

NOTCHPEAKIA, A NEW GENUS OF UPPER CAMBRIAN (SUNWAPTAN) “ENTOMASPIDID” TRILOBITES

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ABSTRACT—Trilobites previously assigned to the Entomaspididae Ulrich *in* Bridge, 1931 are common in Laurentian strata assigned to the upper Sunwaptan Stage of the Upper Cambrian. Most species are poorly known, and typically only sparse cranidial data are available. Large silicified samples from the Lava Dam Member of the Notch Peak Formation, western Utah, contain three new species for which cranidia, librigenae, thoracic segments, and pygidia are known. The species permit clarification of the morphology and affinities of previously described taxa from elsewhere. They are referred to *Notchpeakia* n. gen. (type species: *N. milleri* n. sp.) which, in addition to the type includes *N. taylori* n. sp., *N. notchpeakensis* n. sp., *N. cherrycreekensis* n. sp., and *N. varga* (Westrop, 1986). The “entomaspidid” trilobites are assigned to the traditionally post-Cambrian Harpetidae Hawle and Corda, 1847.

INTRODUCTION

SYSTEMATICS of the “entomaspidid” trilobites have rarely been addressed, and only Ludvigsen (1982, p. 67–68) and Ludvigsen and Westrop (*in* Ludvigsen et al., 1989, p. 47–49) have reviewed the group. A major problem, as with many Upper Cambrian trilobite taxa, is extremely limited knowledge of most named species. This is a general deficiency of the literature (Adrain and Westrop, 2005), but is exacerbated in the “entomaspidids” by the fact that species are quite small, dorsally convex, and often possess sclerites with irregular, spinose, and tuberculate/pitted morphologies. This makes recovery by normal mechanical means problematic, and the group is known mainly from cranidia, with the exception of sets of yoked librigenae fringed by large spines belonging to species of *Bowmania* Walcott, 1925 (e.g., Ludvigsen et al., 1989, pl. 36, fig. 1; Westrop, 1995, pl. 14, fig. 5), and of the mold material of *Entomaspis radiatus* Ulrich *in* Bridge (1931) described by Rasetti (1952). Until recently, the most complete knowledge available of any species was for material from the Rabbitkettle Formation of the Canadian Northwest Territories described by Ludvigsen (1982) and subsequently assigned to *Heterocaryon vargum* Westrop, 1986. These specimens are silicified, and silicified faunas in general offer the potential to transform systematic understanding of the “entomaspidids” and other Cambrian taxa with knowledge of sclerites other than cranidia, and often with large sample sizes which permit realistic assessment of intraspecific variation.

Well-preserved silicified species were described by Adrain and Westrop (2004) from the Windfall Formation of the Cherry Creek Range of eastern Nevada. Here we describe additional new “entomaspidid” species from the Lava Dam Member of the Notch Peak Formation of western Utah. The faunas are diverse, and include “entomaspidids” referable to *Bowmania* and *Kathrynia* Westrop, 1986, in addition to three abundantly represented new species referred herein to *Notchpeakia* new genus. The goals of the present study are to describe these new species, to name a fourth new species from the Windfall Formation of Nevada, to revise the systematics of previously described species referable to *Notchpeakia*, to clarify the status and content of *Heterocaryon* Raymond, 1937, to which some of the species have previously been assigned, and finally to present a hypothesis of ingroup relationship for *Notchpeakia* based on cladistic parsimony analysis.

The trilobites described herein have traditionally been classified in a family Entomaspididae Ulrich *in* Bridge, 1931 (misspelled “Entomaspidae” by Ulrich and many subsequent workers). “Entomaspidids” demonstrate a range of morphological modification involving posterior migration of the anterior sections of the facial

sutures, dramatic broadening of the cephalic doublure, development of a ventral girder on the doublure, reduction in eye size, development of a fringe of radially arranged dorsal pits, and development of fixigenal alae opposite L1. These morphologies are extremely pronounced in *Entomaspis* Ulrich *in* Bridge, 1931, in which the facial sutures have almost contacted each other and the librigena is reduced to a thin strip. All of them are regarded herein as synapomorphic with the Harpetidae Hawle and Corda, 1847, and we follow Adrain *in* Jell and Adrain (2003, p. 471) in regarding Entomaspididae as a junior synonym of Harpetidae. Harpetidae has been a classic “cryptogenetic” (Stubblefield, 1959; Whittington, 1981) group, whose sister group among Cambrian trilobites has been unknown. Another family, Harpididae Hupé, 1953 (=Loganopeltidae Hupé, 1955), has been identified by, e.g., Ebach and McNamara (2002) as possibly related to Harpetidae, but this group lacks several of the putative apomorphies shared by the “entomaspidids” and harpetids.

Full analysis of the phylogenetic structure and relationships of the Upper Cambrian and post-Cambrian Harpetidae is beyond the scope of this work and will be dealt with in a forthcoming study, including new data on silicified occurrences of other Sunwaptan genera. For present purposes, taxa previously classified in Entomaspididae are referred to informally as “entomaspidids,” with the parentheses indicating the probable paraphyletic status of the group (Wiley, 1981).

LOCALITIES AND STRATIGRAPHY

Full locality information has been given by Adrain and Westrop (2005) and is summarized here. Collections were made from shallow water limestones of the Lava Dam Member of the Notch Peak Formation (Hintze et al., 1988; Miller et al., 2001) at one horizon (LAW 25.3 m; 34.1 kg collected) from the lower segment of the section at Lawson Cove in the northern Wah Wah Mountains (Fig. 1.2) and three horizons (LD5 16.8T m [23.8 kg], 25.3 m [34.1 kg], and 30.5 m [73.3 kg]) from section Lava Dam Five in the southern House Range (Fig. 1.3). Both sections are in the Ibex region of Millard County, western Utah. Detailed logs of the sections may be found in Miller et al. (2001, appendix; our measurements correspond to the footages reported by Miller et al., but we have converted them to meters).

PARSIMONY ANALYSIS

Characters.—Character analysis of the general “entomaspidid” group remains difficult due to the large amounts of missing data. However, *Notchpeakia* n. gen. is represented by five species known from silicified cranidia, librigenae, and pygidia, and meaningful analysis of its phylogenetic structure is possible.

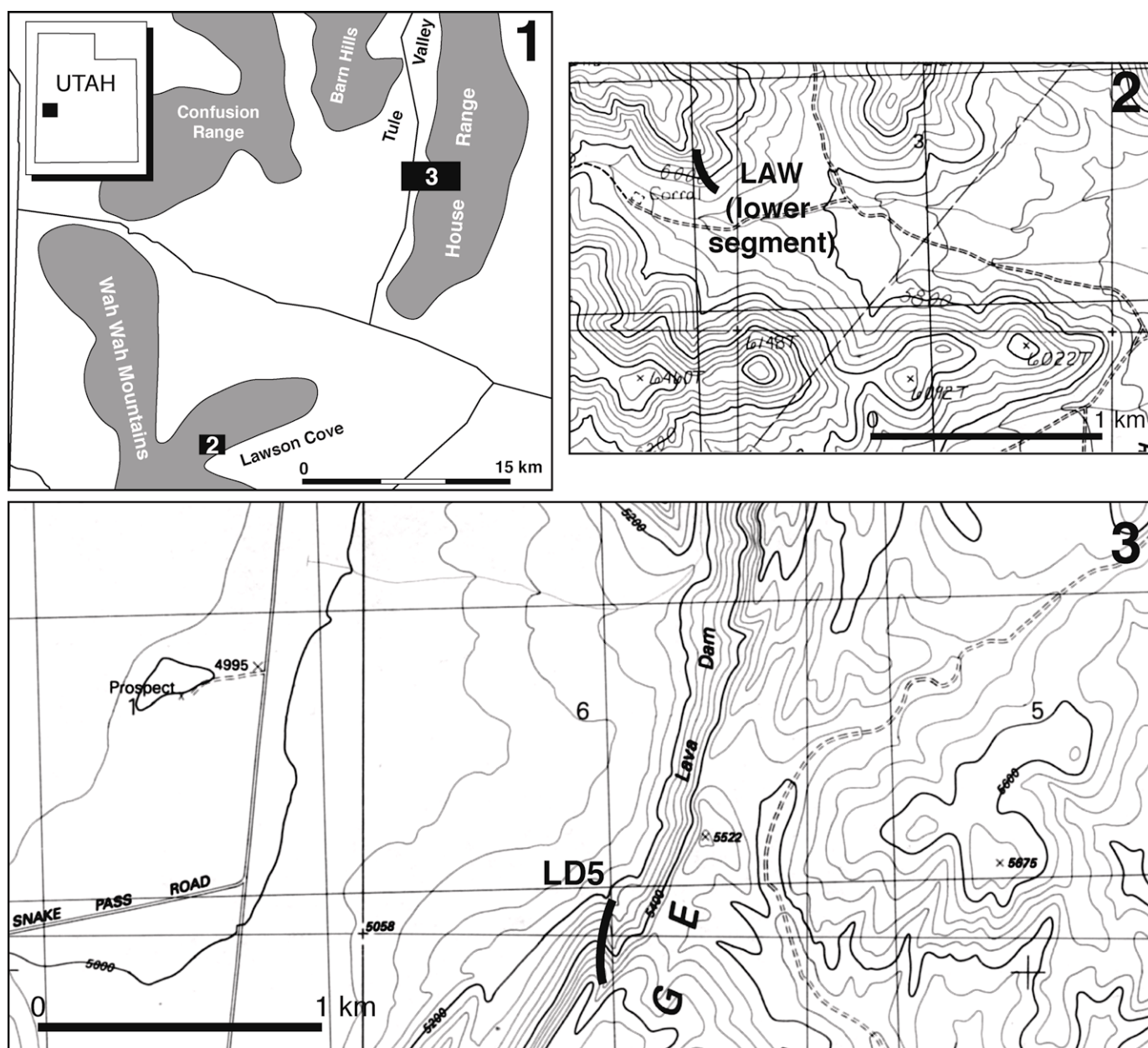


FIGURE 1—3, Location of measured sections depicted in 2 and 3 in the Ibex area, Millard County, western Utah. 2, Line of section of lower segment of Lawson Cove section, northern Wah Wah Mountains. 3, Line of section of Lava Dam Five, southern House Range (see Miller et al., 2001, for detailed lithologic logs of the sections). Base maps taken from United States Geological Survey Grassy Cove (2) and Red Tops (3) 7.5' quadrangle maps.

Cranidium

1. Transverse, pitted furrow crossing L0 behind median tubercle: 0—extremely weak or indiscernible; 1—clearly expressed on all specimens.
2. Cranial pitted sculpture: 0—very fine, pinpointlike pits; 1—large, open, subpolygonal pits.
3. Terrace lines visible on anterior border: 0—yes; 1—no.
4. Prominence of S1 and S2 in large specimens: 0—not prominent, hardly deflecting lateral glabellar margin in dorsal view; 1—very prominent as obvious, indented furrows on all specimens in dorsal view.

Librigena

5. Rows of pits arranged in series on lateral border: 0—none

clearly discernible; 1—at least three rows; 2—two rows on most specimens.

6. Sculpture on dorsal/external aspect of genal spine: 0—tubercles and in some cases pits continued well posteriorly on spine; 1—tubercles and pits terminate just posterior to spine base, most of spine with smooth sculpture.

Pygidium

7. Number of pairs of pygidial spines (including posterior fused pair): 0—5; 1—6.
8. Transverse tubercle rows across axial rings of segments behind first: 0—present; 1—absent.
9. Angle of pygidial pleural spines: 0—more nearly horizontal

TABLE 1—Character matrix for parsimony analysis of *Notchpeakia* n. gen.

	1	2	3	4	5	6	7	8	9	10
<i>cherrycreekensis</i>	0	0	1	0	0	0	1	0	0	0
<i>milleri</i>	1	1	1	1	2	1	2	1	1	1
<i>notchpeakensis</i>	1	1	1	0	1	0	1	1	1	1
<i>taylori</i>	1	0	1	1	1	1	1	1	1	1
<i>varga</i>	0	0	0	0	0	0	1	0	0	0
aff. <i>platystigma</i>	0	0	0	0	?	?	0	0	?	?

laterally, becoming progressively more vertically inclined medially; 1—similar inclination laterally and medially.

10. Expression of border: 0—weak, distal pleural wall essentially terminates ventrally without significant change in morphology, weak border expressed only laterally; 1—strong, independently inflated, rimlike border along most of posteroventral margin.

Analysis.—The character matrix is shown in Table 1. All characters were treated as unordered. The presumptive sister taxon, *Heterocaryon*, is poorly known, but a species from the Cow Head Group of western Newfoundland (Ludvigsen et al., 1989, pl. 36, figs. 10, 11, 15, 16, 19, 20; see discussion below) is well enough represented to serve as outgroup. Outgroup coding for character 8 was not available due to poor preservation of the pygidial axis in the only available specimen; this coding is based on the pygidium of the other Cow Head species (Ludvigsen et al., 1989, pl. 36, fig. 21). The analysis is very small, and an exhaustive search was used. Node support was assessed using nonparametric bootstrapping (10,000 replicates) and Bremer support values.

