Trilobite biostratigraphy and revised bases of the Tulean and Blackhillsian Stages of the Ibexian Series, Lower Ordovician, western United States

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Extensive new field collections and taxonomic work permit the development of a much higher resolution trilobite biostratigraphy for the Lower Ordovician Tulean and Blackhillsian stages of western Laurentia than has previously been possible. The five zones used previously are replaced by 15 formally designated zones, of which one is unaltered from the previous scheme, three are restricted with new boundary definitions, and 11 are newly proposed. The uppermost part of the Blackhillsian Stage has not been studied and may contain additional undescribed diversity. The base of the Tulean Stage is revised downward to the base of the (new) *Litzicurus shawi* Zone, which corresponds to an episode of abrupt trilobite faunal turnover in the form of a "biomere"-style mass extinction and the coordinated first appearance of multiple trilobite genera characteristic of the remainder of the Tulean. A new boundary stratotype for this base is designated at Section HC6 142.0 m in the Garden City Formation of southeastern Idaho. As recognised by previous workers, the correlative interval in the type section of the Tulean Stage in western Utah is poorly fossiliferous and the position of the turnover event cannot be located, only inferred. The base of the Blackhillsian Stage has been defined as the base of the *Trigonocerca typica* Zone by previous authors. This zone is abandoned due to misidentification of the name bearer in the stratotype and the fact that the true first appearance of this species can now be shown to occur within a stratigraphic interval characterised by an otherwise uniform trilobite fauna. The Blackhillsian Stage is revised with a base coinciding with the base of the new *Strigigenalis plicolabeona* Zone, and the boundary stratotype is now a few metres higher in the same section as the original. The new zonal scheme in ascending order includes the Tulean *Litzicurus shawi* Zone (new), *Psalikilus spinosum* Zone (new), *Hintzeia celsaora* Zone (restricted), *Psalikilopsis cuspicaudata* Zone (new), *Psalikilus typicum* Zone (new), *Psalikilus hestoni* Zone (new), *Protopliomerella contracta* Zone (restricted), *Heckethornia hyndeae* Zone (new), *Heckethornia bowiei* Zone (new), *Psalikilus pikum* Zone (new), and the Blackhillsian *Strigigenalis plicolabeona* Zone (new), *Carolinites nevadensis* Zone (new), *Presbynileus ibexensis* Zone, *Pseudocybele paranasuta* Zone (new), an interval presently referred to the "*Pseudocybele nasuta* Zone" (restricted), and an unsampled overlying interval in the highest Blackhillsian. Two of the name bearers of the new zones, *Litzicurus shawi* gen. et sp. nov. and *Psalikilus hestoni* sp. nov. are formally described.

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THE BIOSTRATIGRAPHIC scheme in use for Lower Ordovician trilobites of Laurentia has been based on work done over 60 years ago by Ross (1949). Ross's lettered scheme derived from his sampling of the Garden City Formation in southeastern Idaho and northeastern Utah (Figs 1, 2B, E), which was described in a monograph (Ross 1951a) and two subsequent short papers (Ross 1951b, 1953). Hintze (1951) described the stratigraphy of the Pogonip Group in western Utah (Figs 1, 2A, C) and applied Ross's trilobite zones with some modification. The trilobites were described in a monograph (Hintze, 1953) followed by two short papers updating genus nomenclature

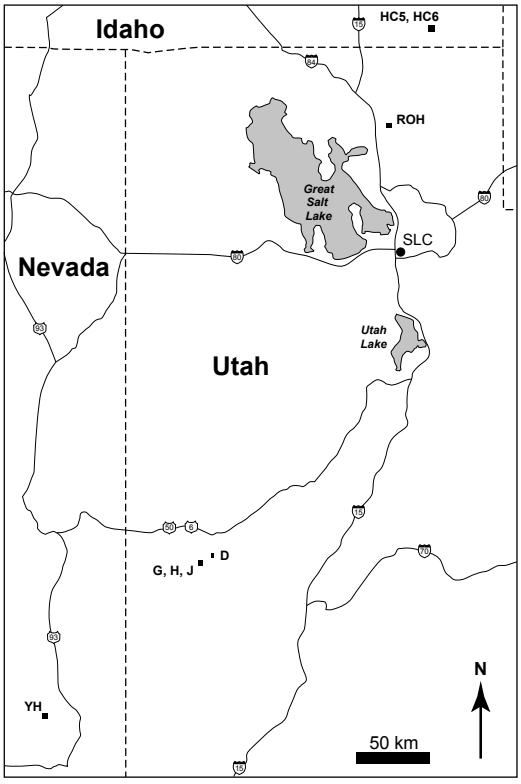


Fig. 1. Location of sections in eastern Nevada, western Utah, northeastern Utah, and southeastern Idaho. D = Hintze's (1951, 1953) Ibex Section D, southern House Range. G = Ibex Section G, H = Ibex Section H, J = Ibex Section J, all southern Confusion Range. HC5 = Ross's (1949, 1951) Locality 5, east side of Hillyard Canyon, HC6 = Ross's (1949, 1951) Locality 6, west side of Hillyard Canyon, both Bear River Range. ROH = Round Hill, Ross's (1949, 1951) Locality 13. YH = Hintze's (1951, 1953) Yellow Hill Section. SLC = Salt Lake City.

(Hintze 1954; Hintze & Jannusson 1956). As outlined by Adrain *et al*. (2001), these works were superb for their time, but considered only a fraction of the available high quality data and species diversity in either region. Nevertheless, there was almost no systematic work building on the original monographs for half a century, apart from three papers by students of Hintze published in 1973 (Demeter 1973; Terrell 1973; Young 1973). Ross *et al*. (1997) formally proposed the Ibexian Series and its constituent stages, in ascending order: the Skullrockian, Stairsian, Tulean, and Blackhillsian. The stages are trilobite-based, and their type sections and boundary stratotypes are in the Ibex region of western Utah. The data supporting them are primarily the identifications and occurrence data given by Hintze (1953). Ross *et al*. (1997) also provided formal names for the amended series of letter zones (see Fig. 3, middle columns, for the lettered and subsequently named Ross/Hintze zones for the Tulean and Blackhillsian).

During the late 1990s an intensive effort was begun to resample the entire Lower Ordovician succession at most of Ross's and Hintze's important sections, including a section at Yellow Hill in eastern Nevada (Figs 1, 2D). Some publications have resulted (Adrain *et al*. 2001, 2003; Adrain & Westrop 2006a, b, 2007a, b; McAdams & Adrain 2009a, b, c) but only now is technical work sufficiently advanced that major works on entire taxonomic groups can be produced, and the "big picture" of faunal diversity and distribution addressed. The present work deals with the trilobite faunas of the top two stages of the Ibexian Series, the Tulean and Blackhillsian. Although further work will certainly increase the numbers of new taxa, we are now able to provide a reasonable estimate of historical sampling versus the diversity actually available for study. All previous work on the Tulean and Blackhillsian trilobite faunas of the Great Basin has resulted in 55 named species distributed amongst 37 genera. Our resampling has increased this (counting taxa published since 2000 along with those awaiting publication) by 16 new genera and 140 formally named or nameable new species, along with a further 75 distinct species which at present are not well enough known to name. That is, the more than half century old work upon which the 1997 stages were based described less than a third of the common species in the sections.

It is important to emphasise that this is not a matter of different taxonomic approaches (e.g., of "lumping" versus "splitting"). While we employ a modern phylogenetic species concept (*sensu* Nixon & Wheeler 1990), the criteria we use to separate species - nonoverlapping morphological variation and pervasive differentiation, even if subtle - are really no different from those applied with great precision by Hintze (1953). The new species in the present work are not more finely parsed or split components of previously named taxa from given horizons. Rather, they are newly discovered and derive either from the many entirely distinct faunas that have previously been missed, or from discoveries of overlooked species at horizons which were sampled by the earlier authors.

It has become apparent that there is much more diversity in the sections than has been appreciated. There are a greater number of distinct faunas, and more rapid faunal turnover. The existing biostratigraphic scheme (Fig. 3, middle) divides the two stages into five trilobite zones. The concept of most of these zones, particularly in the

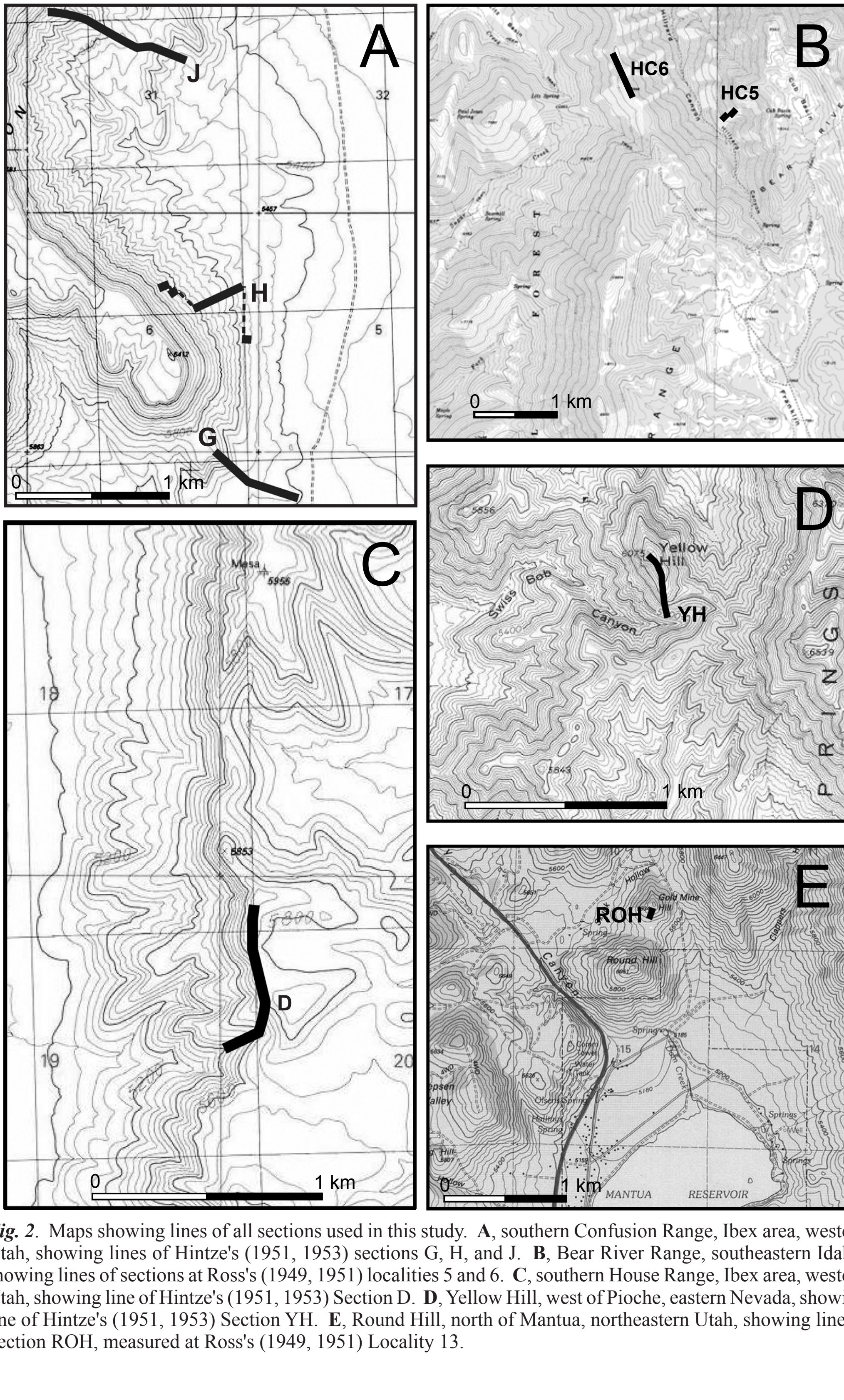


Fig. 2. Maps showing lines of all sections used in this study. **A**, southern Confusion Range, Ibex area, western Utah, showing lines of Hintze's (1951, 1953) sections G, H, and J. **B**, Bear River Range, southeastern Idaho, showing lines of sections at Ross's (1949, 1951) localities 5 and 6. **C**, southern House Range, Ibex area, western Utah, showing line of Hintze's (1951, 1953) Section D. **D**, Yellow Hill, west of Pioche, eastern Nevada, showing line of Hintze's (1951, 1953) Section YH. **E**, Round Hill, north of Mantua, northeastern Utah, showing line of Section ROH, measured at Ross's (1949, 1951) Locality 13.

Global Stages	Series	Stage	Ross (1951)	Ross *et al.* (1997)	This Paper
FLOIAN	IBEXIAN	BLACK-HILLSIAN	J	*Pseudocybele nasuta*	Unstudied
					"Pseudocybele nasuta"
					Pseudocybele paranasuta
			I	*Presbynileus ibexensis*	*Presbynileus ibexensis*
			H	*Trigonocerca typica*	*Carolinites nevadensis*
					Strigigenalis plicolabeona
(approx.)		TULEAN	G(2)	*Protopliomerella contracta*	*Psalikilus pikum*
					Heckethornia bowiei
					Heckethornia hyndeae
TREMADOCIAN					*Protopliomerella contracta*
			G(1)	*Hintzeia celsaora*	*Psalikilus hestoni*
					Psalikilus typicum
					Psalikilopsis cuspicaudata
					Hintzeia celsaora
					Psalikilus spinosum
					Litzicurus shawi

Fig. 3. Trilobite zonation of the Tulean and Blackhillsian stages proposed herein, compared with previous schemes.

Garden City Formation where they were originally proposed, was based on the fauna of only one or two prolific horizons. Trilobites from most of the claimed stratigraphic range of the zones were not photographically documented by either Ross (1951a) or Hintze (1953), but rather given as identifications in faunal lists. Reinvestigation has shown that a majority of these identifications are incorrect, and that multiple completely distinct new faunas appear in stratigraphic succession but have been overlooked.

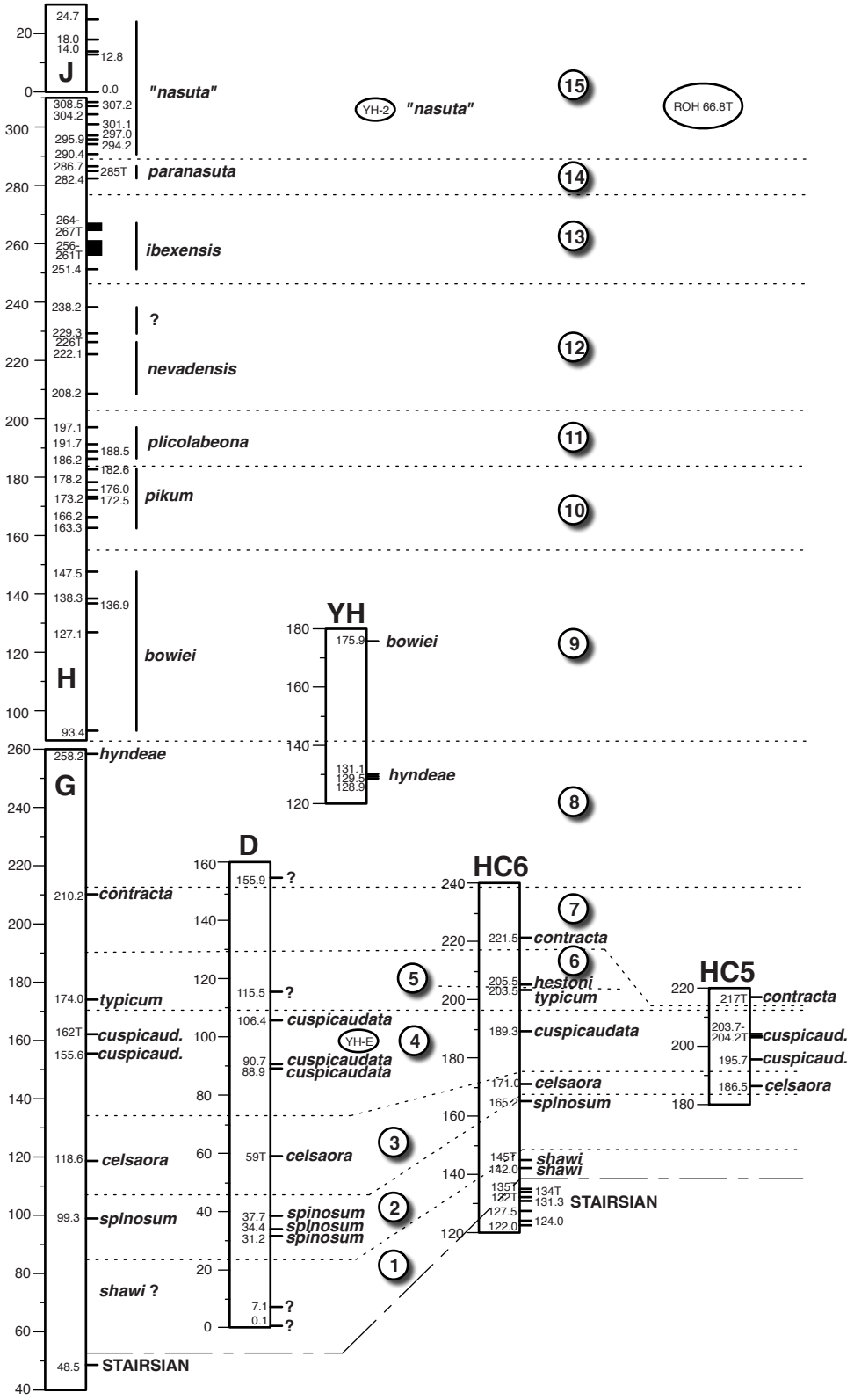
As a result, a considerably more highly resolved biostratigraphic scheme is possible. The goal of this work is to establish this replacement scheme, while recognising that it will be amended and refined as work proceeds. At present it is possible to recognise 15 formally named zones based on the first appearances of individual species (Fig. 3, right hand column). In addition, the new data available permit revision of the scope and base of the Tulean Stage, with a new basal boundary stratotype which is resolved to a few metres. The base of the Blackhillsian Stage is more problematic, as the systematics and identification of the critical species, *Trigonocerca typica* Ross, 1951a, have been confused. It is an inappropriate index species as its first appearance does not coincide with a major faunal change that might be correlated to other regions. The bulk of this paper is devoted to describing each of the new zones and their distribution, along with illustrating some of the constituent trilobite taxa. Two of the zonal name bearers are new species, and these are formally described in a systematics section so that their names are available.

LOCALITIES AND SECTIONS

Ibex, Utah

The composite section of the Pogonip Group in the Ibex area of western Utah was documented by Hintze (1951, 1953, 1973) and contains the type sections of the four stages of the Ibexian Series introduced by Ross *et al*. (1997). The base of the Ibexian is Cambrian in age and lies within the

Fig. 4 (opposite). Sections and sampling horizons and localities used in this study, with new trilobite zonation indicated. Section designations as in Figures 1 and 2. Dashed lines between zones are placed at arbitrary levels to show groupings of horizons, not at exact positions of zonal bases. A question mark indicates that the zonal assignment of the sample has yet to be determined. 1, *Litzicurus shawi* Zone. 2, *Psalikilus spinosum* Zone. 3, *Hintzeia celsaora* Zone. 4, *Psalikilopsis cuspicaudata* Zone. 5, *Psalikilus typicum* Zone. 6, *Psalikilus hestoni* Zone. 7, *Protopliomerella contracta* Zone. 8, *Heckethornia hyndeae* Zone. 9, *Heckethornia bowiei* Zone. 10, *Psalikilus pikum* Zone. 11, *Strigigenalis plicolabeona* Zone. 12, *Carolinites nevadensis* Zone. 13, *Presbynileus ibexensis* Zone. 14, *Pseudocybele paranasuta* Zone. 15, "*Pseudocybele nasuta*" Zone.


J
H
G
D
YH
HC6
HC5
"nasuta"
paranasuta
ibexensis
?
nevadensis
plicolabeona
pikum
bowiei
hyndeae
contracta
typicum
cuspicaud.
cuspicaud.
celsaora
spinosum
shawi ?
STAIRSIAN
cuspicaudata
cuspicaudata
cuspicaudata
celsaora
spinosum
spinosum
spinosum
?
?
?
YH-2
YH-E
ROH 66.8T
heston
shawi
shawi
STAIRSIAN
contracta
cuspicaud.
cuspicaud.
celsaora

Hintze	OM (ft)	NM (m)	Ross *et al.* Zonation	New Zonation
G-19	758	258.2	*Protopliomerella contracta*	*Heckethornia hyndeae*
G-18	735	230.1	*Protopliomerella contracta*	inadequate sample
G-17	690	210.2	*Protopliomerella contracta*	*Protopliomerella contracta*
G-14	585	174	*Protopliomerella contracta*	*Psalikilus typicum*
		162T		*Psalikilopsis cuspicaudata*
G-13	537	158.1	*Protopliomerella contracta*	*Psalikilopsis cuspicaudata*
G-12	529	155.6	*Protopliomerella contracta*	*Psalikilopsis cuspicaudata*
		148.2		unzoned (possibly new)
G-9	407	118.6	*Hintzeia celsaora*	*Hintzeia celsaora*
G-8	306	99.3	*Hintzeia celsaora*	*Psalikilus spinosum*
		99T		*Psalikilus spinosum*
		97T		*Psalikilus spinosum*
		94.5T		*Psalikilus spinosum*
G-7	194	68.9	unzoned	possibly *Litzicurus shawi*
		67.4T		possibly *Litzicurus shawi*
G-6	183	61.4	unzoned	possibly *Litzicurus shawi*

Table 1. Tulean horizons yielding silicified trilobite samples at Ibex Section G, showing equivalents of Hintze's (1953) original sampling horizons in new measurements. Hintze = Hintze's (1953) sample numbers. OM = Hintze's (1951, 1953) original measurement in feet. NM = new measurement in metres.

Lava Dam Member of the Notch Peak Formation (Miller *et al*. 2001, 2003). The Cambrian-Ordovician boundary lies within the lower Barn Canyon Member of the House Formation, within the lowermost Skullrockian Stage of the Ibexian. The boundary between the Skullrockian and the overlying Stairsian Stage occurs near the contact between the House and the overlying Fillmore Formation. The Stairsian Stage approximately corresponds to the unnamed lowest member ("basal ledge-forming limestone member" of Hintze [1973]) of the Fillmore. The interval dealt with herein begins with the (redefined) base of the Tulean which is thus very difficult to document at Ibex (see discussion below), but which must correspond approximately to the base of the second "slope-forming shaly siltstone member" of Hintze (1973). The Tulean ranges through this and the two overlying members, and the base of the Blackhillsian Stage is approximately at the base of the penultimate "calcarenite member" of the Fillmore. The upper part of the Blackhillsian is represented by much of the overlying Wah Wah Formation, and the base of the Whiterockian Stage of the Middle Ordovician occurs in the upper part of the Wah Wah.

A continuous section through the Tulean Stage is available in Ibex Sections G and H in the southern Confusion Range on the west side of the Tule Valley (Figs 1, 2A, 4), although it contains two long offsets along strike. We remeasured and logged both sections (Appendices 1-3), and metreages given are our own new measurements. Most of Hintze's sampling horizons have been successfully located (Tables 1, 2). Section H has two sets of measurements in feet marked at intervals with yellow highway paint. One reflects Hintze's (1951, 1953) original measurements, which identify the positions of his sampling horizons. A second reflects a remeasurement in 1965 which formed the basis for the footages given by Hintze (1973) and Ross *et al*. (1997). In making reference to the original sampling horizons, we have elected to use Hintze's original (1951, 1953) footages, as they are the measurements tied directly to the sampling horizons reported in Hintze's (1953) monograph and they permit certainty that Hintze's original sampling has been (in most cases) replicated.

The boundary stratotype for the base of the Tulean selected by Ross *et al*. (1997) is in Hintze's "1965 C-Section," which is approximately the same as his 1953 Section D, in the southern House Range on the east side of the Tule Valley (Figs 1, 2C, 4). Relocating Hintze's original sampling horizons at this section is much more difficult, because the original painted numbers have mostly disappeared and the numbers currently marked on the rocks are the 1965 remeasurements. These were not tied directly to the sampling horizons. We proceeded by remeasuring the section in metres, and by collecting all promising horizons. Section D contains the lower part of the Tulean, but terminates well below the base of the Blackhillsian. Further to the north in the House Range, upper Tulean and Blackhillsian strata are exposed in Hintze's (1973) Mesa Section, which is unfortunately relatively far from any roads and

Hintze	OM (ft)	NM (m)	Ross *et al.* Zonation	New Zonation
H-32	745		*Pseudocybele nasuta*	not resampled
H-31	731	290.4	*Pseudocybele nasuta*	*"Pseudocybele nasuta"*
	722	286.7	*Pseudocybele nasuta*	*Pseudocybele paranasuta*
	718	285T	*Pseudocybele nasuta*	*Pseudocybele paranasuta*
	710	282.4	*Pseudocybele nasuta*	*Pseudocybele paranasuta*
H-30	705		*Pseudocybele nasuta*	*Pseudocybele paranasuta*
H-29	670		*Presbynileus ibexensis*	not resampled
	650-660	264-267T	*Presbynileus ibexensis*	*Presbynileus ibexensis*
	630-640	256-261T	*Presbynileus ibexensis*	*Presbynileus ibexensis*
H-28	630		*Presbynileus ibexensis*	*Presbynileus ibexensis*
H-27	610	251.4	*Presbynileus ibexensis*	*Presbynileus ibexensis* (at 611')
H-26	572	238.2	*Presbynileus ibexensis*	*Presbynileus ibexensis* (at 573')
H-25	545		*Presbynileus ibexensis*	not resampled
H-24	525	222.1	*Trigonocerca typica*	*Carolinites nevadensis*
H-23	483	208.2	*Trigonocerca typica*	*Carolinites nevadensis*
H-22	460		*Trigonocerca typica*	not resampled
H-21	450	197.1	*Trigonocerca typica*	*Strigigenalis plicolabeona* (at 443')
H-20	434	191.7	*Trigonocerca typica*	*Strigigenalis plicolabeona*
H-19	416	185.6	*Protopliomerella contracta*	*Psalikilus pikum*
H-18	412		*Protopliomerella contracta*	not resampled
H-17	410	182.6	*Protopliomerella contracta*	*Psalikilus pikum*
H-16	380	172.5	*Protopliomerella contracta*	*Psalikilus pikum*
H-15	357	163.3	*Protopliomerella contracta*	*Psalikilus pikum* (at 354')
	305	138.3	*Protopliomerella contracta*	inadequate sample
H-13	300	136.9	*Protopliomerella contracta*	inadequate sample
H-11	276	127.1	*Protopliomerella contracta*	*Heckethornia bowiei*
H-7	190	93.4	*Protopliomerella contracta*	*Heckethornia bowiei*
H-6	186		*Protopliomerella contracta*	not resampled
H-3	160		*Protopliomerella contracta*	not resampled
H-2	104		*Protopliomerella contracta*	not resampled
H-1	82		*Protopliomerella contracta*	not resampled

Table 2. Tulean and Blackhillsian horizons yielding silicified trilobite samples at Ibex Section H, showing integration with Hintze's original (1951, 1953) measurements. Hintze = Hintze's (1953) sample numbers. OM = Hintze's (1951, 1953) original measurement in feet. NM = new measurement in metres. Additional newly sampled horizons and their zonal assignments are indicated on Figure 4.

difficult to sample in the bulk quantities necessary for our revision.

Bear River Range, Idaho

The localities which furnished most of the species for Ross's (1951a) monograph of the trilobites of the Garden City Formation are his Locality 5 on the east side of Hillyard Canyon, Bear River Range, Franklin County, Idaho, and particularly Locality 6 on the west side of Hillyard Canyon (Figs 1, 2B, 4). We remeasured (in metres) and recollected these as our Sections HC5 and HC6. Section HC5 is generally poorly exposed, as it proceeds up the side of the valley through woods and cover. Section HC6 is well exposed along the ridge crest, and runs from the Upper Cambrian contact with the underlying St. Charles Formation to a termination either within or just above the (restricted) Tulean *Protopliomerella contracta* Zone. Section HC5 continues stratigraphically higher, though the upper parts are almost entirely covered. Ross's (1951a, pp. 27-29) lettered zones are fairly detailed through the well exposed section to the top of HC6, up to and including the upper Tulean *P. contracta* Zone. Above that, his "Zone H" was based on a single horizon at his Locality 8 (Clarkston Mountain), from which he retrieved only a single named species, *Trigonocerca typica* Ross, 1951a. His "Zone I" contained no illustrated trilobites. His "Zone J"

was based on a 10 foot interval at Locality 8 and a similarly narrow interval (see below) at Locality 13 near Mantua, northern Utah.

Mantua, Utah

Ross (1951a) illustrated trilobite material from his "Zone J" from two localities, Locality 8 (Clarkston Mountain, northern Utah) and Locality 13 (Round Hill, near Mantua, northern Utah). We recollected the latter (Figs 1, 2E, 4). In contrast to Ross's (1951a, p. 23) report of a "complete trilobite assemblage of Zone J" through an 85 foot unit, we found silicified trilobites at a single rich horizon from which float blocks weather in place along strike at our ROH 66.8T m. We also made smaller talus collections at ROH 62.5T m and ROH 70.1T m, which contained a fauna identical to that from ROH 66.8T m.

Yellow Hill, Nevada

Hintze (1953, pp. 52-56) measured and described a section through the Yellow Hill Limestone (Westgate & Knopf 1932) at Yellow Hill in the Ely Springs Range, near Pioche, Lincoln County, eastern Nevada (Figs 1, 2D, 4). We recollected this section in 2008. The area is heavily faulted, but a continuous section is present through the *Heckethornia hyndeae* and *H. bowiei* zones. Isolated fault-bounded exposures away from the main section also yield well preserved silicified faunas of the *Psalikilopsis cuspicaudata* (locality YH-E) and "*Pseudocybele nasuta*" (locality YH-2) zones. Due to lack of time, collections from the main continuous section were made with reference to key marker beds in Hintze's (1953) description, using his footages converted to metres. Hintze (1953) obtained a float block which included the type material of his new taxa *Carolinites nevadensis* and *Trigonocerca piochensis*, and which is assigned herein to the *Carolinites nevadensis* Zone. The origin of this sample is unknown, as the in situ section (on which Hintze found the block) is much older and terminates at the highest point of Yellow Hill in the *H. bowiei* Zone. We have thus far found no rocks of *C. nevadensis* Zone age, yet they must be present, presumably in another local fault block.

REVISION OF THE TULEAN STAGE AND A NEW BASAL BOUNDARY STRATOTYPE

Ross *et al*. (1997) placed the stratotype for the base of Tulean Stage in the upper part of Hintze's (1973) 1965 C-Section (equivalent to Section D of Hintze [1953] and herein) on the basis of the first appearance of the species *Menoparia genalunata* Ross, 1951a, and *Hintzeia celsaora* (Ross, 1951a). They noted (Ross *et al*. 1997, p. 18) that a stratigraphic interval from which fossils had not been recovered underlies these lowest occurrences at both Sections D and G at Ibex, and concluded that "We expect that additional attempts to collect fossils from the poorly exposed shaly beds below unit 2 of member 2 will require that the base of the stage be redefined downward."

We concur with this conclusion. However, matters are complicated in that the species used by Ross *et al*. (1997) to draw the base of the stage were misidentified in the stratotype and in fact have genuine ranges beginning much higher than these authors realised. Further, a precise and maximally correlative candidate for the stadial boundary, corresponding to an episode of abrupt trilobite turnover, can be identified in the Garden City Formation in Idaho but cannot be located with any precision in the poorly fossiliferous lower interval at the designated stadial type section in western Utah.

On the basis of the extensive new collections reported herein, it is clear that *Hintzeia celsaora*, the name bearer of what Ross *et al*. (1997) considered the lower zone of the Tulean (Zone G(1) of Ross [1951a]) is restricted in its occurrence to a narrow stratigraphic interval higher in the section (see discussion of the restricted *Hintzeia celsaora* Zone below). The lowest species of *Hintzeia* to occur at Ibex is *H. firmimarginis* (Hintze, 1953). It occurs with no other pliomerids with which it might be confused in our new *Psalikilus spinosum* Zone. *Hintzeia celsaora* (=*H. aemula* [Hintze, 1953]) occurs only in the overlying (restricted) *H. celsaora* Zone.

Ross *et al*. (1997) considered that the species *Menoparia genalunata* occurs throughout the Tulean Stage and that it may be used as an alternative to *H. celsaora* to mark the base of the Tulean. In fact this species is restricted in occurrence to the narrow stratigraphic interval of our new *Psalikilopsis cuspicaudata* Zone. Species potentially assignable to *Menoparia* occur in other zones of the Tulean above it and beneath it, but they are clearly distinct and most are new and unnamed. The species Ross *et al*. (1997) used to draw the base of the Tulean is almost certainly that termed *Menoparia* sp. nov. 3 herein (Fig. 8J, N). This is the oldest remopleuridid species recovered from the Tulean at Ibex and it is common at horizons representing our new *Psalikilus spinosum* Zone. At Ibex, it occurs with no other remopleuridid species with which it might be confused. It differs from the younger *M. genalunata* (Fig. 10C, G) in numerous ways, including the possession of a prominent raised line sculpture on all dorsal surfaces (versus a much finer, more subdued, and in some areas

Fig. 5. New boundary stratotype for the revised base of the Tulean Stage, section HC6, west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho.

effaced sculpture), deeply impressed glabellar furrows, and most obviously in the complete lack of interocular fixigenae. *Menoparia* sp. nov. 3 occurs also in the *P. spinosum* Zone of the Garden City Formation, where Ross (1953, p. 636, pl. 62, figs 8, 12) assigned it to "*Apatokephalus* ? sp." In the Garden City Formation, the species co-occurs with a second species which does possess interocular fixigenae and which is more similar to *M. genalunata* (and which was confused with *M. genalunata* by Ross [1953]). This species (*Menoparia* sp. nov. 4 herein, not figured) is itself distinct from the younger *M. genalunata* and in any case does not occur at Ibex.

Hence, even if the lower boundary of the Tulean were to be drawn in approximately the position suggested by Ross *et al*. (1997), some redefinition would be necessary as the critical taxa involved have much narrower ranges than supposed and begin much higher in the section. Placing the boundary higher to conform to the correct ranges serves no useful purpose, and would exclude an underlying interval containing generically similar trilobite faunas on the basis of an essentially arbitrary first appearance of a species (*H. celsaora*) of a genus whose oldest representative enters the succession at a lower stratigraphic level.

Perusal of the faunal lists below and of the illustrations herein will reveal that lower Tulean trilobite assemblages have a fairly stable generic composition, involving the ubiquitous genera *Aulacoparia* Hintze & Jannusson, 1956, *Psalikilus* Ross, 1951a, and *Menoparia* Ross, 1951a, with other common elements (such as *Benthamaspis* Poulsen, 1946) added up section. A sensible and maximally correlative base for the stage would be at the first occurrences of these genera and the assemblages they typify. New field sampling has identified this level to within a few metres in the Garden City Formation in the Bear River Range.

At Section HC6, the last known Stairsian trilobite fauna occurs in float blocks weathering in place at HC6 135T m (Fig. 5). Bioclastic beds rich in articulate brachiopods occur at HC6 138.0 m and HC6 140.5 m. Neither of these horizons yields silicified fossils, but the latter contains fragmentary pygidia of *Aulacoparia* in crackout. The new *Litzicurus shawi* Zone is known from rich silicified collections 1.5 m higher in the section (HC6 142.0 m) and float blocks weathering in place at HC6 145T m. This zone contains the first well represented and nameable species of *Aulacoparia* and the first appearance of *Psalikilus* and *Menoparia*. It is 23.2 m below the level of the base of the Tulean drawn using the criteria of Ross *et al*. (1997), which is a fauna assigned herein to the *Psalikilus spinosum* Zone at HC6 165.2 m.

The transition between the Stairsian and Tulean faunas is abrupt and involves turnover of the entire generic and subfamilial makeup of the assemblages. The hystricurid subfamilies Hystricurinae Hupé, 1953, and Hillyardininae Adrain & Westrop, 2007b, dominate the upper Stairsian faunas, along with such taxa as *Pseudoclelandia* Ross, 1951a, and *Pyraustocranium* Ross, 1951a. All disappear in what appears to be the final "biomere"-style cratonic mass extinction on the Laurentian continent. Cratonic mass exinctions mark the top of the Marjuman, Steptoean, Sunwaptan, Skullrockian and Stairsian stages. Asaphids are completely absent from the Stairsian Stage, but with the appearance of *Aulacoparia* at the base of the Tulean, they again become dominant faunal elements. The apparently related genera *Psalikilus* and *Litzicurus* appear at the base of the Tulean, along with a third as yet unnamed taxon. By the lower Tulean *Hintzeia celsaora* Zone, *Psalikilus* is the only remaining member of this group.

As the abrupt extinction event coincides with a revised base for the Tulean, it is potentially correlatable across Laurentia even if individual species are not. Eastern Laurentian faunas such as those described by Boyce (1989) record very similar abrupt turnover, from Boyce's (1989, fig. 4) *Randaynia saundersi* Zone, which is dominated by hystricurines and hillyardines and is of similar generic aspect to the upper Stairsian in western Laurentia, to his *Strigigenalis brevicaudata* Zone, which features asaphids and bathyurids such as *Benthamaspis* and *Peltabellia* Whittington, 1953, closely comparable to western Laurentian Tulean faunas.

Ross *et al*. (1997) located all of their boundary stratotypes in the Ibex region of western Utah, where the rocks of the Pogonip Group are better exposed, more densely fossiliferous, and the succession more complete than in the Garden City Formation in southeastern Idaho. However, following from the discussion above, the level that is more appropriate as the base of a revised Tulean Stage is best represented in Idaho at Section HC6.

