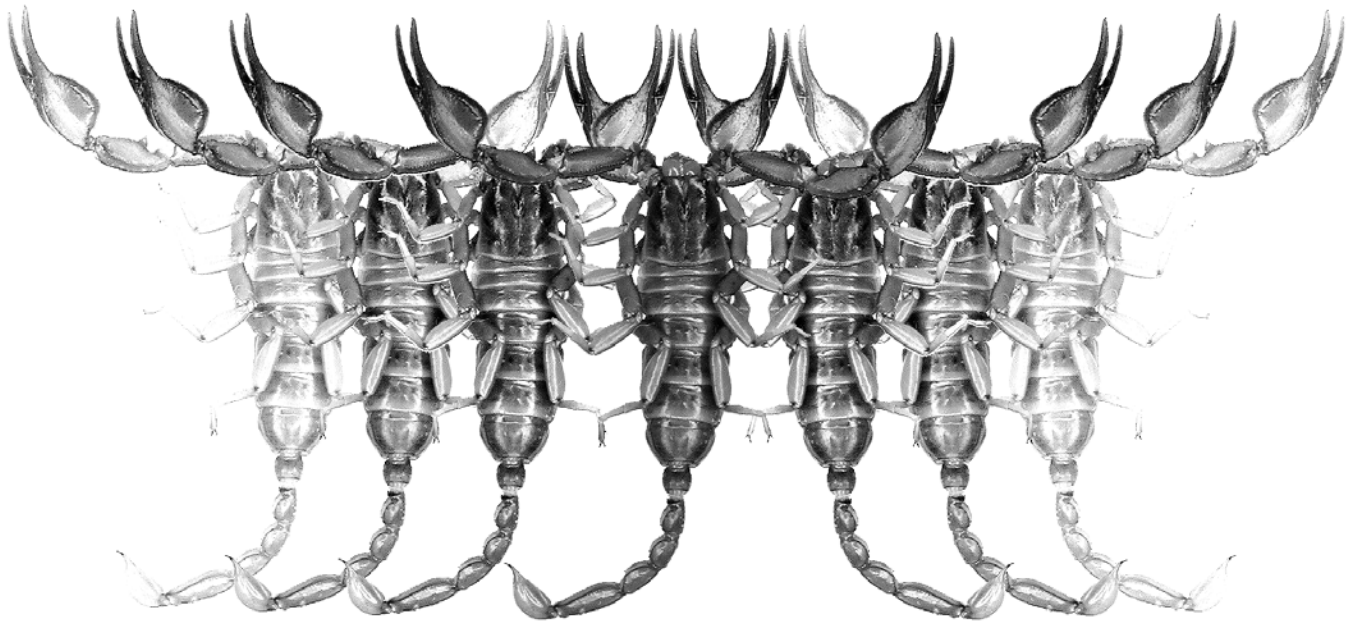


# *Euscorpius*

Occasional Publications in Scorpiology



**New Picobuthoid Scorpions  
(Scorpiones: Buthidae) from Oman**

**Graeme Lowe**

**March 2010 — No. 93**

# *Euscorpius*

## Occasional Publications in Scorpiology

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## New picobuthoid scorpions (Scorpiones: Buthidae) from Oman

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### Summary

Five new species of diminutive buthid scorpions are described from Oman. Two belong to *Microbuthus* Kraepelin, 1898, a genus with heavily sclerotized, smooth, strongly pitted posterior metasomal segments, abbreviated telson, and pedipalps with 9 femoral and 6–7 external patellar trichobothria: *M. gardneri*, **sp. nov.**, from the Al Hajar Mountains, and *M. kristensenorum*, **sp. nov.**, from the Dhofar Mountains and Hadhramaut of Yemen, which was long misidentified as *M. pusillus* Kraepelin, 1898. Two additional new species are placed in a new genus *Picobuthus*, **gen. nov.**, differentiated by granular posterior metasomal segments, elongate telson, pedipalps with 7–9 femoral and 5 external patellar trichobothria: type species *P. wahibaensis*, **sp. nov.**, from the Wahiba Sands, and *P. dundoni*, **sp. nov.**, from sand deserts in central Oman. A second new genus, *Femtobuthus*, **gen. nov.**, is monotypic with type species *F. shutuae*, **sp. nov.**, from the southern coast and plateau of Jiddat Al Harasis, differentiated by enlarged, granular, dentate metasomal segments, abbreviated telson, and pedipalps with 6 femoral and 5 external patellar trichobothria. The relationship of *Microbuthus* and the two new genera to other buthid scorpions is discussed, and their trichobothrial homologies are addressed. These three genera are hypothesized to represent a monophyletic ‘picobuthoid’ lineage that originated in the Arabian Peninsula.

