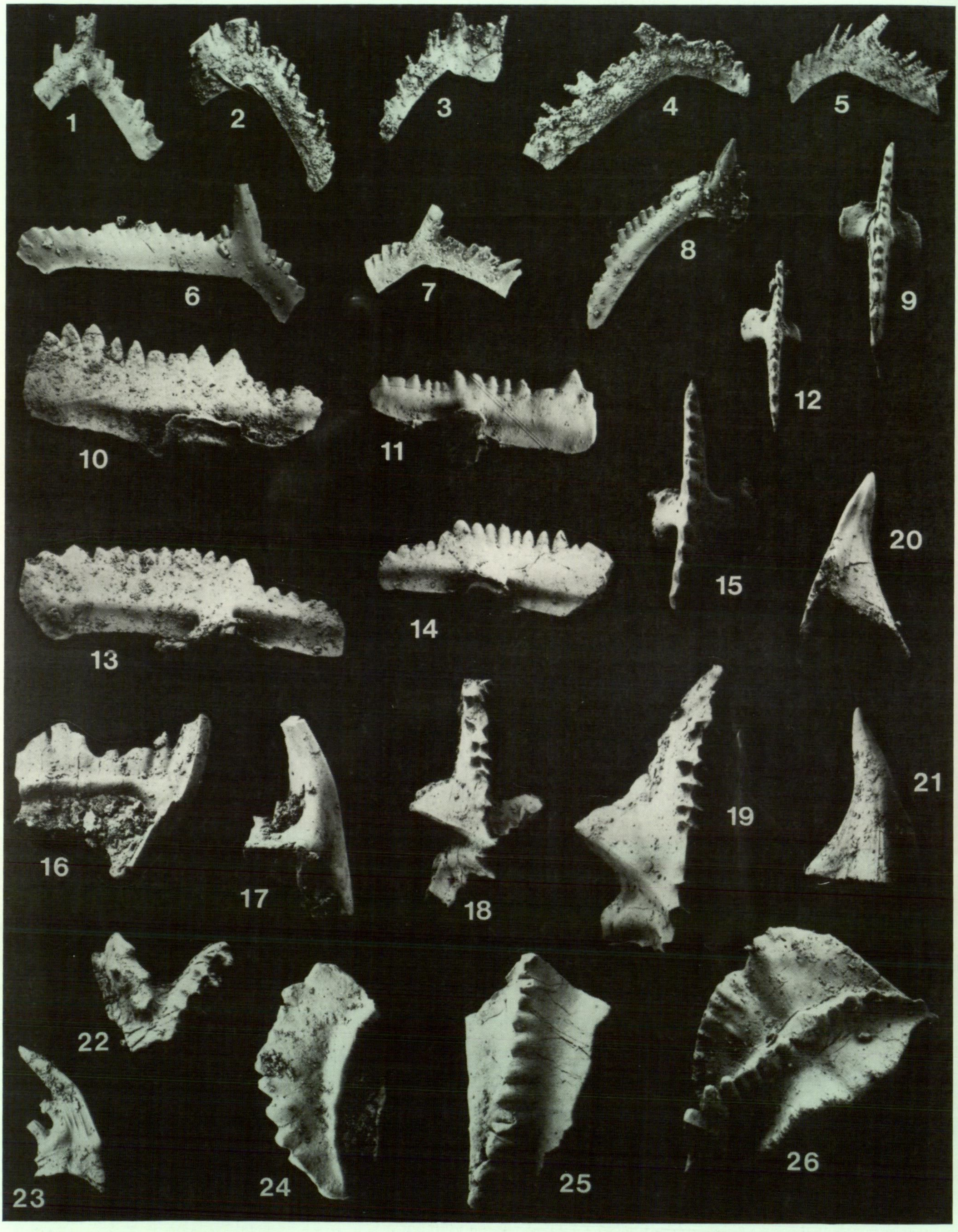
Polygnathoides siluricus Branson and Mehl, 1933
Figure 7.26

Material
Three Pa elements.

Occurrence
The zonal index species, *Polygnathoides siluricus*, is restricted to the "coral gardens unit" of the Jack Formation in the Graveyard Creek Group; it has been recovered from both the Upper and Lower Bullock Creek sections. In the former it occurs through a stratigraphic interval of 16 m and in the latter through a possible interval of approximately 17 m (reconnaissance sample).