Hence we revise the Tulean Stage downward to the base of the *Litizicurus shawi* Zone, and designate a replacement boundary stratotype at HC6 142.0 m (Fig. 5). As noted above, *Aulacoparia* appears at 140.5 m, but the material is not identifiable to species level. It is possible that further work may refine the boundary further, but there are now only 5.5 m between the last pre-extinction Stairsian fauna and the first appearance of *Aulacoparia*, and only 7 m between it and the base of the Tulean as marked by the first

appearance of *Litizicurus shawi* sp. nov.

THE BASE OF THE BLACKHILLSIAN STAGE AND THE *TRIGONOCERCA TYPICA* PROBLEM

Ross *et al*. (1997, p. 19) established a stratotype for the base of the Blackhillsian Stage at the base of their *Trigonocerca typica* Zone, 5.8 m above the base of unit 2 of the informal member 5 of the Fillmore Formation at Section H, which corresponds to Hintze's (1953) sampling horizon H-15, or approximately H 163.3 m in the present study (our sampling horizon is about 1 m below Hintze's listed level). Although they stated in their text that this level corresponds to the beginning of the range of *T. typica*, both their range chart (Ross *et al*. 1997, pl. 1A) and Hintze's (1953, p. 35) faunal list give it instead as the beginning of the supposed range of *Dimeropygiella blanda* Hintze, 1953, with the first appearance of *T. typica* higher in the section at Hintze's sampling horizon H-16 (H 172.5 m in this study). In their text, Ross *et al*. (1997, p. 19) specifically considered that the beginning of the range of "*D. blanda*" was 8.8 m (29 ft) lower than that of *T. typica*. Hence, it appears that they intended to draw the base of the *T. typica* Zone at H 172.5 m, not at around H 163.3 m.

Regardless, the base of the stage is rendered problematic because the systematics of species of *Trigonocerca* Ross, 1951a, through the interval are more complicated than previously realised. The earliest known species of the genus (*Trigonocerca* sp. nov. 1 below) occurs in the Tulean *Heckethornia bowiei* Zone at H 127.1 m. The next highest species we have sampled is from H 182.6 m. Hintze (1953, p. 35) reported *T. typica* as common at his horizon H-16 (H 172.5 m). Our samples from the same horizon contain a common species of *Presbynileus* and a less common species of *Ptyocephalus*, but only a single fragmentary librigena that might represent *Trigonocerca*. The species at H 182.6 m is distinct from that at H 127.1 m.

At H 191.7 m, *Trigonocerca* is very common, and this is the horizon (Hintze's H-20) from which all of the material Hintze (1953, pl. 11, figs 6-11) illustrated as *T. typica* was derived. *Trigonocerca* is also common at H 208.2 m (Hintze's H-23) and was also identified at this horizon as *T. typica* by Hintze (1953) and Ross *et al*. (1997). Strangely, Hintze (1953, p. 34) indicated that the species was also common at H 222.1 m (his H-24). We have a very large sample from this horizon, and *Trigonocerca* does not occur within it. The genus is absent from all higher horizons.

Our new samples now reveal that the occurrences of *Trigonocerca* at H 182.6 m, H 191.7 m, and H 208.2 m, all of which have been identified by previous workers as *T. typica*, actually record three distinct species. In fact, the entire faunas of each of these horizons are in general distinct from each other and represent three separate zones in the new zonation below.

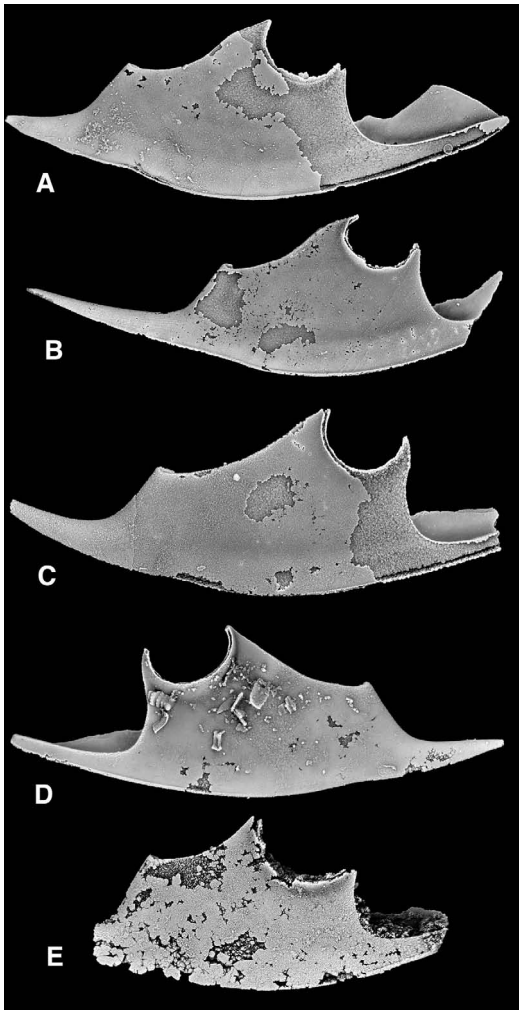


Fig. 6. Comparison of librigenae of three species of *Trigonocerca* from the critical interval near the base of the Blackhillsian Stage at Ibex Section H. All views are external. **A, B**, *Trigonocerca piochensis* Hintze, 1953, from the *Carolinites nevadensis* Zone at Section H 208.2 m. Note the relatively short, S-shaped posterior branch of the facial suture. **A**, SUI 116029, x3. **B**, SUI 116030, x3. **C, D**, *Trigonocerca* sp. nov. 2 from the *Strigigenalis plicolabeona* Zone at Section H 191.7 m. Note the much longer posterior branch of the facial suture that lacks a pronounced S shape. **C**, SUI 116031, x4. **D**, SUI 116032, x4.5. **E**, *Trigonocerca typica* Ross, 1951a, from the *Psalikilus pikum* Zone at H 182.6 m. Note the very short posterior branch of the facial suture. SUI 116033, x7.5.

As Hintze (1953, p. 238) recognised when he erected *T. piochensis*, differentiation of species of *Trigonocerca* is somewhat subtle due to the general lack of dorsal characters in these effaced trilobites. Nevertheless, the criteria he used to separate *T. piochensis* from the species at H 191.7 m (which he was using as exemplar of *T. typica*) are valid. *Trigonocerca piochensis* was based on material from Yellow Hill in eastern Nevada, where it is associated with *Carolinites nevadensis* Hintze, 1953. The fauna from H 208.2 m contains both of these species, and is assigned herein to the new *Carolinites nevadensis* Zone. The fauna at H 191.7 m contains a very different species of *Carolinites* Kobayashi, 1940, and, as recognised by Hintze, a species of *Trigonocerca* distinct from *T. piochensis*.

Complicating matters further is the fact that the type material of *T. typica* is not from Ibex, but rather from Ross's Locality 8 in the Garden City Formation at Clarkston Mountain, northern Utah. Ross (1951a) reported only one other trilobite from the type horizon, an unillustrated pliomerid not identified to species level. The type material of *T. typica* (Ross 1951a, pl. 26, figs 5-13) is a poor basis for comparison, as it includes only a few large, exfoliated pygidia with the median spine broken, two juvenile pygidia, a hypostome, and a single small cranidium and glued-on right librigena. Nevertheless, only one of the three Utah species seems likely to be conspecific with Ross's types.

Full taxonomic treatment of these three species is beyond the scope of this paper. However, given the significance of the distinctions for definition of the Blackhillsian Stage, some remarks on morphology are necessary. One of the most obvious characters which consistently differentiate the three species occurring in Section H is the length and shape of the posterior branch of the facial suture as revealed by the shape of the librigena in external view (Fig. 6). Librigenae of *T. piochensis* from H 208.2 m (Fig. 6A, B) have a consistently moderately long, but strongly S-shaped suture. Those of *Trigonocerca* sp. nov. 2 from H 191.7 m (Fig. 6C, D) have a uniformly much longer suture lacking any obvious S-shape. All librigenae of the species from H 182.6 m (Fig. 6E) have a much shorter suture than either of the two higher species. While Ross (1951a, pl. 26, figs 11-13) illustrated only one librigena of *T. typica*, it obviously has a very short posterior branch of the facial suture and is closest to and probably conspecific with the species at H 182.6 m.

One could therefore follow the criterion of Ross *et al*. (1997) for the base of the Blackhillsian, with these clarifications, and position it at the first (and only known) appearance of *T. typica* at H 182.6 m. A major problem with this, however, is that the assemblage at H 182.6 m is essentially the same as that at H 163.3 m through H 178.2 m, and at H 185.6 m, with common *Psalikilus pikum* Hintze, 1953. *Trigonocerca typica* is merely a late-appearing element of an already established fauna. Its first appearance does not mark a useful zonal boundary, let alone a stadial boundary.

A trilobite based stage boundary around this level is likely to be of limited utility no matter where it is located, since unlike most of the stage boundaries beneath it, it does not closely coincide with a significant mass extinction event. Rather, any level chosen will be one of many similar coordinated species turnovers within faunas of largely similar generic aspect. Despite this, a minor revision to the Blackhillsian results in a base that is in keeping with the spirit of that selected by Ross *et al*. (1997), in that the Tulean is punctuated by the end of the range of the ubiquitous genus *Psalikilus*.

This can be achieved by recognising the fauna shared by horizons H 163.3 m through H 185.6 m as one zone, the new *Psalikilus pikum* Zone, and the almost completely different fauna from H 186.2 m through H 197.1 m as another new zone, the *Strigigenalis plicolabeona* Zone, and by moving the stratotype for the base of the Blackhillsian up section to the base of the latter, as defined by the first appearance of the name bearer at H 186.2 m.

ZONATION

Conventions used in the following species lists and figures are as follows. Nameable new species awaiting description are identified as "sp. nov." with a number following. Species which are definitely new but which are currently not represented by a sufficient number of specimens for formal naming are identified as "sp. nov." with a letter following. Species which are distinct from others within a zone but which are represented by so few specimens that firm taxonomic conclusions cannot yet be drawn are identified as "sp." with a number following. For each genus, numbering or lettering in each category proceeds from the stratigraphically lowest species in order up section. An asterisk in front of a species in a list indicates that the species ranges up from the preceding zone.

Much taxonomic work remains to be done and the genus assignments in these lists should be regarded as provisional. With the many new species discovered, the genus-group distinctions between the asaphids *Aulacoparia* (*Aulacoparia*) Hintze & Jaanusson, 1956, and *Aulacoparia* (*Aulacoparina*) Hintze & Jaanusson, 1956, are no longer clear-cut and all of the Ibex species are referred for

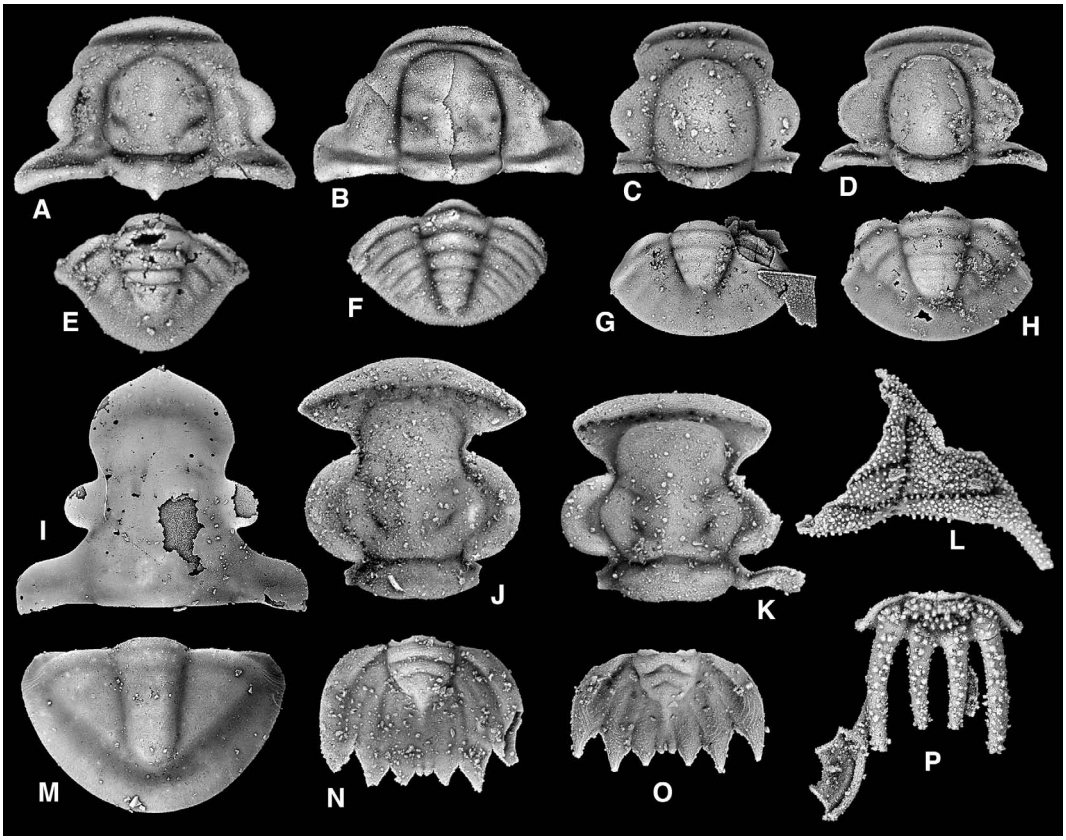


Fig. 7. Trilobites of the *Litzicurus shawi* Zone. All views are dorsal. **A, E**, *Psalikilus* sp. nov. 1. **A**, cranidium, SUI 115101, x7.5 (HC6 145T m). **E**, pygidium, SUI 115102, x10 (HC6 145T m). **B, F**, Hystricuridae gen. nov. 1 sp. nov. 1. **B**, cranidium, SUI 115103, x6 (HC6 142.0 m). **F**, pygidium, SUI 115104, x7.5 (HC6 142.0 m). **C**, **G**, *Peltabellia* sp. nov. 1. **C**, cranidium, SUI 115105, x7.5 (HC6 145T m). **G**, pygidium, SUI 115106, x6 (HC6 145T m). **D**, **H**, *Peltabellia* sp. nov. 2. **D**, cranidium, SUI 115107, x12 (HC6 142.0 m). **H**, pygidium, SUI 115108, x7.5 (HC6 142.0 m). **I**, **M**, *Aulacoparia* sp. nov. 1. **I**, cranidium, SUI 115109, x6 (HC6 142T m). **M**, pygidium, SUI 115110, x5 (HC6 142T m). **J**, **N**, *Menoparia* sp. nov. 1. **J**, cranidium, SUI 115111, x8 (HC6 145T m). **N**, pygidium, SUI 115112, x7.5 (HC6 145T m). **K**, **O**, *Menoparia* sp. nov. 2. **K**, cranidium, SUI 115113, x9 (HC6 145T m). **O**, pygidium, SUI 115114, x12 (HC6 145T m). **L**, **P**, Cheiruridae gen. nov. 1 sp. nov. 1. **L**, cranidium, SUI 115115, x7.5 (HC6 142.0 m). **P**, pygidium, SUI 115116, x10 (HC6 142.0 m; attached is a small cheek belonging to *Litzicurus shawi* sp. nov.). See Figs 25-31 for illustrations of the zonal name bearer, *Litzicurus shawi*.

the present to an undivided *Aulacoparia*. The bathyurid *Peltabellia* was discussed by Adrain & Westrop (2005). Multiple new species are assigned to it herein for convenience, but the group is almost certainly paraphyletic and will be subject to revision when formally studied. The status of *Licnocephala* Ross, 1951a, is probably the same. Most new remopleuridid species are assigned to *Menoparia* Ross, 1951a, pending detailed study. Many species are assigned herein to *Benthamaspis*, but work in progress suggests that three distinct clades, two of which are currently unnamed, may ultimately be recognised within this group.

It is obviously not possible to justify at length the many new species indicated in the lists and figures in the space available, and this is deferred to forthcoming detailed taxonomic works. With only single dorsal views of cranidia and sometimes pygidia illustrated, differences between some taxa may not be readily apparent. *Benthamaspis* sp. nov. 1 (Fig. 9J, N) and *Benthamaspis* sp. nov. 3 (Fig. 10M, R), for example, appear very similar in the views provided. It is emphasised that abundant material is available for each taxon identified as new, and multiple characters which unambiguously separate them have been recorded. In the case of the *Benthamaspis* species noted above, the species have anterior borders of completely different shape and much different

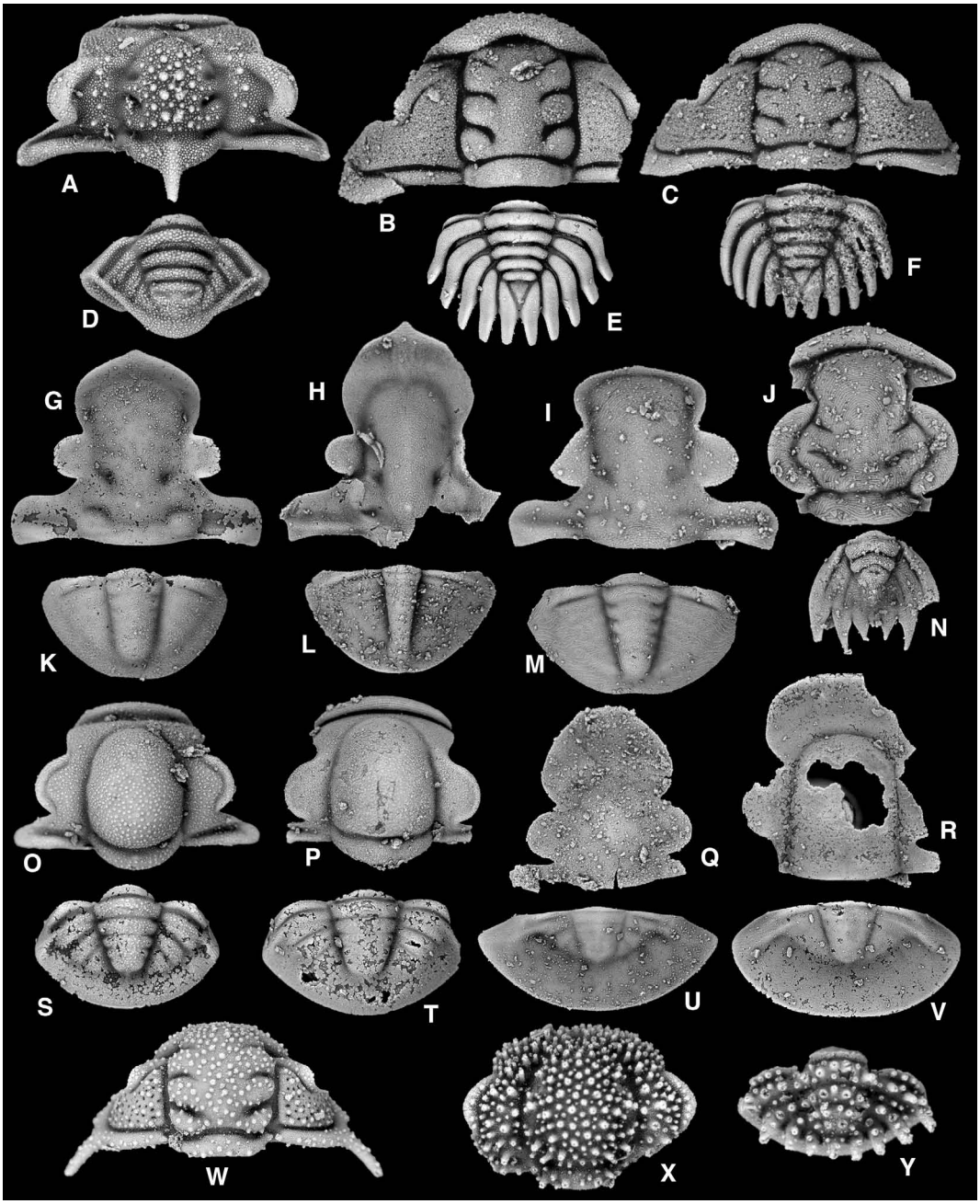


Fig. 8. Trilobites of the *Psalikilus spinosum* Zone. All views are dorsal. **A**, **D**, *Psalikilus spinosum* Hintze, 1953. **A**, cranidium, SUI 115117, x10 (G 99T-A m). **D**, pygidium, SUI 115118, x10 (G 99-T-A m). **B**, **E**, *Hintzeia firmimarginis* (Hintze, 1953). **B**, cranidium, SUI 115119, x7.5 (G 99.3 m). **E**, pygidium, SUI 115120, x4 (G 99T-A m). **C**, **F**, *Hintzeia* sp. nov. 1. **C**, cranidium, SUI 115121, x12 (HC6 165.2 m). **F**, pygidium, SUI 115122, x6 (HC6 165.2 m). **G**, **K**, *Aulacoparia* sp. nov. 3. **G**, cranidium, SUI 115123, x4 (G 99.3 m). **K**, pygidium, SUI 115124, x6 (G 99.3 m). **H**, **L**, *Aulacoparia* sp. nov. 4. **H**, cranidium, SUI 115125, x12 (HC6 165.2 m). **L**, pygidium, SUI 115126, x5 (HC6 165.2 m). **I**, **M**, *Aulacoparia* sp. nov. 5. **I**, cranidium, SUI 115127, x10 (HC6 165.2 m). **M**, pygidium, SUI 115128, x5 (HC6 165.2 m). **J**, **N**, *Menoparia* sp. nov. 3. **J**, cranidium, SUI 115129, x6 (HC6 165.2 m). **N**, pygidium, SUI 115130, x6 (HC6 165.2 m). **O**, **S**, *Peltabellia* sp. nov. 3. **O**, cranidium, SUI 115131, x7.5 (G 99.3 m). **S**, pygidium, SUI 115132, x7.5 (G 99T-A m). **P**, **T**, *Peltabellia* sp. nov. 4. **P**, cranidium, SUI 115133, x6 (G 99.3 m). **T**, pygidium, SUI 115134, x7.5 (G 99T-A m). **Q**, **U**, *Licnocephala* sp. nov. 1. **Q**, cranidium, SUI 115135, x7.5 (HC6 165.2 m). *(continued opposite)*

relative widths (this can be seen to some extent in dorsal view, as the anterior sections of the facial suture of *Benthamaspis* sp. nov. 1 [Fig. 9J] are more nearly subparallel than those of *Benthamaspsis* sp. nov. 3 [Fig. 10M], which are more strongly anteriorly convergent due to a much narrower anterior border). There are multiple other characters which also pervasively differentiate the species, although they are obviously closely related. This is true of all such comparisons which can be made throughout the figures.

1. *Litzicurus shawi* Zone (new) (Fig. 7)

Horizons. HC6 142.0 m, 145T m. Possibly represented in the interval G 61.4-68.9 m.

Species.
Asaphidae
- *Aulacoparia* sp. nov. 1 (Fig. 7I, M)
- *Aulacoparia* sp. nov. 2

Bathyuridae
- *Licnocephala* sp. 1
- *Peltabellia* sp. nov. 1 (Fig. 7C, G)
- *Peltabellia* sp. nov. 2 (Fig. 7D, H)

Cheiruridae
- Cheiruridae gen. nov. 1 sp. nov. 1 (Fig. 7L, P)

Hystricuridae
- Hystricuridae gen. nov. sp. nov. 1 (Fig. 7B, F)
- *Litzicurus shawi* gen. et sp. nov. (Figs 25-31
- *Psalikilus* sp. nov. 1 (Fig. 7A, E)

Leiostegiidae
- *Leiostegium* sp. 1

Remopleurididae
- *Menoparia* sp. nov. 1 (Fig. 7J, N)
- *Menoparia* sp. nov. 2 (Fig. 7K, O)
- *Menoparia* sp. nov. A

Remarks. The boundary stratotype for the base of the *Litzicurus shawi* Zone is the same as that for the revised Tulean Stage, discussed above, and placed at Section HC6 142.0 m at the first appearance of the name bearer. Its top is defined by the base of the overlying *Psalikilus spinosum* Zone, which at HC6 is drawn at 165.2 m.

The assemblages from HC6 142.0 m and HC6 145T m are quite different. Definitely shared between them are the species *Litzicurus shawi* sp. nov. (as documented in the Systematic Palaeontology section below), a second new genus and species, and two new species of *Peltabellia*. A new species of *Psalikilus* is quite common at HC6 145T m, but only a single librigena is known from HC6 142.0 m. It has a shorter genal spine and may not be conspecific. Species of a new genus of cheirurid, of *Licnocephala*, and of *Leiostegium* Raymond, 1913, have only been found at HC6 142.0 m. The species of *Aulacoparia* and *Menoparia* are clearly distinct between the horizons. Whether these differences have any biostratigraphic significance is unknown.

Ross (1951a) apparently missed these rich horizons in his sampling of the section. As discussed below, the lowest post-Stairsian trilobites he found (his "Zone G(1)") at HC6 were almost certainly from horizons HC6 165.2-171.0 m. We found no fossiliferous horizons between 145T m and 165.2 m.

At Ibex, the equivalent of the *Litzicurus shawi* Zone occurs within a poorly fossiliferous interval. At Section G this interval ranges from the last rich Stairsian fauna at 48.5 m to beds representing the *Psalikilus spinosum* Zone at 94.5T m, 97T m, 99T m and 99.3 m. This interval is on a long dip slope and is partially covered. Horizons yielding silicified fossils occur at 61.4 m, 67.4T m and 68.9 m. These are all fairly rich in very fragmentary specimens of *Aulacoparia*. Hintze (1953, pl. 16, fig. 12) illustrated a partial librigena from his horizon G-7 (194', approximately 65 m in our measurements) which is typical of the state of preservation. Hence, the equivalent of the *Litzicurus shawi* Zone and the lowest evidence for the base of the redefined Tulean Stage occurs at G 61.4 m, leaving a 12.9 m interval within which the end-Stairsian extinction is located.

One of many indications that yet more diversity and distinct faunas remain to be discovered is a small sample from G 72.5T m. Trilobites are not well preserved, but the fauna is dominated by two common species of *Aulacoparia*, each of which is clearly new. Hence, there may be at least one additional distinct assemblage lying between the *Litzicurus shawi* and *Psalikilus spinosum* Zones. Alternatively, the sample may also represent the *Litzicurus shawi* interval, and as in several younger cases the asaphid species at Ibex may be differentiated from approximately coeval species occurring in the Garden City Formation.

Because it has not previously been sampled, all of the species occurring in the *Litzicurus shawi* Zone are new. Individual samples are of relatively low diversity (10 spp. at HC6 142.0 m; 8 spp. at HC6 145T m) compared to those of succeeding

U, pygidium, SUI 115136, x5 (HC6 165.2 m). **R**, **V**, *Licnocephala* sp. nov. 2. **R**, cranidium, SUI 115137, x6 (G 99.3 m). **V**, pygidium, SUI 115138, x5 (G 99T-A m). **W**, Cheiruridae gen. nov. 1 sp. nov. 2, cranidium, SUI 115139, x10 (G 99T-A m). **X**, **Y**, Dimeropygidae gen. nov. sp. nov. 1. **X**, cranidium, SUI 115140, x10 (G 99T-A m). **Y**, pygidium, SUI 115141, x12 (G 99T-A m).

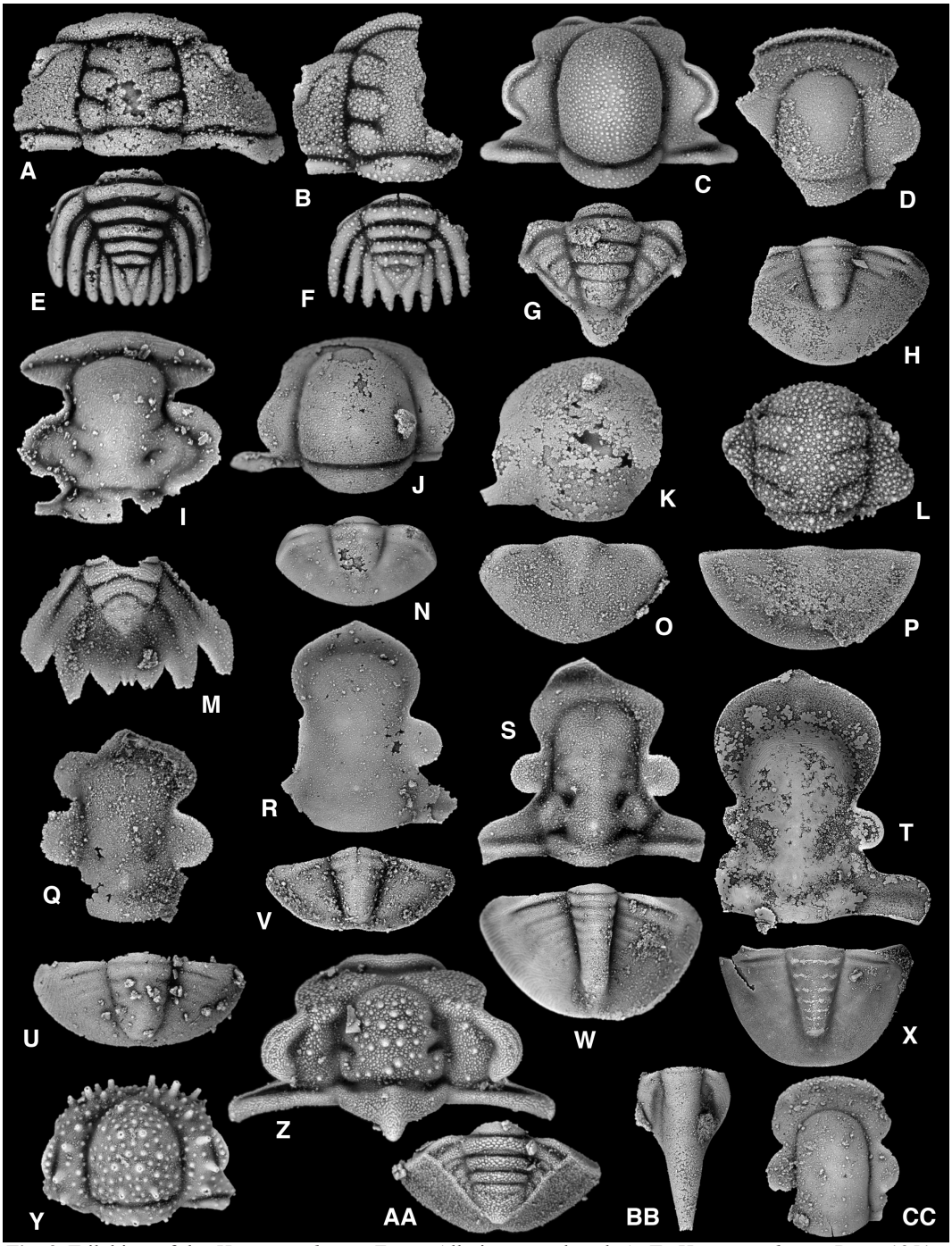


Fig. 9. Trilobites of the *Hintzeia celsaora* Zone. All views are dorsal. **A**, **E**, *Hintzeia celsaora* Ross, 1951a. **A**, cranidium, SUI 115142, x6 (G 118.6 m). **E**, pygidium, SUI 115143, x6 (G 118.6 m). **B**, **F**, Pliomeridae gen. nov. sp. nov. 1. **B**, cranidium, SUI 115144, x7.5 (HC5 186.5 m). **F**, pygidium, SUI 115145, x10 (HC5 186.5 m). **C**, **G**, *Psalikilopsis* sp. nov. 1. **C**, cranidium, SUI 115146, x6 (HC5 186.5 m). **G**, pygidium, SUI 115147, x6 (HC5 186.5 m). **D**, **H**, *Peltabellia* sp. nov. 5. **D**, cranidium, SUI 115148, x8 (HC5 186.5 m). **H**, pygidium, SUI 115149, x5 (HC5 186.5 m). **I**, **M**, *Menoparia* sp. nov. 5. **I**, cranidium, SUI 115150, x10 (D 193.6T m). **M**, pygidium, SUI 115151, x7.5 (HC5 186.5 m). **J**, **N**, *Benthamaspis* sp. nov. 1. **J**, cranidium, SUI 115152, x7.5 (HC5 186.5 m). **N**, pygidium, SUI 115153, x7.5 (HC5 186.5 m). **K**, **O**, *Benthamaspis* sp. nov. 2. **K**, cranidium, SUI 115154, x7.5 (HC5 186.5 m). **O**, pygidium, SUI 115155, x7.5 (HC5 186.5 m). *(continued opposite)*

zones and are strongly numerically dominated by *L. shawi* and species of *Aulacoparia*.

2. *Psalikilus spinosum* Zone (new) (Fig. 8)

Horizons. HC6 165.2 m. G 94.5T m, 97T m, 99.3 m, 99T m. D 31.2 m, 34.4 m, 37.7 m.

Species.
Asaphidae
- *Aulacoparia* sp.
- *Aulacoparia* sp. nov. 3 (Fig. 8G, K)
- *Aulacoparia* sp. nov. 4 (Fig. 8H, L)
- *Aulacoparia* sp. nov. 5 (Fig. 8I, M)
- *Protopresbynileus* sp. 1

Bathyuridae
- *Licnocephala* sp. nov. 1 (Fig. 8Q, U)
- *Licnocephala* sp. nov. 2 (Fig. 8R, V)
- *Peltabellia* sp. nov. 3 (Fig. 8O, S)
- *Peltabellia* sp. nov. 4 (Fig. 8P, T)
- *Peltabellia* sp. nov. A

Cheiruridae
- Cheiruridae gen. nov. 1 sp. nov. 2 (Fig. 8W)

Dimeropygidae
- Dimeropygidae gen. nov. sp. nov. 1 (Fig. 8X, Y)

Hystricuridae
- *Litzicurus orbus* (Ross, 1953)
- *Psalikilus spinosum* Hintze, 1953 (Fig. 8A, D)

Pliomeridae
- *Hintzeia firmimarginis* (Hintze, 1953) (Fig. 8B, E)
- *Hintzeia* sp. nov. 1 (Fig. 8C, F)

Remopleurididae
- *Menoparia* sp. nov. 3 (Fig. 8J, N)
- *Menoparia* sp. nov. 4

Remarks. The *Psalikilus spinosum* Zone occupies the lower part of what Ross *et al*. (1997) termed their *Hintzeia celsaora* Zone, which was equivalent to Ross's original Zone G(1). *Hintzeia celsaora* occurs both in the Garden City Formation and at Ibex, where *H. aemula* Hintze, 1953, is a subjective junior synonym as correctly determined by Demeter (1973, p. 58). However, as discussed above, *H. celsaora* has a much more restricted stratigraphic range than that claimed by Ross *et al*. (1997). At Ibex Section G, it is known from a single horizon, G 118.6 m. Similarly, in the Garden City Formation, we have sampled it only from HC6 171.0 m. Faunas recovered from the interval between the distinctive *Litzicurus shawi* Zone and the appearance of *H. celsaora* represent a second new assemblage, here termed the *Psalikilus spinosum* Zone. No species occurring in this zone are shared with either the underlying or overlying zones. The basal boundary stratotype of the *Psalikilus spinosum* Zone is drawn at Ibex Section G 94.5T m at the first appearance (in samples derived from along-strike talus blocks weathering in place) of *Psalikilus spinosum* Hintze, 1953. Its top is at the base of the overlying *H. celsaora* Zone at G 118.6 m. In the Garden City Formation, the zone is known from a single rich horizon at HC6 165.2 m. The name bearer, along with species of *Licnocephala* and *Menoparia*, seems definitely to be shared between the regions. Species of *Hintzeia* and *Aulacoparia*, however, are unique to either region.

3. *Hintzeia celsaora* Zone (restricted) (Fig. 9)

Horizons. HC5 186.5 m. HC6 171.0 m. G 118.6 m. D 59T m.