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### Introduction

*Microbuthus* was created as a monotypic genus by Kraepelin in 1898, for a very small scorpion, *Microbuthus pusillus*, from Djibouti on the African coast in the Gulf of Aden. Subsequently, Birula (1905) determined that *Butheolus litoralis* described earlier by Pavesi (1885) from Asab, Eritrea, also belonged to *Microbuthus*. Vachon (1949) described a third species, *Microbuthus fagei*, from the coast of Mauritania, to which Lourenço (2002) added the subspecies, *M. fagei maroccanus* from Morocco. This was later elevated to species status (Lourenço & Duhem, 2007). Kovařík (2003) reviewed East African scorpions and relegated *M. litoralis* to nomen dubium, because the type could not be located and Birula’s diagnosis was ambiguous. A fifth species, *M. flavorufus* was described by Lourenço & Duhem (2007) from a single specimen collected along the northern coast of the Red Sea in Egypt.

In the 112 years since its creation, *Microbuthus* has remained enigmatic. The paucity of records and limited availability of material might be attributable to the diminutive size of these scorpions, making them easily overlooked by collectors. The genus seems to exhibit a disjunct, relict distribution along the western and eastern continental margins of North Africa, and the adjacent southwest corner of the Arabian Peninsula. However,

these regions have not been intensively sampled by modern collecting methods, and could well harbor a hidden diversity of small or secretive scorpions. A recent survey of the scorpion fauna of Oman by ultraviolet detection found two species of *Microbuthus*, one new to science, and a second determined to belong to an undescribed species that was long misidentified as *M. pusillus*. In addition, three novel species of small buthids similar to *Microbuthus*, but differentiated by their metasomal morphologies, were discovered and are herein placed into two new genera, *Picobuthus*, **gen. nov.**, and *Femtobuthus*, **gen. nov.** These three genera are hypothesized to represent a monophyletic ‘picobuthoid’ lineage that originated in the Arabian Peninsula.

### Methods

Scorpions were collected by ultraviolet (UV) detection at night and preserved in the field by standard methods (Williams, 1968; Stahnke, 1972a; Sissom, Polis & Watt, 1990). Locality data were recorded using portable GPS units. Specimens were examined under a dissecting microscope, either air dried or submerged in 70% isopropyl alcohol, under both white light epillumination and UV fluorescent illumination (Prendini, 2003; Volschenk, 2005). Trichobothria and microsetae were visualized either by UV fluorescence microscopy

of submerged specimens, or by oblique transillumination of air dried specimens to highlight cuticular surface topography by optical refraction. Measurements were made with an ocular reticule, following biometric definitions in Lamoral (1979) and Sissom et al. (1990) with the following modifications: carapace anterior width taken between medial pair of lateral eyes; metasomal segment depths not including enlarged lobate dentition on ventrosubmedian or ventrolateral carinae; telson length taken from anterior limit of vesicle to tip of aculeus; telson vesicle length taken from anterior limit of vesicle to inflexion point on posterior slope of vesicle; telson measurements made with dorsal surface of vesicle level; pedipalp chela length taken as chord length from external proximal limit of manus to apex of fixed finger; pedipalp manus width and depth measured with articular condyles level. The preocular length is defined as the distance from the center of the median ocular tubercle to the anterior margin of the carapace. The Mann-Whitney U statistic was applied to test for sexual dimorphism in morphometric ratios. Carinal terminology follows Stahnke (1970), with metasomal amendments by Prendini (2001b, 2004), but with dorsal carinae on metasoma V termed 'dorsolateral' carinae, and pedipalp chelal amendments by Soleglad & Sissom (2001). The formula for numbers of macrosetae in basitarsal bristle combs is formatted as follows: AR1/BR1 AL1/BL1: AR2/BR2 AL2/BL2: AR3/BR3 AL3/BL3, where A = retrosuperior, B = retroinferior, R = right tarsus, L = left tarsus, and 1–3 denote legs I–III. The retroinferior series is the more retrolateral of the two series on the inferior margin, and the retrosuperior series is the series on the superior margin (Haradon, 1984). Trichobothrial nomenclature follows Vachon (1974, 1975), except for new homologies proposed here for picobuthoid trichobothria on the pedipalp chela fixed finger.