Results.—Analysis yielded a single tree of length 13 (Fig. 2). Although each is highly autapomorphic, *Notchpeakia milleri* n. sp. and *N. taylori* n. sp. are interpreted as sister taxa, based on the prominence of their glabellar furrows and lack of sculpture on the genal spine. These species, plus *N. cherrycreekensis* n. sp., form a well-supported clade for which synapomorphies are a strong transverse furrow on L0, absence of tubercle rows on the pygidial axial rings behind the first, similarly inclined pygidial pleural spines, and a strong pygidial border. *Notchpeakia cherrycreekensis* is united with this clade on the basis of loss of dorsal terrace lines on the anterior border.

SYSTEMATIC PALEONTOLOGY

Repository.—Figured material is housed in the Paleontology Repository, Department of Geoscience, University of Iowa, Iowa City, with specimen number prefix SUI.

Family HARPETIDAE Hawle and Corda, 1847

Synonyms.—Entomaspidae ULRICH in BRIDGE, 1931, p. 212 (nom. corr. from Entomaspidae); Heterocaryoninae HUPÉ, 1953, p. 195.

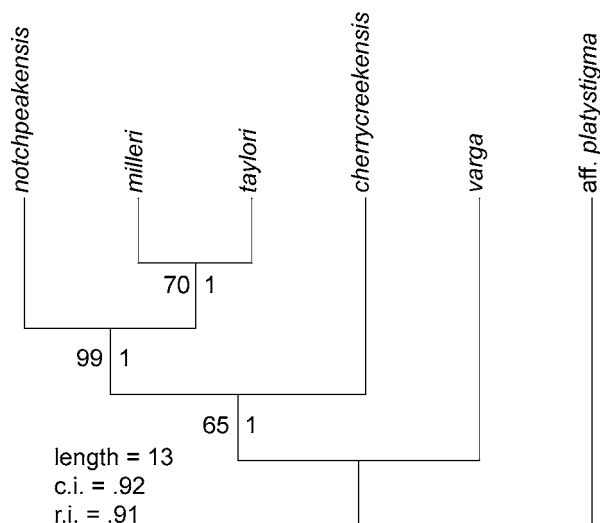


FIGURE 2—Hypothesis of ingroup relationship for *Notchpeakia* n. gen. based on matrix of Table 1. Analysis yielded a single most parsimonious tree. Numbers to left of nodes are nonparametric bootstrap values based on 10,000 iterations. Numbers to right of nodes are Bremer support values.

Sunwaptan genera included.—*Bowmania* Walcott, 1925; *Conococheaguea* Rasetti, 1959; *Entomaspis* Ulrich in Bridge, 1931 (= *Hypothetica* Ross, 1951, from the Stairsian Stage of the Lower Ordovician, fide Adrain in Jell and Adrain, 2003, p. 387); *Heterocaryon* Raymond, 1937; *Notchpeakia* n. gen.; *Kathrynina* Westrop, 1986.

Discussion.—Modern understanding of the “entomaspidid” group and its content derives from Ludvigsen’s (1982) review, with the subsequent addition of *Kathrynina* Westrop, 1986. The most recent overview of the group was by Ludvigsen and Westrop in Ludvigsen et al. (1989).

Genus HETEROCARYON Raymond, 1937

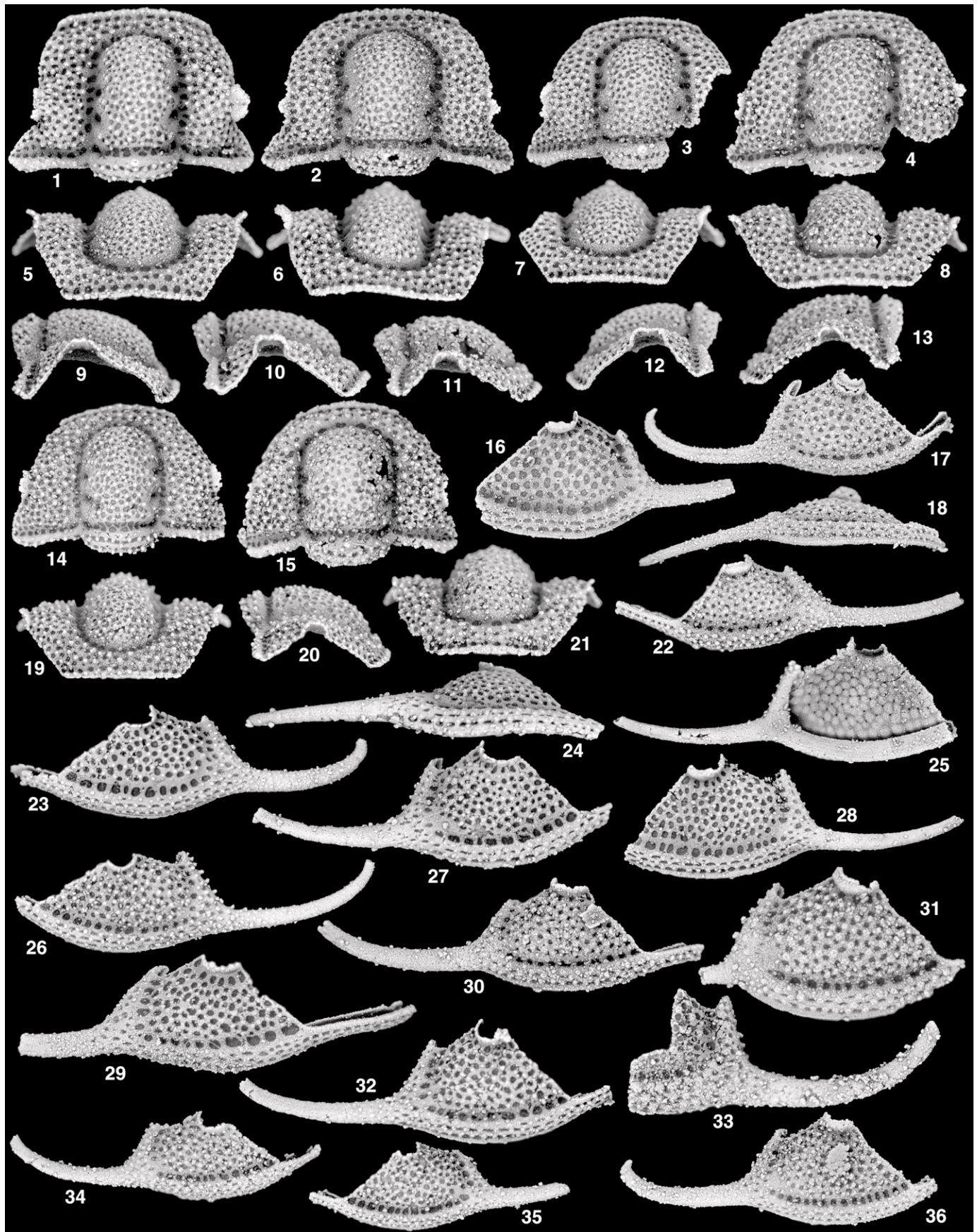
Type species.—*Heterocaryon platystigma* Raymond, 1937.

Other species.—*Heterocaryon tuberculatum* Rasetti, 1944; two additional species are probably represented by the Shallow Bay Formation material assigned to *H. platystigma* by Ludvigsen and Westrop in Ludvigsen et al. (1989; see discussion below).

Diagnosis.—Anterior border relatively long, with dorsal sculpture of raised lines but lacking tubercles; anterior border furrow typically very long (sag., exsag.) and troughlike, preglabellar field concomitantly short; eye ridge prominent on sparsely tuberculate or smooth interocular fixigena; cranial sculpture of tubercles

FIGURE 3—*Notchpeakia milleri* n. sp., from the Lava Dam Member, Notch Peak Formation (Sunwaptan), sections Lava Dam Five, southern House Range, and Lawson Cove, northern Wah Wah Mountains, Millard County, Utah. 1, 5, 9, Cranidium, holotype, SUI 101485, dorsal, anterior, and right lateral views, $\times 7.5$ (LD5 16.8T m). 2, 6, 10, Cranidium, SUI 101486, dorsal, anterior, and right lateral views, $\times 7.5$ (LD5 16.8T m). 3, 7, 12, Cranidium, SUI 101487, dorsal, anterior, and left lateral views, $\times 7.5$ (LD5 25.3 m). 4, 8, 13, 26, Cranidium, SUI 101488, dorsal, anterior, right lateral, and ventral views, $\times 7.5$ (LD5 16.8T m). 11, 19, 22, 24, Cranidium, SUI 101489, right lateral, dorsal, ventral, and anterior views, $\times 7.5$ (LD5 16.8T m). 14, 15, 18, 23, Cranidium, SUI 101490, right lateral, dorsal, anterior, and ventral views, $\times 7.5$ (LD5 16.8T m). 16, 17, 21, Cranidium, SUI 101491, dorsal, left lateral, and anterior views, $\times 7.5$ (LD5 16.8T m). 20, 25, 30, Cranidium, SUI 101492, dorsal, anterior, and right lateral views, $\times 7.5$ (LD5 16.8T m). 27, 28, 35, Cranidium, SUI 101493, dorsal, anterior, and right lateral views, $\times 7.5$ (LD5 30.5 m). 29, 31, 36, Cranidium, SUI 101494, dorsal, right lateral, and anterior views, $\times 7.5$ (LD5 30.5 m). 32, 33, 39, Cranidium, SUI 101495, dorsal, anterior, and right lateral views, $\times 7.5$ (LD5 25.3 m). 34, 41, 42, Cranidium, SUI 101496, dorsal, left lateral, and anterior views, $\times 10$ (LD5 30.5 m). 37, 38, 48, Cranidium, SUI 101497, dorsal, left lateral, and anterior views, $\times 10$ (LD5 30.5 m). 40, 44, 45, Cranidium, SUI 101498, dorsal, anterior, and right lateral views, $\times 10$ (LD5 30.5 m). 43, 49, 50, Cranidium, SUI 101499, dorsal, anterior, and left lateral views, $\times 12$ (LD5 16.8T m). 46, 51, 52, Cranidium, SUI 101500, dorsal, right lateral, and anterior views $\times 10$ (LAW 25.3 m). 47, 53, 54, Cranidium, SUI 101501, anterior, right lateral, and dorsal views, $\times 10$ (LAW 25.3 m).





most prominent on glabella, weaker or absent on fixigena and frontal area.

Discussion.—Raymond (1937, p. 1119, pl. 3, fig. 13) erected *Heterocaryon* on the basis of a single heavily retouched photograph of the holotype cranidium of the type species, his new *H. platystigma* from the Gorge Formation of Vermont. The only unretouched photographs available of the type occurrence are Ludvigsen and Westrop's (in Ludvigsen et al., 1989, pl. 36, figs. 6, 7) oblique and dorsal views of the holotype. Ludvigsen and Westrop (in Ludvigsen et al., 1989, p. 48, pl. 36, figs. 8–21) assigned and illustrated seven cranidia and two pygidia from six different conglomerate boulders from the Shallow Bay Formation of western Newfoundland. In light of accumulating knowledge of typical ranges of intrasample variation of Sunwaptan trilobites as revealed by rich silicified faunas (Adrain and Westrop, 2004, 2005), and of the range of variation of “entomaspidid” species described from large samples from the Notch Peak Formation herein, it now appears that the Newfoundland material, while definitely belonging to *Heterocaryon*, represents two separate species. Three of the cranidia (Ludvigsen et al., 1989, pl. 36, figs. 11, 15, 19) have relatively fine and subdued but abundant tubercles on the glabella as well as very subdued L1 and only moderate glabellar inflation. The other four (Ludvigsen et al., 1989, pl. 36, figs. 8, 12, 17, 18) have much larger, more widely spaced, and fewer glabellar tubercles, more prominent L1, and much greater inflation of the glabella. This variation is not size-related, as most of the cranidia are similar in size, and the coarse-tubercled morphology is consistent in two specimens (Ludvigsen et al., 1989, pl. 36, figs. 17, 18) that differ considerably in size. The two illustrated pygidia also have quite different morphology, as one (Ludvigsen et al., 1989, pl. 36, fig. 20) has broad pleurae and seven pairs of pleural spines whereas the other (Ludvigsen et al., 1989, pl. 36, fig. 21) has much narrower pleurae and six pairs of spines. Available information is scant, but the species do not occur together in any one boulder collection. The second pygidium may belong with the species with the larger, sparser tubercles, as it occurs in boulder BPN 240 along with one such illustrated cranidium (Ludvigsen et al., 1989, pl. 36, figs. 8, 9). Of the two Shallow Bay Formation species, the taxon with smaller, more densely crowded tubercles is most similar to Raymond's (1937) holotype of *H. platystigma*. *Heterocaryon platystigma*, however, appears to have a longer preglabellar field and a shorter (sag., exsag.), less trough-like anterior border furrow. More material from both the Gorge Formation and the Shallow Bay Formation is required to assess the problem, but the Newfoundland taxon is tentatively regarded as a similar, but separate species.

Gilman Clark and Shaw (1968, p. 1016, pl. 125, figs. 4–6) assigned a cranidium from the Gorge Formation to *H. platystigma*. This specimen, with its long preglabellar field, broad frontal area, apparently strongly divergent anterior sections of the facial suture, upturned, rimlike anterior border, and suboval glabella, is

most similar to *Conococheaguea ovata* Rasetti, 1959, from the Frederick Limestone of Maryland, and may represent a new species of that genus.