Species.
Asaphidae
- *Aulacoparia* sp. nov. 6 (Fig. 9Q, U)
- *Aulacoparia* sp. nov. 7 (Fig. 9R, V)
- *Aulacoparia* sp. nov. 8 (Fig. 9S, W)
- *Aulacoparia quadrata* (Hintze, 1953) (Fig. 9T, X)

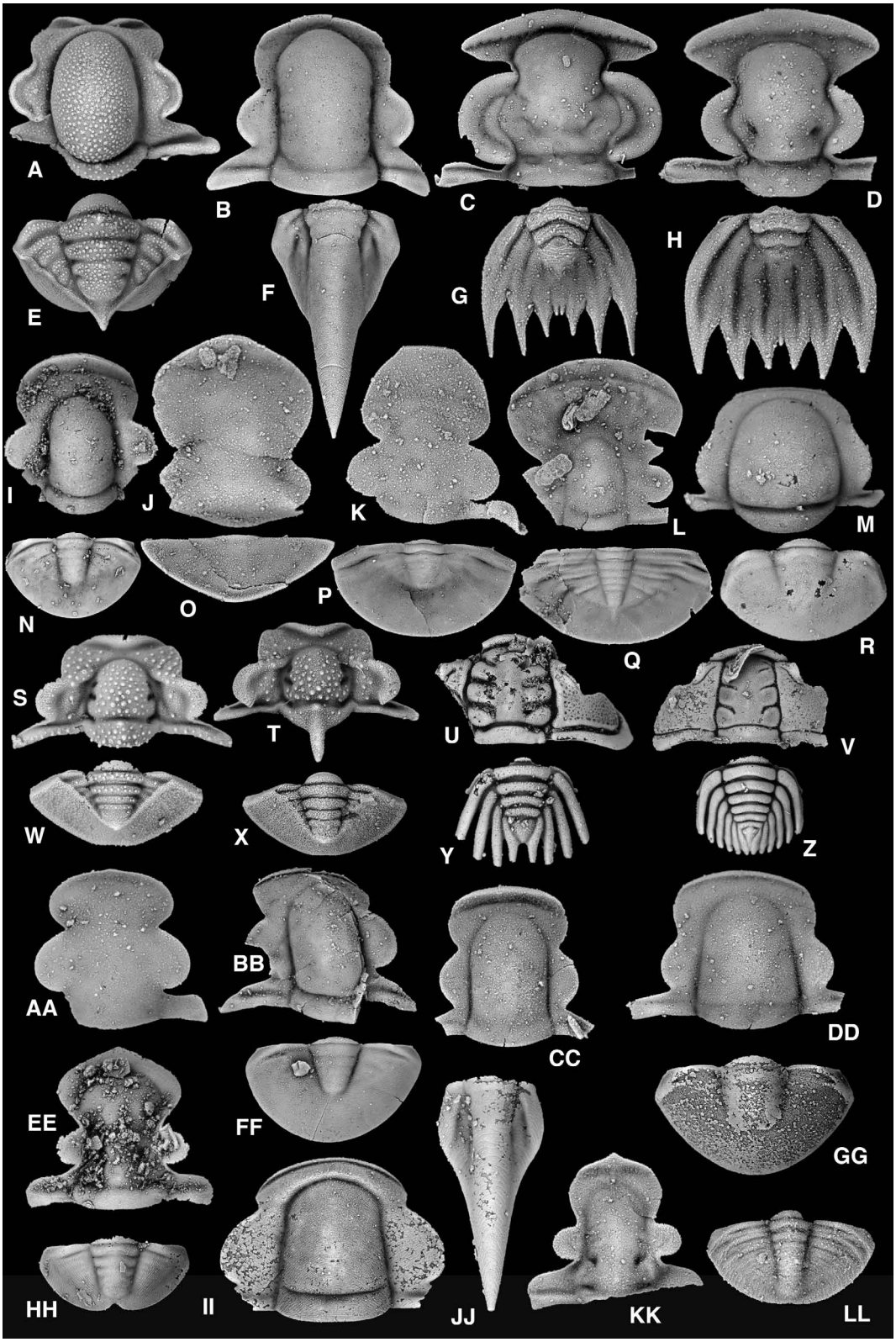
Bathyuridae
- Bathyuridae gen. nov. 1 sp. nov. A (Fig. 9P)
- *Benthamaspis* sp. nov. 1 (Fig. 9J, N)
- *Benthamaspis* sp. nov. 2 (Fig. 9K, O)
- *Gladiatoria* sp. nov. 1 (Fig. 9BB, CC)
- *Peltabellia* sp. nov. 5 (Fig. 9D, H)
- *Psalikilopsis* sp. nov. 1 (Fig. 9C, G)

Cheiruridae
- Cheiruridae gen. nov. 1 sp. nov. A (Fig. 9L)

Dimeropygidae
- Dimeropygidae gen. nov. sp. nov. 2 (Fig. 9Y)

Hystricuridae
- *Psalikilus paraspinosum* Hintze, 1953 (Fig.

L, Cheiruridae gen. nov. 1 sp. nov. A, cranidium, SUI 115156, x10 (HC5 186.5 m). **P**, Bathyuridae gen. nov. 1 sp. nov. A, pygidium, SUI 115157, x7.5 (HC5 186.5 m). **Q**, **U**, *Aulacoparia* sp. nov. 6. **Q**, cranidium, SUI 115158, x10 (G 118.6 m). **U**, pygidium, SUI 115159, x7.5 (G 118.6 m). **R**, **V**, *Aulacoparia* sp. nov. 7. **R**, cranidium, SUI 115160, x7.5 (HC5 186.5 m). **V**, pygidium, SUI 115161, x7.5 (HC6 171.0 m). **S**, **W**, *Aulacoparia* sp. nov. 8. **S**, cranidium, SUI 115162, x7.5 (HC6 171.0 m). **W**, pygidium, SUI 115163, x5 (HC6 171.0 m). **T**, **X**, *Aulacoparia quadrata* (Hintze, 1953). **T**, cranidium, SUI 115164, x3 (D 193.6T m). **X**, pygidium, SUI 115165, x1.5 (D 193.6 m). **Y**, Dimeropygidae gen. nov. sp. nov. 2, cranidium, SUI 115166, x8 (HC5 186.5 m). **Z**, **AA**, *Psalikilus paraspinosum* Hintze, 1953. **Z**, cranidium, SUI 115167, x12 (G 118.6 m). **AA**, pygidium, SUI 115168, x12 (G 118.6 m). **BB**, **CC**, *Gladiatoria* sp. nov. 1. **BB**, pygidium, SUI 115169, x6 (HC5 186.5 m). **CC**, cranidium, SUI 115170, x7.5 (HC5 186.5 m).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9Z, AA)
Pliomeridae
Hintzeia celsaora (Ross, 1951a) [=*H. aemula* (Hintze, 1953)] (Fig. 9A, E)
Pliomeridae gen. nov. sp. nov. 1 (Fig. 9B, F)
Remopleurididae
Menoparia sp. nov. 5 (Fig. 9I, M)

Remarks. *Hintzeia celsaora* Ross, 1951a, effectively has no stratigraphic range, as it is known from a single horizon in each of four sections, two in the Bear River Range, and two at Ibex. The fauna occurring at these horizons is unique, with no species shared with the underlying or overlying zones. It is referred to a restricted *Hintzeia celsaora* Zone. The stratotype for the base of the zone is Section HC6 171.0 m and its top is the base of the overlying *Psalikilopsis cuspicaudata* Zone which at HC6 is drawn at 189.3 m. Apart from the name bearer, the only other species of this zone which have been named are *Aulacoparia quadrata* (Hintze, 1953) and *Psalikilus paraspinosum* Hintze, 1953.

4. *Psalikilopsis cuspicaudata* Zone (new) (Fig. 10)

Horizons. HC5 195.7, 203.7-204.2 m. HC6 189.3 m. G 155.6, 162T m. D 88.9, 90.7, 106.4 m. YH-E, YH-F.

Species.
Asaphidae
**Aulacoparia* sp. nov. 8 (Fig. 10KK, LL)
Aulacoparia venta (Hintze, 1953) (Fig. 10EE, HH)
Protopresbynileus sp. 2 (Fig. 10AA)
Bathyuridae
Bathyuridae gen. nov. 1 sp. nov. 1 (Fig. 10J, O)
Benthamaspis sp. nov. 3 (Fig. 10M, R)
Benthamaspis sp. nov. 4 (Fig. 10DD, GG)
Benthamaspis sp. nov. 5 (Fig. 10II)
Gladiatoria gladiator (Ross, 1951a) (Fig. 10B, F)
Gladiatoria sp. nov. 2 (Fig. 10CC, JJ)
Licnocephala bicornuta Ross, 1951a (Fig. 10L, Q)
Licnocephala sp. nov. 3 (Fig. 10K, P)
Peltabellia sp. nov. 6 (Fig. 10I, N)
Peltabellia sp. nov. 7 (Fig. 10BB, FF)
Psalikilopsis cuspicaudata Ross, 1953 (Fig. 10A, E)
Cheiruridae
Cheiruridae gen. nov. 1 sp. nov. B
Dimeropygidae
Dimeropygidae gen. nov. sp. nov. 3
Dimeropygidae gen. nov.? sp. nov. A
Hystricuridae
Psalikilus sp. nov. 2 (Fig. 10S, W)
Psalikilus sp. nov. 3 (Fig. 10T, X)
Psalikilus sp. nov. 4
Psalikilus sp. nov. 5
Leiostegiidae
Leiostegium sp. 2
Pliomeridae
Pliomeridae gen. nov. *quattuor* (Hintze, 1953) (Fig. 10U, Y)

Fig. 10. Trilobites of the *Psalikilopsis cuspicaudata* Zone. All views are dorsal. **A**, **E**, *Psalikilopsis cuspicaudata* Ross, 1953. **A**, cranidium, SUI 115171, x6 (HC5 195.7 m). **E**, pygidium, SUI 115172, x5 (HC6 189.3 m). **B**, **F**, *Gladiatoria gladiator* (Ross, 1951a). **B**, cranidium, SUI 115173, x6 (HC5 195.7 m). **F**, pygidium, SUI 115174, x5 (HC5 195.7 m). **C**, **G**, *Menoparia genalunata* Ross, 1951a. **C**, cranidium, SUI 115175, x10 (HC5 195.7 m). **G**, pygidium, SUI 115176, x10 (HC6 189.3 m). **D**, **H**, *Scinocephalus solitecti* Ross, 1951a. **D**, cranidium, SUI 115177, x10 (HC6 189.3 m). **H**, pygidium, SUI 115178, x10 (HC6 189.3 m). **I**, **N**, *Peltabellia* sp. nov 6. **I**, cranidium, SUI 115179, x6 (G 162T m). **N**, pygidium, SUI 115180, x3 (G 162T m). **J**, **O**, Bathyuridae gen. nov. 1 sp. nov. 1. **J**, cranidium, SUI 115181, x10 (HC5 195.7 m). **O**, pygidium, SUI 115182, x6 (HC5 195.7 m). **K**, **P**, *Licnocephala* sp. nov. 3. **K**, cranidium, SUI 115183, x7.5 (HC5 195.7 m). **P**, pygidium, SUI 115184, x6 (HC6 189.3 m). **L**, **Q**, *Licnocephala bicornuta* Ross, 1951a. **L**, cranidium, SUI 115185, x7.5 (HC5 195.7 m). **Q**, pygidium, SUI 115186, x6 (HC6 189.3 m). **M**, **R**, *Benthamaspis* sp. nov. 3. **M**, cranidium, SUI 115187, x10 (G 162T m). **R**, pygidium, SUI 115188, x7.5 (G 162T m). **S**, **W**, *Psalikilus* sp. nov. 2. **S**, cranidium, SUI 115189, x10 (G 162T m). **W**, pygidium, SUI 115190, x7.5 (G 162T m). **T**, **X**, *Psalikilus* sp. nov. 3. **T**, cranidium, SUI 115191, x6 (HC5 195.7 m). **X**, pygidium, SUI 115192, x6 (HC6 189.3 m). **U**, **Y**, Pliomeridae gen. nov. *quattuor* (Hintze, 1953). **U**, cranidium, SUI 115193, x3 (G 162T m). **Y**, pygidium, SUI 115194, x7.5 (G 162T m). **V**, **Z**, *Protopliomerella* sp. nov. 1. **V**, cranidium, SUI 115195, x4 (G 162T m). **Z**, pygidium, SUI 115196, x6 (G 162T m). **AA**, *Protopresbynileus* sp. 2, cranidium, SUI 115197, x10 (HC6 189.3 m). **BB**, **FF**, *Peltabellia* sp. nov. 7. **BB**, cranidium, SUI 115198, x6 (HC5 195.7 m). **FF**, pygidium, SUI 115199, x4 (HC6 189.3 m). **CC**, **JJ**, *Gladiatoria* sp. nov. 2. **CC**, cranidium, SUI 115200, x7.5 (HC5 195.7 m). **JJ**, pygidium, SUI 115201, x6 (G 162T m). **DD**, **GG**, *Benthamaspis* sp. nov. 4. **DD**, cranidium, SUI 115202, x7.5 (HC5 195.7 m). **GG**, pygidium, SUI 115203, x7.5 (D 241.7 m). **EE**, **HH**, *Aulacoparia venta* (Hintze, 1953). **EE**, cranidium, SUI 115204, x5 (G 162T m). **HH**, pygidium, SUI 115205, x4 (G 162T m). **II**, *Benthamaspis* sp. nov. 5, cranidium, SUI 115206, x5 (D 241.7 m). **KK**, **LL**, *Aulacoparia* sp. nov. 8. **KK**, cranidium, SUI 115207, x7.5 (HC5 195.7 m). **LL**, pygidium, SUI 115208, x7.5 (HC5 195.7 m).

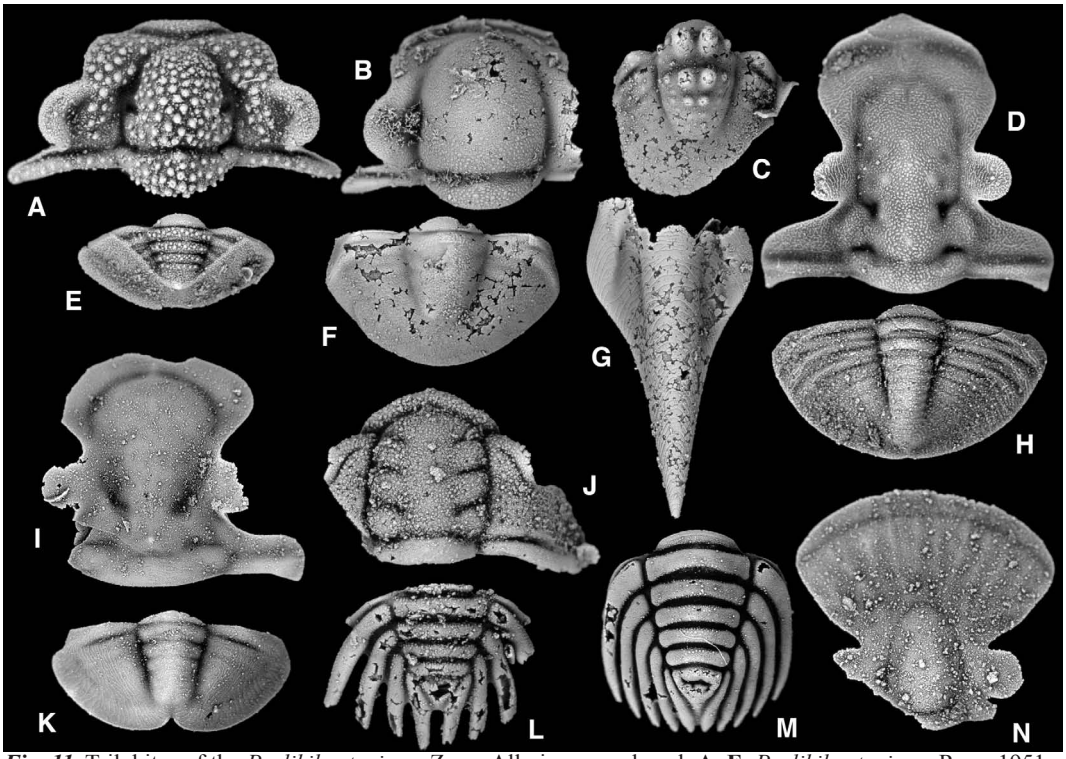


Fig. 11. Trilobites of the *Psalikilus typicum* Zone. All views are dorsal. **A**, **E**, *Psalikilus typicum* Ross, 1951a. **A**, cranidium, SUI 115209, x10 (HC6 203.5 m). **E**, pygidium, SUI 115210, x7.5 (HC6 203.5 m). **B**, **F**, *Benthamaspis* sp. nov. 6. **B**, cranidium, SUI 115211, x7.5 (G 174.0 m). **F**, pygidium, SUI 115212, x6 (G 174.0 m). **C**, *Gelasinocephalus* sp. nov. A, pygidium, SUI 115213, x5 (G 174.0 m). **D**, **H**, *Aulacoparia* sp. nov. 8. **D**, cranidium, SUI 115214, x7.5 (HC6 203.5 m). **H**, pygidium, SUI 115215, x10 (HC6 203.5 m). **G**, *Gladiatoria* sp. nov. 2, pygidium, SUI 115216, x6 (G 174.0 m). **I, K**, *Aulacoparia venta* (Hintze, 1953). **I**, cranidium, SUI 115217, x6 (HC6 203.5 m). **K**, pygidium, SUI 115218, x7.5 (HC6 203.5 m). **J**, **L**, Pliomeridae gen. nov. *quattuor* (Hintze, 1953). **J**, cranidium, SUI 115219, x7.5 (G 174.0 m). **L**, pygidium, SUI 115220, x6 (G 174.0 m). **M**, *Protopliomerella* sp. nov. 2, pygidium, SUI 115221, x6 (HC6 203.5 m). **N**, *Licnocephala* sp. nov. A, cranidium, SUI 115222, x7.5 (HC6 203.5 m).

Protopliomerella sp. nov. 1 (Fig. 10V, Z)
Remopleurididae
Menoparia genalunata Ross, 1951a (Fig. 10C, G)
Scinocephalus solitecti Ross, 1951a (Fig. 10D, H)
Telephinidae
Opipeuterella sp. 1
Opipeuterella sp. 2

Remarks. The fauna of the *Hintzeia celsaora* Zone is abruptly replaced both at Ibex and in the Bear River Range by a new assemblage of almost entirely different species. Only a single species, *Aulacoparia* sp. nov. 8, apparently ranges through (cf. Figs 9S, W, 10KK, LL). This new assemblage occurs through a narrow stratigraphic interval in every relevant section in southeastern Idaho, western Utah, and eastern Nevada, and is assigned to the new *Psalikilopsis cuspicaudata* Zone. The name bearer is a very distinctive bathyurid trilobite (Fig. 10A, E) which is restricted to the zone and common at every horizon assigned to it. Only one other species of *Psalikilopsis* has been found; an undescribed taxon (Fig. 9C, G) from the underlying *H. celsaora* Zone. Pygidial morphology of the species is very different and there is no chance of confusing them, given an adequate sample. The boundary stratotype for the base of the *Psalikilopsis cuspicaudata* Zone is the first appearance of the name bearer at Ibex Section G 155.6 m and its top is defined by the base of the overlying *Psalikilus typicum* Zone at G 174.0 m.

5. *Psalikilus typicum* Zone (new) (Fig. 11)

Horizons. G 174.0 m. HC6 202T, 203.0 m, 203.5 m.

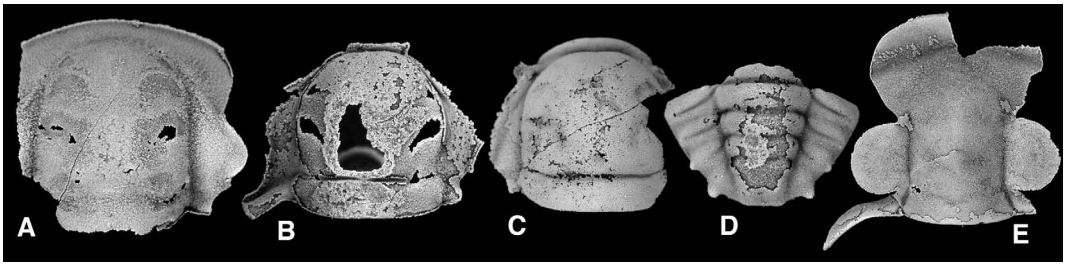


Fig. 12. Trilobites of the *Psalikilus hestoni* Zone. All views are dorsal, and all specimens are from HC6 205.5 m. **A**, *Benthamaspis* sp. nov. A, cranidium, SUI 115223, x5. **B**, *Opipeuterella* sp. nov. A, cranidium, SUI 115224, x6. **C**, **D**, *Opipeuterella* sp. nov. 1. **C**, cranidium, SUI 115225, x6. **D**, pygidium, SUI 115226, x6. **E**, *Licnocephala* sp. nov. 4, cranidium, SUI 115227, x4. See Figs 22-24 for illustrations of the zonal name bearer, *Psalikilus hestoni*.

Species.
Asaphidae
**Aulacoparia venta* (Hintze, 1953) (Fig. 11I, K)
**Aulacoparia* sp. nov. 8 (Fig. 11D, H)
Bathyuridae
**Benthamaspis* sp. nov. 3
**Benthamaspis* sp. nov. 4
Benthamaspis sp. nov. 6 (Fig. 11B, F)
Gelasinocephalus sp. nov. A (Fig. 11C)
**Gladiatoria* sp. nov. 2 (Fig. 11G)
Licnocephala sp. nov. A (Fig. 11N)
**Peltabellia* sp. nov. 6
Cheiruridae
Cheiruridae gen. nov. 1 sp. nov. C
Hystricuridae
Psalikilus typicum Ross, 1951a (Fig. 11A, E)
Pliomeridae
**Pliomeridae gen. nov. *quattuor* (Hintze, 1953) (Fig. 11J, L)
Protopliomerella sp. nov. 2 (Fig. 11M)

Remarks. As is obvious from the faunal list above, of all the zones recognised herein the *Psalikilus typicum* Zone has the most species ranging through from the underlying zone. Nevertheless, *Psalikilopsis cuspicaudata* does not range through, nor do any of the four species of *Psalikilus* which occur in the *P. cuspicaudata* Zone. Instead, *Psalikilus typicum* Ross, 1951a, is present. This faunal succession can be recognised both at Ibex and in the Bear River Range. Given this biostratigraphic value, a new *Psalikilus typicum* Zone is recognised with a boundary stratotype for its base drawn at the first appearance of the name bearer at Ibex Section G 174.0 m. Its top is the base of the overlying *Psalikilus hestoni* Zone which has not been found in Section G, where no fossiliferous horizons have been found between G 174.0 m and the base of the *Protopliomerella contracta* Zone at G 210.2 m. At Section HC6 in the Bear River Range, the base of the *P. typicum* Zone is at HC6 203.0 m and the top is the base of the *P. hestoni* Zone at HC6 205.5 m.

6. *Psalikilus hestoni* Zone (new) (Fig. 12)

Horizons. HC6 205.5 m.

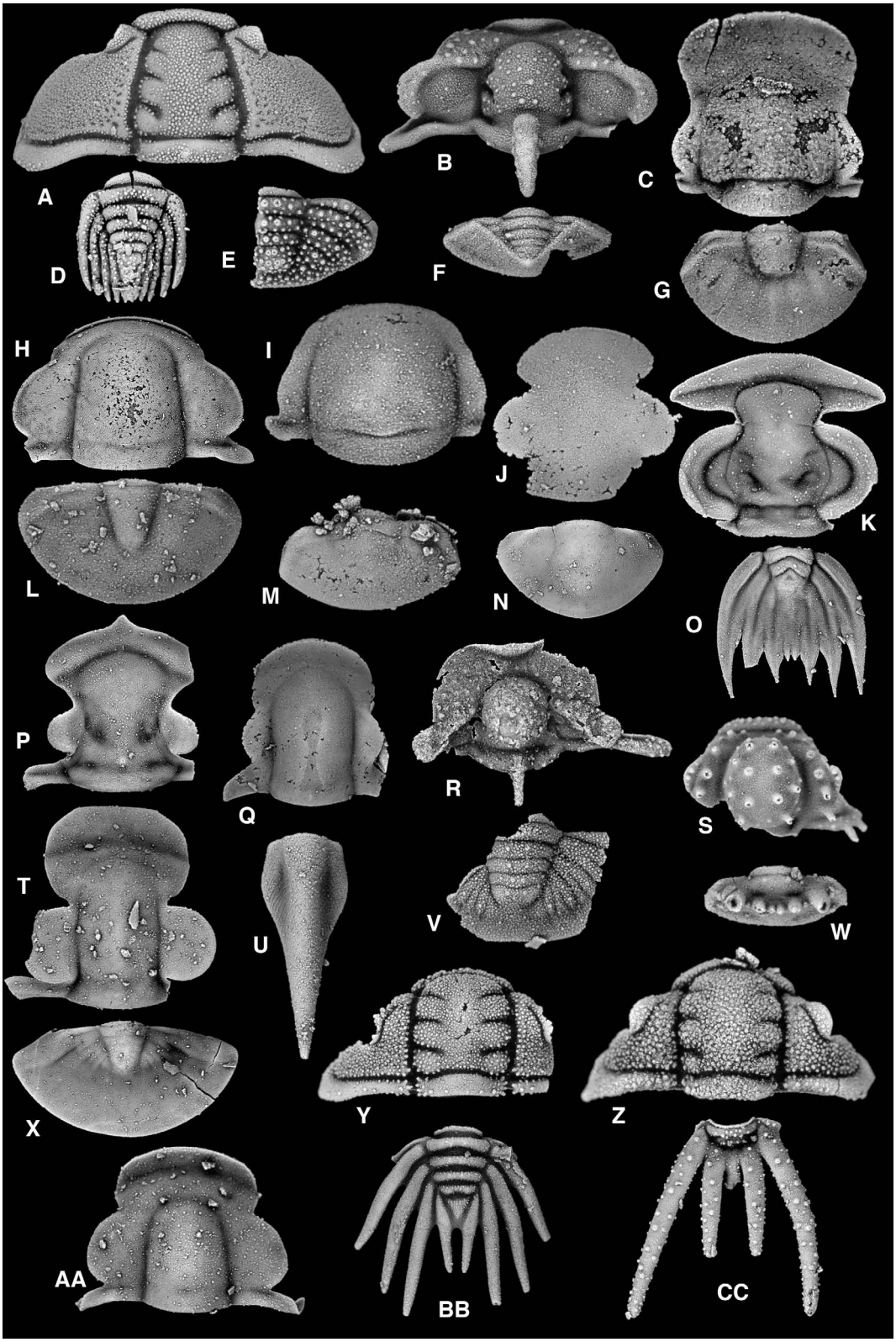
Species.
Bathyuridae
Benthamaspis sp. nov. A (Fig. 12A)
Gladiatoria sp. 1
Licnocephala sp. nov. 4 (Fig. 12E)
Hystricuridae
Psalikilus hestoni sp. nov. (Figs 22-24)
Telephinidae
Opipeuterella sp. nov. 1 (Fig. 12C, D)
Opipeuterella sp. nov. A (Fig. 12B)

Remarks. A unique fauna of unusually low diversity was recovered from a single horizon at Section HC6 in the Bear River Range. It cannot be assigned to either the underlying *Psalikilus typicum* Zone or the overlying *Protopliomerella contracta* Zone as it has no species in common with either. Hence, it is assigned to a new *Psalikilus hestoni* Zone. Its basal boundary stratotype is at HC6 205.5 m, which is the only known horizon at which the name bearer and the rest of the fauna occur. At Ibex Section G the correlative position of the zone is within an unfossiliferous interval between G 174.0 m and G 210.2 m.

7. *Protopliomerella contracta* Zone (restricted) (Fig. 13)

Horizons. HC6 221.5 m. HC5 217.0T m. G 210.2 m.

Species.
Asaphidae
Aulacoparia sp. nov. 9 (Fig. 13P)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Protopresbynileus willdeni (Hintze, 1953) (Fig. 13J, N)
Ptyocephalus fillmorensis (Hintze, 1953)
Bathyuridae
Bathyuridae gen. nov. 2 sp. (Fig. 13E)
Bathyuridae gen. nov. 3 sp. 1
Benthamaspis sp. nov. 7 (Fig. 13C, G)
Benthamaspis sp. nov. 8 (Fig. 13H, L)
Benthamaspis sp. nov. 9 (Fig. 13I, M)
Benthamaspis sp. nov. B (Fig. 13AA)
Bolbocephalus sp. 1 (Fig. 13V)
Gladiatoria sp. nov. 3 (Fig. 13Q, U)
Licnocephala sp. nov. 5 (Fig. 13 T, X)
Licnocephala sp. nov. B
Licnocephala sp. nov. C
Peltabellia sp.
Cheiruridae
Cheiruridae gen. nov. 1 sp. nov. D (Fig. 13CC)
Dimeropygidae
Heckethornia smithi McAdams & Adrain, 2009b (Fig. 13S, W)
Hystricuridae
Psalikilus sp. nov. 7 (Fig. 13B, F)
Psalikilus sp. nov. 8
Psalikilus sp. nov. A (Fig. 13R)
Pliomeridae
Ibexaspis sp. nov. 1 (Fig. 13Y)
Ibexaspis sp. nov. A (Fig. 13Z)
Pliomeridae gen. nov. sp. nov. 2 (Fig. 13BB)
Protopliomerella contracta (Ross, 1951a) (Fig. 13A, D)
Remopleurididae
Menoparia lunalata Ross, 1953 (Fig. 13K, O)
Remopleurididae gen. et sp. nov.

Remarks. Ross *et al*. (1997, p. 19) claimed that this zone ranged through 183 m of strata in sections G and H at Ibex, but this is based almost entirely upon misidentification of species and lack of study and illustrations of faunas through most of this supposed range. In fact *Protopliomerella contracta* Ross, 1951a (Fig. 13A, D), occurs at only a single horizon in Section G, G 210.2 m. Similarly, the species is known from a single horizon near the top of Section HC6 in the Garden City Formation, and from a single talus collection weathering in place from Section HC5. In either region, the fauna associated with *P. contracta* has no species in common with the underlying zones. Only a single species, *Protopresbynileus willdeni* (Hintze, 1953), is potentially shared with the overlying *Heckethornia hyndeae* Zone. This species is an effaced asaphid known from relatively small amounts of material; further study may reveal distinctions between the samples from either zone. Although the faunas of this zone are well preserved, almost all of the species are new and undescribed. The boundary stratotype for the base of the zone is the first appearance of the name bearer at Section HC6 221.5 m. Section HC6 terminates above HC6 221.5 m and the base of the overlying *H. hyndeae* Zone was not found, nor were any other fossiliferous horizons. At Ibex Section G the *P. contracta* Zone base is at G 210.2 and the top is defined by the base of the *H. hyndeae* Zone at G 258.2 m.

8. *Heckethornia hyndeae* Zone (new) (Fig. 14)

Horizons. G 258.2 m. YH 128.9, 129.5, 131.1 m.

Species.
Asaphidae
Aulacoparia sp. nov. 10

Fig. 13. Trilobites of the *Protopliomerella contracta* Zone. All views are dorsal. **A**, **D**, *Protopliomerella contracta* (Ross, 1951a). **A**, cranidium, SUI 115228, x7.5 (G 210.2 m). **D**, pygidium, SUI 115229, x7.5 (HC6 221.5 m). **B**, **F**, *Psalikilus* sp. nov. 7. **B**, cranidium, SUI 115230, x7.5 (G 210.2 m). **F**, pygidium, SUI 115231, x10 (G 210.2 m). **C**, **G**, *Benthamaspis* sp. nov. 7. **C**, cranidium, SUI 115232, x10 (G 210.2 m). **G**, pygidium, SUI 115233, x7.5 (G 210.2 m). **E**, Bathyuridae gen. nov. 2 sp., pygidium, SUI 115234, x7.5 (G 210.2 m). **H**, **L**, *Benthamaspis* sp. nov. 8. **H**, cranidium, SUI 115235, x5 (G 210.2 m). **L**, pygidium, SUI 115236, x7.5 (G 210.2 m). **I**, **M**, *Benthamaspis* sp. nov. 9. **I**, cranidium, SUI 115237, x10 (G 210.2 m). **M**, pygidium, SUI 115238, x10 (G 210.2 m). **J**, **N**, *Protopresbynileus willdeni* (Hintze, 1953). **J**, cranidium, SUI 115239, x10 (G 210.2 m). **N**, pygidium, SUI 115240, x6 (HC6 221.5 m). **K**, **O**, *Menoparia lunalata* Ross, 1953. **K**, cranidium, SUI 115241, x6 (HC6 221.5 m). **O**, pygidium, SUI 115242, x7.5 (HC6 221.5 m). **P**, *Aulacoparia* sp. nov. 9, cranidium, SUI 115243, x7.5 (HC6 221.5 m). **Q**, **U**, *Gladiatoria* sp. nov. 3. **Q**, cranidium, SUI 115244, x6 (G 210.2 m). **U**, pygidium, SUI 115245, x7.5 (G 210.2 m). **R**, *Psalikilus* sp. nov. A, cranidium, SUI 115246, x9 (HC6 221.5 m). **S**, **W**, *Heckethornia smithi* McAdams & Adrain, 2009b. **S**, cranidium, SUI 113348, x7.5 (G 210.2 m). **W**, pygidium, SUI 113378, x12 (G 210.2 m). **T**, **X**, *Licnocephala* sp. nov. 5. **T**, cranidium, SUI 115247, x6 (HC6 221.5 m). **X**, pygidium, SUI 115248, x5 (HC6 221.5 m). **V**, *Bolbocephalus* sp. 1, pygidium, SUI 115249, x7.5 (G 210.2 m). **Y**, *Ibexaspis* sp. nov. 1, cranidium, SUI 115250, x8 (G 210.2 m). **Z**, *Ibexaspis* sp. nov. A, cranidium, SUI 115251, x10 (G 210.2 m). **AA**, *Benthamaspis* sp. nov. B, cranidium, SUI 115252, x9 (HC6 221.5 m). **BB**, Pliomeridae gen. nov. sp. nov. 2, pygidium, SUI 115253, x5 (G 210.2 m). **CC**, Cheiruridae gen. nov. 1 sp. nov. D, pygidium, SUI 115254, x6 (G 210.2 m).

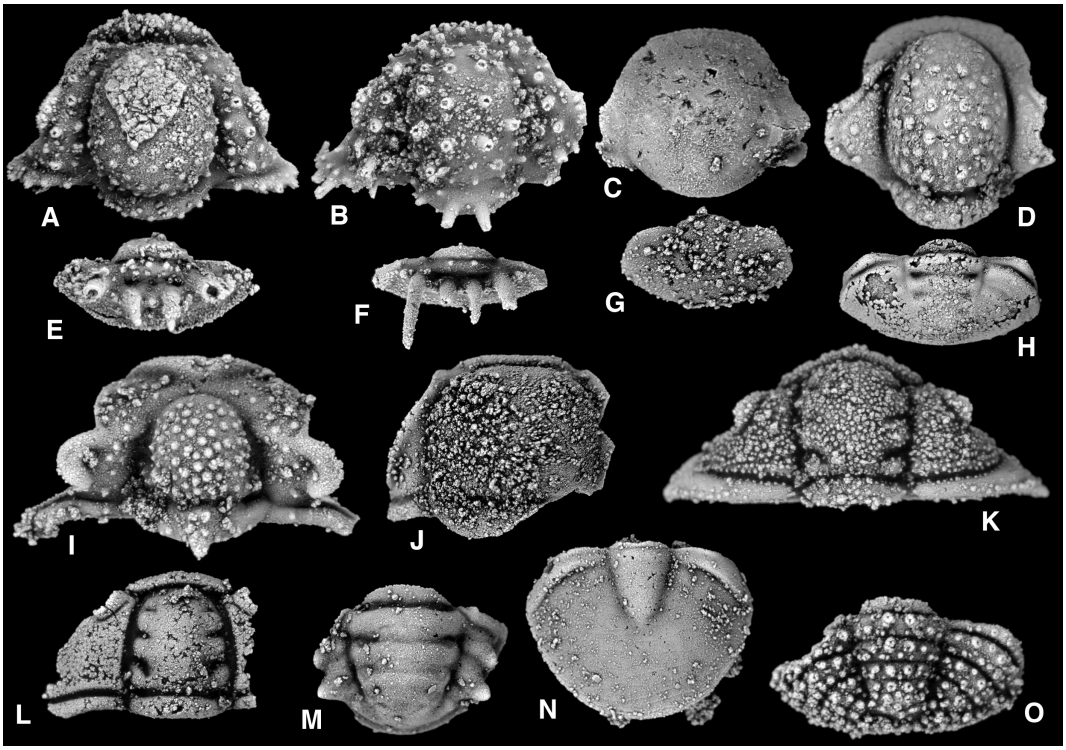
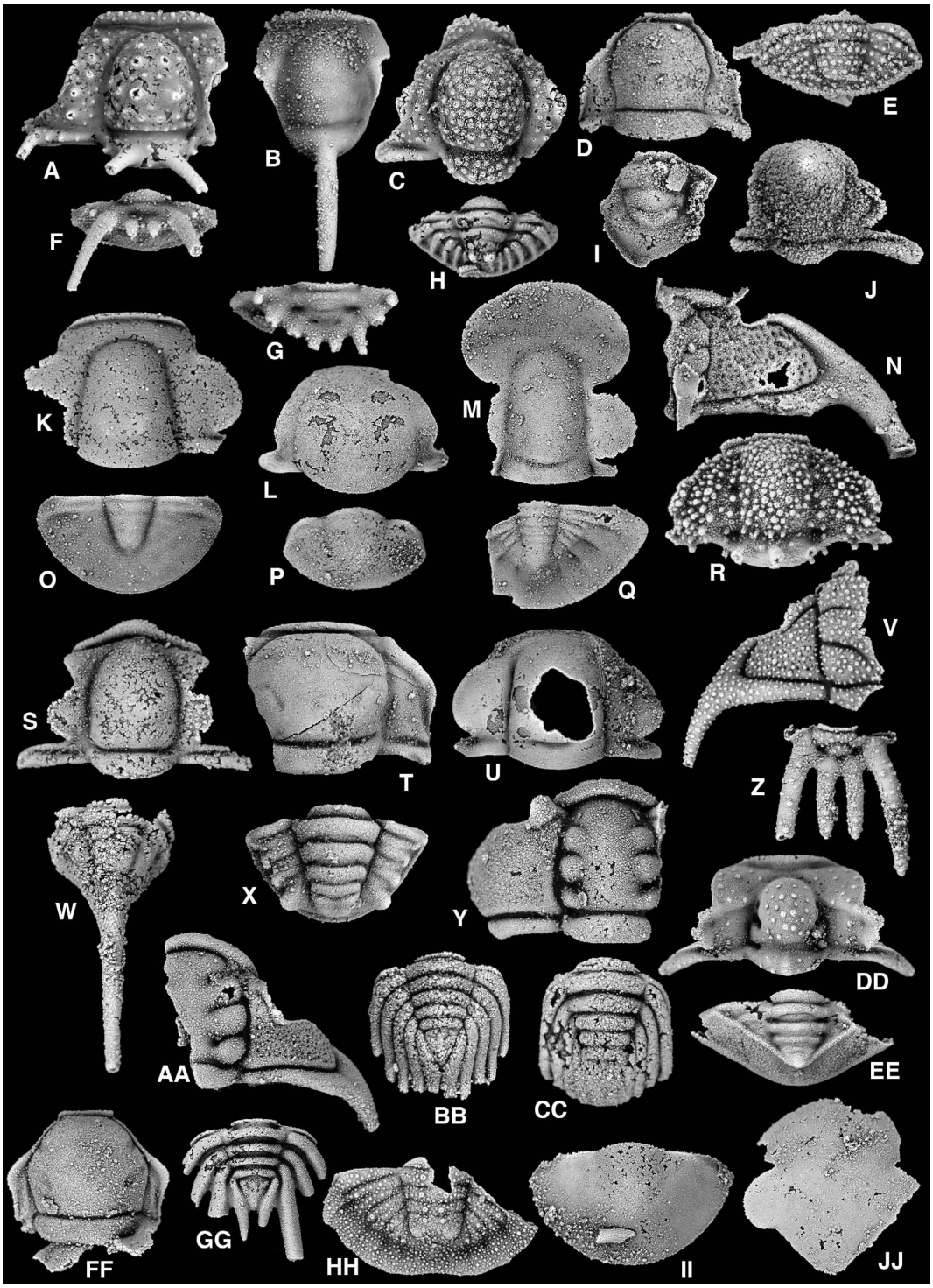


Fig. 14. Trilobites of the *Heckethornia hyndeae* Zone. All views are dorsal, and all specimens are from YH 128.9 m. **A**, **E**, *Heckethornia hyndeae* McAdams & Adrain, 2009b. **A**, cranidium, SUI 113393, x9. **E**, pygidium, SUI 113422, x12. **B**, **F**, *Heckethornia numani* McAdams & Adrain, 2009b. **B**, cranidium, SUI 113382, x7.5. **F**, pygidium, SUI 113391, x12. **C**, **G**, *Benthamaspis* sp. nov. 10. **C**, cranidium, SUI 115255, x10. **G**, pygidium, SUI 115256, x10. **D**, **H**, Bathyuridae gen. nov. 4 sp. nov. 1. **D**, cranidium, SUI 115257, x10. **H**, pygidium, SUI 115258, x4. **I**, *Psalikilus* sp. nov. 9, cranidium, SUI 115259, x12. **J**, **M**, "*Carolinites*" sp. nov. 1. **J**, cranidium, SUI 115260, x6. **M**, pygidium, SUI 115261, x7.5. **K**, *Ibexaspis* sp. nov. 2, cranidium, SUI 115262, x10. **L**, *Protopliomerella* sp., cranidium, SUI 115263, x10. **N**, *Benthamaspis* sp. nov. C, pygidium, SUI 115264, x6. **O**, Bathyuridae gen. nov. 2 sp. nov. A, pygidium, SUI 115265, x10.