## Abbreviations

*Specimen depositories*: BMNH, Natural History Museum, London; GL, collection of the author; NHMB, Naturhistorisches Museum Basel; MNHN, Muséum National d'Histoire Naturelle, Paris; ONHM, Oman Natural History Museum, Muscat; VF, collection of Victor Fet, Marshall University, West Virginia. *Biometrics*: L, length; W, width; D, depth.

## Systematics

Within the scorpion family Buthidae, the genera *Microbuthus* Kraepelin, 1898, *Picobuthus*, **gen. nov.**, and *Femtoothus*, **gen. nov.**, together comprise a 'picobuthoid' group, diagnosed by the following shared characters:

### Diagnosis of picobuthoid group

Small to very small scorpions, adults < 25 mm; body dorsoventrally compressed; carapace strongly trapezoidal, posterior W/ anterior W 1.9–2.6, surface densely granular, carinae indistinct (Figs. 5, 27, 46, 67, 91); frontal region of carapace sloped downward from median ocular tubercle, with narrow anterior marginal shelf; tergites granular, weakly monocarinate or tricarinate; carapace, tergites, metasoma and pedipalps bearing numerous short, clavate microsetae; telson narrower than metasoma V, vesicle with serrulate ventromedian carina bearing transverse granules, lacking subaculear tubercle or spine; aculeus short, stout, sharply bent; pectine with small number of teeth (< 16), fulcra and middle lamellae present; pedipalp chela slender, with long, narrow, curved fingers leaving wide gap with tips closed; base of fixed finger with interior and exterior lobes overhanging articulation of movable finger; finger dentition greatly reduced, lacking closely-spaced rows of primary denticles, with non-imbricated linear series of non-contiguous, minute granules separated by several enlarged spiniform denticles; both fingers with enlarged apical teeth; neobothriotaxic minorante, type A $\beta$  (Vachon, 1974) (Figs. 135–168): femur: 2 external ( $et_1$  near base of segment,  $et_2$  near middle), 2–3 dorsal (either  $d_2$  and  $d_5$ , or  $d_2$ ,  $d_3$  and  $d_5$  absent), 2–4 internal (either  $i_4$ , or  $i_2$  and  $i_4$  absent); patella: 5–7 external (either  $esb_2$  or  $em$  may be absent), 4 dorsal ( $d_2$  absent;  $d_1$ ,  $d_3$  and  $d_5$  either straddling or external to dorsomedian carina), 1 internal; manus: 4 external ( $Eb_3$  and  $Esb$  absent), 2 ventral; fixed finger: 6 ( $esb$  absent),  $eb$  at base of finger,  $est$  and  $et$  in basal half of finger,  $db$  and  $dt$  in apical half of finger, with  $db$  distal to  $dt$ ,  $db$  on internal surface,  $it$  distal to  $db$ .

### Genus *Microbuthus* Kraepelin, 1898

*Microbuthus* Kraepelin, 1898: 42; Kraepelin, 1899: 37; Birula, 1917a: 164; Birula, 1917b: 55; Werner, 1934: 270; Vachon, 1949: 389–393; Vachon, 1950: 392, fig. 581; Vachon, 1952: 317–321, fig. 581; Stahnke, 1972b: 127; Francke, 1985: 10, 16; Vachon, 1974: 906, 909–910, fig. 42; Lamoral & Reynders, 1975: 512; Vachon, 1975: 1598; Vachon & Kinzelbach, 1987: 92; Sissom, 1990: 102; Nenilin & Fet, 1992: 17; Lowe, 1993: 2; Kovařík, 1998: 115; Fet & Lowe, 2000: 181; Lourenço 2001: 176, tab. I; Soleglad & Fet, 2001: 32; Lourenço, 2002: 165, 168–169, fig. 20; Soleglad & Fet, 2003a: 12, 26–27, tab. 2; Soleglad & Fet, 2003b: 66–68, 72, 78–79, 88, tab. 3–4, 9, fig. 115; Fet, Soleglad & Lowe, 2005: 3, 5, 7–8, 12, 22, figs. 1, 12, 23, tab. 1; Prendini & Wheeler, 2005: 451, 454, 481; Dupré, 2007: 7, 13, 16; Lourenço & Duhem, 2007: 439–442, 444, fig. 14; Qi & Lourenço, 2007: 81–82; Kaltsas, Stathi & Fet, 2008:



220; Navidpour & al., 2008: 17; Lourenço & Duhem, 2009: 51; Kovařík, 2009: 23, 31.

**Type species.** *Microbuthus pusillus* Kraepelin, 1898.

**Diagnosis.** A member of the picobuthoid group (see diagnosis above), differentiated as follows: metasoma (Figs. 20–22, 40–41) with segments I–III granulate, reticulate or rugose, with distinct carinae, segments IV–V dark, heavily sclerotized, with lateral and ventral surfaces smooth, convex, bearing numerous pits or depressions; ventrolateral carinae of V obsolete, or smooth to crenulate; telson vesicle abbreviated, deep, steeply sloped or truncated posteriorly; legs III–IV with tibial spurs present, reduced or lost; retrosuperior margins of basitarsi I–III with or without bristle combs; fixed finger of chelicera armed ventrally with two large denticles nearly equal in size (Figs. 19, 38); pedipalp fixed finger moderately to strongly deflected upward at base, strongly curved (Figs. 11, 33); trichobothria (Figs. 127, 133–134, 135–147): femur: 2 external, 3 dorsal ( $d_2$  and  $d_5$  absent) in  $\beta$  configuration (Vachon, 1975), 4 internal; patella: 6–7 external ( $em$  may be absent), 4 dorsal ( $d_2$  absent), 1 internal; manus: 4 external ( $Eb_3$  and  $Esb$  absent), 2 ventral; fixed finger: 6 ( $esb$  absent). See Table 1 for comparison with other picobuthoid genera.

***Microbuthus gardneri*, sp. nov.**

Figs. 1–22, 110, 114, 121–127, 133, 135–140, Tab. 2

*Microbuthus* sp.: Soleglad & Fet, 2003a: 5, fig. 4; Soleglad & Fet, 2003b: 7, 67, 157; Santiago-Blay, Soleglad & Fet, 2004: 8; Fet, Soleglad & Lowe, 2005: 6, 12, fig. 12; Prendini & Wheeler, 2005: 454. *Microbuthus pusillus*: Prendini & Wheeler, 2005: 454.

**Type material**

**Holotype:** adult ♂, **Oman**, Jabal Bani Jabir, UV detection, rocky terrain, on bare rock by burial tower, 22°49.6'N 59°01.59'E, 1640 m a.s.l., 14 September 1995, 19:40 h, leg. G. Lowe, M.D. Gallagher & J. Dundon (NHMB).