Heterocaryon tuberculatum is known from a single incomplete internal mold of a cranidium (Rasetti, 1944, p. 241, pl. 36, fig. 55; Ludvigsen et al., 1989, pl. 36, fig. 2) from a boulder in the Lévis Formation of Quebec. Ludvigsen and Westrop (in Ludvigsen et al., 1989, p. 48, pl. 36, figs. 3–5) assigned two cranidia from the Shallow Bay Formation of Newfoundland to the species. These cranidia may not belong to *H. tuberculatum*, and may not be conspecific with each other. One, GSC 70638 (Ludvigsen et al., 1989, pl. 36, figs. 3, 4), is a close match for the unique holotype of *H. tuberculatum* in glabellar sculpture, but its glabella appears to expand forward in contrast to narrowing forward in *H. tuberculatum*, and its S1 and S2 are much less prominent. More strikingly, *H. tuberculatum* has a very short (sag., exsag.) anterior border and a long, troughlike anterior border furrow, similar to that of both of the species illustrated by Ludvigsen et al. (1989) as *H. platystigma* (see above). In contrast, GSC 70638 has an extremely short, sharply incised anterior border furrow and a concomitantly longer preglabellar field. Caution must be exercised, as the holotype of *H. tuberculatum* is an internal mold whereas GSC 70638 retains the cuticle. Nevertheless, this is unlikely to account for the gross differences in anterior morphology and the specimens are probably not conspecific. A second Newfoundland specimen assigned, GSC 70622 (Ludvigsen et al., 1989, pl. 36, fig. 5), clearly has much larger tubercles on the glabella, and also has prominent large tubercles on the preglabellar field and frontal area as well as on the anterior border. It is unlikely to be conspecific with the other Newfoundland specimen or with *H. tuberculatum*.

Stitt (1971, p. 22, pl. 7, fig. 11) assigned a cranidium from the Signal Mountain Limestone of Oklahoma to *H. tuberculatum*. The specimen is not easily interpreted from Stitt's tiny photograph, but it is densely tuberculate over its fixigenae and frontal area, has a short anterior border and very short border furrow, and an L0 which appears to be transversely subdivided. It is certainly not *H. tuberculatum* and likely represents a species of *Notchpeakia* n. gen.

Ludvigsen and Westrop in Ludvigsen et al. (1989, p. 48, pl. 36, figs. 22–24) erected *Heterocaryon forteyi* for three cranidia from the Shallow Bay Formation of western Newfoundland. The taxon had been referred in open nomenclature to *Heterocaryon* by Kindle (1982, pl. 1.5, fig. 16) and to *Calymenidius* Rasetti, 1944 by Fortey (1983, p. 208, pl. 23, fig. 8). The species resembles some of those assigned to *Notchpeakia* below in its subrectangular, parallel-sided glabella with short glabellar furrows, as well as its strong tuberculate sculpture. The cranidium is much wider than those of any species assigned to *Notchpeakia*, although small cranidia of, e.g., *N. notchpeakensis* n. sp. do have wider

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FIGURE 4—*Notchpeakia milleri* n. sp., from the Lava Dam Member, Notch Peak Formation (Sunwaptan), section Lava Dam Five, southern House Range, Utah. 1, 5, 9, Cranidium, SUI 101502, dorsal, anterior, and right lateral views, $\times 10$ (LD5 25.3 m). 2, 6, 10, Cranidium, SUI 101503, dorsal, anterior, and right lateral views, $\times 10$ (LD5 25.3 m). 3, 7, 12, Cranidium, SUI 101504, dorsal, anterior, and left lateral views, $\times 10$ (LD5 25.3 m). 4, 8, 13, Cranidium, SUI 101505, dorsal, anterior, and left lateral views, $\times 10$ (LD5 30.5 m). 11, 15, 21, Cranidium, SUI 101506, right lateral, dorsal, and anterior views, $\times 10$ (LD5 30.5 m). 14, 19, 20, Cranidium, SUI 101507, dorsal, anterior, and right lateral views, $\times 10$ (LD5 30.5 m). 16, Left librigena, SUI 101508, external view, $\times 7.5$ (LD5 16.8T m); 17, 18, Right librigena, SUI 101509, external and ventrolateral views, $\times 7.5$ (LD5 16.8T m). 22, Left librigena, SUI 101510, external view, $\times 10$ (LD5 16.8T m). 23, Left librigena, SUI 101511, external view, $\times 10$ (LD5 30.5 m). 24, 27, Right librigena, SUI 101512, ventrolateral and external views, $\times 10$ (LD5 25.3 m). 25, 28, Left librigena, SUI 101513, internal and external views, $\times 10$ (LD5 16.8T m). 26, Left librigena, SUI 101514, external view, $\times 10$ (LD5 30.5 m). 29, Right librigena, SUI 101515, external view, $\times 10$ (LD5 25.3 m). 30, Right librigena, SUI 101516, external view, $\times 10$ (LD5 16.8T m). 31, Right librigena, SUI 101517, external view, $\times 10$ (LD5 16.8T m). 32, Right librigena, SUI 101518, external view, $\times 10$ (LD5 16.8T m). 33, Left librigena, SUI 101519, external view, $\times 10$ (LD5 float). 34, Right librigena, SUI 101520, external view, $\times 10$ (LD5 30.5 m). 35, Left librigena, SUI 101521, external view, $\times 10$ (LD5 30.5 m). 36, Right librigena, SUI 101522, external view, $\times 7.5$ (LD5 16.8T m).

fixigenae than adults. Other major differences include the apparent absence of pitted sculpture underlying the tubercles, the apparent very small size of the librigenae, and the anterior border that is considerably longer sagittally than exsagittally, with a dorsal terrace line sculpture. In the absence of knowledge of any sclerites other than the cranidium, we now regard the affinities of this species as indeterminate; it is not obviously an "entomaspidid." Fortey (1983) compared the species with members of *Glyptometopus* Rasetti, 1961 and considered that "in some respects it is transitional between the two genera [i.e., *Calymenidius* and *Glyptometopus*]." However, we are in the process of revising *Glyptometopus* on the basis of well-preserved, new silicified species from Nevada, and the taxon does not seem to be related to either *Calymenidius* or to "*Heterocaryon*" fortleyi.

Genus NOTCHPEAKIA new genus

Type species.—*Notchpeakia milleri* n. sp.

Other species.—*Notchpeakia cherrycreekensis* n. sp.; *N. notchpeakensis* n. sp.; *N. taylori* n. sp.; *Heterocaryon vargum* Westrop, 1986; *Heterocaryon* cf. *H. tuberculatum* of Winston and Nicholls (1967, p. 76, pl. 11, figs. 15, 18) and *Heterocaryon tuberculatum* of Stitt (1971; possibly conspecific with Winston and Nicholls's material); *Heterocaryon* n. sp. aff. *H. tuberculatum* of Fortey (1983, p. 206, text-fig. 3); *Heterocaryon vargum* of Loch et al. (1993, fig. 6.10); *Notchpeakia*? n. sp. A herein.

Diagnosis.—Anterior border very short; anterior border furrow very short (sag., exsag.) and incised; relatively strong and dense tuberculate sculpture on fixigena, frontal area, and preglabellar field of most species; eyes tiny; eye ridge faint or not discernible; L0 and librigenal lateral border usually subdivided by linear series of aligned pits; cranidium and librigenal field with prominent pitted sculpture; pygidium with five or six pairs of splayed, subrectangular pleural spines and vertical, wall-like distal pleural area.

Etymology.—After the Notch Peak Formation.

Discussion.—Members of *Notchpeakia* are distinguished from the more poorly known species assigned to *Heterocaryon* in the possession of a very short versus very long anterior border, very faint versus prominent eye ridge, and generally abundant versus nearly absent tuberculate sculpture on the fixigena and frontal area. More contrasts would likely emerge with more comprehensive knowledge of *Heterocaryon*, for which, e.g., librigenae are entirely unknown.

A thoracic axial spine is known only in two species, but it

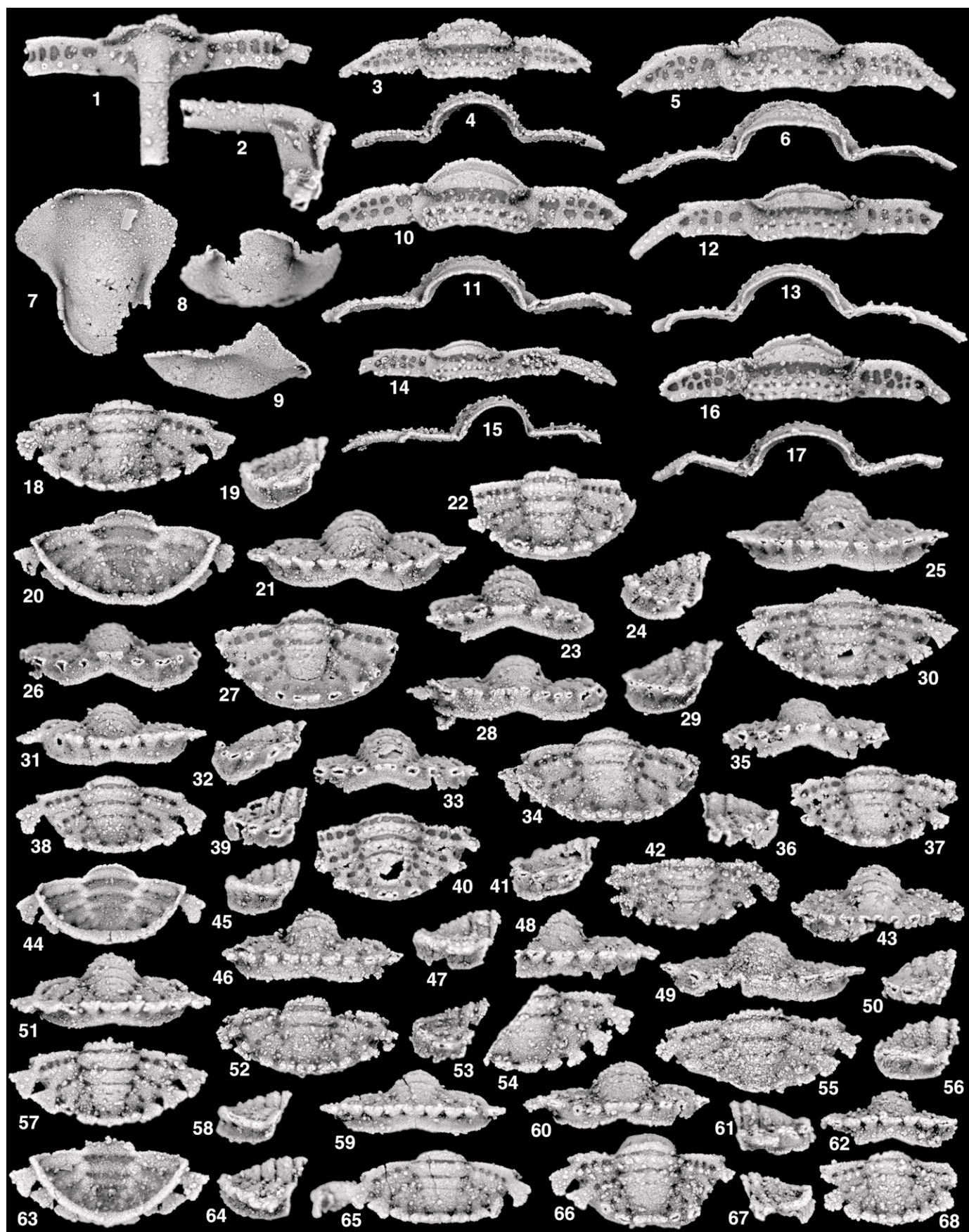
has a highly unusual morphology. The spine appears to be composite in construction (Figs. 5.2, 8.32, 8.33) with a dorsal portion derived from a base set anteriorly on the axial ring and a ventral portion derived from the rear of the axial ring. Viewed laterally, these portions are separated proximally by an elongate lateral furrow, but are completely fused distally, at least in *N. taylori*. At what level this distinctive feature is synapomorphic is unknown, because data are missing for the remainder of species of *Notchpeakia* and for most other "entomaspidids." The morphology is not evident on a spine-bearing thoracic segment of *Bowmania lassieae* illustrated by Adrain and Westrop (2004, pl. 16, fig. 13).

Two specimens from the San Saba Member of the Wilberns Formation, Texas, illustrated by Winston and Nicholls (1967, pl. 11, figs. 15, 18) as *Heterocaryon* cf. *H. tuberculatum*, represent a species of *Notchpeakia*, characterized by an inflated, strongly forwardly expanding glabella. A specimen from the Signal Hill Limestone of Oklahoma misidentified by Stitt (1971, p. 22, pl. 7, fig. 11) as *Heterocaryon tuberculatum* is possibly conspecific with Winston and Nicholls's specimens. More material and better illustrations from either region would be required to adequately assess the occurrences. Similarly, a cranidium from the Mistaya Formation of Alberta illustrated by Loch et al. (1993, fig. 6.10) as *Heterocaryon vargum* does not appear to belong to that species, as it has a more ovate, inflated glabella with dense, relatively fine tuberculate sculpture. It is not well enough known to assess with confidence, but appears similar to the Oklahoma and Texas cranidia.