Fig. 15 (opposite). Trilobites of the *Heckethornia bowiei* Zone. All views are dorsal. **A**, **F**, *Heckethornia bowiei* McAdams & Adrain, 2009b. **A**, cranidium, SUI 113443, x6 (H 127.1 m). **F**, pygidium, SUI 113490, x7.5 (H 93.4 m). **B**, **G**, *Heckethornia morrisseyi* McAdams & Adrain, 2009b. **B**, cranidium, SUI 113495, x6 (H 93.4 m). **G**, pygidium, SUI 113510, x10 (H 93.4 m). **C**, **H**, *Dimeropygiella* sp. nov. 1. **C**, cranidium, SUI 115266, x5 (H 127.1 m). **H**, pygidium, SUI 115267, x6 (H 127.1 m). **D**, **I**, *Opipeuterella* sp. nov. 2. **D**, cranidium, SUI 115268, x7.5 (H 127.1 m). **I**, pygidium, SUI 115269, x7.5 (H 127.1 m). **E**, Bathyuridae gen. nov. 2 sp. nov. 1, pygidium, SUI 115270, x5 (H 93.4 m). **J**, Bathyuridae gen. nov. 5 sp. nov. A, cranidium, SUI 115271, x7.5 (H 93.4 m). **K**, **O**, *Benthamaspis* sp. nov. 12. **K**, cranidium, SUI 115272, x7.5 (H 93.4 m). **O**, pygidium, SUI 115273, x5 (H 93.4 m). **L**, **P**, *Benthamaspis* sp. nov. 13. **L**, cranidium, SUI 115274, x6 (H 93.4 m). **P**, pygidium, SUI 115275, x6 (H 93.4 m). **M**, **Q**, *Licnocephala* sp. nov. 6. **M**, cranidium, SUI 115276, x5 (H 93.4 m). **Q**, pygidium, SUI 115277, x5 (H 93.4 m). **N**, Cheiruridae gen. nov. 2 sp. nov. 1, cranidium, SUI 115278, x4 (H 127.1 m). **R**, *Ceratocephalina* sp. nov. 1, cranidium, SUI 115279, x12 (H 127.1 m). **S**, **W**, *Acidiphorus* sp. nov. 1. **S**, cranidium, SUI 115280, x6 (H 127.1 m). **W**, pygidium, SUI 115281, x7.5 (H 127.1 m). **T**, **X**, *Carolinites* sp. nov. A. **T**, cranidium, SUI 122834, x6 (H 93.4 m). **X**, pygidium, SUI 122835, x7.5 (H 93.4 m). **U**, *Benthamaspis* sp. nov. D, cranidium, SUI 115284, x5 (H 93.4 m). **V**, **Z**, Cheiruruidae gen. nov. 1 sp. nov. 3. **V**, cranidium, SUI 115285, x7.5 (H 127.1 m). **Z**, pygidium, SUI 115286, x6 (H 127.1 m). **Y**, **CC**, *Protopliomerella* sp. nov. 3. **Y**, cranidium, SUI 115287, x7.5 (H 93.4 m). **CC**, pygidium, SUI 115288, x7.5 (H 93.4 m). **AA**, **GG**, Pliomeridae gen. nov. sp. nov. 4. **AA**, cranidium, SUI 115289, x6 (H 93.4 m). **GG**, pygidium, SUI 115290, x4 (H 93.4 m). **BB**, *Cybelopsis* sp. nov. A, pygidium, SUI 115291, x6 (H 127.1 m). **DD**, **EE**, *Psalikilus* sp. nov. 10. **DD**, cranidium, SUI 115292, x7.5 (H 127.1 m). **EE**, pygidium, SUI 115293, x10 (H 93.4 m). **FF**, *Opipeuterella* sp. nov. B, cranidium, SUI 115294, x15 (H 93.4 m). **HH**, *Bolbocephalus* sp. 3, pygidium, SUI 115295, x5 (H 93.4 m). **II**, **JJ**, *Protopresbynileus* sp. nov. 1. **II**, pygidium, SUI 115296, x6 (H 93.4 m). **JJ**, cranidium, SUI 115297, x7.5 (H 93.4 m).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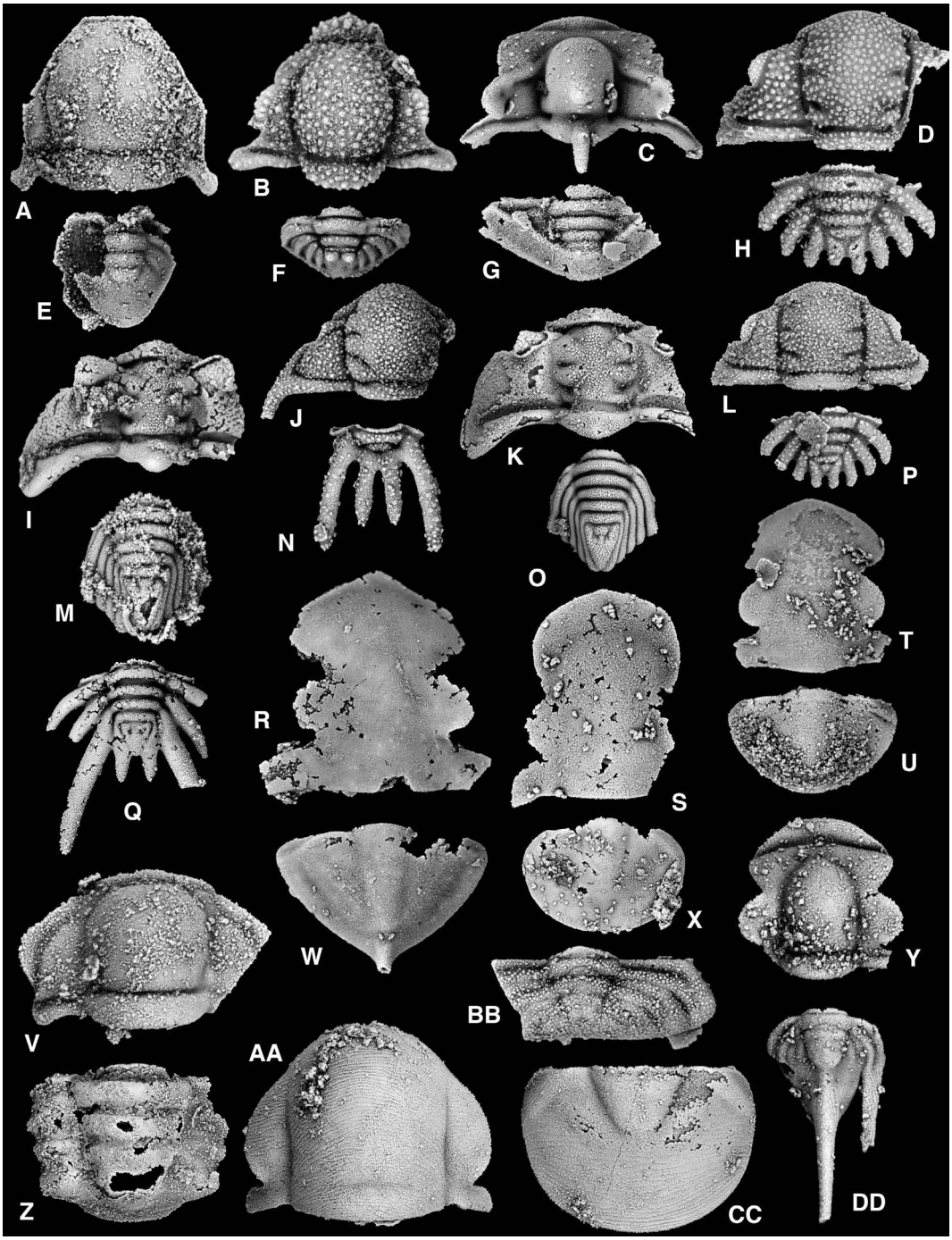


Fig. 16. Trilobites of the *Psalikilus pikum* Zone. All views are dorsal. **A**, **E**, *Opipeuterella* sp. nov. 3. **A**, cranidium, SUI 115298, x10 (H 172.5T m). **E**, pygidium, SUI 115299, x7.5 (H 172.5T m). **B**, **F**, *Dimeropygiella* sp. nov. 2. **B**, cranidium, SUI 115300, x6 (H 172.5 m). **F**, pygidium, SUI 115301, x6 (H 172.5 m). **C**, **G**, *Psalikilus pikum* Hintze, 1953. **C**, cranidium, SUI 115302, x7.5 (H 182.6 m). **G**, pygidium, SUI 115303, x7.5 (H 182.6 m). **D**, **H**, *Ibexaspis* sp. nov. 4. **D**, cranidium, SUI 115304, x7.5 (H 172.5T m). **H**, pygidium, SUI 115305, x10 (H 172.5T m). **I**, **M**, *Lemureops ploogi* McAdams & Adrain, this volume. **I**, cranidium, SUI 110317, x5 (H 172.5 m). **M**, pygidium, SUI 110314, x7.5 (H 172.5 m). **J**, **N**, Cheiruridae gen. nov. 1 sp. nov. 4. **J**, cranidium, SUI 115306, x7.5 (H 172.5T m). **N**, pygidium, SUI 115307, x7.5 (H 172.5T m). **K**, **O**, *Lemureops koppesi* McAdams & Adrain, this volume. **K**, cranidium, SUI 110303, x4.5 (H 172.5T m). *(continued opposite)*

**Protopresbynileus willdeni* (Hintze, 1953)
Ptyocephalus sp. nov. A
Bathyuridae
Bathyuridae gen. nov. 2 sp. nov. A (Fig. 14O)
Bathyuridae gen. nov. 4 sp. nov. 1 (Fig. 14D, H)
Benthamaspis sp. nov. 10 (Fig. 14C, G)
Benthamaspis sp. nov. 11
Benthamaspis sp. nov. C (Fig. 14N)
Bolbocephalus sp. 2
Licnocephala cavigladia Hintze, 1953
Cheiruridae
Cheiruridae gen. nov. 1 sp. nov. E
Dimeropygidae
Heckethornia hyndeae McAdams & Adrain, 2009b (Fig. 14A, E)
Heckethornia numani McAdams & Adrain, 2009b (Fig. 14B, F)
Hystricuridae
Psalikilus sp. nov. 9 (Fig. 14I)
Pliomeridae
Ibexaspis sp. nov. 2 (Fig. 14K)
Pliomeridae gen. nov. sp. nov. 3
Protopliomerella sp. (Fig. 14L)
Telephinidae
"*Carolinites*" sp. nov. 1 (Fig. 14J, M)
Remopleurididae
Menoparia sp. nov. B

Remarks. The fauna of this zone is known from sparse and relatively poorly preserved material at Ibex Section G 258.2 m. Had this been the only collection available it would have been evident that a mostly undescribed fauna was present but the material would have been inadequate for formal naming of most of the species. However, field work in 2008 at Yellow Hill in eastern Nevada revealed horizons containing the same fauna, but with much more numerous and well preserved fossils. With the exception of *Protopresbynileus willdeni* (Hintze), discussed above, all of the species are unique to this interval, which is assigned to the new *Heckethornia hyndeae* Zone. The basal boundary stratotype is drawn at Section YH 128.9 m at the first appearance of the name bearer. The top of the zone at Yellow Hill is defined by the base of the *Heckethornia bowiei* Zone at YH 175.9 m. At Ibex, the base of the *H. hyndeae* Zone is at G 258.2 m and the base of the *H. bowiei* Zone is at H 93.4 m, which is approximately 16 m up section (Appendix 3).

9. *Heckethornia bowiei* Zone (new) (Fig. 15)

Horizons. H 93.4, 127.1, 136.9, 138.3, 147.5 m. YH 175.9 m.

Species.
Asaphidae
Protopresbynileus sp. nov. 1 (Fig. 15 II, JJ)
Ptyocephalus sp. nov. 1
Trigonocerca sp. nov. 1
Bathyuridae
Acidiphorus sp. nov. 1 (Fig. 15S, W)
Bathyuridae gen. nov. 2 sp. nov. 1 (Fig. 15E)
Bathyuridae gen. nov. 5 sp. nov. A (Fig. 15J)
Benthamaspis sp. nov. 12 (Fig. 15K, O)
Benthamaspis sp. nov. 13 (Fig. 15L, P)
Benthamaspis sp. nov. 14
Benthamaspis sp. nov. D (Fig. 15U)
Bolbocephalus sp. 3 (Fig. 15HH)
Licnocephala sp. nov. 6 (Fig. 15M, Q)
Licnocephala? sp. 2
Cheiruridae
Cheiruridae gen. nov. 1 sp. nov. 3 (Fig. 15V, Z)
Cheiruridae gen. nov. 2 sp. nov. 1 (Fig. 15N)
Dimeropygidae
Dimeropygiella sp. nov. 1 (Fig. 15C, H)
Heckethornia bowiei McAdams & Adrain, 2009b (Fig. 15A, F)
Heckethornia morrisseyi McAdams & Adrain, 2009b (Fig. 15B, G)
Hystricuridae
Psalikilus sp. nov. 10 (Fig. 15DD, EE)
Odontopleuridae
Ceratocephalina sp. nov. 1 (Fig. 15R)
Pliomeridae
Cybelopsis sp. nov. A (Fig. 15BB)
Ibexaspis sp. nov. 3
Pliomeridae gen. nov. sp. nov. 4 (Fig. 15AA, GG)
Protopliomerella sp. nov. 3 (Fig. 15Y, CC)

O, pygidium, SUI 110309, x6 (H 172.5T m). **L**, **P**, *Ibexaspis* sp. nov. 5. **L**, cranidium, SUI 115308, x6 (H 172.5T m). **P**, pygidium, SUI 115309, x7.5 (H 172.5T m). **Q**, Pliomeridae gen. nov. sp. nov. A, pygidium, SUI 115310, x6 (H 182.6 m). **R**, **W**, *Trigonocerca typica* Ross, 1951a. **R**, cranidium, SUI 115311, x7.5 (H 182.6 m). **W**, pygidium, SUI 115312, x6 (H 182.6 m). **S**, **X**, *Ptyocephalus* sp. nov. B. **S**, cranidium, SUI 115313, x10 (H 182.6 m). **X**, pygidium, SUI 115314, x6 (H 182.6 m). **T**, **U**, *Presbynileus elongatus* (Hintze, 1953). **T**, cranidium, SUI 115315, x7.5 (H 182.6 m). **U**, pygidium, SUI 115316, x6 (H 172.5 m). **V**, **Z**, *Carolinites* sp. nov. B. **V**, cranidium, SUI 122836, x10 (H 173.2 m). **Z**, pygidium, SUI 122837, x10 (H 172.5T m). **AA**, **CC**, *Benthamaspis distincta* Young, 1973. **AA**, cranidium, SUI 115318, x10 (H 178.2 m). **CC**, pygidium, SUI 122838, x7.5 (H 178.2 m). **BB**, *Scotoharpes* sp. 1, pygidium, SUI 115317, x7.5 (H 172.5 m). **Y**, **DD**, *Acidiphorus* sp. nov. 2. **Y**, cranidium, SUI 115282, x7.5 (H 163.3 m). **DD**, pygidium, SUI 115283, x7.5 (H 163.3 m).

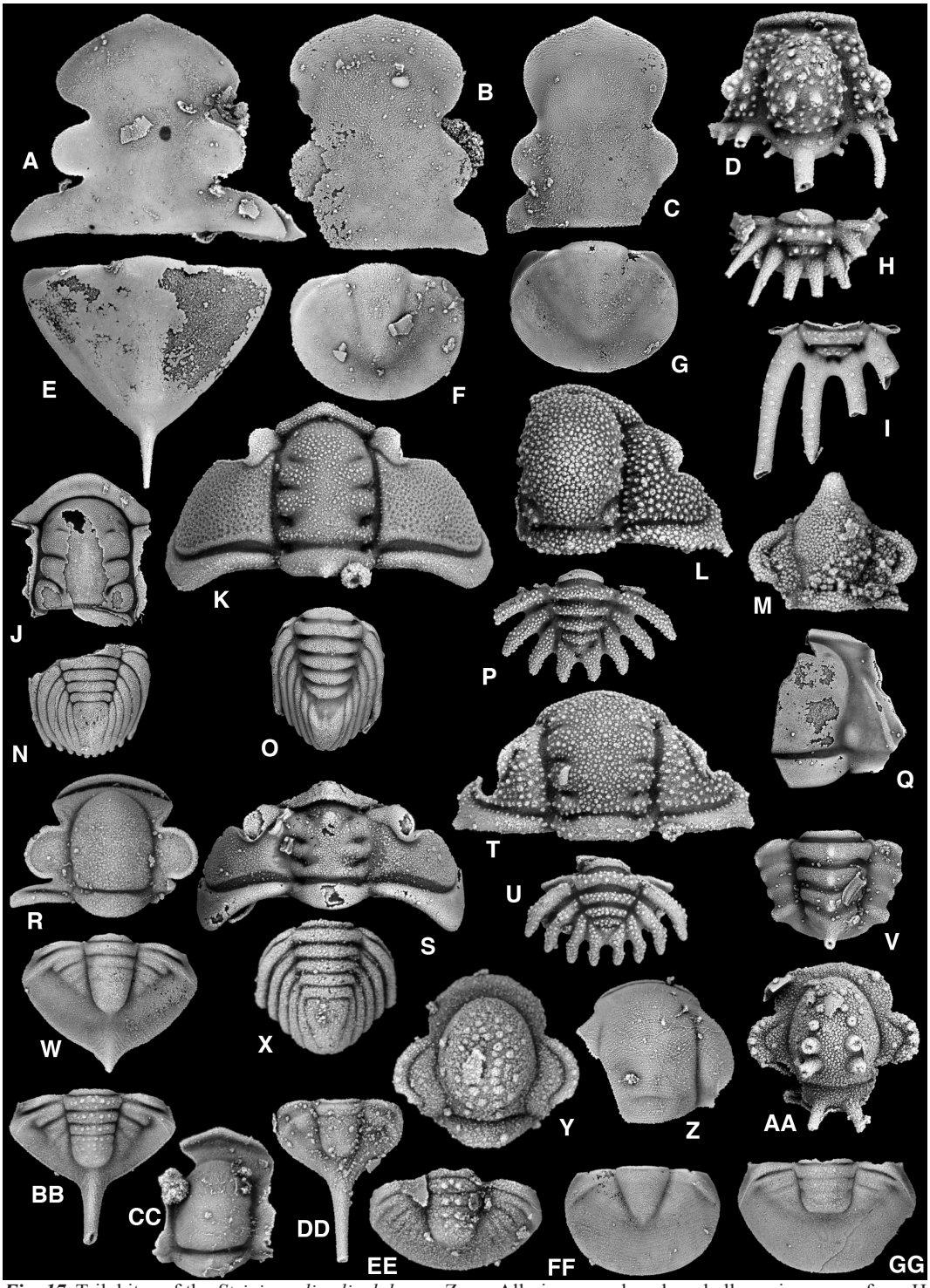


Fig. 17. Trilobites of the *Strigigenalis plicolabeona* Zone. All views are dorsal, and all specimens are from H 191.7 m. **A**, **E**, *Trigonocerca* sp. nov. 2. **A**, cranidium, SUI 115319, x6. **E**, pygidium, SUI 115320, x5. **B**, **F**, *Ptyocephalus* sp. nov. 2. **B**, cranidium, SUI 115321, x5. **F**, pygidium, SUI 115322, x6. **C**, **G**, *Ptyocephalus* sp. nov. 3. **C**, cranidium, SUI 115323, x10. **G**, pygidium, SUI 115324, x4. **D**, **H**, *Heckethornia alticapitis* (Young, 1973). **D**, cranidium, SUI 113526, x7.5. **H**, pygidium, SUI 113548, x12. **I**, Cheiruridae gen. nov. 1 sp. nov. F, pygidium, SUI 115325, x5. **J**, **N**, *Cybelopsis depressa* (Young, 1973). *(continued opposite)*

Remopleurididae
Menoparia sp. nov. 6
Telephinidae
Carolinites sp. nov. A (Fig. 15T, X)
Opipeuterella sp. nov. 2 (Fig. 15D, I)
Opipeuterella sp. nov. B (Fig. 15FF)

Remarks. The *Heckethornia bowiei* Zone encompasses the range of its highly distinctive name bearer (Fig. 15A, F). Its base is drawn at the first appearance of *H. bowiei* at Ibex Section H 93.4 m, and its top is at the base of the overlying *Psalikilus pikum* Zone at H 163.3 m. Hintze's (1951, 1953) samples H-7 through H-14 were all collected from this zone. Hintze (1953, p. 14) assigned H-7 (H 93.4 m of this work) to the *Protopliomerella contracta* Zone, based presumably on misidentification of *Protopliomerella* sp. nov. 3 (Fig. 15Y, CC) as *P. contracta* (Fig. 13A, D). He did not indicate the zonal assignment of the remaining horizons. There is considerable species turnover through the zone, and further subdivision may ultimately be warranted (see below). The interval is notable for the first appearance of many genera, including conventional *Carolinites*, *Ceratocephalina* Whittington, 1956, *Acidiphorus* Raymond, 1925, *Dimeropygiella* Ross, 1951a, *Trigonocerca* and *Cybelopsis* Poulsen, 1927.

The two most prolific horizons within the zone are at H 93.4 and 127.1 m. Although several common species are without doubt shared between them, many others are unique to one or the other. Definitely ranging between the horizons are *Heckethornia bowiei*, *Psalikilus* sp. nov. 10, and *Protopliomerella* sp. nov. 3. Three species of *Benthamaspis* (*B.* sp. nov. 12, *B.* sp. nov. 13, *B.* sp. nov. D) are unique to H 93.4 m and one (*B.* sp. nov. 14) to H 127.1 m. A species of *Carolinites* (the oldest known species with conventional *Carolinites* morphology) occurs at H 93.4 m but not at H 127.1 m. Species of *Opipeuterella* are clearly different between the horizons (cf. Fig. 15 D, FF). *Heckethornia morrisseyi* occurs at H 93.4 m but not at H 127.1 m. There are no species of *Dimeropygiella* or *Acidiphorus* at H 93.4 m but they are common at H 127.1 m.

These distinctions appear to be biostratigraphically meaningful. A collection from Section YH 175.9 m in eastern Nevada contains a fauna very similar to that of H 93.4 m, including both *H. bowiei* and *H. morrisseyi*. As knowledge of the faunas and their distribution increases, it may be worthwhile to recognise separate zones or subzones.

10. *Psalikilus pikum* Zone (new) (Fig. 16)

Horizons. H 163.3, 166.2, 169.8, 172.5, 172.5T, 173.2, 173.8, 176.0, 178.2, 182.6, 185.6 m.

Species.
Asaphidae
Presbynileus elongatus (Hintze, 1953) (Fig. 16T, U)
Ptyocephalus sp. nov. B (Fig. 16S, X)
Trigonocerca typica Ross, 1951a (Fig. 16R, W)
Bathyuridae
Acidiphorus sp. nov. 2 (Fig. 16Y, DD)
Acidiphorus sp. nov. A
Bathyuridae gen. nov. 3 sp. 2
Bathyuridae gen. nov. 5 sp. nov. B
Benthamaspis distincta Young, 1973 (Fig. 16AA, CC)
Benthamaspis sp. nov. E
Cheiruridae
Cheiruridae gen. nov. 1 sp. nov. 4 (Fig. 16J, N)
Dimeropygidae
Dimeropygiella sp. nov. 2 (Fig. 16B, F)
**Heckethornia bowiei* McAdams & Adrain, 2009b
Harpetidae
Scotoharpes sp. 1 (Fig. 16BB)
Hystricuridae
Psalikilus pikum Hintze, 1953 (Fig. 16C, G)
Odontopleuridae
Ceratocephalina sp. nov. 2
Pliomeridae
Ibexaspis sp. nov. 4 (Fig. 16D, H)
Ibexaspis sp. nov. 5 (Fig. 16L, P)

J, cranidium, SUI 115326, x3. **N**, pygidium, SUI 115327, x4. **K**, **O**, *Pseudocybele altinasuta* Hintze, 1973. **K**, cranidium, SUI 115328, x10. **O**, pygidium, SUI 115329, x4. **L**, **P**, *Ibexaspis brevis* (Young, 1973). **L**, cranidium, SUI 115330, x12. **P**, pygidium, SUI 115331, x7.5. **M**, Bathyuridae gen. nov. 5 *unicornis* (Young, 1973), cranidium, SUI 115332, x10. **Q**, **V**, *Carolinites* sp. nov. C. **Q**, cranidium, SUI 115333, x5. **V**, pygidium, SUI 115334, x5. **R**, **W**, *Strigigenalis plicolabeona* (Young, 1973). **R**, cranidium, SUI 115335, x6. **W**, pygidium, SUI 115336, x6. **S**, **X**, *Lemureops kilbeyi* McAdams & Adrain, this volume. **S**, cranidium, SUI 110168, x6. **X**, pygidium, SUI 110212, x10. **T**, **U**, *Ibexaspis* sp. nov. 6. **T**, cranidium, SUI 115337, x10. **U**, pygidium, SUI 115338, x7.5. **Y**, **EE**, Bathyuridae gen. nov. 5 sp. nov. 1. **Y**, cranidium, SUI 115339, x12. **EE**, pygidium, SUI 115340, x5. **Z**, **FF**, *Benthamaspis distincta* Young, 1973. **Z**, cranidium, SUI 115341, x7.5. **FF**, pygidium, SUI 115342, x5. **AA**, Bathyuridae gen. nov. 5 *linearus* (Young, 1973), cranidium, SUI 115343, x10. **BB**, *Acidiphorus teretus* (Young, 1973), pygidium, SUI 115344, x6. **CC**, **DD**, *Acidiphorus* sp. nov. 3. **CC**, cranidium, SUI 115345, x10. **DD**, pygidium, SUI 115346, x6. **GG**, Bathyuridae gen. nov. 3 sp. 3, pygidium, SUI 115347, x5.

Lemureops ploogi McAdams & Adrain, 2009a (Fig. 16I, M)
Lemureops koppesi McAdams & Adrain, 2009a (Fig. 16K, O)
Lemureops sp. nov. B of McAdams & Adrain (2009a)
Pliomeridae gen. nov. sp. nov. A (Fig. 16Q)
Pliomeridae gen. nov. sp. nov. B
Telephinidae
Carolinites sp. nov. B (Fig. 16V, Z)
Opipeuterella sp. nov. 3 (Fig. 16A, E)

Remarks. A new trilobite assemblage, dominated by *Psalikilus pikum*, appears at H 163.3 m and is represented at multiple sampling horizons up to and including H 185.6 m. The fauna is nearly unique, with only two species potentially ranging upward into the *S. plicolabeona* Zone (these are tentative ranges based on small amounts of preliminary photography; more comprehensive systematic work may reveal morphological differentiation). Hence, the interval is assigned to a new *Psalikilus pikum* Zone. *Psalikilus pikum* is present at all horizons and is restricted to the zone. It is the youngest known species of *Psalikilus*. The base of the *P. pikum* Zone is drawn at the first appearance of the name bearer at H 163.3 m and the top is the base of the overlying *S. plicolabeona* Zone at H 186.2 m.

11. *Strigigenalis plicolabeona* Zone (new) (Fig. 17)

Horizons. H 186.2, 187.4, 188.5, 191.7, 197.1 m.

Species.
Asaphidae
Asaphidae gen. nov. 1 sp. 1
**Presbynileus elongatus* (Hintze, 1953)
Ptyocephalus sp. nov. 2 (Fig. 17B, F)
Ptyocephalus sp. nov. 3 (Fig. 17C, G)
Trigonocerca sp. nov. 2 (Fig. 17A, E)
Bathyuridae
Strigigenalis plicolabeona (Young, 1973) (Fig. 17R, W)
Acidiphorus teretus (Young, 1973) (Fig. 17BB)
Acidiphorus sp. nov. 3 (Fig. 17CC, DD)
Bathyuridae gen. nov. 3 sp. 3 (Fig. 17GG)
Bathyuridae gen. nov. 5 *linearus* (Young, 1973) (Fig. 17AA)
Bathyuridae gen. nov. 5 *unicornis* (Young, 1973) (Fig. 17M)
Bathyuridae gen. nov. 5 sp. nov. 1 (Fig. 17Y, EE)
Bathyuridae gen. nov. 5 sp.
**Benthamaspis distincta* Young, 1973 (Fig. 17Z, FF)
Bolbocephalus sp. 4
Cheiruridae
Cheiruridae gen. nov. 1 sp. nov. F (Fig. 17I)
Dimeropygidae
Dimeropygiella blanda Hintze, 1953
Dimeropygiella ovata Hintze, 1953
Dimeropygiella fillmorensis Adrain, Westrop, Landing & Fortey, 2001
Heckethornia alticapitis (Young, 1973) (Fig. 17D, H)
Odontopleuridae
Ceratocephalina trispinea (Young, 1973)
Pliomeridae
Cybelopsis depressa (Young, 1973) (Fig. 17J, N)
Ibexaspis brevis (Young, 1973) (Fig. 17L, P)
Ibexaspis sp. nov. 6 (Fig. 17T, U)
Lemureops kilbeyi McAdams & Adrain, 2009a (Fig. 17S, X)
Lemureops sp. nov. A of McAdams & Adrain (2009a)
Pseudocybele altinasuta Hintze, 1953 (Fig. 17K, O)
Shumardiidae
Leoforteyia hintzei Waisfeld, Vaccari, Chatterton & Edgecombe, 2001
Telephinidae
Carolinites sp. nov. C (Fig. 17Q, V)
Opipeuterella angularis (Young, 1973)

Remarks. The fauna from Section H 191.7 m (Hintze's [1951, 1953] sampling horizon H-20) was studied by Young (1973), who erected several species. Young misassociated the sclerites of most of the taxa he dealt with, and left many sclerites under open nomenclature. Nevertheless, as a result of his work more is known about this assemblage than any other at Ibex. Adrain *et al*. (2001) studied the species of *Dimeropygiella* occurring at the horizon, and Waisfeld *et al*. (2001) thoroughly described a shumardiid, *Leoforteyia hintzei*. An identical assemblage occurs from H 186.2 through H 197.1 m. As noted above, H 191.7 m contains the species of *Trigonocerca* illustrated by Hintze (1953) as *T. typica*, but it is clearly a distinct new species (*Trigonocerca* sp. nov. 2, Fig. 17A, E) and *T. typica* occurs in the higher part of the underlying *P. pikum* Zone. The basal stratotype of the zone is the first appearance of the name bearer at H 186.2 m and the top is the base of the overlying *C. nevadensis* Zone at H 208.2 m.

12. *Carolinites nevadensis* Zone (new) (Fig. 18)

Horizons. H 208.2, 222.1, 226T m.

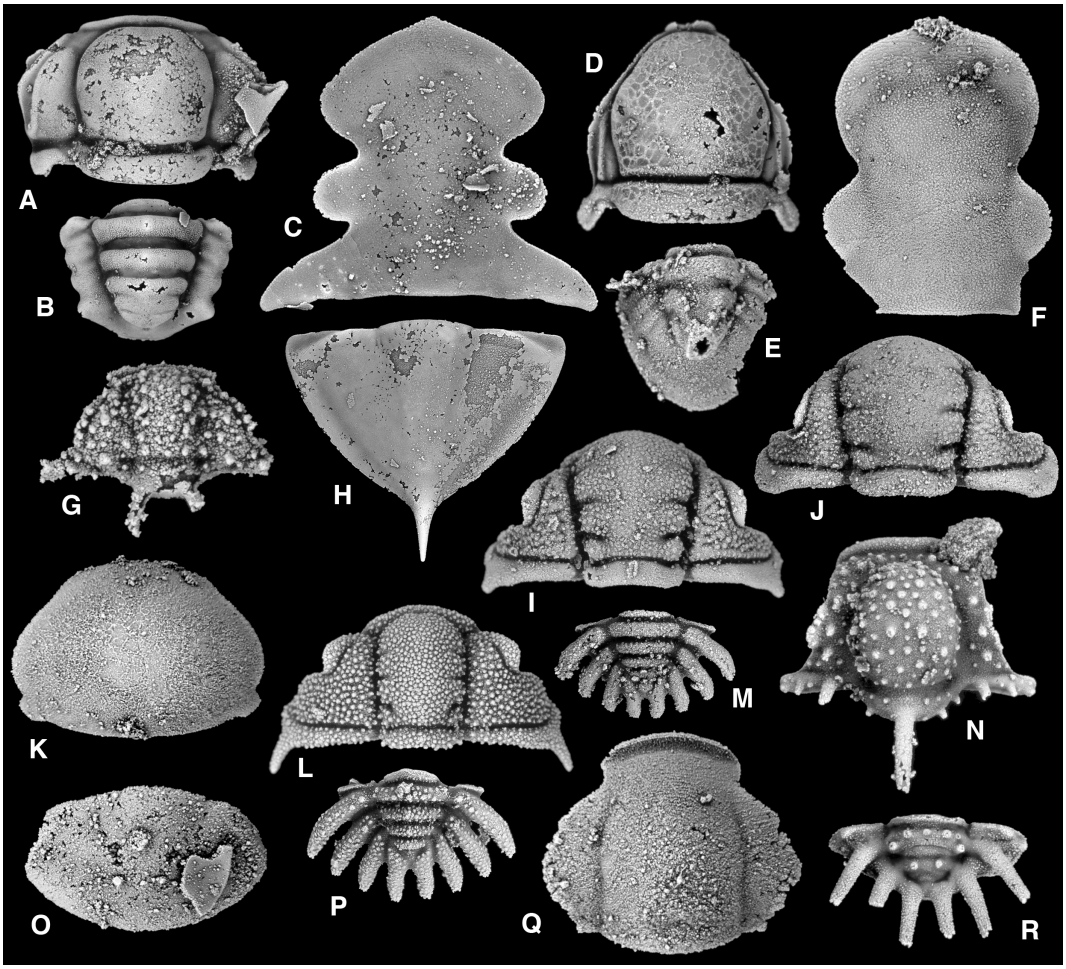


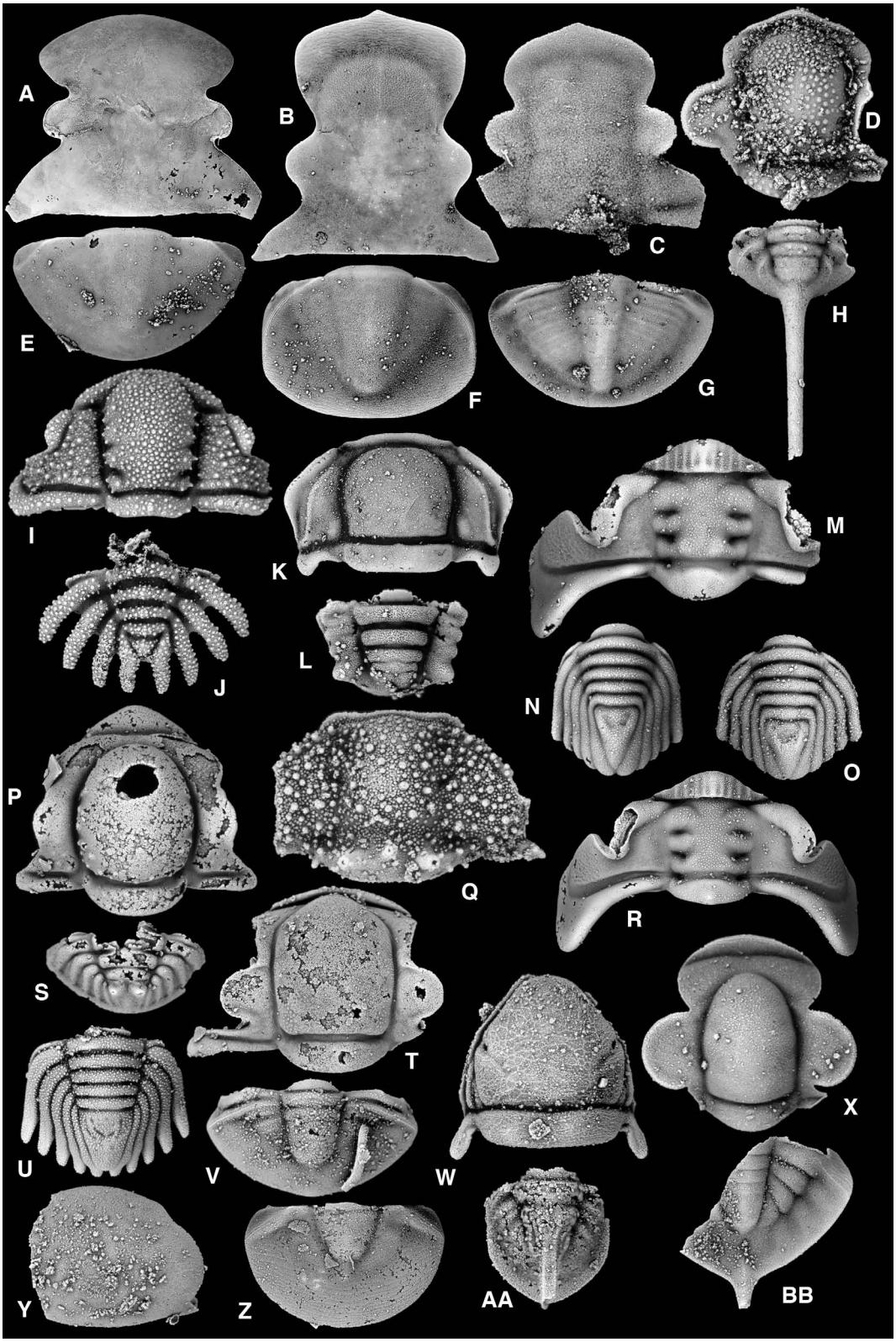
Fig. 18. Trilobites of the *Carolinites nevadensis* Zone. All views are dorsal. **A**, **B**, *Carolinites nevadensis* Hintze, 1953. **A**, cranidium, SUI 115348, x5 (H 222.1 m). **B**, pygidium, SUI 115349, x4 (H 222.1 m). **C**, **H**, *Trigonocerca piochensis* Hintze, 1953. **C**, cranidium, SUI 115350, x5 (H 208.2 m). **H**, pygidium, SUI 115351, x3 (H 208.2 m). **D**, **E**, *Opipeuterella angularis* (Young, 1973). **D**, cranidium, SUI 115352, x10 (H 222.1 m). **E**, pygidium, SUI 115353, x10 (H 222.1 m). **F**, *Ptyocephalus acclivus* (Hintze, 1953), cranidium, SUI 115354, x7.5 (H 222.1 m). **G**, *Ceratocephala* sp. nov. 3, cranidium, SUI 115355, x15 (H 222.1 m). **I**, **M**, *Ibexaspis* sp. nov. 7. **I**, cranidium, SUI 115356, x7.5 (H 222.1 m). **M**, pygidium, SUI 115357, x7.5 (H 222.1 m). **J**, *Ibexaspis* sp. nov. 8, cranidium, SUI 115358, x7.5 (H 208.2 m). **K**, **O**, *Benthamaspis* sp. nov. 15. **K**, cranidium, SUI 115359, x12 (H 208.2 m). **O**, pygidium, SUI 115360, x10 (H 208.2 m). **L**, **P**, *Ibexaspis* sp. nov. 9. **L**, cranidium, SUI 115361, x7.5 (H 222.1 m). **P**, pygidium, SUI 115362, x12 (H 222.1 m). **N**, **R**, *Heckethornia ballionae* McAdams & Adrain, 2009b. **N**, cranidium, SUI 113553, x10 (H 222.1 m). **R**, pygidium, SUI 113582, x10 (H 222.1 m). **Q**, *Benthamaspis distincta* Young, 1973, cranidium, SUI 115363, x12 (H 208.2 m).