Remarks
For synonomy see Klapper and Murphy (1975). These elements have a broad "leaf-shaped" platform, and have distinct transversely arranged trough-like folds developed on both platform halves at the point of greatest width, as in specimens from the Carnic Alps (Walliser 1964, plate 17, figures 1–11). The basal cavity has two lateral lobes that expand parallel to the platform furrows. Jeppsson (1983) presented an apparatus reconstruction. Only the Pa element was found in this study.

◀ **Figure 6** **1–15,** *Ozarkodina excavata excavata* Branson and Mehl, all specimens lateral views, X50 unless otherwise stated. **1,** Pb element Y5306 from BR06-03. **2,** Pb element Y5305 from BR06-03. **3,** Pb element Y5309 from BR05-12. **4,** Sa element Y5312 from BR06-03, anterior view. **5,** Sa element Y5313 from BR06-00, posterior view X66. **6,** Sa element Y5314 from BR05-12, anterior view X66. **7,** Sa element Y5315 from BR06-00, posterior view X66. **8,** Sb element Y5319 from BR02-07, posterior view X66. **9,** Sb element Y5320 from BR04-10. **10,** Sb element Y5321 from BR01-06. **11,** Sb element Y5318 from BR06-00. **12,** Sc element Y5322 from BR07-02, X99. **13,** Sc element Y5324 from BR07-13. **14,** M element Y5328 from BR06-03. **15,** M element Y5325 from BR01-05, X66. **16-27,** *Ozarkodina* sp. A Klapper and Murphy all specimens lateral views X50 unless otherwise stated. **16,** Pa element Y5269 from BR01-06. **17,** Pa element Y5270 from BR01-05. **18,** Pa element Y5271 from BR01-05, X66. **19,** Pa element Y5272 from BR06-00. **20,** Pa element Y5273 from BR06-00. **21,** Pa element Y5274 from BR12-11. **22,** Pb element Y5275 from BR01-06. **23,** Pb element Y5276 from BR01-06. **24,** Pb element Y5278 from BR01-04. **25,** Pb element Y5279 from BR01-04. **26,** Pb element Y5280 from BR06-00. **27,** Pb element Y5277 from BR01-05.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Family Pterospathodontidae Cooper, 1977

Genus *Astropentagnathus* Mostler, 1967

Type species
Astropentagnathus irregularis Mostler 1967

***?Astropentagnathus irregularis* Mostler, 1967**
Figures 7.24–25

Material
Two Pa fragments.

Occurrence
Both fragments were recovered from a small limestone body (sample BR12-08) within the underlying Quinton Formation.

Remarks
For synonymy plus discussion of the multielement reconstruction first proposed by Schönlaub (1971), see Uyeno (1990).

In the Broken River Crossing area only fragments of the Pa element have been recovered, so this identification is made with some reservation. One (Figure 7.24) represents the anterior part of the platform; another (Figure 7.25) represents one of the lateral lobes.

Order Prioniodontida Dzik, 1976

Family Distomodontidae Klapper, 1981

Genus *Distomodus* Branson and Branson, 1947

Type species
Distomodus kentuckyensis, Branson and Branson 1947.

***Distomodus staurognathoides* (Walliser 1964)**
Figures 7.16–17

Material
One Sc element; 1 M element.

Occurrence
Two elements were recovered from a small limestone body (sample BR12-08) within the underlying Quinton Formation.

Remarks
These elements are assigned with some reservation. Pa elements are required for a more definite identification.

Family Icriodontdidae Müller and Müller, 1957

Genus *Icriodus* Branson and Mehl, 1938

Type species
Icriodus expansus, Branson and Mehl 1938.

***Icriodus woschmidti hesperius* Klapper and Murphy, 1975**
Figures 7.18–21

Material
Three Pa elements, two Pb elements.

Occurrence
All specimens were recovered from samples of the upper limestone unit of the Jack Formation.