A cranidium from the Broom Point Member of the Green Point Formation of western Newfoundland described by Fortey (1983) as *Heterocaryon* sp. nov. aff. *H. tuberculatum* has prominent pitting over its dorsal surface, including within its very short anterior border furrow, as well as coarse tubercles on its fixigena, frontal area, preglabellar field, and anterior border. It represents a species of *Notchpeakia*. It can be coded for characters 1–4 in the analysis herein, which place it within the *milleri-taylori-notchpeakensis-cherrycreekensis* clade on the basis of its tuberculate anterior border. Due to missing data it has a labile position within this clade and serves to collapse structure within it to a strict consensus polytomy.

Bowmania pennsylvanica Rasetti, 1959, from the Frederick Limestone of Maryland, is broadly similar to some species included here in *Notchpeakia*, especially in its densely and coarsely tuberculate cranidial sculpture. This species, however, is likely related to members of the *Bowmania/Kathrynina* group, on the

FIGURE 5—*Notchpeakia milleri* n. sp., from the Lava Dam Member, Notch Peak Formation (Sunwaptan), section Lava Dam Five, southern House Range, Utah. 1, 2, Thoracic segment, SUI 101523, dorsal and right lateral views, $\times 15$ (LD5 16.8T m). 3, 4, Thoracic segment, SUI 101524, dorsal and anterior views, $\times 10$ (LD5 30.5 m). 5, 6, Thoracic segment, SUI 101525, dorsal and anterior views, $\times 10$ (LD5 16.8T m). 7–9, Hypostome, SUI 101526, ventral, posterior, and right lateral views, $\times 10$ (LD5 25.3 m). 10, 11, Thoracic segment, SUI 101527, dorsal and anterior views, $\times 10$ (LD5 16.8T m). 12, 13, Thoracic segment, SUI 101528, dorsal and anterior views, $\times 15$ (LD5 16.8T m). 14, 15, Thoracic segment, SUI 101529, dorsal and anterior views, $\times 10$ (LD5 16.8T m). 16, 17, Thoracic segment, SUI 101530, dorsal and anterior views, $\times 12$ (LD5 16.8T m). 18–21, Pygidium, SUI 101531, dorsal, right lateral, ventral, and posterior views, $\times 10$ (LD5 16.8T m). 22–24, Pygidium, SUI 101532, dorsal, posterior, and right lateral views, $\times 10$ (LD5 16.8T m). 25, 29, 30, Pygidium, SUI 101533, posterior, right lateral, and dorsal views, $\times 10$ (LD5 16.8T m). 26, 27, 32, Pygidium, SUI 101534, posterior, dorsal, and right lateral views, $\times 10$ (LD5 16.8T m). 28, 34, 41, Pygidium, SUI 101535, posterior, dorsal, and right lateral views (LD5 16.8T m). 31, 38, 44, 45, Pygidium, SUI 101536, posterior, dorsal, ventral, and right lateral views, $\times 10$ (LD5 16.8T m). 33, 39, 40, Pygidium, SUI 101537, posterior, right lateral, and dorsal views, $\times 10$ (LD5 16.8T m). 35–37, Pygidium, SUI 101538, posterior, left lateral, and dorsal views, $\times 12$ (LD5 16.8T m). 42, 43, 50, Pygidium, SUI 101539, dorsal, posterior, and right lateral views, $\times 12$ (LD5 30.5 m). 46, 52, 53, Pygidium, SUI 101540, posterior, dorsal, and right lateral views, $\times 12$ (LD5 30.5 m). 47, 48, 54, Pygidium, SUI 101541, right lateral, posterior, and dorsal views, $\times 12$ (LD5 16.8T m). 49, 55, 56, Pygidium, SUI 101542, posterior, dorsal, and right lateral views, $\times 10$ (LD5 25.3 m). 51, 57, 63, 64, Pygidium, SUI 101543, posterior, dorsal, ventral, and right lateral views, $\times 12$ (LD5 16.8T m). 58, 59, 65, Pygidium, SUI 101544, right lateral, posterior, and dorsal views, $\times 12$ (LD5 16.8T m). 60, 61, 66, Pygidium, SUI 101545, posterior, left lateral, and dorsal views, $\times 12$ (LD5 16.8T m). 62, 67, 68, Pygidium, SUI 101546, posterior, left lateral, and dorsal views, $\times 12$ (LD5 16.8T m).



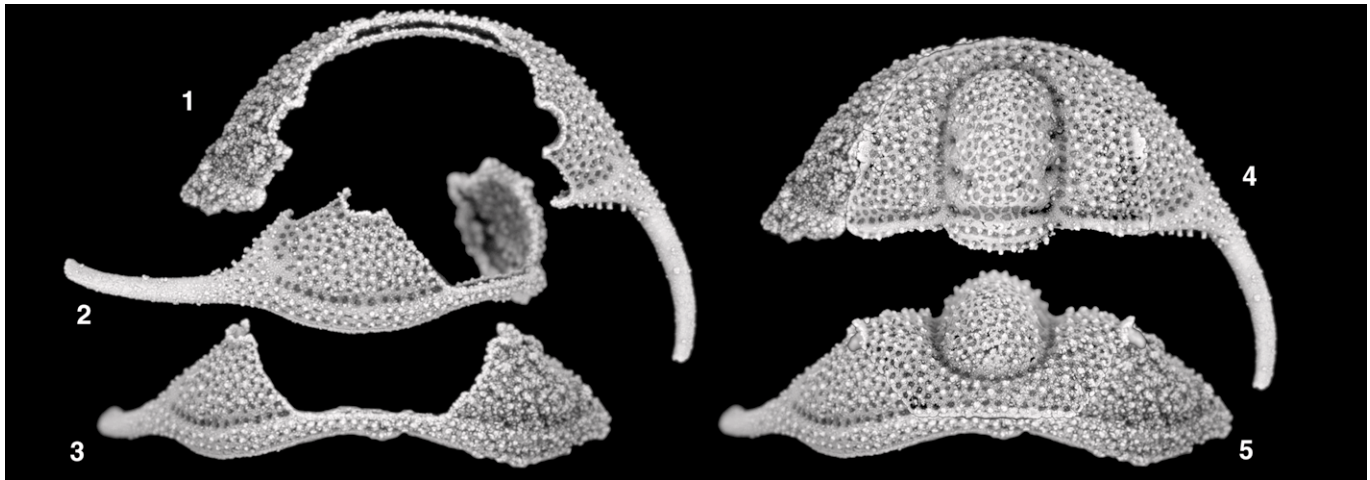


FIGURE 6—*Notchpeakia milleri* n. sp., from the Lava Dam Member, Notch Peak Formation (Sunwaptan), section Lava Dam Five, southern House Range, Utah. 1–3, Yoked librigenae, SUI 101547, dorsal view, external view of right librigena, and anterior view, $\times 10$ (LD5 25.3 m). 4, 5, Same specimen with cranium of almost exactly the right size (SUI 101507, Fig. 4.14, 4.19, 4.20) shown in articulation.

basis of its very long preglabellar field and extremely widely anteriorly divergent anterior sections of the facial suture. “*Bowmania* cf. *B. pennsylvanica*” of Taylor and Halley (1974, p. 21, pl. 2, figs. 12–14) appears to be closely related to Rasetti’s taxon. The species will be revised in a forthcoming work.

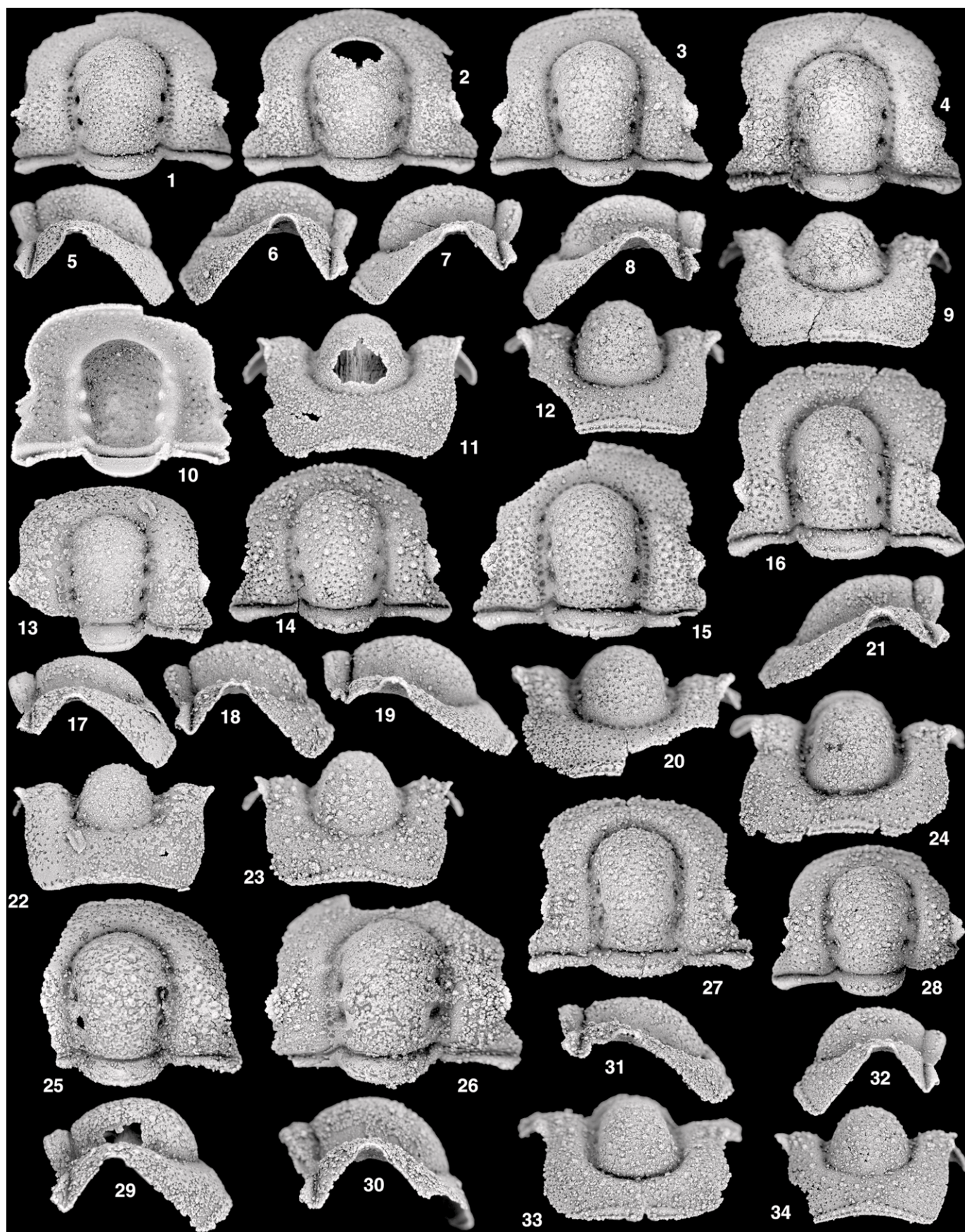
NOTCHPEAKIA MILLERI new species
Figures 3–6

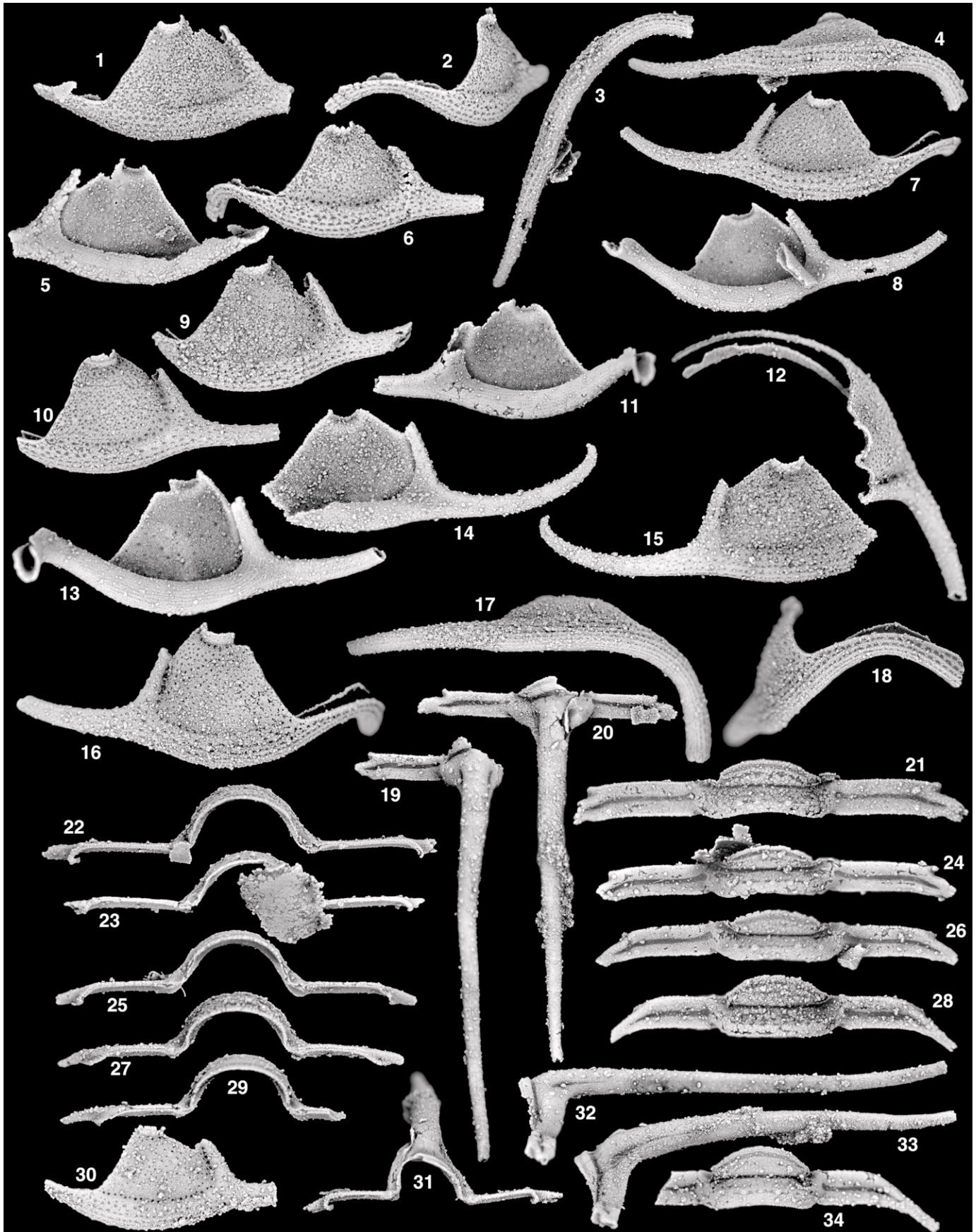
Diagnosis.—Pronounced dorsal cephalic sculpture of relatively large ovate to subpolygonal pits set within meshlike raised ridges, with small tubercles sparsely scattered on ridges; axial and preglabellar furrows, S0, and librigenal lateral border furrow all containing larger, spaced pits; pits aligned in two transverse rows, anterior one larger, on L0; cranial sagittal convexity low for genus; anterior border broad (tr.); librigenal lateral border with two rows of elongate, slotlike pits; genal spine long, longer than remainder of librigena; pygidium with five pairs of pleural spines.