Species.

Asaphidae
- **Presbynileus elongatus* (Hintze, 1953)
- *Ptyocephalus acclivus* (Hintze, 1953) (Fig. 18F)
- *Trigonocerca piochensis* Hintze, 1953 (Fig. 18C, H)

Bathyuridae
- *Acidiphorus* sp. nov. 4
- *Strigigenalis* sp. nov. 1
- *Bathyuridae gen. nov. 3 sp. 3
- *Bathyuridae gen. nov. 5 *linearus* (Young, 1973)
- *Bathyuridae gen. nov. 5 *unicornis* (Young, 1973)
- *Bathyuridae gen. nov. 5 sp. nov. 1
- **Benthamaspis distincta* Young, 1973 (Fig. 18Q)
- *Benthamaspis* sp. nov. 15 (Fig. 18K, O)

Cheiruridae
- *Cheiruridae gen. nov. 1 sp. nov. F
- *Kawina* sp. nov. A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Dimeropygidae
**Dimeropygiella blanda* Hintze, 1953
**Dimeropygiella ovata* Hintze, 1953
Heckethornia ballionae McAdams & Adrain, 2009b (Fig. 18N, R)
Harpetidae
Scotoharpes sp. 2
Odontopleuridae
Ceratocephalina sp. nov. 3 (Fig. 18G)
Pliomeridae
**Cybelopsis depressa* (Young, 1973)
Ibexaspis sp. nov. 7 (Fig. 18I, M)
Ibexaspis sp. nov. 8 (Fig. 18J)
Ibexaspis sp. nov. 9 (fig. 18L, P)
**Lemureops kilbeyi* McAdams & Adrain, 2009a
Telephinidae
Carolinites nevadensis Hintze, 1953 (Fig. 18A, B)
**Opipeuterella angularis* (Young, 1973) (Fig. 18D, E)

Remarks. Faunas at horizons H 208.2 m and 222.1 m were assumed to be the same as that at H 191.7 m by Hintze (1953) and Ross *et al*. (1997) and for the most part have not been illustrated. Both horizons contain rich and well preserved faunas which when photographed in many cases include species distinct from their counterparts at H 191.7 m. In particular, the species *Carolinites nevadensis* Hintze, 1953, is common at both horizons (Fig. 18A, B) and is obviously different from the undescribed *Carolinites* sp. nov. 2 which occurs at H 191.7 m (Fig. 17Q, V). Distinctions between *Trigonocerca piochensis* Hintze, 1953, which is common at H 208.2 m (Fig. 18C, H), and *Trigonocerca* sp. nov. 2, which is common at H 191.7 m (Fig. 17A, E) have been discussed at length above. *Heckethornia ballionae* McAdams & Adrain, 2009b, occurs at the higher horizons (Fig. 18N, R), whereas the closely similar but clearly distinct *H. alticapitis* (Young, 1973) occurs at H 191.7 m (Fig. 17D, H). In addition, species of *Acidiphorus* and *Strigigenalis* are definitely different from those from older horizons, including *Strigigenalis plicolabeona* at H 191.7 m. It is now clear that a different assemblage of trilobites replaces the fauna of the *S. plicolabeona* Zone, which is assigned to a new *Carolinites nevadensis* Zone. The stratotype for the base of the zone is the first appearance of *C. nevadensis* at H 208.2 m. In the faunal list above, multiple species are listed as shared with the underlying *Strigigenalis plicolabeona* Zone (despite the many distinctions just discussed). All of these need to be investigated in detail and there has not been time thus far to carry out extensive photography and taxonomic work. In most cases where such work has been conducted, species have proven distinct, though in some cases very similar. Hence, many of these species will likely prove to be differentiated but until firm evidence of such is developed they are listed as the same.

13. *Presbynileus ibexensis* Zone (Fig. 19)

Horizons. H 238.2, 251.4, 256-261T, 264-267T m.

Species.
Asaphidae
Isoteloides flexus Hintze, 1953 (Fig. 19C, G)
Presbynileus ibexensis (Hintze, 1953) (Fig. 19A, E)
Ptyocephalus yersini (Hintze, 1953) (Fig. 19B, F)
Bathyuridae
Acidiphorus sp. nov. 5 (Fig. 19D, H)
Strigigenalis sp. nov. 2 (Fig. 19T, V)
Acidiphorus sp. 1

Fig. 19. Trilobites of the *Presbynileus ibexensis* Zone. All views are dorsal. **A**, **E**, *Presbynileus ibexensis* (Hintze, 1953). **A**, cranidium, SUI 115364, x2 (H 264-267T m). **E**, pygidium, SUI 115365, x4 (H 264-267T m). **B**, **F**, *Ptyocephalus yersini* (Hintze, 1953). **B**, cranidium, SUI 115366, x5 (H 264-267T m). **F**, pygidium, SUI 115367, x5 (H 264-267T m). **C**, **G**, *Isoteloides flexus* Hintze, 1953. **C**, cranidium, SUI 115368, x7.5 (H 264-267T m). **G**, pygidium, SUI 115369, x5 (H 264-267T m). **D**, **H**, *Acidiphorus* sp. nov. 5. **D**, cranidium, SUI 115370, x7.5 (H 256-261T m). **H**, pygidium, SUI 115371, x7.5 (H 256-261T m). **I**, **J**, *Ibexaspis* sp. nov. 10. **I**, cranidium, SUI 115372, x12 (H 251.4 m). **J**, pygidium, SUI 115373, x10 (H 251.4 m). **K**, **L**, *Carolinites* sp. nov. 2. **K**, cranidium, SUI 115374, x6 (H 264-267T m). **L**, pygidium, SUI 115375, x7.5 (H 264-267T m). **M**, **N**, *Lemureops lemurei* (Hintze, 1953). **M**, cranidium, SUI 110328, x6 (H 251.4 m). **N**, pygidium, SUI 110341, x10 (H 251.4 m). **O**, **R**, *Lemureops willsonpiperi* McAdams & Adrain, this volume. **O**, pygidium, SUI 110274, x7.5 (H 256-261T m). **R**, cranidium, SUI 110213, x4 (H 256-261T m). **P**, **S**, *Dimeropygiella* sp. nov. 3. **P**, cranidium, SUI 115376, x7.5 (H 251.4 m). **S**, pygidium, SUI 115377, x7.5 (H 251.4 m). **Q**, *Ceratocephalina* sp. nov. A, cranidium, SUI 115378, x10 (H 256-261T m). **T**, **V**, *Strigigenalis* sp. nov. 2. **T**, cranidium, SUI 115379, x4 (H 264-267T m). **V**, pygidium, SUI 115380, x6 (H 264-267T m). **U**, *Cybelopsis* sp. nov. B, pygidium, SUI 115381, x7.5 (H 256-261T m). **W**, **AA**, *Opipeuterella* sp. nov. 4. **W**, cranidium, SUI 115382, x10 (H 256-261T m). **AA**, pygidium, SUI 115383, x10 (H 264-267T m). **X**, **BB**, *Punka*? sp. nov. 1. **X**, cranidium, SUI 115384, x12 (H 264-267T m). **BB**, pygidium, SUI 115385, x5 (H 264-267T m). **Y**, *Benthamaspis* sp. nov. F, cranidium, SUI 115386, x7.5 (H 256-261T m). **Z**, *Benthamaspis* sp. nov. G, pygidium, SUI 115387, x5 (H 256-261T m).

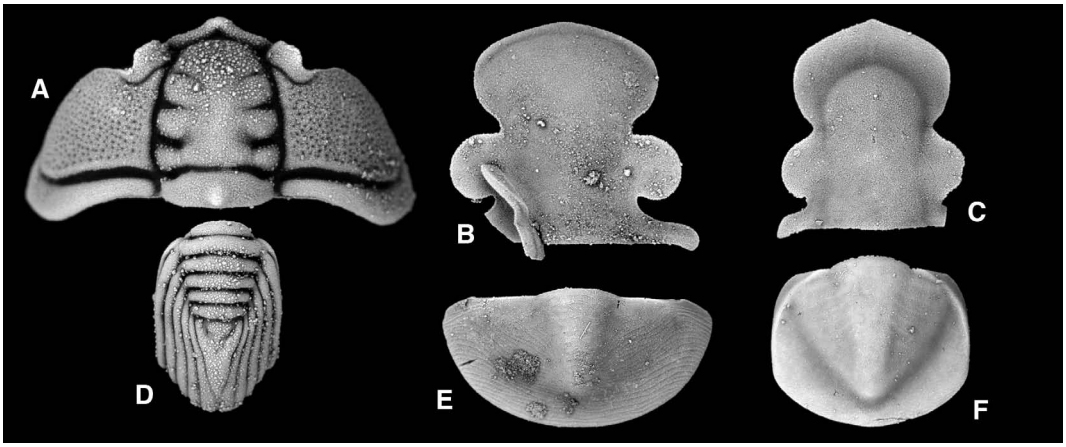

Fig. 20. Trilobites of the *Pseudocybele paranasuta* Zone. All views are dorsal. **A**, **D**, *Pseudocybele paranasuta* McAdams & Adrain, 2009c. **A**, cranidium, SUI 115388, x15 (H 285T m). **D**, pygidium, SUI 115389, x7.5 (H 282.4T m). **B**, **E**, Asaphidae gen. nov. 1 sp. nov. 1. **B**, cranidium, SUI 115390, x6 (H 282.4T m). **E**, pygidium, SUI 115391, x12 (H 285T m). **C**, **F**, *Ptyocephalus* sp. nov. 4. **C**, cranidium, SUI 115392, x7.5 (H 285T m). **F**, pygidium, SUI 115393, x5 (H 285T m).

Benthamaspis sp. nov. F (Fig. 19Y)
Benthamaspis sp. nov. G (Fig. 19Z)
Punka? sp. nov. 1 (Fig. 19X, BB)
Bathyuridae gen. nov. 6 sp. nov. 1
Cheiruridae
Cheiruridae gen. nov. 1 sp. nov. G
Dimeropygidae
Dimeropygiella mccormicki Adrain, Westrop, Landing & Fortey, 2001
Dimeropygiella sp. nov. 3 (Fig. 19P, S)
Odontopleuridae
Ceratocephalina sp. nov. A (Fig. 19Q)
Pliomeridae
Cybelopsis sp. nov. B (Fig. 19U)
Ibexaspis sp. nov. 10 (Fig. 19I, J)
Lemureops lemurei (Hintze, 1953) (Fig. 19M, N)
Lemureops willsonpiperi McAdams & Adrain, 2009a (Fig. 19O, R)
Pseudocybele sp.
Telephinidae
Carolinites sp. nov. 2 (Fig. 19K, L)
Opipeuterella sp. nov. 4 (Fig. 19W, AA)

Remarks. The *Presbynileus ibexensis* Zone is the only zone recognised by Ross *et al*. (1997) that is maintained with exactly the same basal stratotype and range herein. However, we have to date been unable to relocate Hintze's sampling horizon H-25 (545', or 229.3 m), which contained the first appearance of the name bearer and other elements of the zone. Collections from the same approximate level have yielded only poorly preserved sclerites unidentifiable to species level. The lowest well preserved fauna from the zone that we have located is at H 251.4 m, though Adrain *et al*. (2001) described *Dimeropygiella mccormicki* from a sample in the matrix of a thrombolite at H 238.2 m.

14. *Pseudocybele paranasuta* Zone (new) (Fig. 20)

Horizons. 282.4, 282.4T, 285T and 286.7 m.

Species.
Asaphidae
Asaphidae gen. nov. 1 sp. nov. 1 (Fig. 20B, E)
Isoteloides sp. nov. 1
Ptyocephalus sp. nov. 4 (Fig. 20C, F)
Bathyuridae
Acidiphorus sp. 2
Pliomeridae
Pseudocybele paranasuta McAdams & Adrain, 2009c (Fig. 20A, D)

Remarks. Hintze (1951, 1953) assigned the uppermost Fillmore Formation and the lower 130 feet of the Wah Wah Formation at Ibex to Zone J. Ross *et al*. (1997) named this zone the *Pseudocybele nasuta* Zone and asserted (Ross *et al*. 1997, p. 20) that "The base of the zone is 8.8 m (29 ft) above the base of unit 9 of the informal *Calathium* siltstone member (member 6) of the Fillmore Formation. The lower boundary of the zone is defined by the lowest observed occurrence of *Pseudocybele nasuta*…." These authors correctly identified the position of a significant faunal change, as species of the *Presbynileus ibexensis* Zone are completely and suddenly replaced by a new assemblage with much lower

species richness. A species of *Pseudocybele* is common in this new assemblage, but the Ross *et al*. (1997) identification of it as *P. nasuta* is incorrect. Although trilobites from this interval are very common and well preserved, none had ever been illustrated until McAdams & Adrain (2009c) described the species of *Pseudocybele* as their new *P. paranasuta*. It is obviously distinct from the younger species in the "*P. nasuta*" Zone (see McAdams & Adrain, 2009c; cf. Figs 20A, D, 21A, D) in, among other features, the possession of a longer, narrower glabella with more subquadrate lateral lobes, S3 which contacts the axial furrow versus completely shallowed adaxial to it, narrower axial furrow, and a pygidium in which the sixth ring and ribs are merged together into a complex terminal piece versus distinctly expressed.

Hintze (1953, pl. 17, figs 10, 13, 14) illustrated specimens of *Isoteloides* from this interval (his locality H-30, 705', approximately 281 m), but misassociated them with younger specimens (Hinzte 1953, pl. 17, figs 9, 11, 12) from Section J (locality J-8) as "*Isoteloides polaris* Poulsen." New collections indicate that two separate species of *Isoteloides* are involved, both of which are new. Hintze (1953, pl. 15, figs 5-8, 13) recognised that the species of *Ptyocephalus* from this interval is distinct, terming it "*Kirkella* cf. *K. vigilans* (Whittington)." This species is also new, and is illustrated in Figure 20C, F. A third new species of asaphid, apparently representing a new genus (Fig. 20B, E), is common in the collections but was not mentioned by either Hintze (1953) or Ross *et al*. (1997).

The lowest occurrence of *Pseudocybele paranasuta* is in talus blocks collected at H 270T m on a covered slope. The basal stratotype is the lowest in situ occurrence at H 282.4 m. The highest in situ sample is at H 286.7 m. The fauna is similar at all sampling horizons, consisting of three common species of asaphids, *P. paranasuta*, and one or possibly more extremely rare bathyurids.

15. "*Pseudocybele nasuta* Zone" (restricted) (Fig. 21)

Horizons. ROH 66.8T m; H 290.4, 294.2, 297.0, 301.1, 304.2, 307.2, 308.5 m; J 15.6, 16.1, 20.0, 28.1, 40.2 m; locality YH-2.

Species.
Asaphidae
- *Isoteloides* sp.
- *Lachnostoma latucelsum* Ross, 1951a (Fig. 21Q, U)
- *Presbynileus utahensis* Hintze, 1953
- *Ptyocephalus declevitus* (Ross, 1951a) (Fig. 21R, V)
- *Stenorhachis genalticurvata* (Hintze, 1953)
- *Trigonocercella acuta* Hintze, 1953

Bathyuridae
- *Acidiphorus brighti* (Hintze, 1953) (Fig. 21K)
- *Acidiphorus brevus* (Hintze, 1953) (Fig. 21N)
- *Acidiphorus wahwahensis* (Hintze, 1953)
- *Acidiphorus williamsi* (Ross, 1951a) (Fig. 21H, L)
- *Acidiphorus* sp. nov. 6 (Fig. 21J)
- *Acidiphorus* sp. nov. 7
- *Benthamaspis diminutiva* Hintze, 1953 (Fig. 21O, S)
- Bathyuridae gen. nov. 6 sp. nov. 2 (Fig. 21I, M)
- Bathyuridae gen. nov. 6 sp. nov. 3

Cheiruridae
- *Forteyops sexapugius* (Ross, 1951a) (Fig. 21E)
- *Kawina webbi* Hintze, 1953
- *Kawina* sp. nov. B (Fig. 21T)

Dimeropygidae
- *Dimeropygiella caudanodosa* Ross, 1951a
- *Dimeropygiella* sp. nov. 4
- *Ischyrotoma wahwahensis* Adrain, Westrop, Landing & Fortey, 2001

Harpetidae
- *Scotoharpes* sp. 3

Odontopleuridae
- *Meadowtownella*? sp. nov. A

Pliomeridae
- *Cybelopsis* sp. nov. 1 (Fig. 21B, F)
- "*Pseudocybele nasuta* Ross, 1951a" (Fig. 21A, D)
- *Pseudocybele* sp. nov. 1
- *Pseudomera* sp. nov. 1 (Fig. 21C, G)

Telephinidae
- "*Carolinites genacinaca* Ross, 1951a" (Fig. 21P, W)
- *Carolinites* sp. nov. 3
- *Opipeuterella* sp. 3

Remarks. Ross (1949) named "Zone J" for faunas that he collected from his Locality 8, on the west side of Clarkston Mountain, Idaho, and Locality 13, at Round Hill, near Mantua, Utah (Fig. 2E). At Clarkston Mountain, he reported the zone from a 10 foot interval. At Round Hill, he claimed (Ross 1949, p. 488) that silicified trilobites of Zone J occur "in the interval from 270 to 355 feet from the top of the formation". We have not recollected the Clarkston Mountain locality, but at Round Hill, the silicified "Zone J" faunas occur as talus blocks weathering in place along strike at a single horizon (ROH 66.8T). We found no evidence of

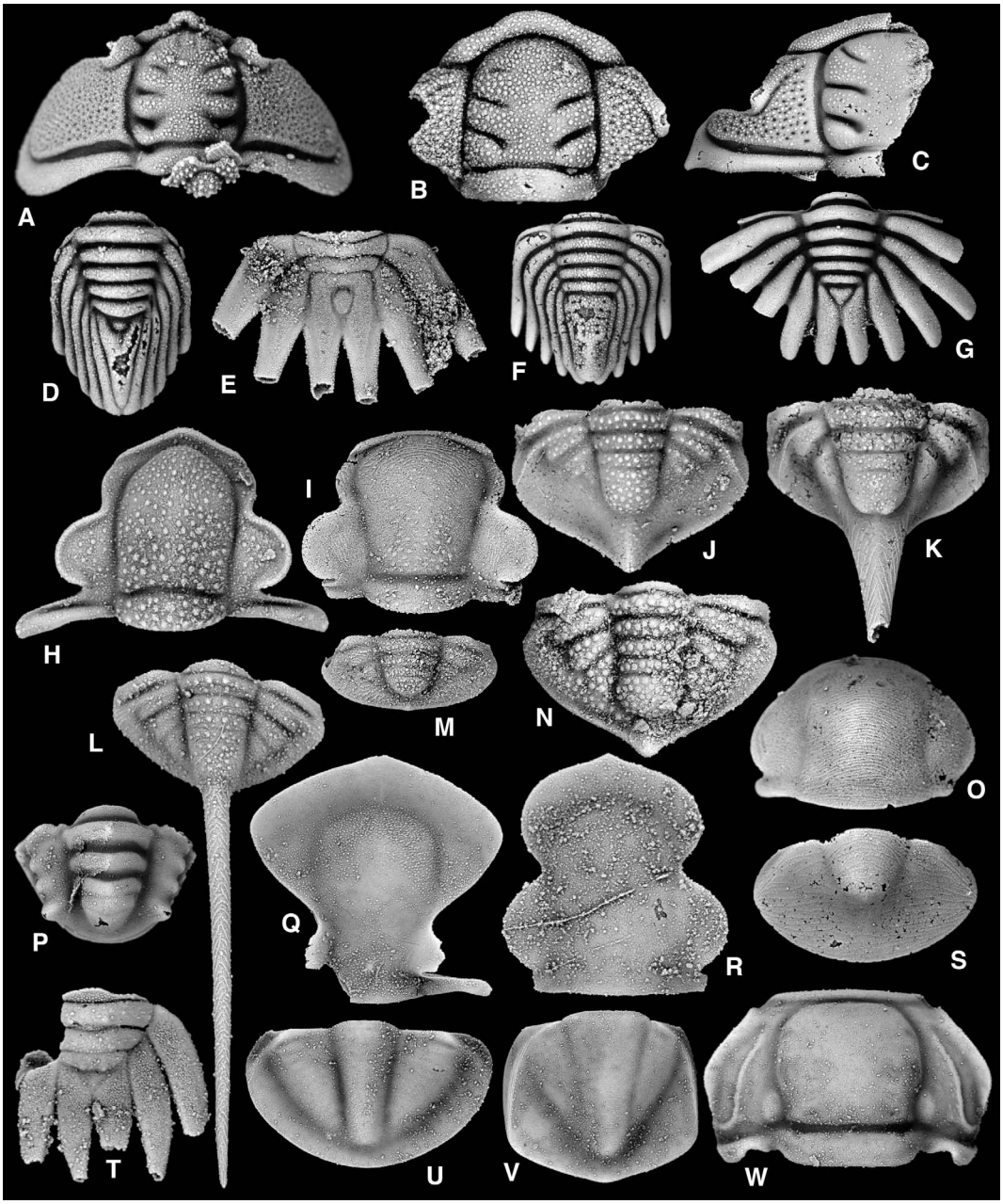

Fig. 21. Trilobites of the "*Pseudocybele nasuta*" Zone. All views are dorsal. **A**, **D**, "*Pseudocybele nasuta* Ross, 1951a." **A**, cranidium, SUI 115394, x10 (J 16.1 m). **D**, pygidium, SUI 115395, x7.5 (J 16.1 m). **B**, **F**, *Cybelopsis* sp. nov. 1. **B**, cranidium, SUI 115396, x6 (J 15.6 m). **F**, pygidium, SUI 115397, x6 (J 16.1 m). **C**, **G**, *Pseudomera* sp. nov. 1. **C**, cranidium, SUI 115398, x4 (J 15.6 m). **G**, pygidium, SUI 115399, x5 (J 16.1 m). **E**, *Forteyops sexapugius* (Ross, 1951a), pygidium, SUI 115400, x5 (J 28.1 m). **H**, **L**, *Acidiphorus williamsi* (Ross, 1951a). **H**, cranidium, SUI 115401, x7.5 (ROH 66.8T m). **L**, pygidium, SUI 115402, x10 (ROH 66.8T m). **I**, **M**, Bathyuridae gen. nov. 6 sp. nov. 2. **I**, cranidium, SUI 115403, x6 (J 16.1 m). **M**, pygidium, SUI 115404, x6 (J 16.1 m). **J**, *Acidiphorus* sp. nov. 6, pygidium, SUI 115405, x6 (J 28.1 m). **K**, *Acidiphorus brighti* (Hintze, 1953), pygidium, SUI 115406, x6 (J 28.1 m). **N**, *Acidiphorus brevus* (Hintze, 1953), pygidium, SUI 115407, x5 (J 15.6 m). **O**, **S**, *Benthamaspis diminutiva* Hintze, 1953. **O**, cranidium, SUI 115408, x7.5 (J 16.1 m). **S**, pygidium, SUI 115409, x7.5 (J 16.1 m). **P**, **W**, "*Carolinites genacinaca* Ross, 1951a." **P**, pygidium, SUI 115410, x6 (ROH 66.8T m). **W**, cranidium, SUI 115411, x4 (ROH 66.8T m). **Q**, **U**, *Lachnostoma latucelsum* Ross, 1951a. **Q**, cranidium, SUI 115412, x5 (ROH 66.8T m). *(continued opposite)*

the 85 foot thick zone reported by Ross.

In addition to Round Hill, we have sampled horizons potentially belonging to this zone from the highest part of Section H at Ibex (beginning at H 290.4 m), Section J at Ibex, and at locality YH-2 at Yellow Hill. These collections reveal that there are two clearly differentiated stratigraphically successive faunas involved. At Ibex, the lower of these assemblages is found at sampled horizons between H 290.4 m and J 16.1 m, inclusive. The higher assemblage is found from J 20.0 m to J 28.1 m, inclusive. The fauna from YH-2 represents the higher assemblage. No bathyurid species are shared between the assemblages and different species of *Carolinites* are present in each (as recognised by McCormick & Fortey [2002], who designated the higher species [McCormick & Fortey 2002, text-fig. 2S-V] "*Carolinites* sp. nov."). Different species of *Pseudocybele* are also present in either assemblage.

These distinct assemblages should be recognised as separate zones. However, the situation is complicated by the fact that we have not resampled Ross's (1951a) Locality 8, which is the type horizon of both *Carolinites genacinaca* Ross, 1951a, and *Pseudocybele nasuta* Ross, 1951a. Ross's published illustrations of these species are tiny and are of mostly juvenile specimens. It is not possible to determine with confidence which of the species we have sampled elsewhere they represent. Hence, it is not possible at present to regard either assemblage as the *Pseudocybele nasuta* Zone. Retaining the name of the zone and restricting it to the correct assemblage would be preferable for purposes of stability and historical continuity. An attractive alternative would be to use the distinct species of *Carolinites* as name bearers, as these pelagic trilobites had wide, possibly intercontinental, distributions (McCormick & Fortey 1999). This is also impossible at present, as the type material of *C. genacinaca* is inadequately known. For the time being, we refer the entire interval to an undivided "*Pseudocybele nasuta* Zone," pending thorough resampling of Ross's (1951a) Locality 8.

Sampling of the Wah Wah Formation above J 28.1 m is incomplete, but there is clearly new and distinct diversity involved and additional unique faunas permitting further resolution of the biostratigraphy may be present. A collection from J 40.2 m, for example, lacks *Pseudocybele* but includes a new species of *Dimeropygiella* (sp. nov. 4 in the list above).

SYSTEMATIC PALAEONTOLOGY

Repository. Type and figured specimens are housed in the Paleontology Repository, Department of Geoscience, University of Iowa, Iowa City, Iowa, USA, with specimen number prefix SUI.

Family HYSTRICURIDAE Hupé, 1953

Remarks. Although Hystricuridae has been regarded as a paraphyletic group from which other aulacopleuroidean families were derived (e.g., Fortey & Owens 1975), progress has been made in identifying major, potentially monophyletic components. Adrain *et al*. (2003) erected Hintzecurinae and restricted Hystricurinae to a putatively monophyletic group. Adrain & Westrop (2007b) erected Hillyardininae. Each of these subfamilies is diagnosed by what appear to be distinctive synapomorphies. Hintzecurinae is very common in the Skullrockian Stage, but became extinct in the mass extinction which terminated the Skullrockian. Hystricurinae occurs in the Skullrockian, is very common in Stairsian faunas, and became extinct in the mass extinction which now punctuates the Stairsian-Tulean boundary (see above). Hillyardininae is entirely restricted to the Stairsian and very common in all Stairsian faunas from the Great Basin. It too became extinct in the Stairsian-Tulean event.

Three genera (*Litzicurus*, *Psalikilus*, and one currently new and unnamed - see Hystricuridae gen. nov. 1 sp. nov. 1 [Fig. 7B, F]) appear immediately following the extinction, in the *Litzicurus shawi* Zone, and share the following synapomorphies: anterior border with distinct W shape in anterior view; preglabellar field with median depression retained at least until early holaspid stage; broad pygidium with at least four segments, usually with median node on at least first segment; pygidium with border and margin distinctively curved in lateral and posterior profile, doublural sector turned under beneath anteriormost part, margin bowed dorsally along lateral part, and turned ventrally around posteromedian part; pygdial border with fine raised lines on at least dorsal aspect. Their sister group is at this point unknown, but they are clearly aulacopleuroideans. Their monophyly seems obvious and a new subfamily should likely be recognised. However, we defer this action until a subsequent taxonomic treatment of the remainder of the taxa in the group enables a cladistic analysis to be undertaken. We tentatively refer the genera

U, pygidium, SUI 115413, x5 (ROH 66.8T m). **R**, **V**, *Ptyocephalus declevitus* (Ross, 1951a). **R**, cranidium, SUI 115414, x7.5 (ROH 66.8T m). **V**, pygidium, SUI 115415, x4 (ROH 66.8T m). **T**, *Kawina* sp. nov. B, pygidium, SUI 115416, x7.5 (J 28.1 m).


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for the present to Hystricuridae.

Although three well differentiated genera appear in the lowest Tulean zone, the group was quickly winnowed. Hystricuridae gen. nov. 1 is restricted to the *Litzicurus shawi* Zone, while *Litzicurus* gen. nov. extends only to the overlying *Psalikilus spinosum* Zone. Only *Psalikilus* itself ranges higher into the Tulean, but with some radical transformations of its morphology. By the *Hintzeia celsaora* Zone the clade is almost unrecognisable as compared to its plesiomorphic condition. Pygidial morphology is dramatically different, with the development of a smooth "wall" on the distal pleural regions, separated from the furrowed proximal pleural areas by a raised ridge (e.g., *Psalikilus paraspinosum* Hintze, 1953, Fig. 9AA; cf. Fig. 7E). This morphology is retained by all subsequent species. A stratigraphically intermediate species, *P. spinosum* Hintze, 1953 (Fig. 8A, D), is also a nearly perfect morphological intermediate, retaining the same basic shape and dimensions as *Psalikilus* sp. nov. 1 (Fig. 7E) but also showing nascent development of the ridge circumscribing the proximal pleural region. Because later species of *Psalikilus* depart so dramatically from the clade's original morphology, many of the original synapomorphies are transformed.

Unravelling the higher level relationships of the (now) four putatively monophyletic "hystricurid" clades along with the other aulacopleuroidean families may ultimately require adjustments to familial assignments. Just as Hintzecurinae is ubiquitous in the latter part of the Skullrockian and Hystricurinae and Hillyardininae in the Stairsian, the clade including *Psalikilus* occurs at all known horizons within the Tulean, and apparently became extinct at the top of the stage. Unlike the other groups, however, these trilobites did not disappear in a mass extinction. The youngest known species is *Psalikilus pikum* Hintze, name bearer of the uppermost Tulean zone.

Psalikilus Ross, 1951a

Type species. *Psalikilus typicum* Ross, 1951a, from the Garden City Formation (Tulean; *Psalikilus typicum* Zone), Section HC6, precise horizon unknown (recovered from HC6 203.5 m in the present study), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA.

Other species. *Psalikilus hestoni* sp. nov.; *P. paraspinosum* Hintze, 1953; *P. pikum* Hintze, 1953; *P. spinosum* Hintze, 1953; multiple other new and undescribed species are noted in the faunal lists above and illustrated in Figs 7-15.

Diagnosis. Median occipital node set far forward, on the anterior edge of the occipital ring or, in the youngest and most derived species, on the rear of the main glabellar lobe; occipital spine usually but not always developed on posteromedial part of ring; palpebral furrow deep; eye ridge usually prominent; librigena with very wide field, tall eye, and usually very long, curved genal spine, with posterior or lateral border furrow extended posteriorly along dorsal aspect of spine in many species.

Remarks. As is evident from the species lists above, there are a great many undescribed species of *Psalikilus* present through the sections, and the genus will be the subject of an extended work in preparation. This work will include a complete cladistic analysis, and most comments on phylogenetic structure within the genus are deferred until then. *Psalikilus* is ubiquitous in Tulean samples, and appears to have had high evolutionary rates. It is one of the most biostratigraphically useful taxa, and in some zones (particularly the *Psalikilopsis cuspicaudata* Zone) it appears that subzonal divisions may eventually be possible based upon the order of appearance of different *Psalikilus* species.

Psalikilus hestoni sp. nov. (Figs 22-24)

Diagnosis. Cranidium with fine granulose sculpture on all dorsal surfaces and relatively sparse, small tubercles; occipital spine not developed in most specimens, but small swelling present, approximately the same size as the occipital node, near rear of occipital ring, extended into very short conical spine in some specimens (Fig. 23Q); S1 very deep; S2 prominent as impressed slot; fringe of spines on adaxial side of genal spine prominent and dorsally set; librigenal

Fig. 22. *Psalikilus hestoni* sp. nov. from Section HC6 205.5 m, Garden City Formation (Tulean, Psalikilus hestoni Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA. Magnifications are x10 except where noted. **A**, **B**, **E**, **H**, **J**, cranidium, SUI 115417, dorsal, right lateral, anterior, ventral, and oblique views. **C**, **D**, **G**, cranidium, SUI 115418, right lateral, dorsal, and anterior views. **F**, **I**, **K**, **L**, cranidium, holotype, SUI 115419, left lateral, dorsal, oblique, and anterior views. **M**, **P**, **U**, cranidium, SUI 115420, right lateral, dorsal, and anterior views, x12. **N**, **O**, **Q**, cranidium, SUI 115421, dorsal, left lateral, and anterior views. **R-T**, cranidium, SUI 115422, left lateral, dorsal, and anterior views.