Remarks
For synonymy and discussion of this subspecies see Simpson (1998). In the three Pa elements

◀ **Figure 7** 1–8, *Ozarkodina* sp. A Klapper and Murphy, all specimens lateral views X50 unless otherwise stated. **1**, Sa element Y5282 from BR01-04, posterior view X66. **2**, Sb element Y5283 from BR01-06. **3**, Sb element Y5284 from BR01-04. **4**, Sc element Y5285 from BR01-06. **5**, Sc element Y5286 from BR01-06. **6**, Sc element Y5287 from BR01-05. **7**, Sc element Y5288 from BR01-04. **8**, M element Y5289 from BR01-06. **9–11**, *Ozarkodina* sp. aff O. *remscheidensis* Zeigler; all specimens X50. **9**, Pa element Y5333 with heart-shaped basal cavity from BR01-04, upper view. **10**, Pa element Y5334 from BR12-12, lateral view. **11**, Pa element Y5335 from BR01-04, lateral view. **12–15**, *Ozarkodina* sp. E Savage. **12**, Juvenile Pa element Y5330 from BR01-06, upper view X50. **13**, Pa element Y5329 from BR01-06, lateral view X50. **14**, Pa element Y5332 from BR12-11, lateral view X33. **15**, Pa element Y5331 with ear-shaped basal cavity from BR01-05, upper view, X50. **16–17**, *Distomodus staurognathoides* (Walliser). **16**, Sc element Y5241 from BR12-08, inner lateral view X50. **17**, M element Y5242 from BR12-08, lateral view X33. **18–21**, *Icriodus woschmidti hesperius* Klapper and Murphy. **18**, Pa element Y5243 from sample BR01-04, upper view X33. **19**, Pa element Y5244 from BR01-04, upper view, X50. **20**, Pb element Y5245 from BR01-05, inner lateral view, X50. **21**, Pb element Y5246 from BR12-11, outer lateral view X50. **22**, ?*Pedavis latialata* Walliser, Pa element fragment Y5337 from BR06-06, upper view X33. **23**, *Pedavis* sp. S element Y5336 from BR01-05, lateral view X50. **24–25**, ?*Astropentagnathus irregularis* Mostler, (also illustrated in Simpson (1999) plate 2, figures 11 and 12 respectively), both Pa element fragments from BR12–08, X50. **24**, Y5238 lower view. **25**, Y5237 upper view. **26**, *Polygnathoides siluricus* Branson and Mehl, Pa element Y5338 from BR04-10, upper view X50.

recovered from the Jack Formation, the long main process bears five or more relatively narrow transverse ridges. A thin median longitudinal ridge is present in grooves between transverse ridges. All specimens have an outer posteriorly directed process, which in one specimen is comparatively long (Figure 7.18) and bears a single row of denticles. One of the two anteriorly directed lobes bears a straight, sharp ridge and both lobes extend from beneath the second denticle posterior to the transverse ridges.

Both figured Pa elements resemble the holotype (Klapper and Murphy 1975, plate 11, figure 13). Minor differences include a relatively shorter section of the main process covered by transverse ridges, and the presence of one undulating ridge-like crest on one of the anteriorly directed lobes (Figure 7.18) in the Broken River material. The slightly uneven nature of the posteriorly directed lobe of the same specimen is possibly a pathologic feature.

Family Icriodellidae Sweet, 1988

Genus *Pedavis* Klapper and Philip, 1971

Type Species

Icriodus pesavis Bischoff and Sanneman 1958.

?*Pedavis latialata* (Walliser 1964)

Figure 7.22

Material

One Pa fragment.

Occurrence

Only from BR06-06 in the "coral gardens" unit of the Jack Formation. This sample comes from a bed above samples yielding the index species *Polygnathoides siluricus* and was the youngest Ludlow index species recovered in this study (see above).

Remarks

For synonymy see Uyeno (1990). The fragmentary Pa element recovered consists of the main process and the inner antero-lateral lobe. The fragment resembles a portion of the holotype of *Pedavis latialata* Walliser (1964, plate 11, figure 13) in general morphology but has a more subdued "icriodontan" ornament on the main process.

Pedavis sp.

Figure 7.23

Material

One specimen.

Occurrence

Sample BR01-05, upper limestone unit of the Jack Formation.

Description

Striated and inclined cone, with sharp ridge developed anteriorly and two small ancillary posterior cones developed at different heights on main cone.

Remarks

This is an Mb (= S) morphotype according to Murphy and Matti's (1982: 46) classification. The Jack Formation specimen has affinities with the M_2 element of *Pedavis breviramus* Murphy and Matti, but their figured specimen (Murphy and Matti 1982, plate 8, figure 13) lacks a distinct ancillary cone. The Jack Formation specimen is also similar to *Pedavis* sp. of Murphy and Matti (1982).

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