Description.—Cranidium subtrapezoidal in outline, width at anterior margin 57% (53–63) of maximum width at posterior, moderately vaulted, with height (sag.) equal to 49% (43–52) of width across palpebral lobes; axial and preglabellar furrows shallow grooves; glabella strongly arched, with height (sag.) occupying 74% (69–75) of cranial height in anterior view, roughly oval in outline, expanding gradually forward so that width at S0 95% (91–99) of width at S2, and rounded anteriorly; lateral profile of glabella nearly horizontal posteriorly but curved downward in front of S2; S0 clearly defined, transverse medially but with distal tips deflected forward; L0 occupies 19% (17–20) of glabellar length; S1 and S2 pitlike near axial furrow, well expressed on ventral surface as small, subcircular

inflations (Fig. 3.22, 3.23, 3.26); L2 and L3 roughly equal in length to L0; frontal lobe long, equal to 36% (33–39) of glabellar length (sag.); preglabellar field short, 14% (11–16) of cranial length, weakly inflated in lateral view; anterior border very short (sag., exsag.), convex rim, sagittal length 4% (4–5) of cranial length, transversely flat (Fig. 3.48, 4.7, 4.8) or very weakly arched (Fig. 3.21, 3.24, 3.52); palpebral lobe semicircular (Fig. 4.1, 4.6), length (exsag.) 26% (23–30) of glabellar length (sag.), centered opposite L2 and separated from fixigena by finely incised palpebral furrow, ascending steeply from fixigena, but horizontal distally; eye ridge variably expressed but evident on some individuals (Fig. 3.1, 3.5), extending inward and forward from palpebral lobe at about 35° to intersect axial furrow near midlength of frontal lobe; interocular fixigena broad, occupying 23% (21–25) of cranial width across palpebral lobes, gently convex in anterior view; anterior branches of facial sutures converge forward and downward along nearly straight path before turning transversely inward along anterior cranial margin (Fig. 3.8, 3.21, 3.25, 3.33, 3.36), posterior branches initially divergent, but curve inward at posterior border furrow; posterior margin of fixigena directed gently backward; posterior border furrow shallow but clearly defined groove; posterior border narrow, convex, expands distally with maximum length (exsag.) equal to 8% (6–10) of cranial length; external surface of fixigena, preglabellar field, frontal area and cranial furrows with large, closely spaced subrectangular to subcircular pits; raised bands between pits with scattered fine tubercles; L0 with median tubercle; in front of tubercle, surface is smooth, but two parallel rows of pits, anterior row larger than posterior row, present behind tubercle, pits

FIGURE 7—*Notchpeakia taylori* n. sp., from the Lava Dam Member, Notch Peak Formation (Sunwaptan), section Lava Dam Five, southern House Range, Utah. 1, 5, 10, Cranidium, holotype, SUI 101548, dorsal, right lateral, and ventral views, $\times 6$ (LD5 16.8T m). 2, 6, 11, Cranidium, SUI 101549, dorsal, left lateral, and anterior views, $\times 7.5$ (LD5 25.3 m). 3, 7, 12, Cranidium, SUI 101550, dorsal, left lateral, and anterior views, $\times 7.5$ (LD5 16.8T m). 4, 8, 9, Cranidium, SUI 101551, dorsal, left lateral, and anterior views, $\times 7.5$ (LD5 16.8T m). 13, 17, 22, Cranidium, SUI 101552, dorsal, right lateral, and anterior views, $\times 6$ (LD5 25.3 m). 14, 18, 23, Cranidium, SUI 101553, dorsal, right lateral, and anterior views, $\times 10$ (LD5 16.8T m). 15, 19, 20, Cranidium, SUI 101554, dorsal, right lateral, and anterior views, $\times 7.5$ (LD5 16.8T m). 16, 21, 24, Cranidium, SUI 101555, dorsal, left lateral, and anterior views, $\times 7.5$ (LD5 16.8T m). 25, 29, Cranidium, SUI 101556, dorsal and right lateral views, $\times 7.5$ (LD5 30.5 m). 26, 30, Cranidium, SUI 101557, dorsal and right lateral views, $\times 7.5$ (LD5 25.3 m). 27, 31, 33, Cranidium, SUI 101558, dorsal, right lateral, and anterior views, $\times 7.5$ (LD5 16.8T m). 28, 32, 34, Cranidium, SUI 101559, dorsal, left lateral, and anterior views, $\times 7.5$ (LD5 16.8T m).





augmented by fine tubercles; anterior and posterior borders lack pits but carry fine tubercles; palpebral lobes smooth.

Librigenae yoked anteriorly (Fig. 4.29); genal spine long, 121% of librigenal field length (exsag.), curved inward distally; librigenal field broad, moderately wide, with width in external view 17% of field length; eye socle of single narrow but inflated band separated from field by shallow furrow containing radially arranged series of pits and from visual surface by finely incised groove; confluent lateral and posterior border furrows shallow but accentuated by sculptural pits; lateral border tubular, and relatively broad, width (tr.) 27% (26–28) of librigenal field width; gently convex doublure extends inward as far as border furrows, with fine terrace ridges extended also along interior aspect of genal spine; sculpture of large pits and associated fine tubercles, similar to cranial sculpture, on entire external surface except for genal spine; on lateral border, pits organized into two conspicuous bands running parallel to margin with much smaller third band developed near adaxial margin on some specimens (Fig. 4.23, 4.26); posterior border with row of well-defined tubercles along posterior margin (Fig. 4.26, 4.31).

Hypostome with broad, subtriangular anterior wings, length (exsag.) equal to about half of hypostomal length; median body convex, subelliptical in outline with well-rounded posterior margin, unequally divided by ill-defined median furrow into short posterior lobe and longer anterior lobe; anterior lobe about twice length of posterior lobe; posterior and lateral borders narrow, separated from median body by well-incised border furrows; lateral border extends along posterior edge of anterior wing as indistinct ridge; anterior margin with narrow rim present only in front of medial body; external surface of hypostome apparently smooth.

Thoracic segments with convex axis that stands well above pleurae and accounts for about two-thirds of segment height; articulating half-ring occupies about half of axial ring; anterior edge of half-ring is narrow, crescentic band set off from rest by shallow, arcuate furrow; articulating furrow well incised, nearly transverse medially but curved forward distally; shape and length of pleurae variable, all with long (exsag.) pleural furrows expressed as areas of large sculptural pits; anterior and posterior pleural bands short (exsag.) and subequal in length; some, probably mid-thorax, segments have straight anterior and posterior pleural margins (Fig. 5.12) and terminate at long, peglike spines that curve gently back and down; some segments of this type (5.1, 5.2) have long, stout, nearly horizontal axial spine; base of spine with elongate groove on lateral aspect; other, probably anterior, segments (Fig. 5.3, 5.4) have narrower pleurae with anterior margins curved backward distally to become continuous with anterior margins of pleural spines; pleural and articulating furrows have sculpture of large, subcircular to subrectangular pits; axial ring with at least one, and commonly two, narrow bands of pits, augmented by fine tubercles on raised bands between pits; tubercles extend onto posterior pleural bands (Fig. 5.16) and, in some cases (Fig. 5.12),

pleural spines; anterior pleural bands, articulating half-ring and axial spine smooth.

Pygidium semielliptical in outline, length (sag.) 84% (79–86) of maximum width, moderately convex, with pygidial height (sag.) in posterior view 36% (33–38) of maximum pygidial width; pleural field fringed by four pairs of tab-shaped, square-tipped spines and fifth, partially fused, posterior pair; all spines widen distally; paired spines decrease somewhat in size, and become more closely spaced, posteriorly; anterior spine pair nearly horizontal (Fig. 5.31) but remaining spines deflected upward; axial furrows expressed as row of sculptural pits; axis convex, accounting for 60% (57–64) of pygidial height (sag.) in posterior view, and occupying 32% (30–33) of pygidial width across anteriormost ring, tapering backward, width at posterior 53% (45–58) of width at anterior, longitudinal profile slopes evenly backward; all pygidia with two well-defined rings on dorsal surface separated by finely etched, transverse ring furrows; third ring is expressed on some specimens (Fig. 5.18, 5.20, 5.57) but merged with terminal piece on others (Fig. 5.22, 5.34); third ring is clearly differentiated from terminal piece on ventral surfaces (Fig. 5.20, 5.63); short, semielliptical articulating half-ring occupies 14% (12–17) of axis length; pleural fields weakly convex and crossed by three well-defined pairs of pleural furrows; furrows accentuated by sculptural pits and do not extend onto marginal spines; anterior and posterior pleural bands subequal in length; interpleural furrows faintly expressed, obscure on some specimens (Fig. 5.27); wall-like distal area descends almost vertically from bases of spines, rimmed ventrally by slightly inflated border; weak (Fig. 5.25, 5.59) to strong (Fig. 5.23, 5.26) medial indentation in posterior margin; doublure narrow and confined to region beneath bases of marginal spines; sculpture of large, subcircular to subrectangular pits along axial and pleural furrows, may also be present along axial ring furrows of larger specimens (Fig. 5.30); best-preserved specimens (Fig. 5.18, 5.30) show transverse row of fine tubercles on axial rings that extend onto posterior pleural bands; remainder of external surface apparently smooth.

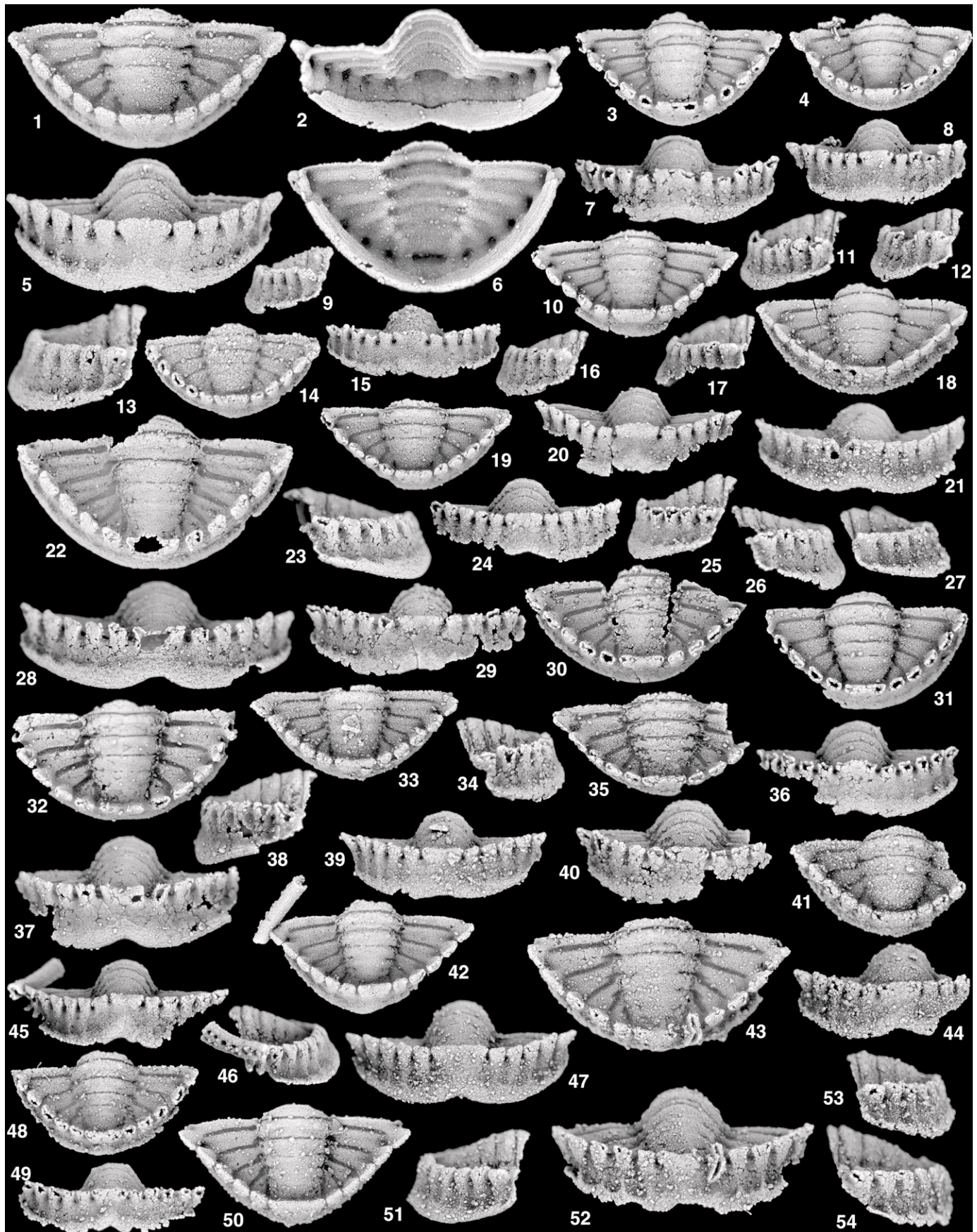
Etymology.—For James F. Miller of the University of Missouri, Springfield.