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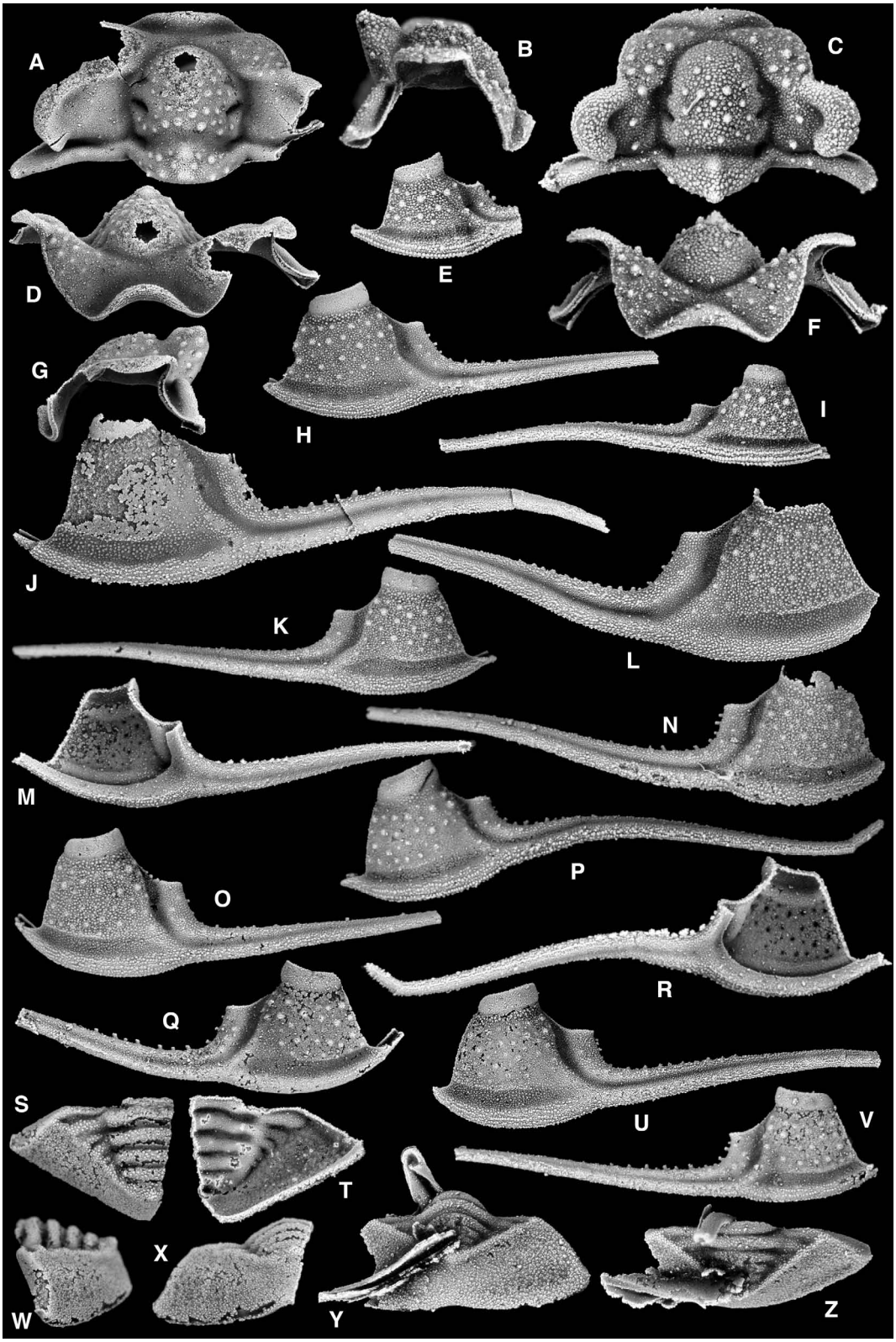
posterior border furrow extended along genal spine, broad near base of spine; pygidial axial rings granulose, lacking tuberculate sculpture.

Description. Cranidium moderately long and very broad, sagittal length 59.1% (57.0%-61.7%) width across midpoint of palpebral lobes, highly vaulted, covered (even in furrows) with dense granulose sculpture overlain by scattered small tubercles; anterior border short compared to sagittal cranidial length, narrow, strongly dorsally arched in anterior view, thicker and longer medially than laterally, with dense granulose sculpture grading into lineations and anastamosing ridges, like that of librigenal border and spine; anterior border doublure almost entirely expressed as anterior face, only slightly wrapped under; anterior border furrow moderately short and deep, with gently V- or M-shaped course, anterior branch of facial suture long, course (in dorsal view) strongly outwardly bowed and posteriorly divergent from corners of anterior border, very steep and anteroventrally curved in lateral view; preglabellar field very short, slightly depressed; frontal areas broad, tapered dorsoposteriorly, triangular, subvertically sloped and anteriorly arched, with scattered small tubercles (upper ones larger) over a densely granulose base prosopon; preglabellar furrow moderately short and shallow, slightly longer at sagittal midline, connected to depression on preglabellar field; glabella moderately vaulted, thimble-shaped, narrow and rounded anteriorly and broader (almost parallel-sided) posteriorly, widest at L2, length 84.2% (78.3%-91.3%) width, with medioposteriorly concentrated small tubercles extending down onto L1 and L2; L1 strongly independently inflated, long, narrow, subrectangular, with tapered anterior portion that connects to bases of L2 and L3 to isolate ends of glabellar furrows from axial furrow; S1 moderately long, deep, strongly medioposteriorly directed, with posteriormost portion shallower and directed nearly straight backwards; L2 distinctly independently inflated, moderately long and wide, tapered laterally, subtriangular; S2 much less extensive than S1, moderately short, deep (shallower on larger specimens), directed backwards at about 45º below horizontal (frames triangle shape of L2 with S1 and axial furrow); L3 poorly defined, just a posteromedially angled sliver between S2 and slight indentation of S3 (where eye ridge approaches glabella); median glabellar lobe very broad, highly inflated, merged with frontal lobe; axial furrow moderately narrow and shallow, deeper laterally and posteriorly, nearly parallel-sided to forwardly divergent along LO-L3, then converges anteriorly, convergent with preglabellar, occipital and posterior border furrows; eye ridge confluent with palpebral lobe, set off by moderately short, very shallow furrows anteriorly and posteriorly (confluent with preglabellar, and axial and palpebral furrows, respectively), directed posterolaterally from S3 at about 250º to palpebral lobe, moderately inflated, more so distal from glabella, moderately long at S3, longer posterolaterally, with several small tubercles scattered proximal to glabella; palpebral lobes very large, reniform, highly vaulted and somewhat inflated, outer rims droop slightly ventrally, widest opposite midpoint of L1, tapered anteromedially; palpebral furrows narrow and deep anteriorly, moderately wide and deep through outermost curvature, narrow and shallow posteriorly, connected anteriorly to posterior eye ridge furrow; posterior branch of facial suture extremely short in dorsal view, steeply posteriorly sloping in lateral view, mainly present as anterior edge of posterior fixigena along posterior projections; sagittal part of posterior fixigena moderately wide and long (about half cranidial length excluding anterior and posterior borders), steeply posteriorly sloped, slightly concave, with scattered small tubercles on median part of field extending down to posterior border, exsagittal area very short, laterally tapered, forming slight rim in front of posterior border furrow; SO shallowly W-shaped, with distal branches (posterior to or alongside L1) short and deep, and median curvature long and moderately deep, confluent with axial and posterior border furrows; LO long medially, tapered anterolaterally to about 1/3 maximum length, highly arched (tr.), moderately inflated, taller posteriorly, laterally confluent with posterior border, with slightly larger granulose sculpture than rest of cranidium, topped by two medium-sized median tubercles: one at anterior margin and one at posterior margin; posterior

Fig. 23. *Psalikilus hestoni* sp. nov. from Section HC6 205.5 m, Garden City Formation (Tulean, Psalikilus hestoni Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA. Magnifications are x12 except where noted. **A**, **D**, **E**, **G**, cranidium, SUI 115423, dorsal, anterior, right lateral, and ventral views. **B**, **C**, **F**, cranidium, SUI 115424, right lateral, dorsal, and anterior views. **H-J**, cranidium, SUI 115425, anterior, left lateral, and dorsal views. **K**, **L**, **N**, cranidium, SUI 115426, dorsal, left lateral, and anterior views. **M**, **O**, **P**, cranidium, SUI 115427, right lateral, dorsal, and anterior views, x15. **Q**, **R**, **U**, cranidium, SUI 115428, dorsal, right lateral, and anterior views. **S**, **T**, **Z**, cranidium, SUI 115429, right lateral, dorsal, and anterior views. **V**, cranidium, SUI 115430, dorsal view, x10. **X**, **Y**, **AA**, cranidium, SUI 115431, dorsal, anterior, and right lateral views, x15.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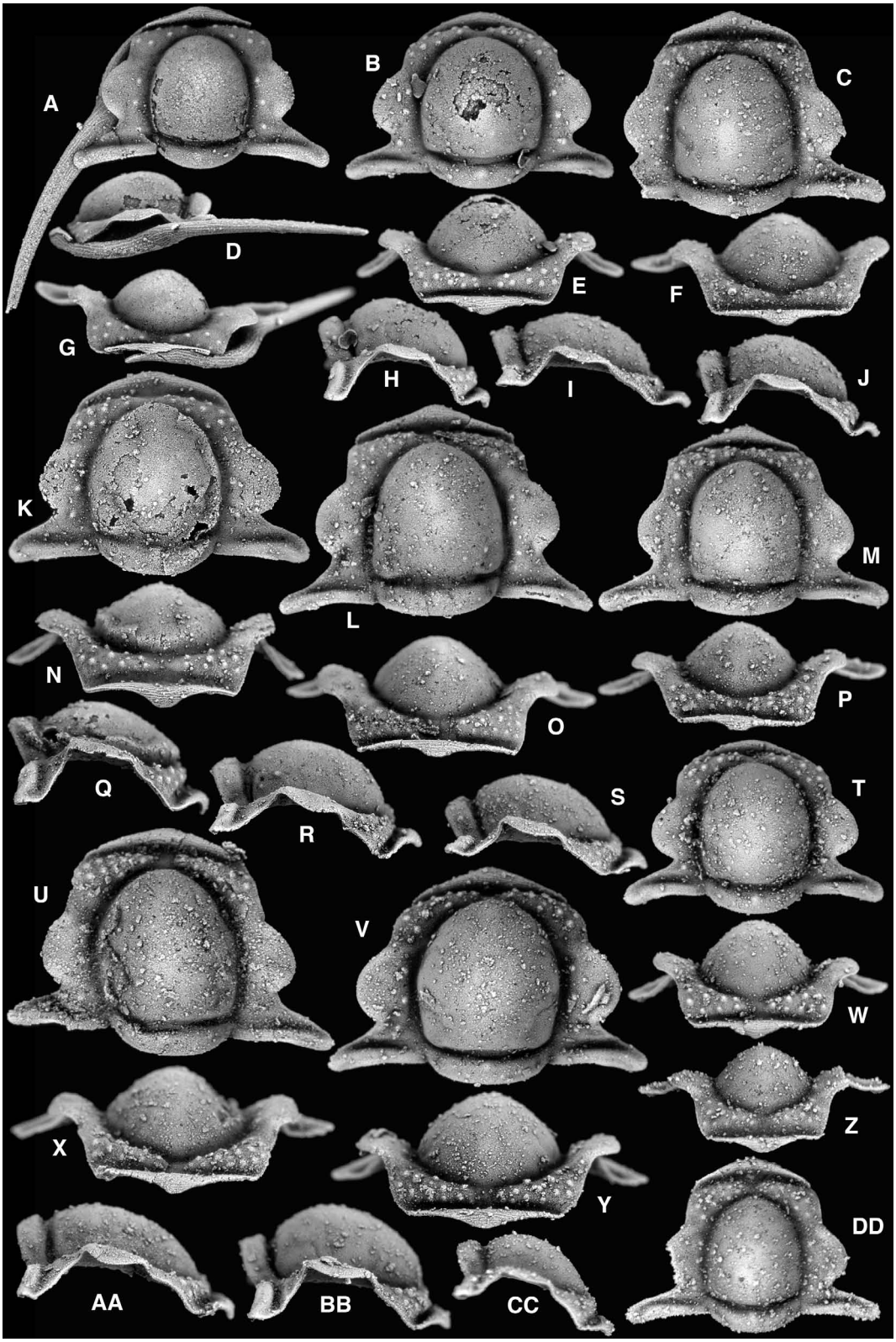
border furrow short, deep, shorter and shallower sagittally, confluent with SO and axial furrow, course slightly posteriorly divergent to parallel-sided along SO and LO, then nearly transverse to slightly posteriorly curved along posterior projections; posterior border short, slightly longer exsagittally, gently posterolaterally curved, with a few small tubercles near axial furrow.

Librigena with narrow, moderately long (compared to length of librigenal field), outwardly convex (more so posteriorly), lenticular eye with width at midpoint 36.4% (33.0%-39.8%) length, and with visual surface of many tiny closely packed lenses; circumocular furrow moderately wide, shallow, filled with densely concentrated tiny granules; anterior branch of facial suture very steep and long along field, slightly angled posteriorly, with shorter, anterodorsally curved portion along anterior projection of lateral border; posterior branch of facial suture very short, posteriorly sloped at about 45º along field, then subhorizontal along lateral border; librigenal field gently convex, trapezoidal, nearly square, with width under midpoint of eye 61.2% (55.6%-65.4%) length along lateral border and length of eye about half length of lateral border, slightly extended posteroventrally into a point that crosses lateral border furrow and joins border, with dense granulose sculpture overlain by scattered small tubercles; lateral border furrow very broad, moderately deep, filled with tiny granules like circumocular furrow, slightly ventrolaterally convex along bottom of field, separated from extension of librigenal posterior border furrow by pointed extension of field; posterior border furrow slightly posteriorly convex along top half of posterior side of field, then angled posteroventrally at about 45º down to genal spine, continuously narrowing posteriorly into median genal spine furrow following curvature of spine; lateral border moderately narrow, slightly inflated, densely granulose with granules organised into subparallel raised lines ventrolaterally (Fig. 24J, M, R), upper portion (along posterior of field) wider and with small peg-like spines extending from ω down along dorsal edge of genal spine, with tapered anterior projection; genal spine very long, flattened, blade-like, with ventral portion (below median furrow) more inflated than dorsal portion, strongly posteriorly tapered to a small point, with dense granulose sculpture, grading into some subparallel raised lines ventrally; doublure narrow, extended to lower edge of border furrow, wider near base of genal spine.

Rostral plate, hypostome and thorax unknown.

Pygidium semilunate in outline, with sagittal length from articulating furrow 27.8% maximum width across posterior edge of articulating facet, highly vaulted, with dense, evenly distributed granulose sculpture; articulating half ring fairly long (approximately equal to length of first axial ring), slightly narrower than first axial ring, with gently convex anterior margin; articulating furrow short, incised, longer and deeper laterally; fulcrum sharply demarcated as raised ridge separating distinguishable inner pleurae from merged outer pleural "wall" structure, with area inside fulcrum triangular in shape; articulating facet large, very short anterodorsally, lengthens posteroventrally to about three times upper length; axial furrow moderately wide, deep, deeper when crossing inter-ring/interpleural furrows (forms apodemal pits), strongly anteriorly divergent; axis moderately arched, higher anteriorly, composed of four rings and small terminal piece, very broad, gently tapered posteriorly to rounded point; sequential axial rings slightly decrease in length posteriorly, each ring individually inflated; inter-ring furrows deep, deeper laterally (into apodemal pits), moderately short (shorter in smaller specimen), shallower anteriorly than posteriorly (see lateral view, Fig. 24W), but without prominent pseudo-articulating half rings; inner pleurae of first three axial rings divided into anterior and posterior bands by deep, moderately long (shorter posteriorly) pleural furrow, pleurae of fourth ring undivided; interpleural furrows longer, shallower than pleural furrows; pleural and interpleural furrows nearly transverse (anteriorly) to moderately posterolaterally angled (posteriorly), none extend onto "wall" of outer pleurae; outer pleurae merged into tall (anteriorly, tapered posteriorly to about half height at sagittal

Fig. 24. *Psalikilus hestoni* sp. nov. from Section HC6 205.5 m, Garden City Formation (Tulean, Psalikilus hestoni Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA. **A**, **D**, **G**, cranidium, SUI 115432, dorsal, anterior, and left lateral views, x10. **B**, **C**, **F**, cranidium, SUI 115433, right lateral, dorsal, and anterior views, x20. **E**, left librigena, SUI 115434, external view, x15. **H**, left librigena, SUI 115435, external view, x10. **I**, right librigena, SUI 115436, external view, x15. **J**, left librigena, SUI 115437, external view, x10. **K**, **M**, right librigena, SUI 115438, external and internal views, x12. **L**, right librigena, SUI 115439, external view, x10. **N**, right librigena, SUI 115440, external view, x12. **O**, left librigena, SUI 115441, external view, x10. **P**, **R**, left librigena, SUI 115442, external and internal views, x15. **Q**, right librigena, SUI 115443, external view, x12. **U**, left librigena, SUI 115444, external view, x10. **V**, right librigena, SUI 115445, external view, x12. **S**, **T**, **W**, **X**, pygidium, SUI 115446, dorsal, ventral, left lateral, and posterior views, x10. **Y**, **Z**, pygidium, SUI 115447, posterodorsal and dorsal views, x15.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line - see Fig. 24X, Y) wall-like structure, gently laterally convex, sloping outward from fulcrum and triangular dorsal area of pygidium to form semilunate outline, with strong dorsal inflection at midline.

Material. Holotype, cranidium, SUI 115419 (Fig. 22F, I, K, L), and assigned specimens SUI 115417, 115418, 115420-115447, from Section HC6 205.5 m, Garden City Formation (Tulean, *Psalikilus hestoni* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA.

Etymology. After Charlton Heston.

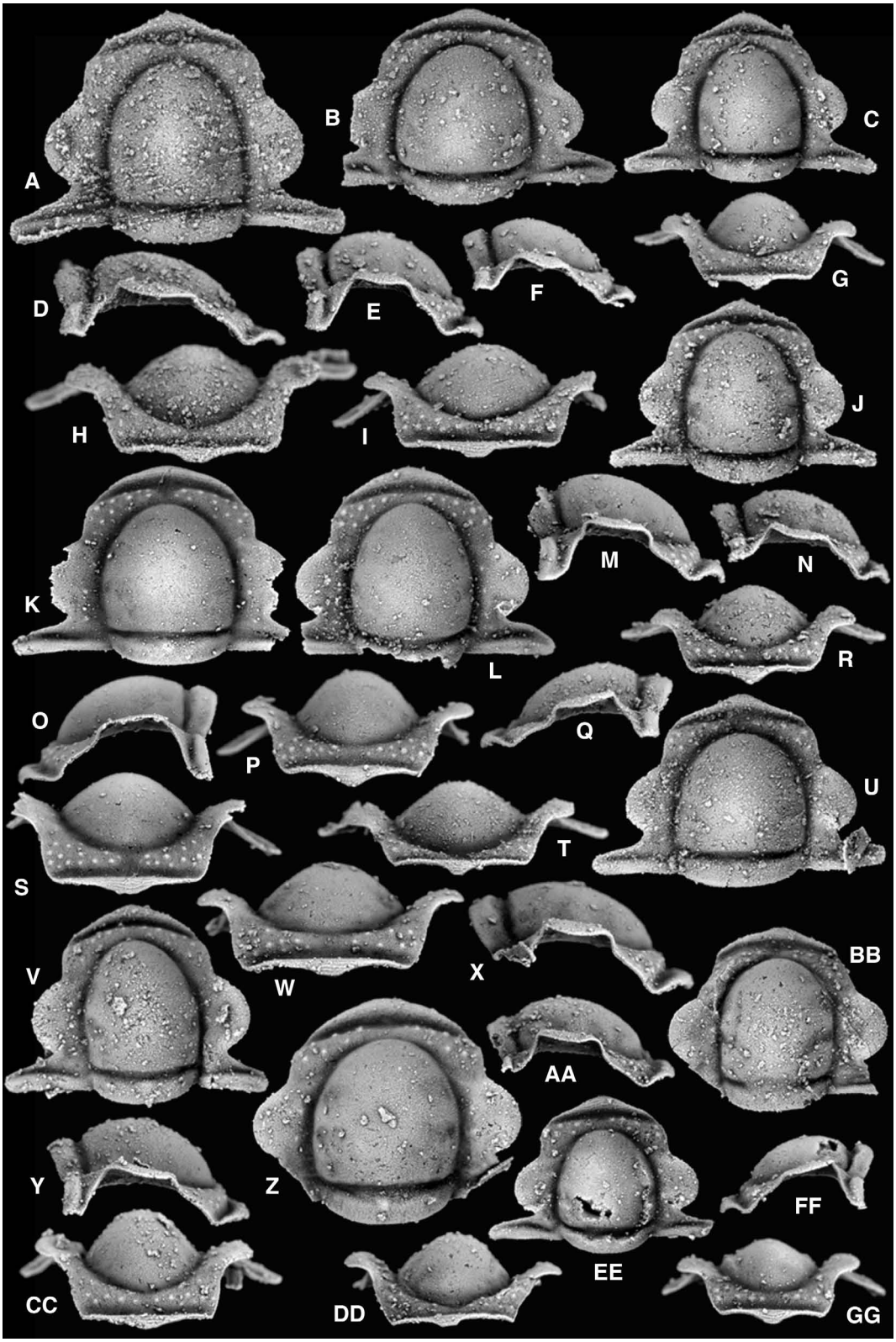
Remarks. *Psalikilus hestoni* closely resembles *P. typicum* Ross, 1951a, from the underlying *P. typicum* Zone in general dimensions, in the lack of an occipital spine, and in the presence of a broad librigenal lateral border furrow separated from the field by a raised ridge. The following comparison is based on extensive new material of *P. typicum* (Fig. 11A, E), which will be described in a forthcoming work. *Psalikilus hestoni* has a granulose dorsal sculpture with scattered and generally subdued tubercles, whereas *P. typicum* has densely crowded larger tubercles on all dorsal cranidial surfaces and the librigenal field. The palpebral lobes are more laterally set in *P. hestoni*, giving the cranidium a more trapezoidal versus subquadrate shape in plan view. The median part of the occipital ring is essentially flat in *P. hestoni*, versus distinctly dorsally "humped" in *P. typicum*. While the librigenal posterior border furrow is extended along the genal spine in both species, in *P. hestoni* it is much broader proximally. The pygidial axial rings of *P. typicum* have a dense sculpture of crowded small tubercles whereas those of *P. hestoni* lack tubercles altogether and instead have a fine granulose sculpture.

Psalikilus hestoni is distinguished from *P. spinosum* Hintze, 1953 (Fig. 8A, D), by the absence of the latter taxon's large paired glabellar tubercles and fairly long occipital spine. The cranidium of *P. hestoni* is much narrower anteriorly, and the eye ridges are set obliquely versus subtransversely. Pygidial differences are profound, as the pygidium of *P. spinosum* lacks a fully developed subvertical "wall" and retains a broad furrowed pleural region and lobate posterior margin. The cranidial contrasts apply also to *P. paraspinosum* Hintze, 1953 (Fig. 9Z, AA). Pygidia of these species are much more comparable, but that of *P. hestoni* differs from that of *P. paraspinosum* in its much greater width

Fig. 25. *Litzicurus shawi* sp. nov. from Section HC6 142.0 m, Garden City Formation (Tulean, *Litzicurus shawi* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA. All magnifications are x10. **A**, **E**, **G**, cranidium with attached left librigena, SUI 115448, dorsal, left lateral, and anterior views. **B**, **E**, **H**, cranidium, SUI 115449, dorsal, anterior, and right lateral views. **C**, **F**, **I**, cranidium, SUI 115450, dorsal, anterior, and right lateral views. **J**, **M**, **P**, cranidium, SUI 115451, right lateral, dorsal, and anterior views. **K**, **N**, **Q**, cranidium, SUI 115452, dorsal, anterior, and right lateral views. **L**, **O**, **R**, cranidium, SUI 115453, dorsal, anterior, and right lateral views. **S**, **T**, **W**, cranidium, SUI 115454, right lateral, dorsal, and anterior views. **U**, **X**, **AA**, cranidium, SUI 115455, dorsal, anterior, and right lateral views. **V**, **Y**, **BB**, cranidium, SUI 115456, dorsal, anterior, and right lateral views. **Z**, **CC**, **DD**, cranidium, SUI 115457, anterior, right lateral, and dorsal views.

Fig. 26 (overleaf). *Litzicurus shawi* sp. nov. from Section HC6 145T m, Garden City Formation (Tulean, *Litzicurus shawi* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA. Magnifications are x12 except where noted. **A**, **D**, **H**, cranidium, SUI 115458, dorsal, right lateral, and anterior views. **B**, **E**, **I**, cranidium, SUI 115459, dorsal, right lateral, and anterior views. **C**, **F**, **G**, cranidium, SUI 115460, dorsal, right lateral, and anterior views. **J**, **N**, **R**, cranidium, SUI 115461, dorsal, right lateral, and anterior views. **K**, **O**, **S**, cranidium, SUI 115462, dorsal, left lateral, and anterior views. **L**, **M**, **P**, cranidium, SUI 115463, dorsal, right lateral, and anterior views. **Q**, **T**, **U**, cranidium, SUI 115464, left lateral, anterior, and dorsal views, x10. **V**, **Y**, **CC**, cranidium, SUI 115465, dorsal, right lateral, and anterior views. **W**, **X**, **Z**, cranidium, SUI 115466, anterior, right lateral, and dorsal views. **AA**, **BB**, **DD**, cranidium, SUI 115467, right lateral, dorsal, and anterior views, x10. **EE-GG**, cranidium, SUI 115468, dorsal, left lateral, and anterior views.

Fig. 27 (page 587). *Litzicurus shawi* sp. nov. from Section HC6 142.0 m, Garden City Formation (Tulean, *Litzicurus shawi* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA. Magnifications are x10 except where noted. **A**, **D**, **G**, **K**, cranidium, holotype, SUI 115469, dorsal, anterior, right lateral, and ventral views, x9. **B**, **E**, **H**, cranidium, SUI 115470, dorsal, anterior, and right lateral views, x9. **C**, **F**, **J**, cranidium, SUI 115471, dorsal, anterior, and right lateral views. **I**, **M**, **P**, cranidium, SUI 115472, right lateral, dorsal, and anterior views. **L**, **N**, **O**, cranidium, SUI 115473, dorsal, right lateral, and anterior views. **Q-S**, left librigena, SUI 115474, external, ventrolateral, and internal views. **T**, left librigena, SUI 115475, external view. **U**, **V**, left librigena, SUI 115476, external and ventrolateral views. **W**, right librigena, SUI 115477, external view. **X**, left librigena, SUI 115478, external view, x15. **Y**, right librigena, SUI 115479, external view.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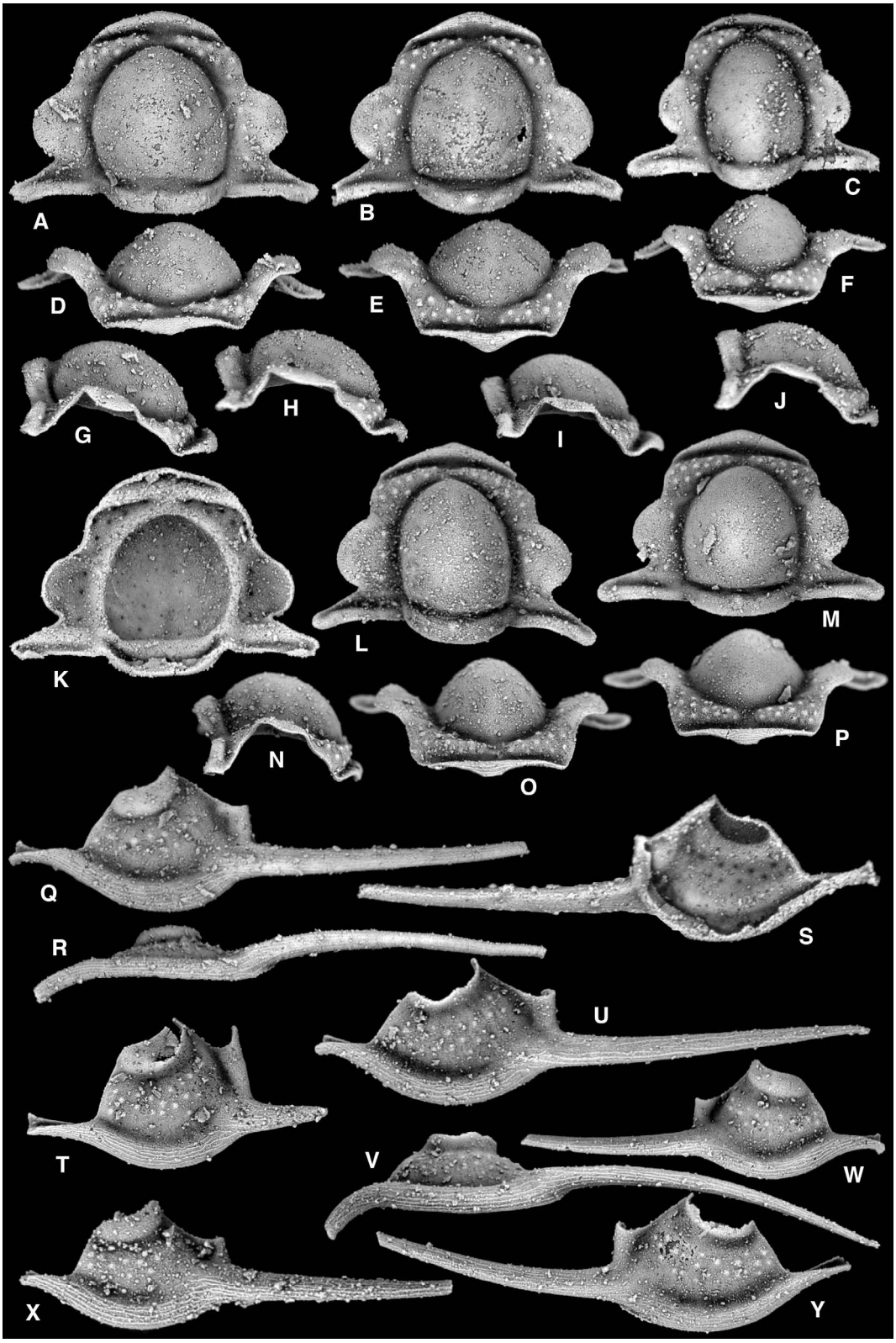
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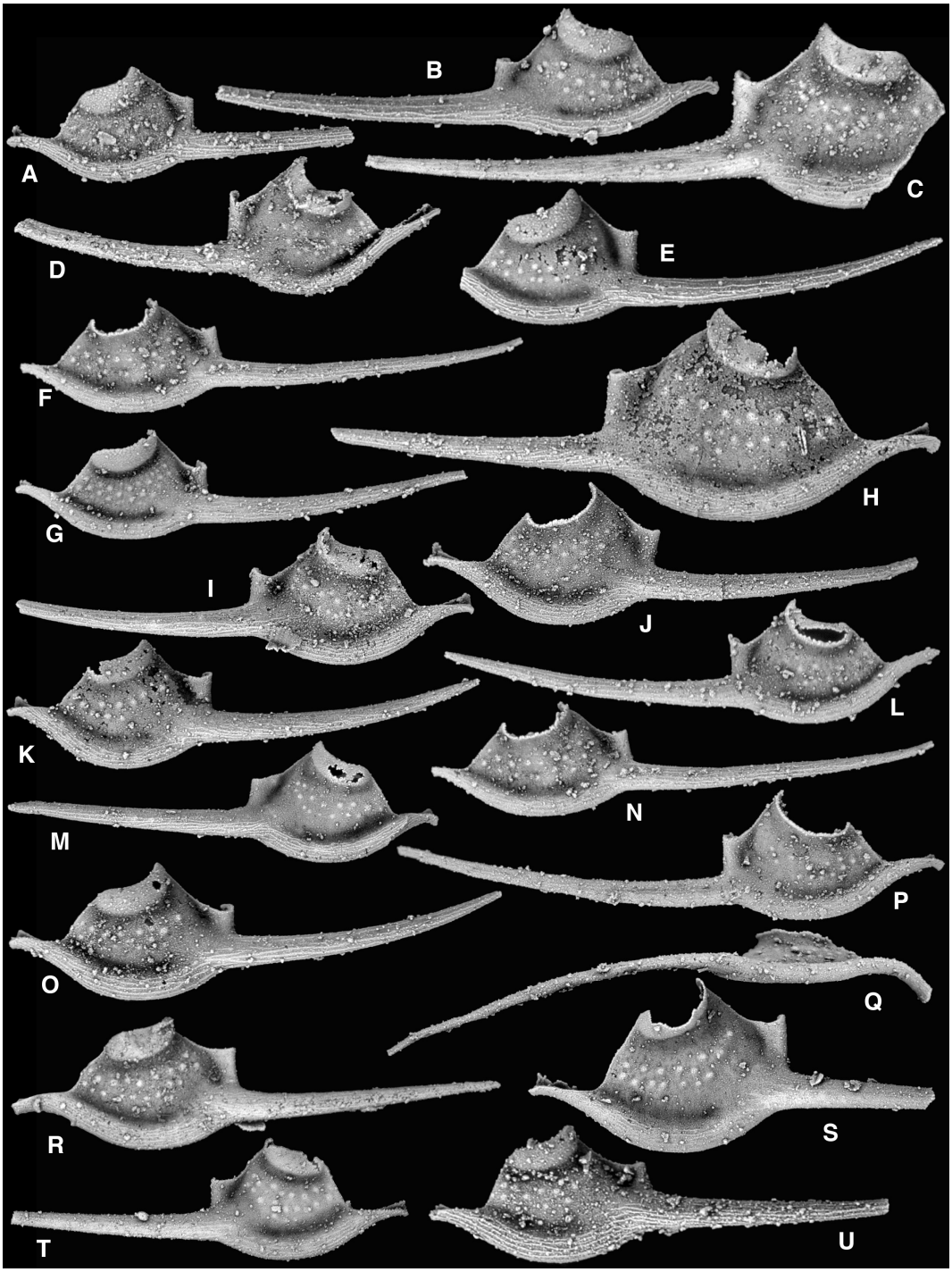


Fig. 28. *Litzicurus shawi* sp. nov. from Section HC6 142.0 m and 145T m, Garden City Formation (Tulean, *Litzicurus shawi* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho. **A**, left librigena, SUI 115480, external view, x12 (HC6 145T m). **B**, right librigena, SUI 115481, external view, x15 (HC6 145T m). **C**, right librigena, SUI 115482, external view, x10 (HC6 142.0 m). **D**, right librigena, SUI 115483, external view, x10 (HC6 145T m). **E**, left librigena, SUI 115484, external view, x15 (HC6 145T m). **F**, left librigena, SUI 115485, external view, x10 (HC6 145T m). **G**, left librigena, SUI 115486, external view, x12 (HC6 145T m). **H**, right librigena, SUI 115487, external view, x10 (HC6 142.0 m). *(continued opposite)*

relative to its length and relatively narrower axis. *Psalikilus pikum* Hintze, 1953 (Fig. 16C, G), is the youngest known species of the genus and is not closely comparable to *P. hestoni*, as it has the occipital node moved forward onto the rear of the glabella and developed into a short spine, a long occipital spine, a small, subparallel-sided glabella with only S1 strongly expressed, and many other obvious differences. *Psalikilus hestoni* will be compared with the other unnamed species listed and illustrated herein in a forthcoming systematic work on the genus.

Litzicurus gen. nov.

Type species. *Litzicurus shawi* sp. nov., from Section HC6 142.0 m and 145T m, Garden City Formation (Tulean, *Litzicurus shawi* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA.

Other species. *Litzicurus orbus* (Ross, 1953) from Section HC6 165.2 m, Garden City Formation (Tulean, *Psalikilus spinosum* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA.

Diagnosis. Glabella moderately inflated, glabellar furrows barely impressed; eye long and narrow; librigenal field narrow; long, only moderately curved genal spine; librigenal lateral border and genal spine with strong sculpture of fine raised lines; pygidium subtriangular with five axial rings.

Etymology. After the Litz Basin, which is near the type locality; gender is masculine.

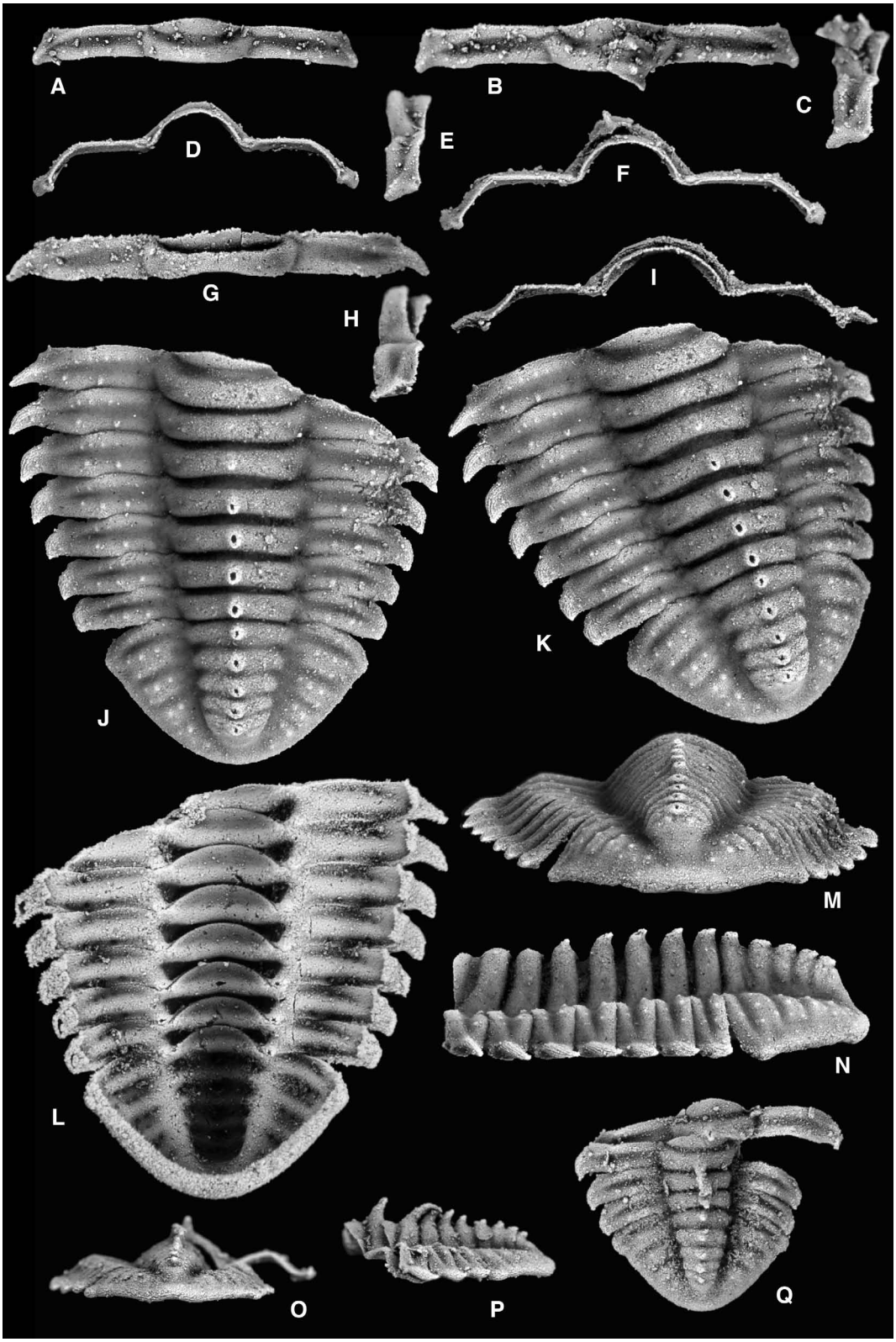
Remarks. *Litzicurus* is distinguished from the plesiomorphic morphology of *Psalikilus* (Fig. 7A, E) by the lack of strongly impressed glabellar furrows, lack of a secondary occipital node or spine behind the occipital node, the possession of a longer, more dorsally inflated glabella, a much narrower librigenal field, and pygidium with a greater number of segments and a nearly flat ventral margin. *Litzicurus* is distinguished from a third, unnamed, psalikiline genus (Hystricuridae gen. nov. sp. nov. 1, Fig. 7B, F) in the presence versus absence of tuberculate cranidial sculpture, much shorter (exsag.) posterior fixigenal projections, and pygidia with strong tuberculospinose sculpture and a distinct margin, versus lacking sculpture except for a median node on the first axial ring and lacking a border entirely, with segment divisions visible along the pygidial margin.