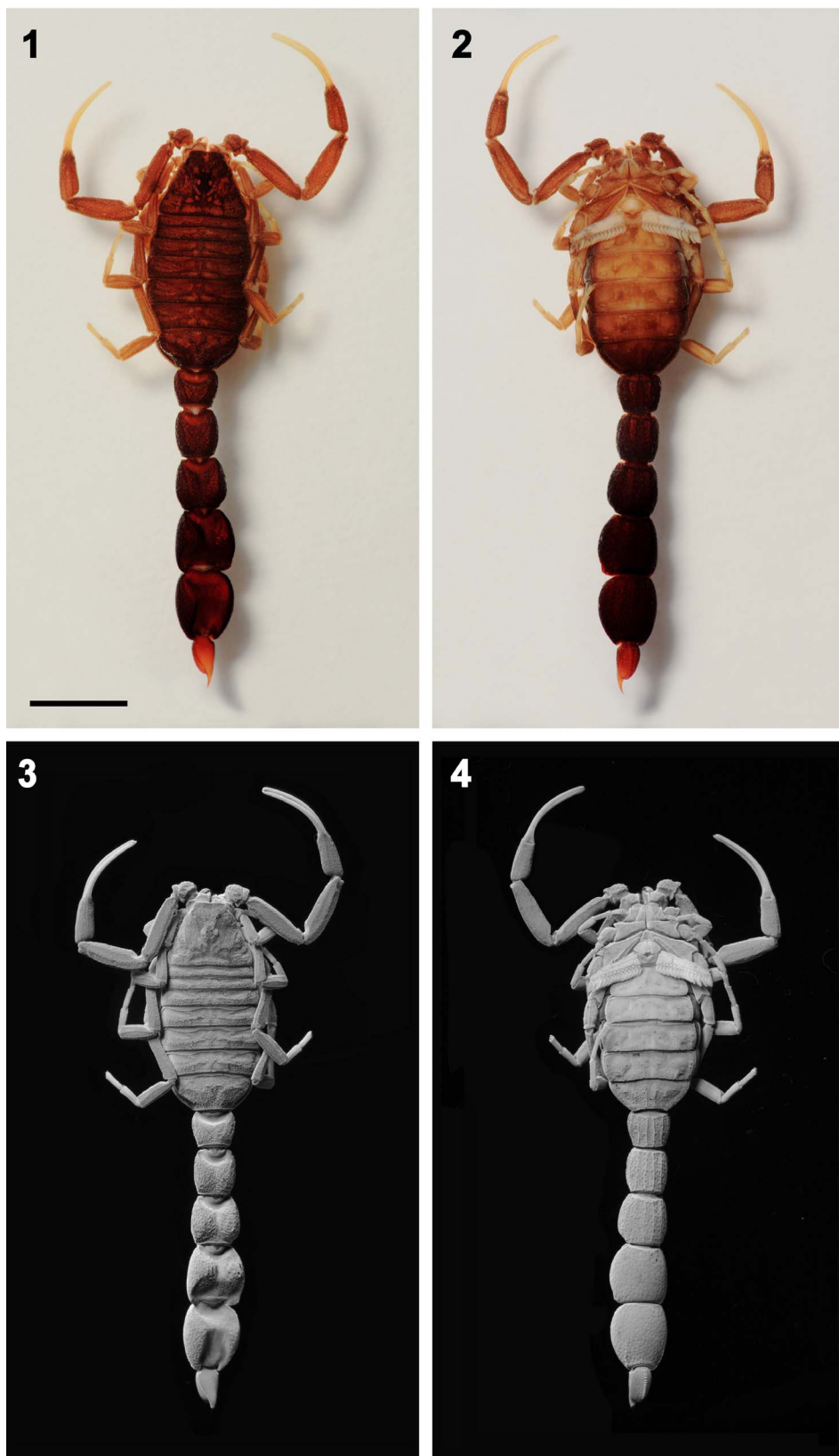
**Paratypes:** **Oman:** 3 ♂, 1 ♀, same locality as holotype (NHMB); 2 ♂, 1 ♀, Jabal Bani Jabir, under stones and rock on limestone plateau, 22°50'N 59°02'E, 1650 m a.s.l., 06 November 1992, leg. A.S. Gardner, SQU 40, 42 (GL, NHMB); 4 ♂, 1 ♀, between Sultan Qaboos University and Rusail, UV detection, gravel plain, 23°34'N 58°10'E, 50 m a.s.l., 18 October 1993, leg. A.S. Gardner (ONHM, VF); 1 ♀, near Sultan Qaboos University Campus, UV detection on ground, open rocky plain, 23°34.47'N 58°10.06'E, 50 m a.s.l., 23 October 1993, 0:28 h, leg. G. Lowe & A.S. Gardner (MNHN); 1 ♀, near Sultan Qaboos University Campus, Al Khod, UV detection, on rocky ground, 23°34'N

58°09'E, 50 m a.s.l., 24 September 1994, leg. A.S. Gardner (ONHM); 1 ♀, Jabal Bani Jabir, rocky hillside, 22°48.93'N 59°03.32'E, 1660 m a.s.l., 13 April 1995, leg. A.S. Gardner (BMNH); 2 ♀, Jabal Ukhayr (site F/1.1), UV detection, bottom of rocky slope on edge of wadi on sand between small rocks, 22°42.34'N 58°47.58'E, 486 m a.s.l., 13 December 2001, 18:45–21:15 h, leg. A. Winkler (GL, NHMB); 1 juvenile ♂, 1 juvenile ♀, Jabal Bani Jabir (site F/2), rock rolling, on ground under small rocks, 22°49.86'N 59°01.36'E, 1686 m a.s.l., 14 December 2001, 15:30–17:30 h, leg. A. Winkler (NHMB).