Types and occurrence.—Holotype, cranidium, SUI 101485, from section Lava Dam Five 16.8T m; paratypes SUI 101486–101499, 101502–101547 from section Lava Dam Five; assigned specimens SUI 101500 and 101501 from section Lawson Cove 25.3 m.

Discussion.—*Notchpeakia milleri*, the type species, has many autapomorphies but is nested in a derived position within the genus. Particularly striking is the pattern of expanded sculptural pits reflected on all sclerites except the hypostome. These pits are open, shallow, and subpolygonal in outline, and in series they replace the typical grooves of the axial furrows, S0, the librigenal lateral and posterior border furrows, the thoracic pleural and ring

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FIGURE 8—*Notchpeakia taylora* n. sp., from the Lava Dam Member, Notch Peak Formation (Sunwaptan), section Lava Dam Five, southern House Range, Utah. 1, 5, Left librigena, SUI 101560, external and internal views, $\times 7.5$ (LD5 30.5 m). 2, 6, 11, Left librigena and yoked doublure, SUI 101561, anterior, external, and internal views, $\times 7.5$ (LD5 30.5 m). 3, 4, 7, 8, Right librigena and yoked doublure, SUI 101562, ventral, ventrolateral, external, and internal views, $\times 7.5$ (LD5 16.8T m). 9, Left librigena, SUI 101563, external view, $\times 7.5$ (LD5 25.3 m). 10, Left librigena, SUI 101564, external view, $\times 7.5$ (LD5 16.8T m). 12, 13, 16–18, Right librigena and yoked doublure, SUI 101565, dorsal, internal, external, ventrolateral, and anterior views, $\times 7.5$ (LD5 16.8T m). 14, 15, Right librigena, SUI 101566, internal and external views, $\times 7.5$ (LD5 30.5 m). 19, 32, Thoracic segment, SUI 101567, dorsal and left lateral views, $\times 7.5$ (LD5 16.8T m). 20, 31, 33, Thoracic segment, SUI 101568, dorsal, anterior, and left lateral views, $\times 6$ (LD5 25.3 m). 21, 22, Thoracic segment, SUI 101569, dorsal and anterior views, $\times 10$ (LD5 25.3 m). 23, 24, Thoracic segment, SUI 101570, anterior and dorsal views, $\times 10$ (LD5 25.3 m). 25, 26, Thoracic segment, SUI 101571, anterior and dorsal views, $\times 10$ (LD5 16.8T m). 27, 28, Thoracic segment, SUI 101572, anterior and dorsal views, $\times 10$ (LD5 25.3 m). 29, 34, Thoracic segment, SUI 101573, anterior and dorsal views, $\times 10$ (LD5 30.5 m). 30, Left librigena, SUI 101574, external view, $\times 7.5$ (LD5 float).



furrows, and the pygidial pleural and ring furrows. The species is also unique in its relatively low, uninflated cephalon, the possession of five versus the typical six pygidial segments, and the manner in which the pygidial pleural spines expand distally and splay out around the margin of the pygidium.

The hypostome is identified on the basis of similarity to that of *Bowmania lassieae* Adrain and Westrop, 2004 (pl. 16, fig. 20). Both are strongly reminiscent of the hypostomes of post-Cambrian harpetids (e.g., Chatterton and Ludvigsen, 1976, pl. 7, fig. 10). This is the only “entomaspidid” hypostome recovered. It could potentially belong instead to *Notchpeakia taylori* n. sp., but is assigned to *N. milleri* on the basis of the latter’s much more common occurrence at horizon LD5 25.3 m.

NOTCHPEAKIA TAYLORI new species
Figures 7–9

Diagnosis.—Cephalic sculpture subdued and partially effaced; cranidium strongly vaulted in sagittal profile; librigenal field broad but lacking tubercles except for rare traces of effaced examples; thoracic and pygidial pleural furrows deep, long (exsag.) grooves, pleural bands lacking sculpture; tuberculate sculpture extremely reduced or absent from dorsal surface of pygidium, including first axial ring.

Description.—Cranidium (excluding posterior fixigenae) subrectangular in outline, length (sag.) 85% (77–91) of width across midlength of palpebral lobes; anterior margin rounded; strongly convex, with height (sag.) in anterior view equal to 66% (64–70) of maximum width; axial and preglabellar furrows gently impressed grooves accentuated by row of sculptural pits; anteriorly rounded glabella roughly oval in outline, occupying 83% (79–86) of cranial length (sag.) and 44% (42–47) of cranial width across midlength of palpebral lobes, strongly convex, accounting for 61% (57–63) of cranial height (sag.) in anterior view, longitudinal profile arched gently upward between S0 and S2, then curved sharply downward to become nearly vertical near preglabellar furrow; S0 narrow, well incised, transverse to weakly curved; L0 occupies 17% (15–18) of glabellar length (sag.); S1 and S2 pitlike near axial furrow, well expressed on ventral surface as small, subcircular inflations; L2 and L3 roughly equal in length to L0; frontal lobe long, accounting for 40% (36–44) of glabellar length (sag.); preglabellar field short, 17% (14–21) of cranial length (sag.), sloping nearly straight down from glabella at 53° (48–57); anterior border furrow very shallow groove accentuated by sculptural pits; anterior margin bowed dorsally in anterior view; anterior border short, accounting for 23% (16–31) of frontal area length sagittally and narrowing laterally to give subtriangular outline in anterior view, very weakly convex, barely raised above level of preglabellar field; palpebral lobe semielliptical, centered opposite L2 and equal to 24% (22–26) of glabellar length, curved gently upward but not raised above crest of interocular fixigena (Fig. 7.12, 7.22, 7.34); palpebral furrow poorly defined, nearly

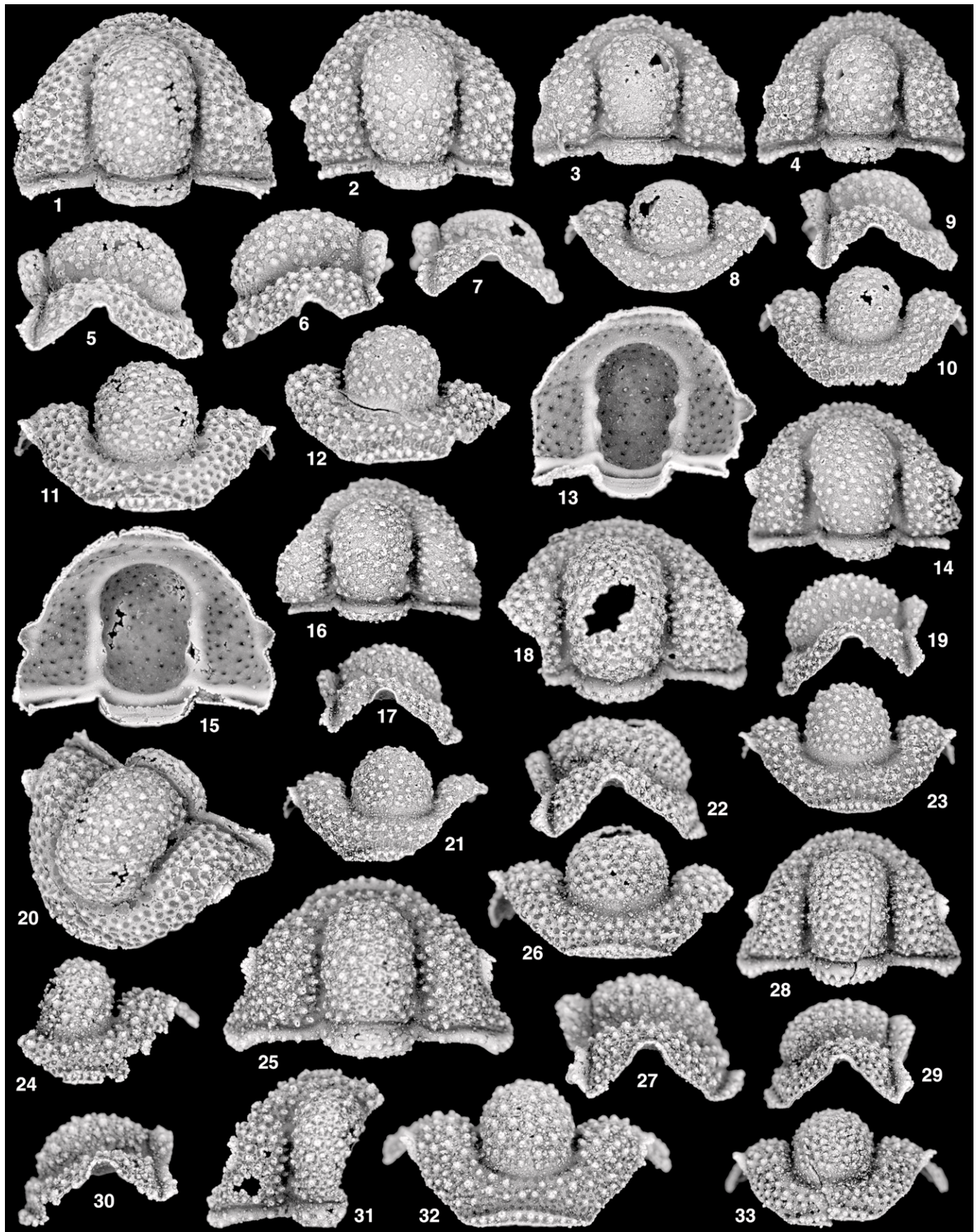
straight groove; eye ridge barely visible (Fig. 7.1, 7.3) to indistinguishable (Fig. 7.15); interocular fixigena gently inflated in anterior view, equal to 20% (18–24) of cranial width across midlength of palpebral lobes; anterior branches of facial sutures initially weakly divergent before curving gradually inward to anterior border, turned abruptly inward along anterior cranial margin; posterior branches of facial sutures moderately posteriorly divergent but curved gently inward at posterior border furrow; posterior border furrow short (exsag.), well-incised groove, curved gently backward; convex posterior border expands distally, maximum length (exsag.) 10% (9–10) of cranial length (sag.); external surface of fixigenae (excluding posterior border), preoccipital glabella, and preglabellar field with pitted sculpture augmented by scattered tubercles, tubercles best developed on smaller specimens (Fig. 7.14, 7.28), more subdued on larger specimens, although still well defined as pits on ventral surfaces (Fig. 7.10); pits present in axial, preglabellar, and anterior border furrows; other furrows lack sculpture; anterior border with row of pits near anterior border, and with row of tubercles on smaller specimens; L0 with transverse row of pits, with fine tubercles on raised bands between pits; posterior border and palpebral lobes smooth.

Librigenae yoked anteriorly (Fig. 8.12); genal spine long, equal to librigenal field length (exsag.) and curved inward distally; width of field 72% (67–75) overall librigenal width; eye socle of single narrow band; confluent lateral and posterior border furrows shallow but clearly defined; lateral border tubular, width 40% (38–42) of that of field; gently convex doublure extends inward as far as border furrows, with fine terrace lines extended posteriorly along inner aspect of genal spine; sculpture of fine pits and scattered tubercles on genal field (Fig. 8.10), tubercles expressed as pits on ventral surface (Fig. 8.13), larger pits present in border furrows, along lateral border and yoke, and on proximal parts of genal spine; on border and yoke, pits arranged in rows oriented parallel to margin.