Litzicurus shawi sp. nov. (Figs 25-31)

Diagnosis. Glabella lacking sculpture; tuberculate sculpture on interocular and posterior fixigena sparse; palpebral furrow extremely shallow or completely effaced; preglabellar field with medial depressed region; only moderate tuberculate sculpture on librigenal field; pygidium with short median spines on all five axial rings, and lacking a posterior spine.

Description. Cranidium slightly shorter than wide (excluding posterior projections), with sagittal length 86.6% (79.8%-93.6%) width across midpoint of palpebral lobes, highly vaulted (tr. and sag.; mainly due to glabella), mostly effaced, but with some tuberculate sculpture; anterior border moderately long, longest medially and strongly tapered laterally, subtriangular to crescentic in shape, modestly inflated, with sculpture of subparallel raised lines; border doublure only a rim ventrally, visible anteriorly as moderately wide, subtriangular median ventral projection; anterior border furrow short, deep, incised laterally, longer and shallower medially; anterior branch of facial suture fairly short, gently bowed laterally, fairly steeply inclined in lateral view; preglabellar field anteriorly inflated (lateral view), short, with depressed median region connected to anterior border furrow, sculpture of small tubercles; frontal areas moderately broad, short, subtriangular, with sculpture and inflation like that of preglabellar field; preglabellar furrow very short, deep, incised, shallower at junction with median depressed region on preglabellar field, strongly anteriorly convex; glabella highly inflated, ovoid, long, wide, widest at L2, with width 93.5% (82.7%-104.0%) length, effaced, with individual lobes ill defined on most specimens, but more clearly demarcated on some (e.g., Figs 25C, V, 26C, J, V, Z, BB); L1 and L2 subquadrate, roughly equal in area; S1 and S2

I, right librigena, SUI 115488, external view, x10 (HC6 142.0 m). **J**, left librigena, SUI 115489, external view, x10 (HC6 142.0 m). **K**, left librigena, SUI 115490, external view, x12 (HC6 142.0 m). **L**, right librigena, SUI 115491, external view, x12 (HC6 145T m). **M**, right librigena, SUI 115492, external view, x10 (HC6 142.0 m). **N**, left librigena, SUI 115493, external view, x10 (HC6 145T m). **O**, left librigena, SUI 115494, external view, x12 (HC6 142.0 m). **P**, **Q**, right librigena, SUI 115495, external and ventrolateral views, x10 (HC6 145T m). **R**, left librigena, SUI 115496, external view, x10 (HC6 142.0 m). **S**, left librigena, SUI 115497, external view, x10 (HC6 142.0 m). **T**, right librigena, SUI 115498, external view, x10 (HC6 142.0 m). **U**, left librigena, SUI 115499, external view, x15 (HC6 142.0 m).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long, shallow, with S1 curved posteromedially at about 45º; S2 nearly transverse to slightly posteromedially angled and narrower than S1; L3 short, subrectangular; S3 (when visible, e.g., Fig. 26BB) shorter than S1 and S2, very narrow, extremely shallow; axial furrow very narrow, deep, incised, parallel-sided until S2, then strongly anteriorly convergent; fixigenae narrow, moderately inclined up to palpebral lobes, mostly effaced, but with widely spaced small tubercles following rim of axial furrow; eye ridge (e.g., Figs 26B, 27A, B) moderately short, tapered anteromedially, only slightly inflated, with short, extremely shallow furrows to the anterior and posterior; palpebral lobes very large, nearly semicircular, widest just past midpoint of length, slope anteroventrally (lateral view) with slightly inflated laterally downturned rim (e.g., Figs 25A, M, 26B, 27B, L); palpebral furrow effaced, visible as change from pale tone of rim to darker grey of lobe; posterior branch of facial suture slightly shorter than anterior branch, slopes posteriorly at about 45º in lateral view; posterior fixigena short, moderately wide, triangular with strongly tapered point at distal edges; SO moderately short, tapered laterally, deep, confluent with axial furrow but separated from posterior border furrow by slight ridge; LO moderately long medially, tapered laterally, crescentic, slightly inflated, with large median tubercle just posterior from SO; doublure short, reaches nearly to SO, tapered laterally, ends short of lateral parts of ring; posterior border furrow mainly short, deep, incised, but extremely shallow medially and distally, course transverse to slightly anteriorly convex; posterior border short, slightly flared distally, slightly independently inflated, with short rim of doublure.

Librigena with eye large, long (compared to length of librigenal field along lateral border), moderately narrow, outwardly convex (more so posteriorly), strongly anteroventrally angled, lenticular in shape, with visual surface of many tiny, closely packed lenses; circumocular furrow broad, moderately deep, narrower and shallower near anterior and posterior edges of eye and on larger specimens; anterior branch of facial suture long, approximately equally split in length along field and along anterior projection of lateral border, steeply sloped (about 150º) along field, then subhorizontal along border; posterior branch of facial suture moderately long, more gently sloped (about 60º) along field, then subhorizontal along lateral border; librigenal field arc-shaped, long, moderately wide, with width at midpoint of eye 42.3% (37.0%-48.6%) length along lateral border (some large specimens [Figs 27T, 28C,H, S] have wide, shorter librigenal fields), slightly convex (more strongly posteriorly), with sculpture of minuscule granules overlain by small tubercles forming two convex-outward arcs centered on librigenal field, with proximal arc longer than distal arc in most specimens by about 1/3, with a few scattered small tubercles; lateral border furrow broad, moderately deep over most of length, but shallow to indistinguishable near base of genal spine, anterior section long and gently outwardly curved, posterior section short and posterolaterally angled; lateral border wide, gently outwardly curved, moderately highly inflated, separated into long anterior section and short posterior section by genal spine, with long, tapered anterior projection, and with sculpture of fine, closely spaced subparallel raised lines following curvature of border; genal spine conical, extremely long, broad at base and tapered to a fine point, gently posteromedially curved, with linear sculpture like that of lateral border; doublure moderately narrow, not quite reaching lateral border furrow, only slightly tapered in width anteriorly (inside of doublure shows in dorsal view at tip of anterior projection of lateral border), with small Panderian notch located nearly at posterior edge of border.

Rostral plate and hypostome not recovered.

Incomplete thoracopygidia demonstrate thorax of at least seven segments; thorax gently posteriorly tapered, with anterior three segments widest, approximately equally wide, and posterior four segments progressively narrower; posterior four segments with prominent, medium sized, conical median spines, third segment with median tubercle, second segment with faint median tubercle, and first preserved segment effaced; lateral tips of all but seventh segment with broad-based, flattened but slightly inflated, triangular, slightly posteriorly curved spine, seventh segment with blunt tips, all pleural spines/tips with subparallel raised lines following curvature; articulating half rings semilunate, long medially and strongly tapered laterally; articulating furrows likewise tapered, moderately deep; axial rings broadly U-shaped, moderately long, slightly

Fig. 29. *Litzicurus shawi* sp. nov. from Section HC6 142.0 m and 145T m, Garden City Formation (Tulean, *Litzicurus shawi* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA. **A**, **D**, **E**, thoracic segment, SUI 115500, dorsal, anterior, and right lateral views, x12 (HC6 145T m). **B**, **C**, **F**, thoracic segment, SUI 115501, dorsal, right lateral, and anterior views, x12 (HC6 145T m). **G**-**I**, thoracic segment, SUI 115502, dorsal, right lateral, and anterior views, x12 (HC6 145T m). **J**-**N**, thoracopygidium, SUI 115503, dorsal, oblique, ventral, posterior, and left lateral views, x15 (HC6 142.0 m). **O**-**Q**, posterior thoracic segments and pygidium, SUI 115504, posterior, left lateral, and dorsal views, x12 (HC6 142.0 m).

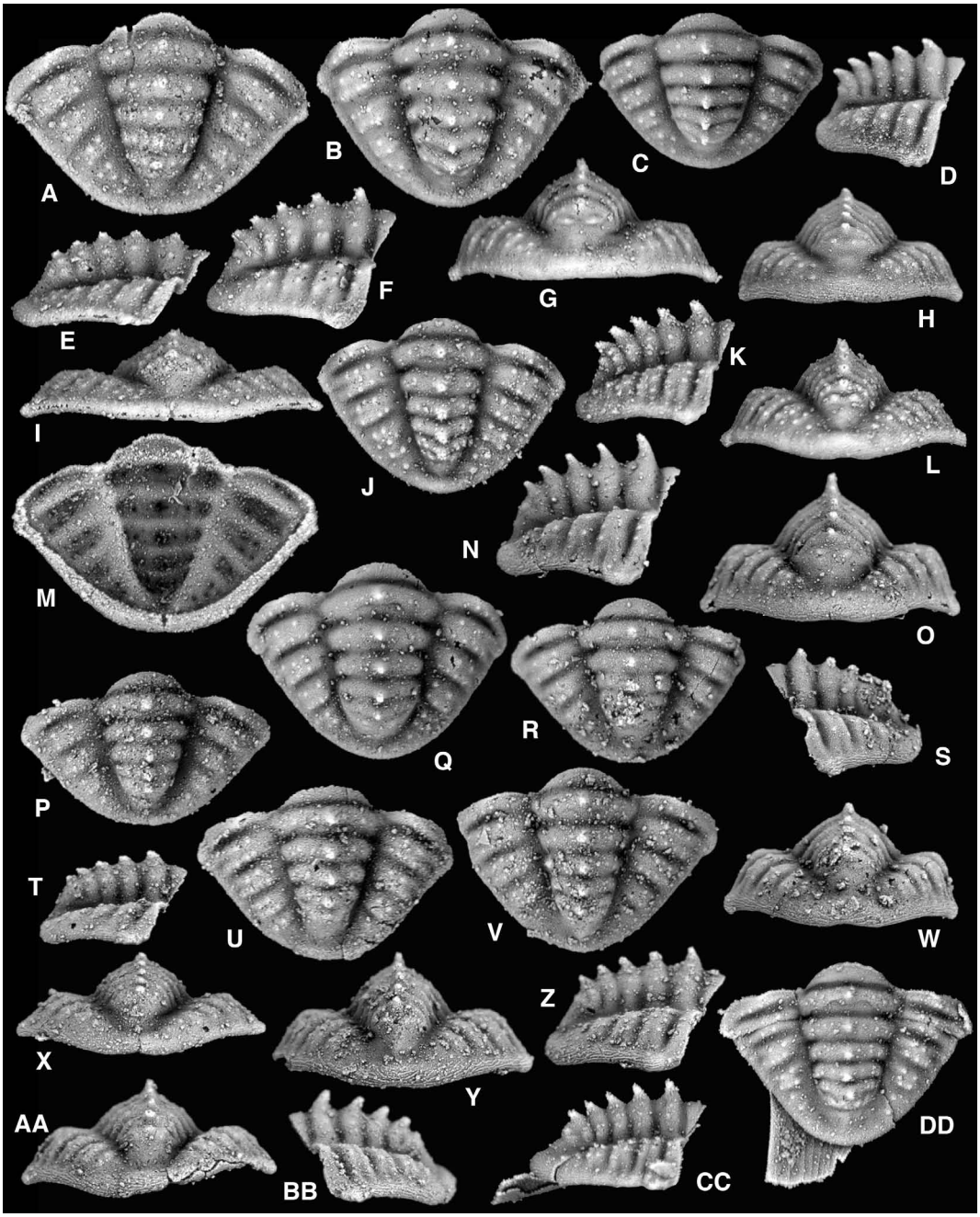

Fig. 30. *Litzicurus shawi* sp. nov. from Section HC6 142.0 m, Garden City Formation (Tulean, *Litzicurus shawi* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA. **A**, **E**, **I**, **M**, pygidium, SUI 115505, dorsal, right lateral, posterior, and ventral views, x10. **B**, **F**, **G**, pygidium, SUI 115506, dorsal, right lateral, and posterior views, x10. **C**, **D**, **H**, pygidium, SUI 115507, dorsal, right lateral, and posterior views, x12. **J**-**L**, pygidium, SUI 115508, dorsal, right lateral, and posterior views, x10. **N**, **O**, **Q**, pygidium, SUI 115509, right lateral, posterior, and dorsal views, x12. **P**, **T**, **X**, pygidium, SUI 115510, dorsal, right lateral, and posterior views, x12. **R**, **S**, **W**, pygidium, SUI 115511, dorsal, left lateral, and posterior views, x12. **U**, **AA**, **BB**, pygidium, SUI 115512, dorsal, posterior, and left lateral views, x12. **V**, **Y**, **Z**, pygidium, SUI 115513, dorsal, posterior, and right lateral views, x12. **CC**, **DD**, pygidium, SUI 115514, right lateral and dorsal views, x10.

tapered anterolaterally; axis moderately wide, 40.2% (36.9%-41.8%) total width of segment (excluding spines), tapered posteriorly, highly transversely arched, less arched posteriorly; axial furrow moderately narrow and shallow, anteriorly divergent along posterior portion of axial ring of each segment, then anteriorly convergent along tapered anterior portion of axial ring and articulating furrow, making individual diamond shapes; pleurae long, with short anterior and posterior bands of nearly equal length, with broad, horizontal inner pleural area, relatively gentle fulcral angle, downsloping (about 45-50º), narrower outer pleurae (about 3/4 width of inner pleurae), with inner pleurae decreasing in width and outer pleurae increasing in width posteriorly to approximate equal width on seventh segment, with sculpture of 2-3 small tubercles on posterior band (decreasing anteriorly), and 3-5 tiny tubercles on anterior band (increasing anteriorly); articulating facets separated from rest of anterior pleural band by slightly raised, posterolaterally angled ridge, triangular, long distally and tapered proximally, longer and larger in area on anterior segments; pleural furrow long, laterally tapered to a point slightly sagittal from pleural spine, moderately shallow; axial ring doublure obscured, narrow, laterally curved rim of doublure extends inward from pleural spines.

Pygidium highly vaulted (mainly axially, not pleurally), subequilaterally triangular in shape, with sagittal length (excluding articulating half ring) 62.8% (59.0%-65.8%) maximum width across tips of first segment, with five distinct axial rings and a small triangular terminal piece, and tuberculospinose sculpture; articulating half ring long medially, tapered laterally, semilunate; articulating furrow moderately long, deep; axis wide, about 1/3 total pygidial width, tapered posteriorly, highly vaulted (less vaulted posteriorly); axial rings moderately long, decrease in length posteriorly, mainly effaced but with prominent median spine as on posterior thoracic segments; inter-ring furrows moderately long and deep, with large pseudoarticulating half ring in first inter-ring furrow on most specimens; axial furrow moderately wide and deep, shallower posteriorly and very shallow behind terminal piece; articulating facet short, narrow post-fulcral wedge; fulcral angle about 60º anteriorly, gentler posteriorly, causing moderate to slight vaulting of pleural region; pleurae very similar to thoracic pleurae, with moderately long and deep pleural furrows, very shallow interpleural furrows, and sculpture of two small tubercles centered on posterior pleural band and 3-4 on anterior pleural band, with one tubercle opposite terminal piece (tuberculation effaced on some specimens); posterior border moderately thick, thicker posteromedially, slightly inflated, with sculpture of subparallel raised lines, with slight nubby projection opposite first pleural furrow; doublure moderately short, longest posteromedially, tapered anterolaterally, with sculpture of subparallel raised lines.

Material. Holotype, cranidium, SUI 115469 (Fig. 27A, D, G, K), from Section HC6 142.0 and assigned specimens SUI 115448-115468, 115470-115526, from Section HC6 142.0 m and 145T m, Garden City Formation (Tulean, *Litzicurus shawi* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA.

Etymology. After Robert Shaw.

Remarks. *Litzicurus shawi* is compared with *L. orbus* (Ross, 1951a), the only other known species, under discussion of that taxon below.

Litzicurus orbus (Ross, 1953) (Fig. 32)

1953 *Pseudohystricurus orbus*; Ross, p. 640, pl. 63, figs 10, 11, 13-20, 23.
2001 *Pseudohystricurus orbus* Ross; Adrain *et al*., p. 953, tabs 1, 2.

Diagnosis. Densely tuberculate frontal areas and fixigenae; palpebral lobes narrow with impressed palpebral furrow; glabella and occipital ring covered with sparse but distinct tubercles; glabella only moderately inflated in sagittal profile; posterior fixigenal projections narrow; pygidium without strong median nodes on axial segments and with long median spine projecting posteriorly from the rear of the axis.

Material. Illustrated specimens SUI 115527-115530, from Section HC6 165.2 m, Garden City Formation (Tulean, *Psalikilus spinosum* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA, and SUI 115531 from Section G 99.3 m, Fillmore Formation (Tulean, *Psalikilus spinosum* Zone), southern Confusion Range, Ibex area, Millard County, western Utah, USA.

Remarks. Ross (1953) assigned this species to *Pseudohystricurus*, the type species of which is *P. obesus* Ross, 1951a, from the underlying Stairisan Stage. Adrain *et al*. (2001) followed the interpretation of *P. orbus* as a dimeropygid, but expressed uncertainty as to whether Ross (1953) had properly assigned the spinose pygidium. With the discovery of the older type species of

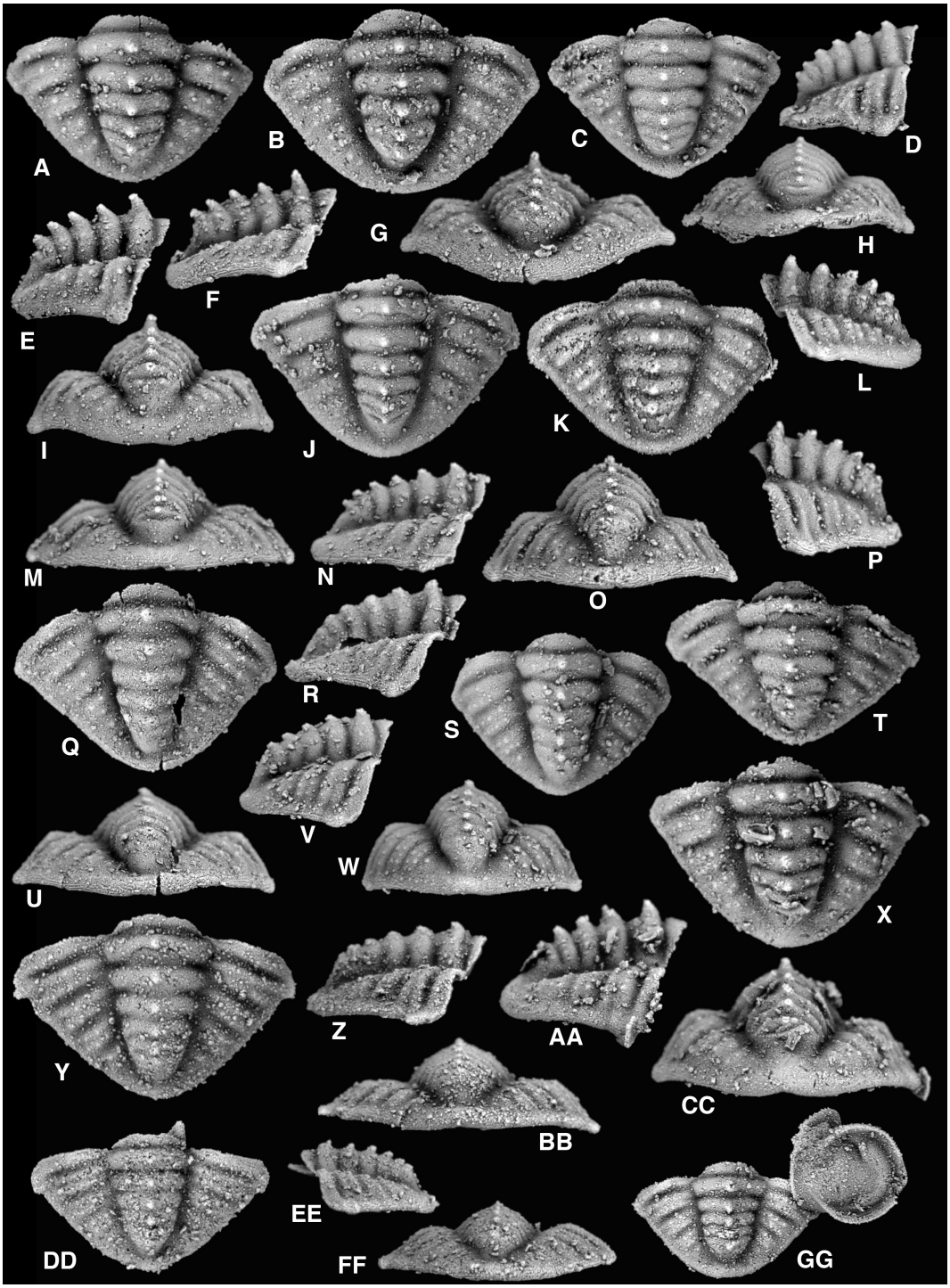

Fig. 31. *Litzicurus shawi* sp. nov. from Section HC6 142.0 m and 145T m, Garden City Formation (Tulean, *Litzicurus shawi* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA. Magnifications are x12 except where noted. **A**, **C**, **I**, pygidium, SUI 115515, dorsal, right lateral, and posterior views (HC6 142.0 m). **B**, **F**, **G**, pygidium, SUI 115516, dorsal, right lateral, and posterior views (HC6 142.0 m). **C**, **D**, **H**, pygidium, SUI 115517, dorsal, right lateral, and posterior views (HC6 145T m). **J**, **M**, **N**, pygidium, SUI 115518, dorsal, posterior, and right lateral views (HC6 145T m). **K**, **L**, pygidium, SUI 115519, dorsal and left lateral views, x10 (HC6 142.0 m). **O**, **P**, **T**, pygidium, SUI 115520, *(continued opposite)*

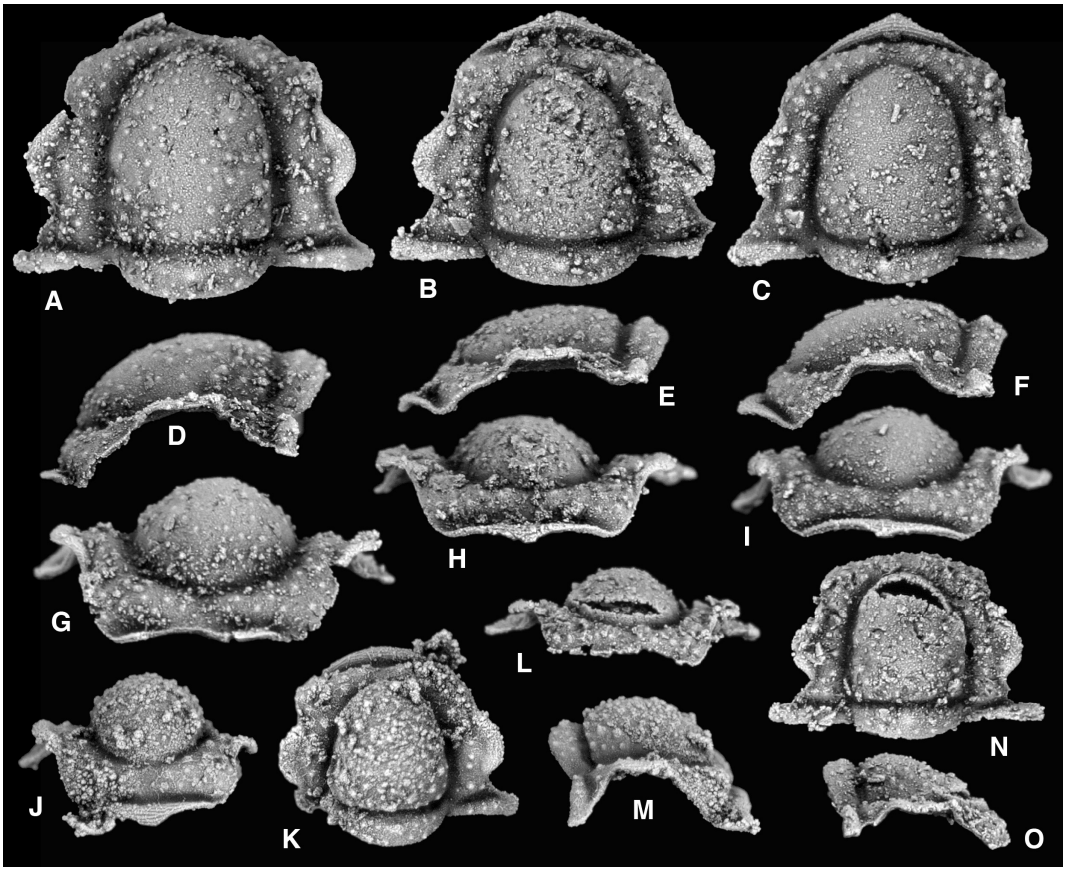

Fig. 32. All magnifications are x15. **A-I**, **L**, **N**, **O**, *Litzicurus orbus* (Ross, 1953) from Section HC6 165.2 m, Garden City Formation (Tulean, *Psalikilus spinosum* Zone), west side of Hillyard Canyon, Bear River Range, Franklin County, southeastern Idaho, USA. **A**, **D**, **G**, cranidium, SUI 115527, dorsal, left lateral, and anterior views. **B**, **E**, **H**, cranidium, SUI 115528, dorsal, left lateral, and anterior views. **C**, **F**, **I**, cranidium, SUI 115529, dorsal, left lateral, and anterior views. **L**, **N**, **O**, cranidium, SUI 115530, anterior, dorsal, and right lateral views. **J**, **K**, **M**, ?*Litzicurus orbus* (Ross, 1953), from Section G 99.3 m, Fillmore Formation (Tulean, Psalikilus spinosum Zone), southern Confusion Range, Ibex area, Millard County, western Utah, USA, cranidium, SUI 115531, anterior, dorsal, and right lateral views.

Litzicurus described above, it is clear that *L. orbus* is not a dimeropygid, and that Ross (1953) made the correct pygidial assignment.

Ross (1953) illustrated cranidia, a librigena, and two pygidia when he erected the species. We resampled *L. orbus* from the Garden City Formation at only one horizon, HC6 165.2 m, and found only very rare cranidia. Hence, it is possible that Ross sampled a different nearby horizon which we did not locate, at which the species is more common.

Although they are obviously closely related, *Litzicurus orbus* differs from the older *L. shawi* in numerous ways. Cranidia of *L. orbus* have a much shallower median depression on the preglabellar field than does *L. shawi*. The glabella of *L. orbus* is more parallel-sided, longer in dorsal view relative to its width, and less dorsally inflated in sagittal profile. Tuberculate sculpture on the interocular fixigena is dense in *L. orbus* but reduced in most specimens of *L. shawi* to only the primary ontogenetic tubercles. The palpebral lobe is narrower in *L. orbus*, and separated from the interocular fixigena by a distinct depressed palpebral furrow. The lobe in specimens of *L. shawi* is broader and grades into the interocular

posterior, left lateral, and dorsal views (HC6 145T m). **Q**, **R**, **U**, pygidium, SUI 115521, dorsal, right lateral, and posterior views, x10 (HC6 142.0 m). **S**, **V**, **W**, pygidium, SUI 115522, dorsal, right lateral, and posterior views (HC6 145T m). **X**, **AA**, **CC**, pygidium, SUI 115523, dorsal, right lateral, and posterior views (HC6 142.0 m). **Y**, **Z**, **BB**, pygidium, SUI 115524, dorsal, right lateral, and posterior views (HC6 145T m). **DD-FF**, pygidium, SUI 115525, dorsal, left lateral, and posterior views (HC6 145T m). **GG**, pygidium, SUI 115526, dorsal view (with hypostome of *Aulacoparia* sp. nov. 1 attached), x10 (HC6 142.0 m).

fixigena with no furrow evident in most specimens. The glabella of *L. shawi* lacks sculpture in most specimens; that of *L. orbus* is completely covered by small to moderate sized tubercles. Similarly, the occipital ring in *L. shawi* displays only the median node and in some specimens a few tiny, nearly effaced tubercles. The occipital ring of *L. orbus* is densely tuberculate. The posterior projections of *L. orbus* protrude laterally only a little past the lateral extent of the palpebral lobe; they are much wider in *L. shawi*. The librigena of *L. orbus* is known only from the single specimen illustrated with small photos by Ross (1953, pl. 63, figs 18-20, 23). It appears to have the genal spine base set more towards the field, and to have larger and more densely crowded tubercles on the field. Pygidia illustrated by Ross (1953, pl. 63, figs 13, 14) are very similar in overall shape to those of *L. shawi*, with the obvious exception that they have a very robust and long spine developed posteriorly from the rear of the axis. They also appear to lack the median nodes which are prominent on the axial rings of specimens of *L. shawi*, and to have a more prominent border and deeper border furrow.

A single specimen of *Litzicurus* has been found in western Utah, at Section G 99.3 m (Fig. 32J, K, M). It is only about half the size of most of those recovered from the Garden City Formation. It does appear to show some differences, including a more dorsally vaulted profile and a slightly different, less parallel-sided, glabellar shape. Without more material, it is impossible to know whether these differences are significant. Specimens from the Garden City Formation are somewhat flattened, whereas the Ibex specimen retains its original shape. Preservational and ontogenetic factors could possibly account for the differences, or the Ibex specimen could represent a separate species. Much larger samples from both horizons would be required to assess these possibilities with any confidence. The Ibex specimen does show the lightly depressed preglabellar field, impressed palpebral furrows, and generally dense dorsal cranidial sculpture characteristic of *L. orbus*.