Thoracic segments with flat pleura that terminate at pleural spine that is flexed gently downward; spines incompletely preserved but apparently short; convex axis stands well above pleurae and accounts for almost all of segment height in anterior view; articulating half-ring occupies a little less than half of axial ring; anterior edge of half-ring is short, crescentic band set off from rest by shallow, arcuate furrow; articulating furrow is short, well-incised groove, nearly transverse medially but curved forward distally; shape of pleurae variable, but all have short pleural furrows; anterior and posterior pleural bands short and subequal in width; midthorax segments have straight anterior and posterior pleural margins (Fig. 8.21); very long, stout, nearly horizontal axial spine present on some segments (Fig. 8.19, 8.20); base of spine defined laterally by shallow furrows (Fig. 8.20, 8.30, 8.31); probable anterior segments (Fig. 8.28, 8.33) have narrower pleurae with anterior margins curved backward distally to become

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FIGURE 9—*Notchpeakia taylori* n. sp., from the Lava Dam Member, Notch Peak Formation (Sunwaptan), section Lava Dam Five, southern House Range, Utah. Specimens are $\times 10$ and from horizon LD5 16.8T m except where noted otherwise. 1, 2, 5, 6, 13, Pygidium, SUI 101575, dorsal, anteroventral, posterior, ventral, and right lateral views. 3, 7, 11, Pygidium, SUI 101576, dorsal, posterior, and right lateral views. 4, 8, 12, Pygidium, SUI 101577, dorsal, posterior, and right lateral views. 9, 14, 15, Pygidium, SUI 101578, right lateral, dorsal, and posterior views. 10, 17, 20, Pygidium, SUI 101579, dorsal, right lateral, and posterior views. 16, 19, 24, Pygidium, SUI 101580, right lateral, dorsal, and posterior views. 18, 21, 27, Pygidium, SUI 101581, dorsal, posterior, and left lateral views. 22, 23, 28, Pygidium, SUI 101582, dorsal, left lateral, and posterior views. 25, 29, 30, Pygidium, SUI 101583, right lateral, posterior, and dorsal views. 26, 31, 36, Pygidium, SUI 101584, left lateral, dorsal, and posterior views. 32, 37, 38, Pygidium, SUI 101585, dorsal, posterior, and right lateral views (LD5 30.5 m). 33, 39, Pygidium, SUI 101586, dorsal and posterior views. 34, 35, 40, Pygidium, SUI 101587, left lateral, dorsal, and posterior views. 41, 44, 53, Pygidium, SUI 101588, dorsal, posterior, and left lateral views (LD5 25.3 m). 42, 45, 46, Pygidium, SUI 101589, dorsal, posterior, and left lateral views. 43, 52, 54, Pygidium, SUI 101590, dorsal, posterior, and left lateral views. 47, 50, 51, Pygidium, SUI 101591, posterior, dorsal, and right lateral views. 48, 49, Pygidium, SUI 101592, dorsal and posterior views.



continuous with anterior margins of pleural spines; in all segments, posterior half of axial ring with single, transverse row of weak pits and associated fine tubercle; remainder of external surfaces of segments appear smooth.

Pygidium semicircular in outline, length (sag.) 51% (46–53) of maximum width, moderately convex, with height (sag.) in posterior view 44% (38–50) of maximum width; pleural field fringed by five pairs of spines and partially or wholly fused posteromedian pair, all spines expanded distally, decreasing in size posteriorly; anterior spine pair directed upward and outward at about 45° (Fig. 9.1, 9.2), remaining spines more steeply inclined, becoming nearly vertical posteriorly; axial furrows shallow, defined largely by abrupt change in slope between axis and pleural field; axis convex, occupying 59% (54–66) of pygidial height in posterior view and with width at first axial ring equal to 33% (30–36) of maximum pygidial width, tapering backward, with width at anterior equal to 60% (52–69) width at posterior, lateral profile sloping steadily backward; axial rings and ring furrows variably expressed on dorsal surface; first two rings always well defined and separated by finely incised, transverse ring furrows that deepen near axial furrow; third ring well expressed (Fig. 9.4, 9.32, 9.48); fourth typically expressed laterally but obscured medially; tiny fifth ring weakly expressed on some specimens (Fig. 9.32, 9.42), not differentiated from terminal piece on others; short, semielliptical articulating half-ring accounts for 12% (8–15) of axis length, bounded posteriorly by finely incised, transverse articulating furrow; first axial ring twice as long as articulating half-ring, equal to 22% (20–25) of axis length, and other rings decrease progressively in size towards rear; pleural fields flat (Fig. 9.2, 9.5) and crossed by four pairs of shallow but well-defined pleural furrows that are clearly expressed on ventral surfaces (Fig. 9.6); tiny fifth pair running posteriorly from terminus of axial furrows; interpleural furrows fainter and strongly expressed only on some specimens (Fig. 9.22); anterior and posterior bands subequal in length; distal area descends steeply from marginal spines and is inflated ventrally to form convex border (Fig. 9.5, 9.13); weak (Fig. 9.8) to strong (Fig. 9.28) median indentation in posterior margin; doublure narrowest sagittally, ascends vertically to underlie border (Fig. 9.2); external surface of pygidium smooth except for fine terrace ridges on doublure.

Etymology.—For Michael E. Taylor, formerly of the U.S. Geological Survey.

Types and occurrence.—Holotype, cranium, SUI 101548, from section Lava Dam Five 16.8T m; paratypes SUI 101549–SUI 101592 from section Lava Dam Five.

Discussion.—*Notchpeakia taylori* attains a larger maximum size, has a more forwardly expanding glabella, and is more dorsally vaulted and less tuberculate than all other species. As such, it is the species most similar to *Heterocaryon tuberculatum*, yet this resemblance is very likely homoplastic. Several apomorphies support a derived sister-species relationship with the type species, *N. milleri*, as documented in the analysis section above.

NOTCHPEAKIA NOTCHPEAKENSIS new species

Figures 10, 11, 12.4, 12.9, 12.10

Diagnosis.—Glabella elongate with nearly parallel sides; cephalic pitting expanded into subpolygonal depressions but very strong tuberculate sculpture also retained; anterior border very narrow (tr.) and anterior sections of facial suture concomitantly strongly forwardly convergent; librigenal field relatively narrow.

Etymology.—From the Notch Peak Formation.

Types and occurrence.—Holotype, cranium, SUI 101593 from section Lawson Cove 25.3 m; paratypes SUI 101594–101598, 101603, 101604, 101606, 101609–101613, 101615–101618, 101620, 101623, 101626 from section Lawson Cove 25.3 m; assigned specimens SUI 101599–101602, 101605, 101607, 101608, 101614, 101619, 101621, 101622, 101624, 101625, 101627, 101630, from section Lava Dam Five.

Discussion.—*Notchpeakia notchpeakensis* retains general similarities with the plesiomorphs *N. cherrycreekensis* n. sp. and *N. varga* (Westrop, 1986), but displays several synapomorphies indicating its relationship to the *N. milleri*/*N. taylori* pair. These include modification of the pygidial pleural spine array to an even size and inclination, loss of tubercles on the posterior pygidial axial rings, the development of the cephalic tuberculate sculpture into broad subpolygonal pits, and subdivision of L0 and the librigenal lateral border by elongate pit series.

NOTCHPEAKIA CHERRYCREEKENSIS new species

Figure 13

Heterocaryon vargum WESTROP, 1986; ADRAIN AND WESTROP, 2004, p. 23, pl. 14, figs. 1–33.

Diagnosis.—Very similar to *N. varga*, but differing in anterior border with complete absence of dorsal subparallel terrace lines; anterior border with width (tr.) 78%–80% cranial sagittal length versus 96%–103%; glabella narrowing slightly around frontal lobe versus expanding around frontal lobe; pygidium relatively longer (sag.), with stronger posteromedian indentation.

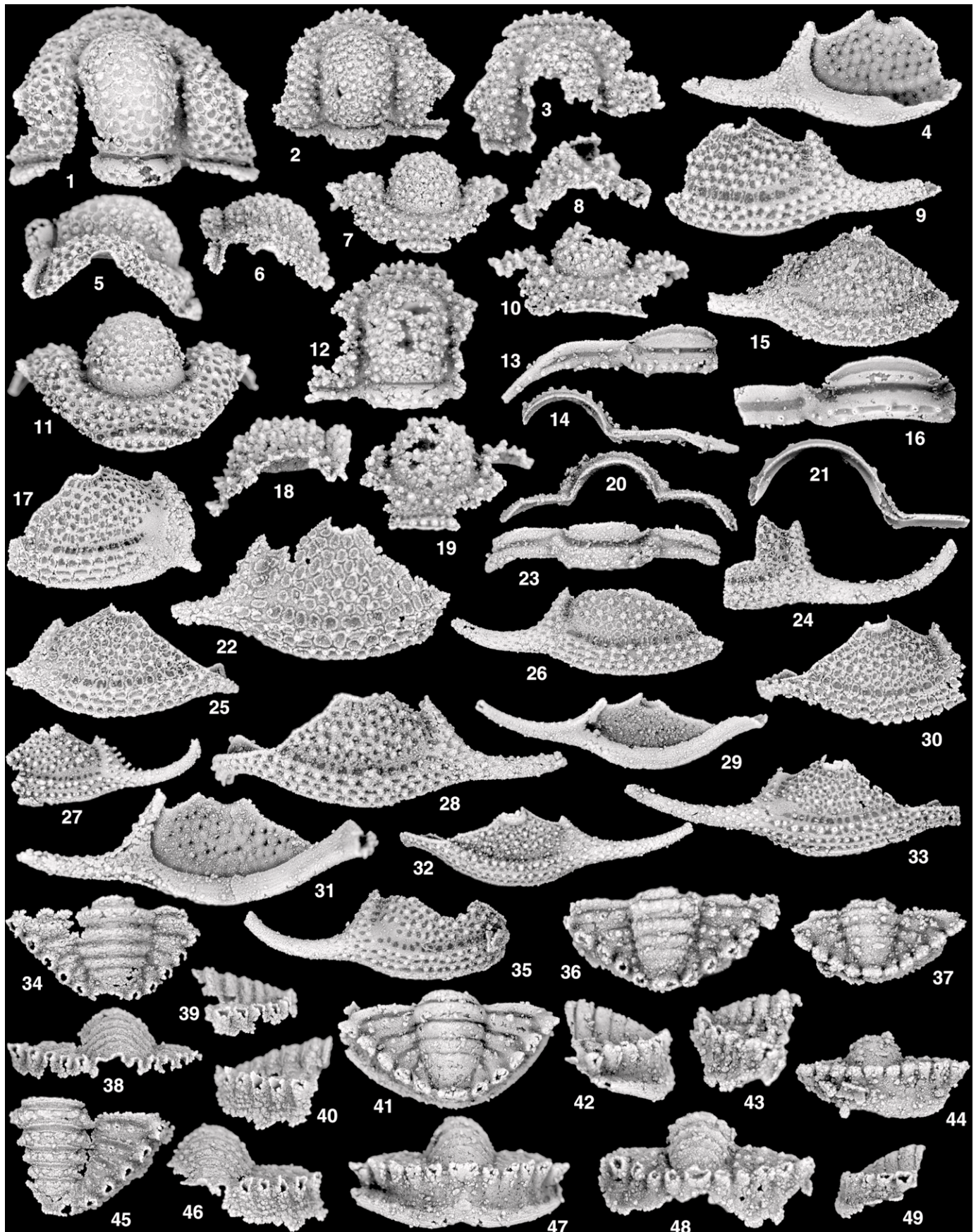
Etymology.—From the Cherry Creek Range.

Types and occurrence.—Holotype, cranium, SUI 99220; paratypes SUI 99221–99233, all from the Bullwhacker Member, Windfall Formation, section CHC 1 371–373T m, Barton Canyon, east slope of Cherry Creek Range, White Pine County, Nevada.

Discussion.—With a growing understanding of the fairly limited range of true intraspecific variation evident in large silicified samples, a species from the Windfall Formation previously (Adrain and Westrop, 2004) assigned to *varga* can now be confidently discriminated based on considerably narrower anterior areas of the cranium and glabella, and the loss of dorsal terrace lines on the anterior border, which is synapomorphic for the genus with the exception of *N. varga*. The pygidium of *N. varga* (Ludvigsen, 1982, fig. 55i–55k, 55m, 55n) is relatively shorter and wider than that of *N. cherrycreekensis*.

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FIGURE 10.—*Notchpeakia notchpeakensis* n. sp., from the Lava Dam Member, Notch Peak Formation (Sunwaptan), sections Lava Dam Five, southern House Range, and Lawson Cove, northern Wah Wah Mountains, Millard County, Utah. 1, 5, 11, 15, 20, Cranium, holotype, SUI 101593, dorsal, right lateral, anterior, ventral, and oblique views, $\times 7.5$ (LAW 25.3 m). 2, 6, 12, 13, Cranium, SUI 101594, dorsal, left lateral, anterior, and ventral views, $\times 7.5$ (LAW 25.3 m). 3, 7, 8, Cranium, SUI 101595, dorsal, right lateral, and anterior views, $\times 7.5$ (LAW 25.3 m). 4, 9, 10, Cranium, SUI 101596, dorsal, right lateral, and anterior views, $\times 7.5$ (LAW 25.3 m). 14, 19, 23, Cranium, SUI 101597, dorsal, left lateral, and anterior views, $\times 7.5$ (LAW 25.3 m). 16, 17, 21, Cranium, SUI 101598, dorsal, right lateral, and anterior views, $\times 7.5$ (LAW 25.3 m). 18, 22, 26, Cranium, SUI 101599, dorsal, right lateral, and anterior views, $\times 7.5$ (LD5 float). 24, 30, 31, Cranium, SUI 101600, anterior, left lateral, and dorsal views, $\times 12$ (LD5 30.5 m). 25, 27, 32, Cranium, SUI 101601, dorsal, right lateral, and anterior views, $\times 10$ (LD5 30.5 m). 28, 29, 33, Cranium, SUI 101602, dorsal, left lateral, and anterior views, $\times 7.5$ (LD5 float).