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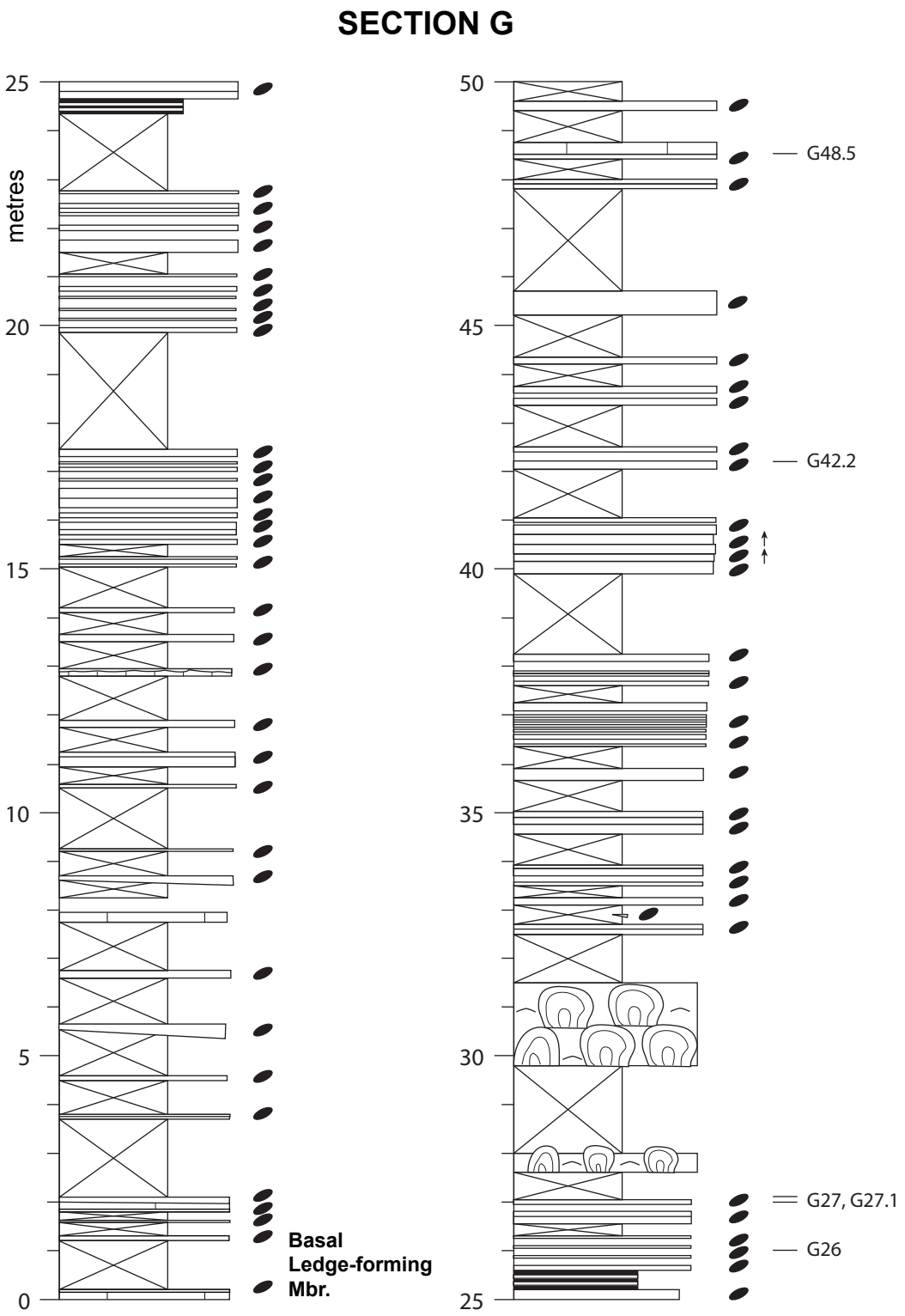
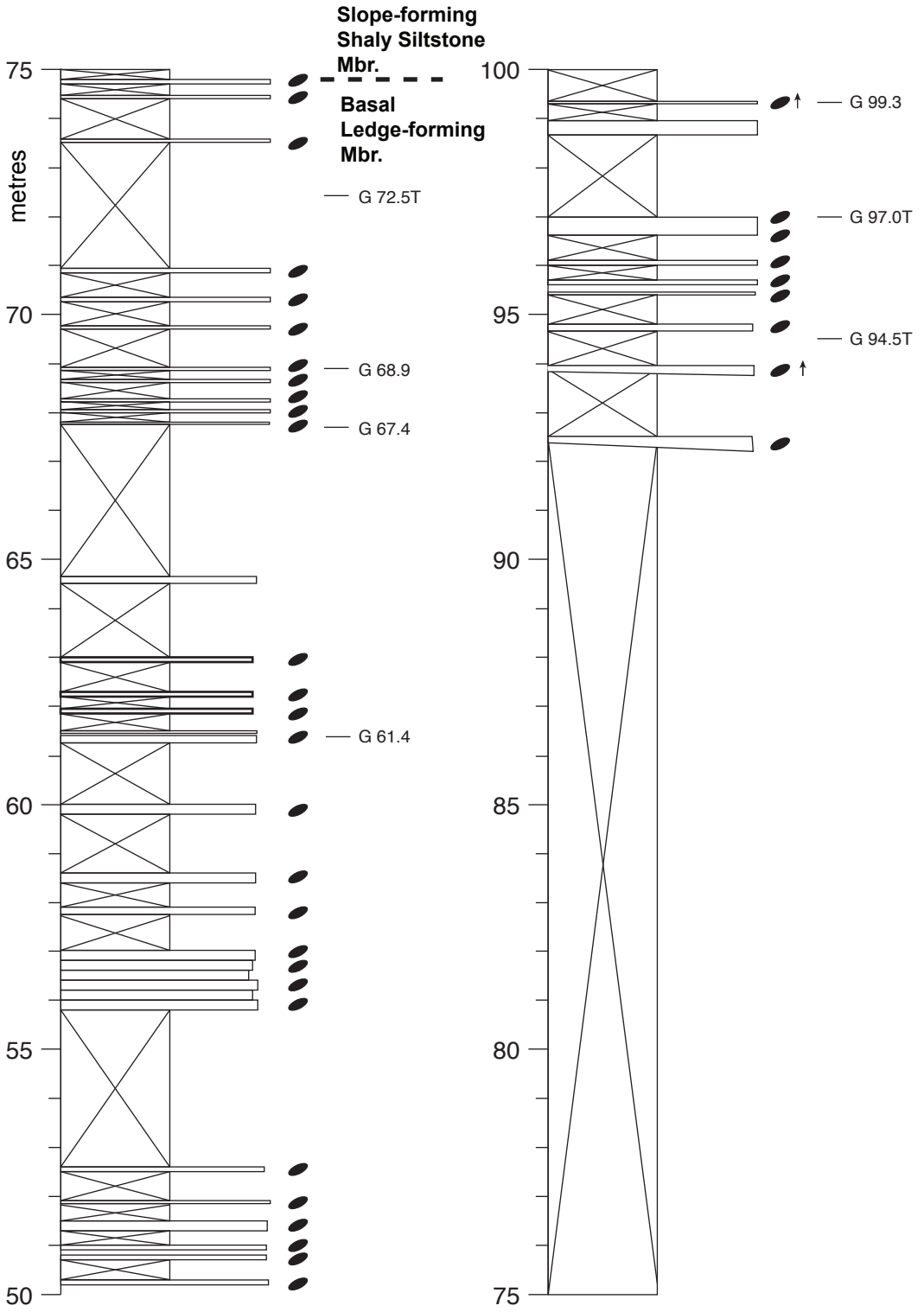
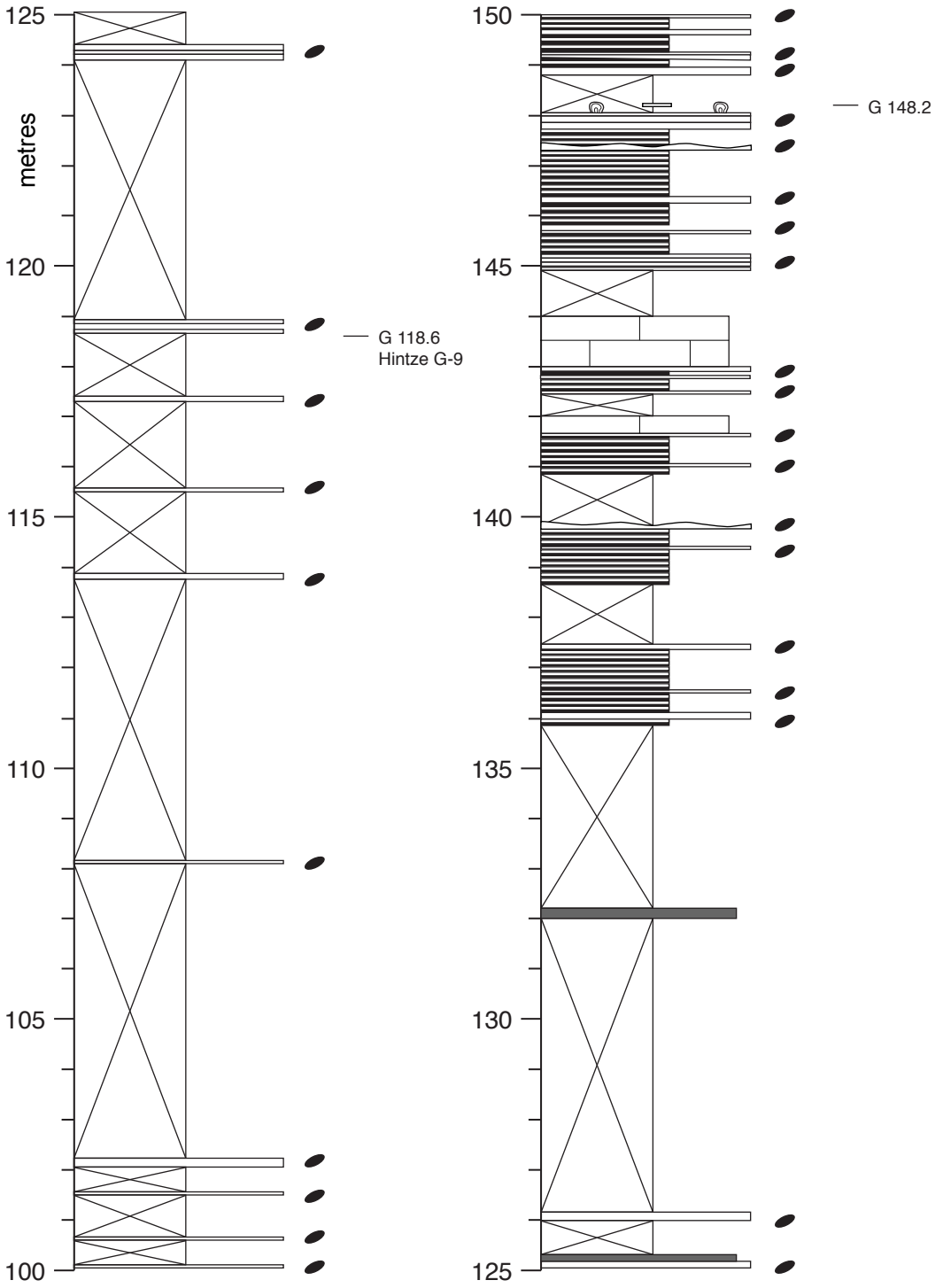
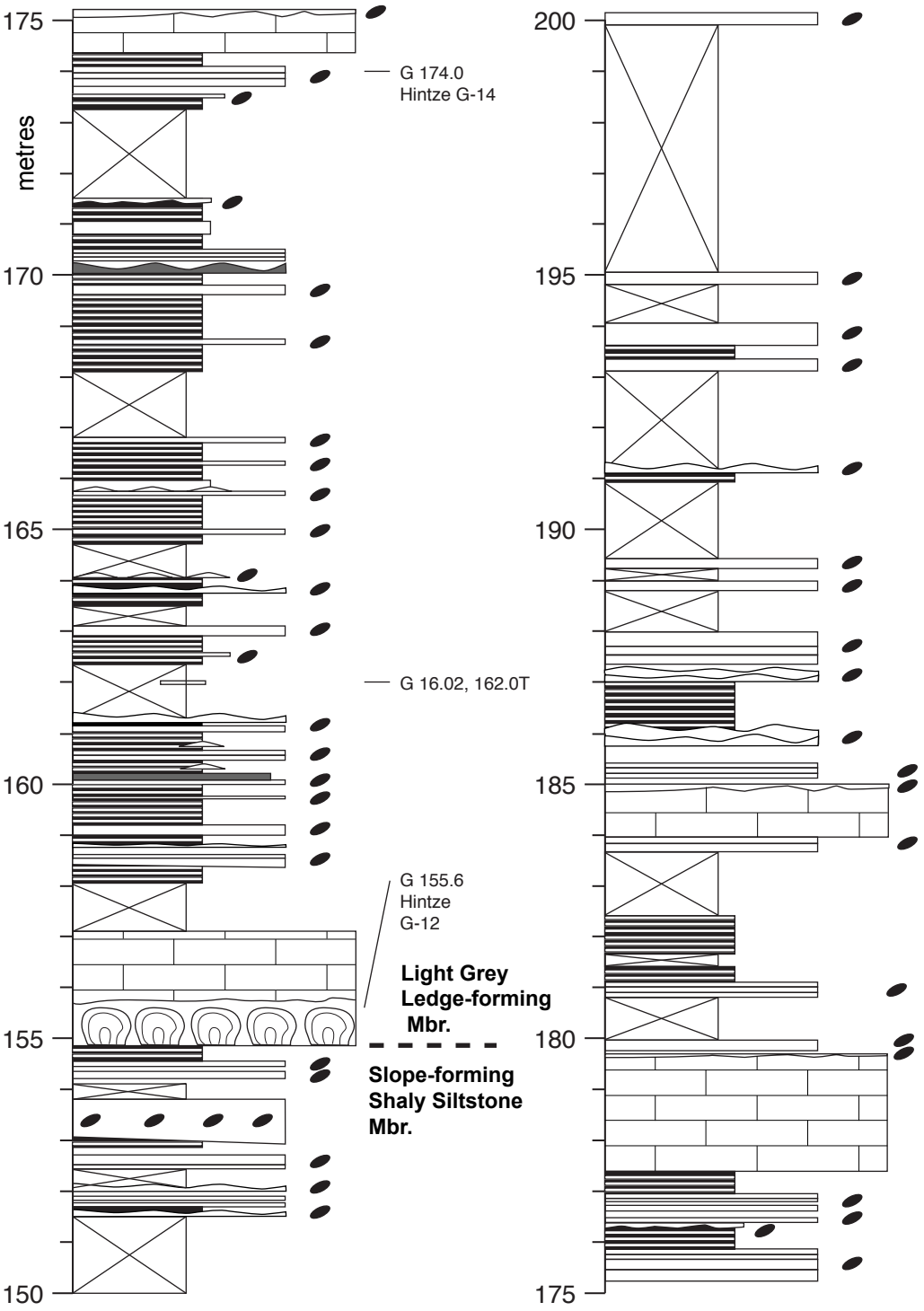
APPENDIX 1: Stratigraphic log of Ibex Section G through part of the Fillmore Formation. See Figures 1, 2A for position and line of section. The section is arranged over six pages in paired columns representing 25 m of strata each. A legend can be found on the last page of Appendix 2. *(continued opposite)*

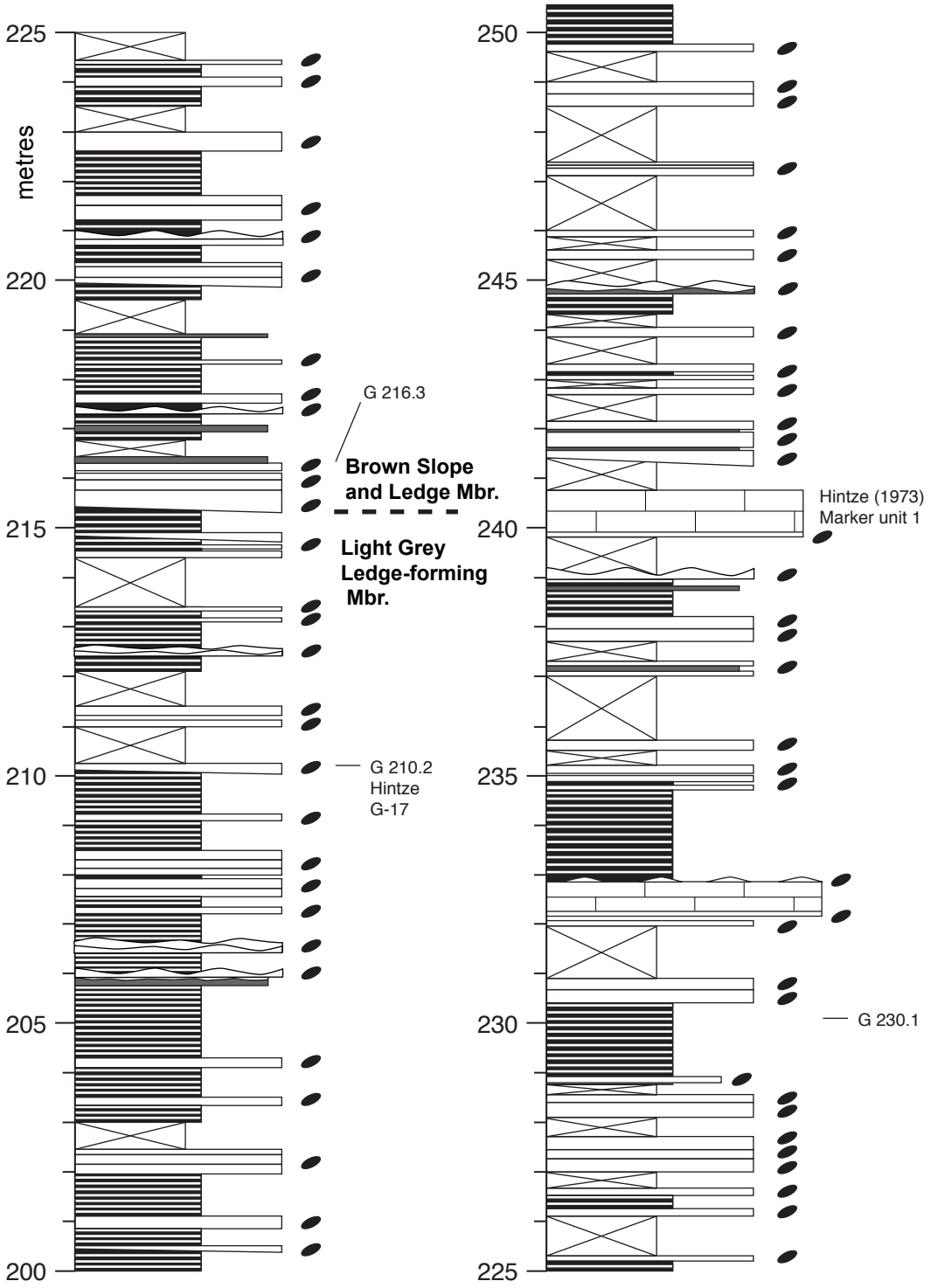


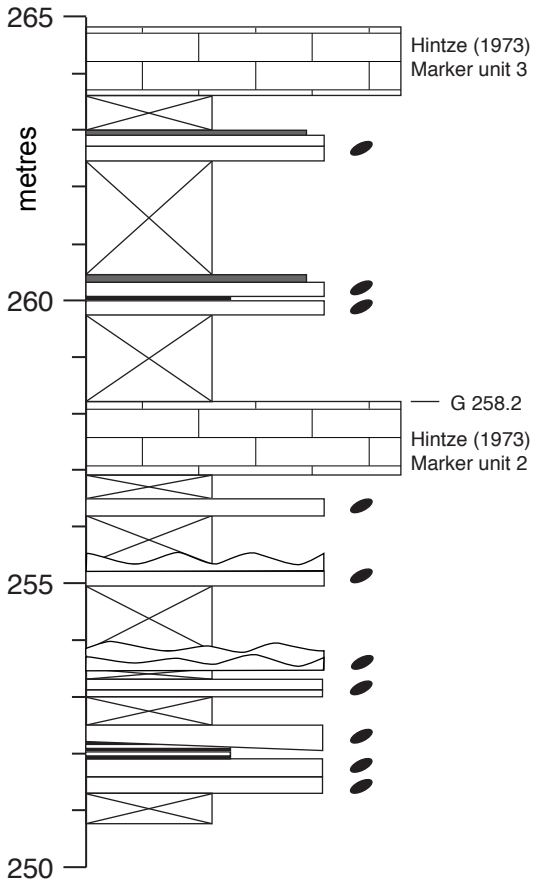
Our new sampling horizons are indicated in metres to the right of the columns and the positions of Hintze's (1951,1953) sampling horizons are indicated using his numbering scheme.



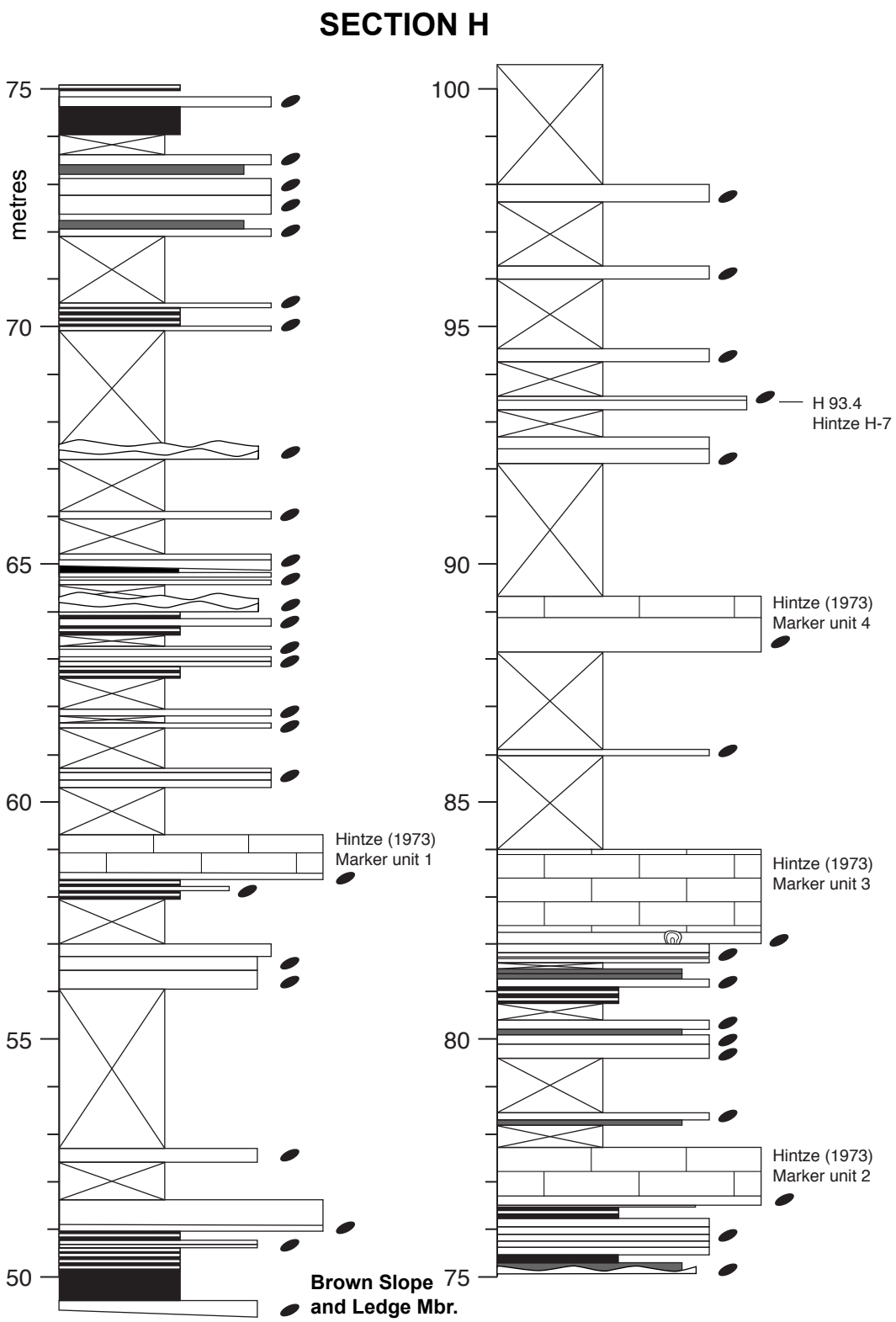

125
metres
120
115
110
105
100
G 118.6
Hintze G-9
150
145
140
135
130
125
G 148.2


metres
175
170
165
160
155
150
200
195
190
185
180
175
G 174.0
Hintze G-14
G 16.02, 162.0T
G 155.6
Hintze
G-12
Light Grey
Ledge-forming
Mbr.
Slope-forming
Shaly Siltstone
Mbr.

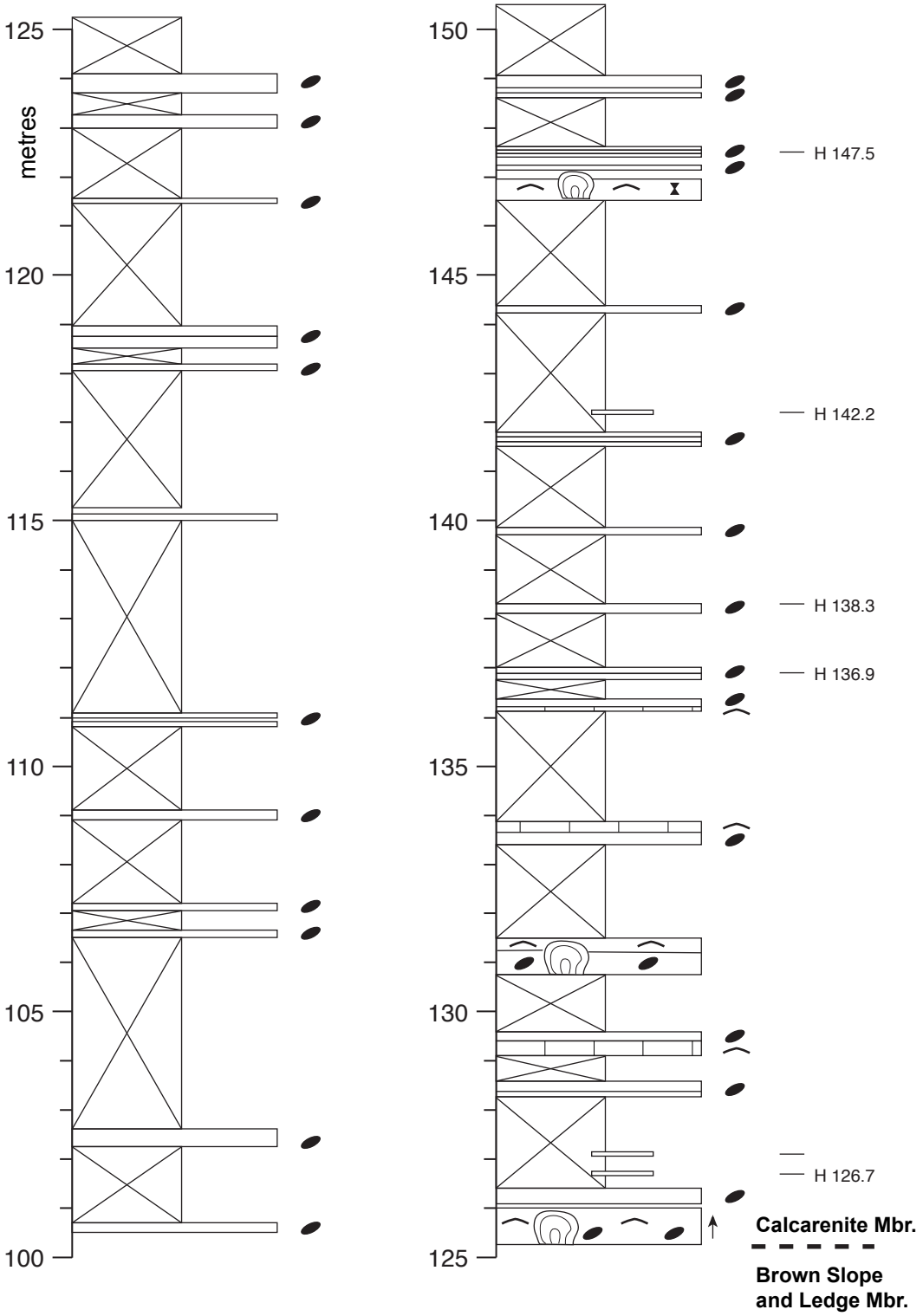

metres
225
220
215
210
205
200
250
245
240
235
230
225
G 216.3
Brown Slope
and Ledge Mbr.
Light Grey
Ledge-forming
Mbr.
G 210.2
Hintze
G-17
Hintze (1973)
Marker unit 1
G 230.1

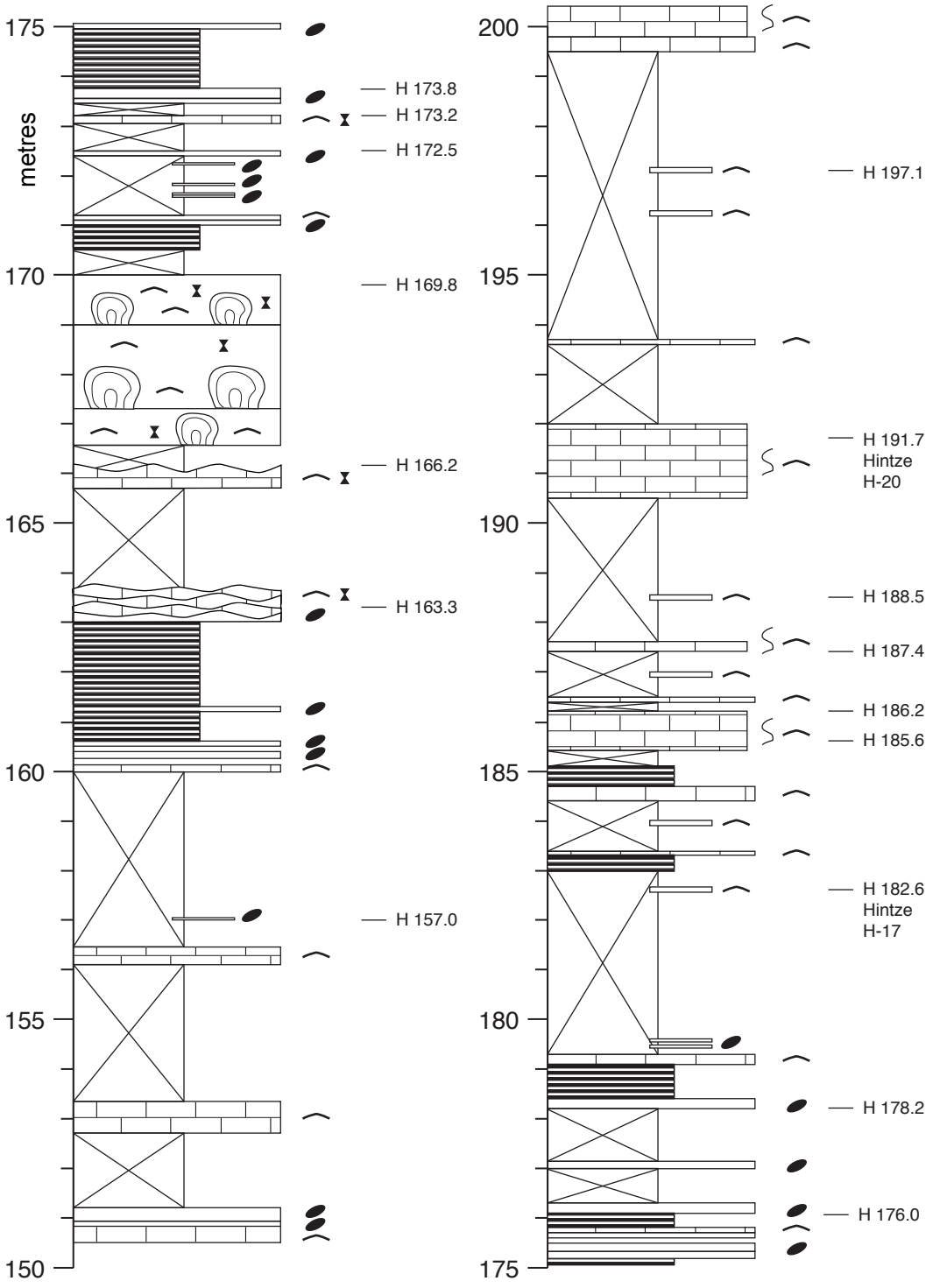

265
260
255
250
metres
Hintze (1973)
Marker unit 3
G 258.2
Hintze (1973)
Marker unit 2

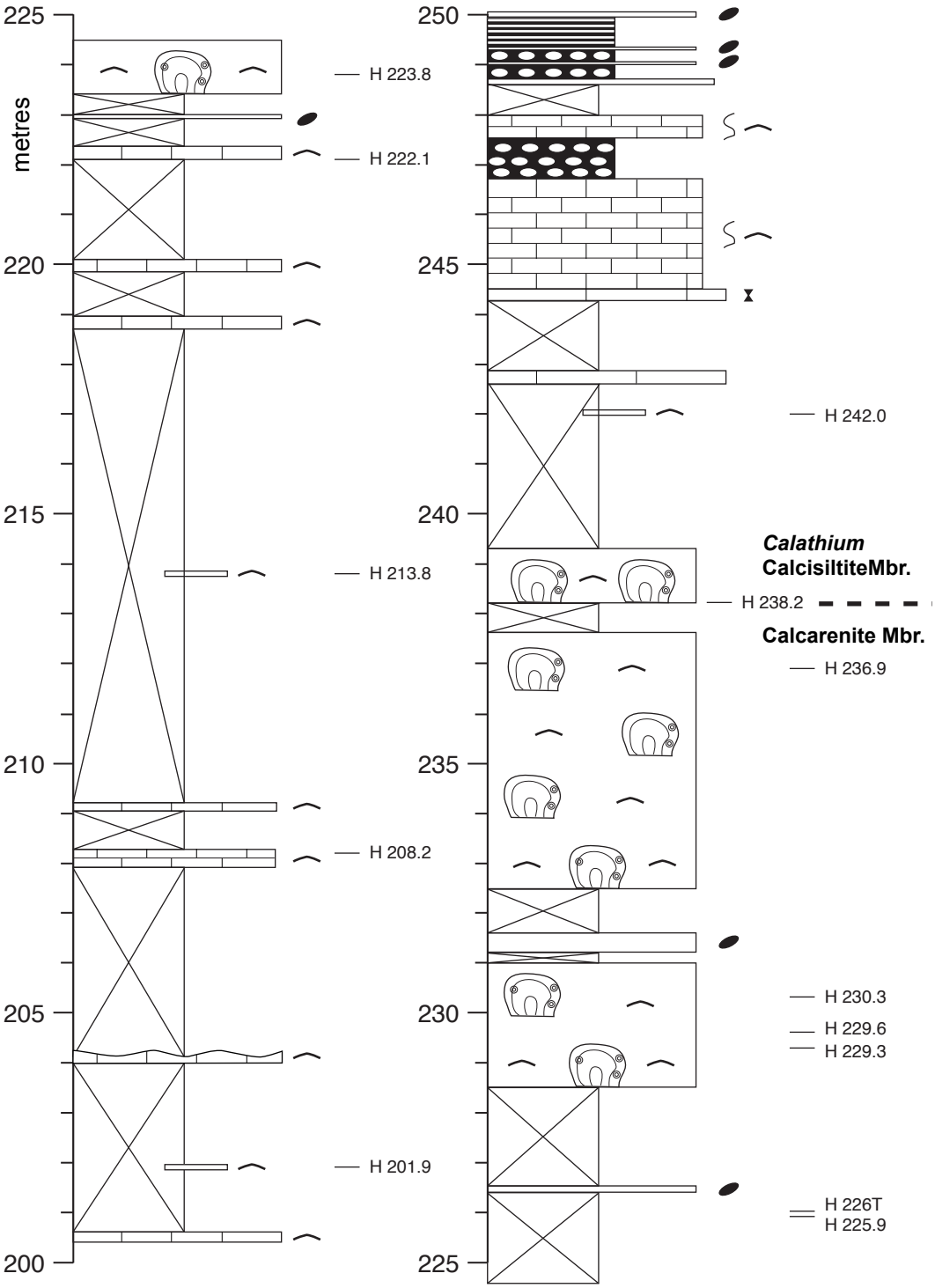
APPENDIX 2: Stratigraphic log of Ibex Section H through the upper part of the Fillmore Formation and lowest part of the Wah Wah Formation. See Figures 1, 2A for position and line of section. *(continued opposite)*

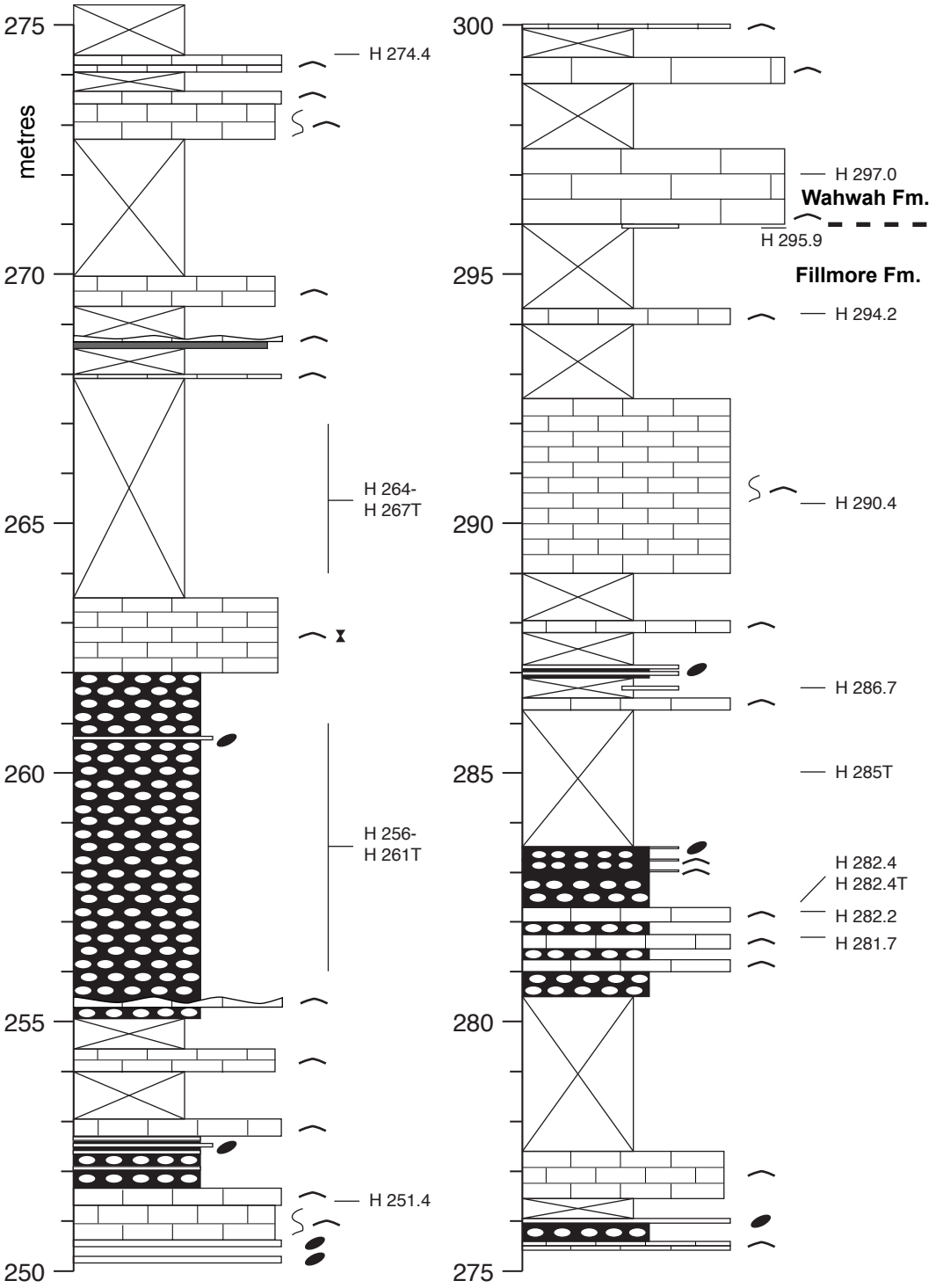


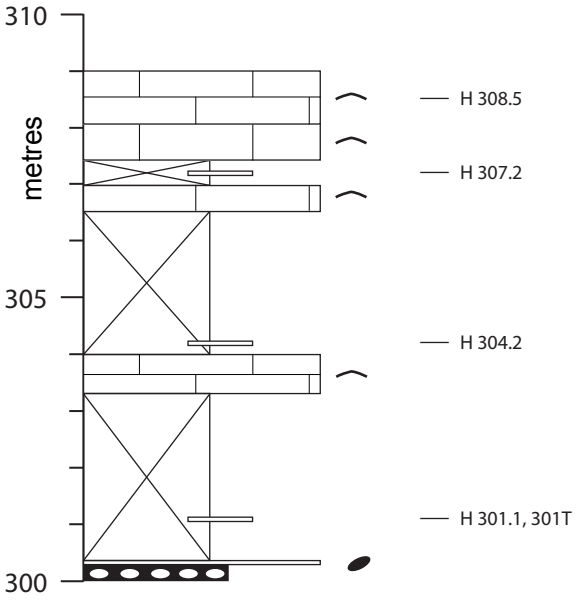
The section is arranged over six pages in paired columns representing 25 m of strata each. A legend can be found on the last page. Our new sampling horizons are indicated in metres to the right of the columns and the positions of Hintze's (1951,1953) sampling horizons are indicated using his numbering scheme.




metres
175
170
165
160
155
150
H 173.8
H 173.2
H 172.5
H 169.8
H 166.2
H 163.3
H 157.0
200
195
190
185
180
175
H 197.1
H 191.7
Hintze
H-20
H 188.5
H 187.4
H 186.2
H 185.6
H 182.6
Hintze
H-17
H 178.2
H 176.0


metres
225
220
215
210
205
200
250
245
240
235
230
225
H 223.8
H 222.1
H 213.8
H 208.2
H 201.9
H 242.0
Calathium
CalcisiltiteMbr.
H 238.2
Calcarenite Mbr.
H 236.9
H 230.3
H 229.6
H 229.3
H 226T
H 225.9


metres
275
270
265
260
255
250
H 274.4
H 264-
H 267T
H 256-
H 261T
H 251.4
300
295
290
285
280
275
H 297.0
Wahwah Fm.
H 295.9
Fillmore Fm.
H 294.2
H 290.4
H 286.7
H 285T
H 282.4
H 282.4T
H 282.2
H 281.7



Shale or siliciclastic mudstone

Thin-bedded (cm) calcisiltite or calcareous siltstone with mm — cm shale interbeds; minor lime mudstone

Shale with lime mudstone nodules; lenses of packstone or rudstone may be present

Calcisiltite or calcareous siltstone

Bioclastic pack- grain- or rudstone; minor intercalations of mud- and wackestone

Heterolithic facies: cm — dm thick layers of variably bioturbated lime mudstone—wackestone, pack- and grainstone. Planar to irregular hardgrounds

Thrombolitic buildup

Sponge-thrombolitic buildup

Intraclastic rudstone ("flat pebble conglomerate")

Sand-sized intraclasts

Strongly bioturbated, rubbly weathering unit

Bioclasts

Grading

Wave ripples

Scoured base

APPENDIX 3: Stratigraphic logs showing correlation of upper part of Section G (right column) and lower part of Section H (left column). Lower 49 m are not shown as they repeat part of Section G and contain no new sampling horizons. A legend can be found on the last page of Appendix 2.