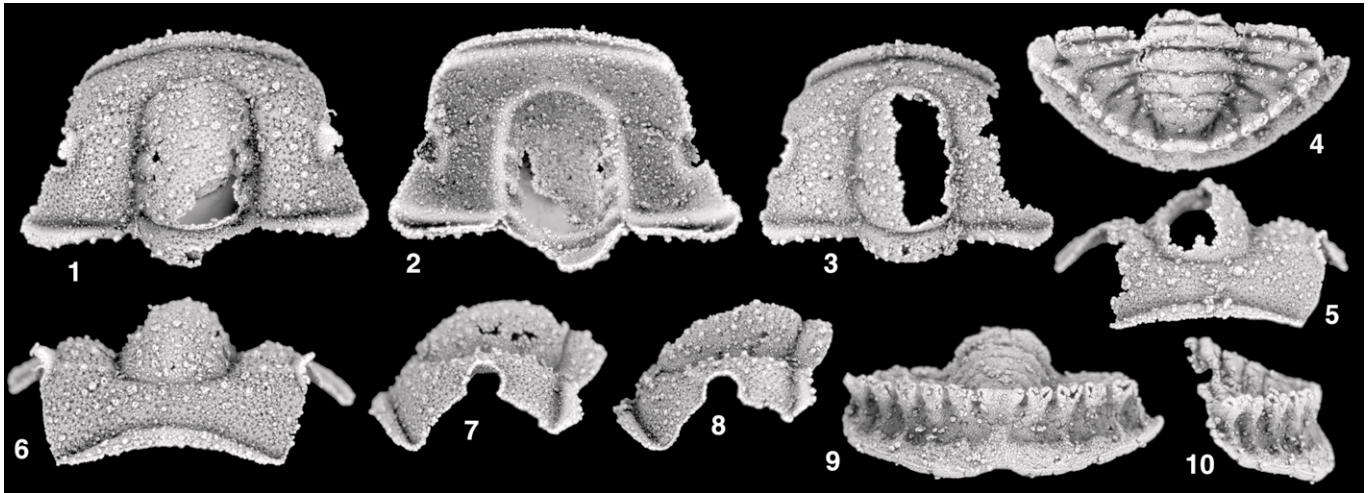


FIGURE 12—1–3, 5–8, *Notchpeakia* n. sp. A, from section Lawson Cove, horizon LAW 25.3 m, northern Wah Wah Mountains, Millard County, Utah. 1, 2, 6, 7, Cranidium, SUI 101628, dorsal, ventral, anterior, and left lateral views, $\times 12$. 3, 5, 8, Cranidium, SUI 101629, dorsal, anterior, and left lateral views, $\times 12$. 4, 9, 10, *Notchpeakia notchpeakensis* n. sp., from section Lava Dam Five, horizon LD5 25.3 m, southern House Range, Millard County, Utah, pygidium, SUI 101630, dorsal, posterior, and left lateral views, $\times 10$.

NOTCHPEAKIA VARGA (Westrop, 1986)

Heterocaryon tuberculatum RASETTI, 1944; LUDVIGSEN, 1982, p. 72, fig. 25, fig. 55A–55N.

Heterocaryon vargum WESTROP, 1986; p. 80, pl. 40, figs. 4–6; LUDVIGSEN AND WESTROP IN LUDVIGSEN ET AL., 1989, p. 48.

non *Heterocaryon vargum* WESTROP; LOCH ET AL., 1993, fig. 6.10.

non *Heterocaryon vargum* WESTROP; ADRAIN AND WESTROP, 2004, p. 23, pl. 14, figs. 1–33 [= *Notchpeakia cherrycreekensis* n. sp.].

Discussion.—*Notchpeakia varga*, from the Mistaya Formation of Alberta, is known from one cranidium from its type horizon and section plus a second, smaller cranidium with a more elongate glabella from a separate horizon and section. Despite the paucity of information, there are no obvious differences between the holotype cranidium and the silicified specimens from the Rabbit-kettle Formation of the Northwest Territories illustrated by Ludvigsen (1982, fig. 55a, 55b, 55l), and it is assumed the two sets of material are conspecific. Other occurrences (Winston and Nicholls, 1967; Stitt, 1971; Fortey, 1983) placed in synonymy of the species by Westrop (1986, p. 80) are regarded herein as separate taxa (see genus discussion above). *Notchpeakia varga* was compared with the closely related and similar *N. cherrycreekensis* n.

sp. above. Based on parsimony analysis, it is the basal and most plesiomorphic representative of the genus.

Loch et al. (1993, fig. 6.10) assigned a third cranidium from the Mistaya Formation to *varga*. Although Adrain and Westrop (2004) accepted this assignment, it now appears likely to be incorrect (see genus discussion above).

NOTCHPEAKIA? new species A

Figure 12.1–12.3, 12.5–12.8

Material and occurrence.—Assigned specimens SUI 101628 and SUI 101629 from section Lawson Cove 25.3 m.

Discussion.—Two cranidia from the Lawson Cove section appear to represent *Notchpeakia* n. gen. in their short, incised anterior border furrow, densely pitted sculpture, and presence of tubercles over the fixigena and frontal areas. They differ from all other species in the relatively compact area of the glabella in plan view, broad interocular fixigena, and relatively prominent eye ridges. Knowledge of the remainder of the exoskeleton would be necessary to evaluate adequately the species. No sclerites which could be associated with the cranidia were recovered.

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FIGURE 11—*Notchpeakia notchpeakensis* n. sp., from the Lava Dam Member, Notch Peak Formation (Sunwaptan), sections Lava Dam Five, southern House Range, and Lawson Cove, northern Wah Wah Mountains, Millard County, Utah. 1, 5, 11, Cranidium, SUI 101603, dorsal, right lateral, and anterior views, $\times 10$ (LAW 25.3 m). 2, 6, 7, Cranidium, SUI 101604, dorsal, right lateral, and anterior views, $\times 10$ (LAW 25.3 m). 3, 8, 10, Cranidium, SUI 101605, dorsal, left lateral, and anterior views, $\times 12$ (LD5 30.5 m). 4, 9, Left librigena, SUI 101606, internal and external views, $\times 10$ (LAW 25.3 m). 12, 18, 19, Cranidium, SUI 101607, dorsal, left lateral, and anterior views, $\times 12$ (LD5 30.5 m). 13, 14, Thoracic segment, SUI 101608, dorsal and anterior views, $\times 10$ (LD5 25.3 m). 15, Right librigena, SUI 101609, external view, $\times 7.5$ (LAW 25.3 m). 16, 21, Thoracic segment, SUI 101610, dorsal and anterior views, $\times 12$ (LAW 25.3 m). 17, Left librigena, SUI 101611, external view, $\times 7.5$ (LAW 25.3 m). 20, 23, Thoracic segment, SUI 101612, anterior and dorsal views, $\times 12$ (LAW 25.3 m). 22, Right librigena, SUI 101613, external view, $\times 10$ (LAW 25.3 m). 24, Left librigena, SUI 101614, external view, $\times 7.5$ (LD5 float). 25, Right librigena, SUI 101615, external view, $\times 7.5$ (LAW 25.3 m). 26, Right librigena, SUI 101616, external view, $\times 7.5$ (LAW 25.3 m). 27, Left librigena, SUI 101617, external view, $\times 12$ (LAW 25.3 m). 28, 31, Left librigena, SUI 101618, external and internal views, $\times 10$ (LAW 25.3 m). 29, 32, Left librigena, SUI 101619, internal and external views, $\times 7.5$ (LD5 30.5 m). 30, Left librigena, SUI 101620, external view, $\times 7.5$ (LAW 25.3 m). 33, Right librigena, SUI 101621, external view, $\times 10$ (LD5 30.5 m). 34, 38, 39, Pygidium, SUI 101622, dorsal, posterior, and left lateral views, $\times 10$ (LD5 25.3 m). 35, Right librigena, SUI 101623, external view, $\times 10$ (LAW 25.3 m). 36, 43, 48, Pygidium, SUI 101624, dorsal, right lateral, and posterior views, $\times 15$ (LD5 16.8T m). 37, 44, 49, Pygidium, SUI 101625, dorsal, posterior, and right lateral views, $\times 12$ (LD5 30.5 m). 40, 45, 46, Pygidium, SUI 101626, right lateral, dorsal, and posterior views, $\times 10$ (LAW 25.3 m). 41, 42, 47, Pygidium, SUI 101627, dorsal, left lateral, and posterior views, $\times 10$ (LD5 25.3 m).

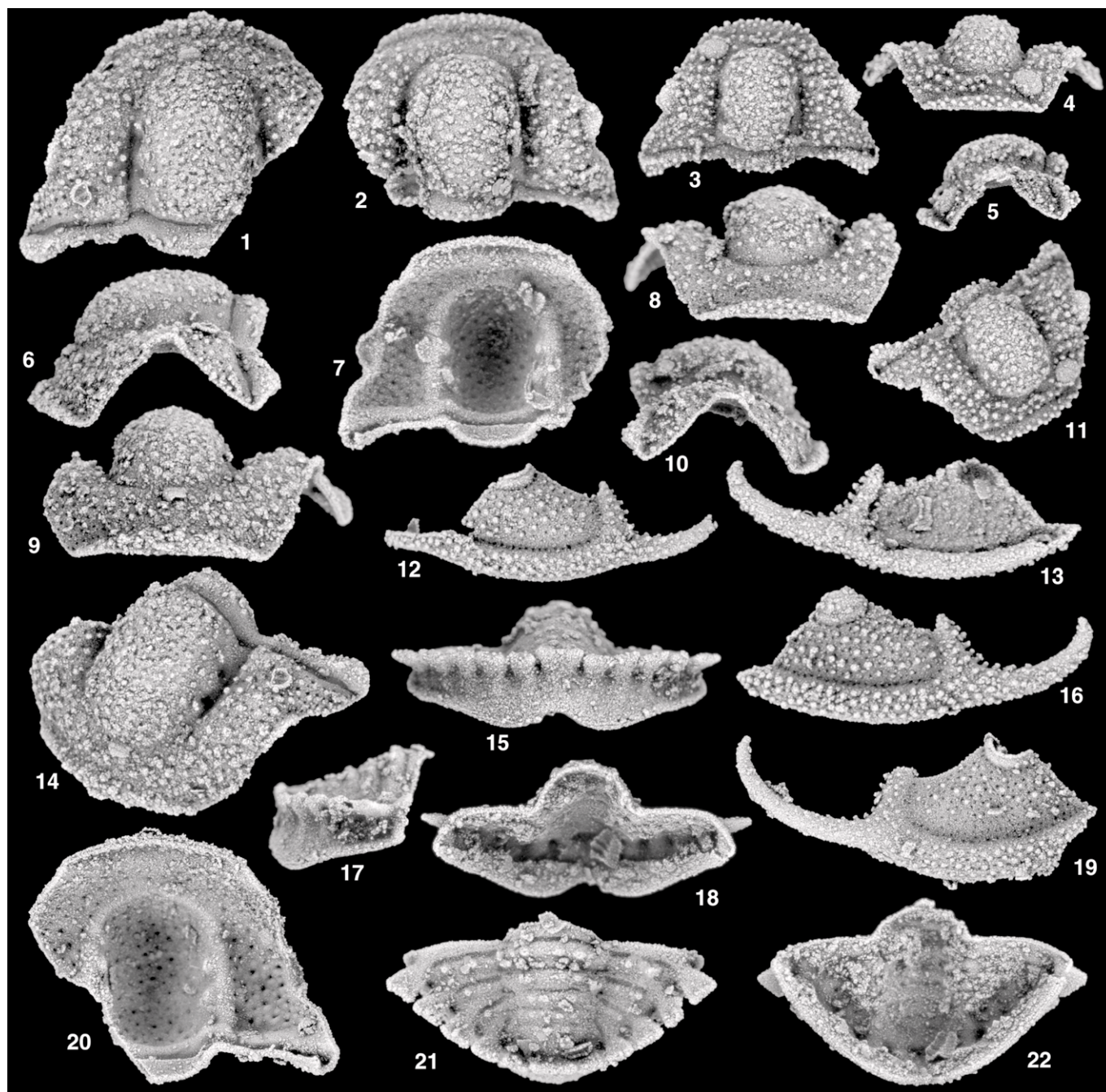


FIGURE 13—*Notchpeakia cherrycreekensis* n. sp., from the Bullwhacker Member, Windfall Formation, section CHC 1 371–373T m, Barton Canyon, east slope of Cherry Creek Range, White Pine County, Nevada. 1, 6, 9, 14, 20, Cranidium, holotype, SUI 99220, dorsal, left lateral, anterior, oblique, and ventral views, $\times 9$. 2, 7, 8, 10, Cranidium, SUI 99222, dorsal, ventral, anterior, and right lateral views, $\times 12$. 3–5, 11, Cranidium, SUI 99224, dorsal, anterior, left lateral, and oblique views, $\times 12$. 12, Left librigena, SUI 99225, external view, $\times 15$. 13, 16, Left librigena, SUI 99228, internal and external views, $\times 15$. 15, 17, 18, 21, 22, Pygidium, SUI 99231, posterior, right lateral, anteroventral, dorsal, and ventral views, $\times 12$. 19, Right librigena, SUI 99230, external view, $\times 12$.

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