**Diagnosis.** A member of the genus *Microbuthus* differentiated as follows: adults 17–26 mm in length; base color uniform coal black, pedipalp fingers and leg tarsi orange-yellow, telson reddish brown (Figs. 1–2); metasomal segments (Figs. 20–22) stout, L/W ratios: I < 0.90, II < 1.12, III < 1.2, IV < 1.1, V < 1.2, segments III–IV thickened, wider than I–II, lateral and ventral surfaces of III with heavy rugose reticulation merging with weak ventrosubmedian carinae; segments IV–V heavily sclerotized, swollen, ventral and lateral surfaces strongly convex, pitted, lacking macrosetae, dorsal surfaces widely, deeply excavated; posterior slope of dorsal surface of IV with coarse granules; ventrolateral carinae on V distinct, crenulate, extending over posterior 1/5–1/4 of segment; telson widest at base, slightly tapering posteriorly; vesicle deepest near middle, ventral surface with scattered shallow depressions bearing few very short setae, ventromedian carina with 11–16 granules; leg III patella L/D 2.9–3.2; legs III–IV with well developed tibial spurs; basitarsi I–III without bristle combs (Fig. 6); pedipalps slender (Figs. 8–11, 14), femur L/W > 3.6, patella L/W > 3.1 (Figs. 8–9); chela fixed finger with  $dt$  at 1/4 of length from tip; pectine teeth: males 14–16, females 10–13.

**Etymology.** The specific epithet is a patronym honoring Dr. Andrew S. Gardner, who collected and contributed many important scorpion specimens from Oman, including type material for this species.

**Comparisons.** *M. gardneri* can be differentiated from other *Microbuthus* species by the morphometrics of the metasoma, telson and pedipalps: metasoma IV–V are more stout and swollen, metasoma III is partially swollen and sclerotized, the telson vesicle is deeper, and the pedipalp femur and patella are more slender. This can be quantified by comparing metasomal morphometric ratios of different *Microbuthus* species (c.f. Table 2). Coloration is also distinctive: the uniform deep black color of the dorsal surface of *M. gardneri* extends over the legs, pedipalp femur and patella, whereas these appendages are pale yellow in *M. kristensenorum*, and yellow to reddish-yellow in *M. flavorufus*. The pedipalps



**Figures 1–4:** *Microbuthus gardneri*, sp. nov., holotype male. Habitus viewed under reflected white light (1, 2) and UV fluorescence (3, 4). 1, 3. Dorsal aspect. 2, 4. Ventral aspect. Scale bar: 4 mm.

are spotted brown in *M. maroccanus*, yellowish in *M. fagei*, and the femur may be more lightly pigmented than the patella in *M. pusillus*.

*M. gardneri* is closest to *M. pusillus* and *M. flavorufus* in the proportions of metasomal segments IV–V, but differs from them in having more slender pedipalps. In slenderness of the pedipalp femur and patella, *M. gardneri* is closer to *M. kristensenorum*. Females of *M. gardneri* differ from females of *M. kristensenorum* as follows: heavier granulation on carapace and tergites; more robust legs; metasoma I–III more elongated; posterior dorsal excavation of metasoma V smooth; dense pilosity absent on metasoma IV–V and telson; clavate microsetae sparser, shorter; dorsointernal and dorsoexternal carinae of pedipalp femur weaker; dorsointernal, dorsomedian and dorsoexternal carinae of pedipalp patella weaker, less continuous; pedipalp chela fingers leave narrower gap when closed.

### Description of holotype male (adult)

**Coloration** (Figs. 1–2). Dry preserved specimen uniform charcoal black; under alcohol, dark chestnut brown color of underlying cuticle visible in patches; pedipalp fingers pale orange-yellow; legs with basitarsi, telotarsi, and distal portions of tibiae pale yellow; metasoma IV–V rufo-piceous; telson deep reddish brown, darker proximally; sternites III–V dirty yellow brown, VI dark brown, VII blackish brown; coxosternal area with dark brown reticulation.

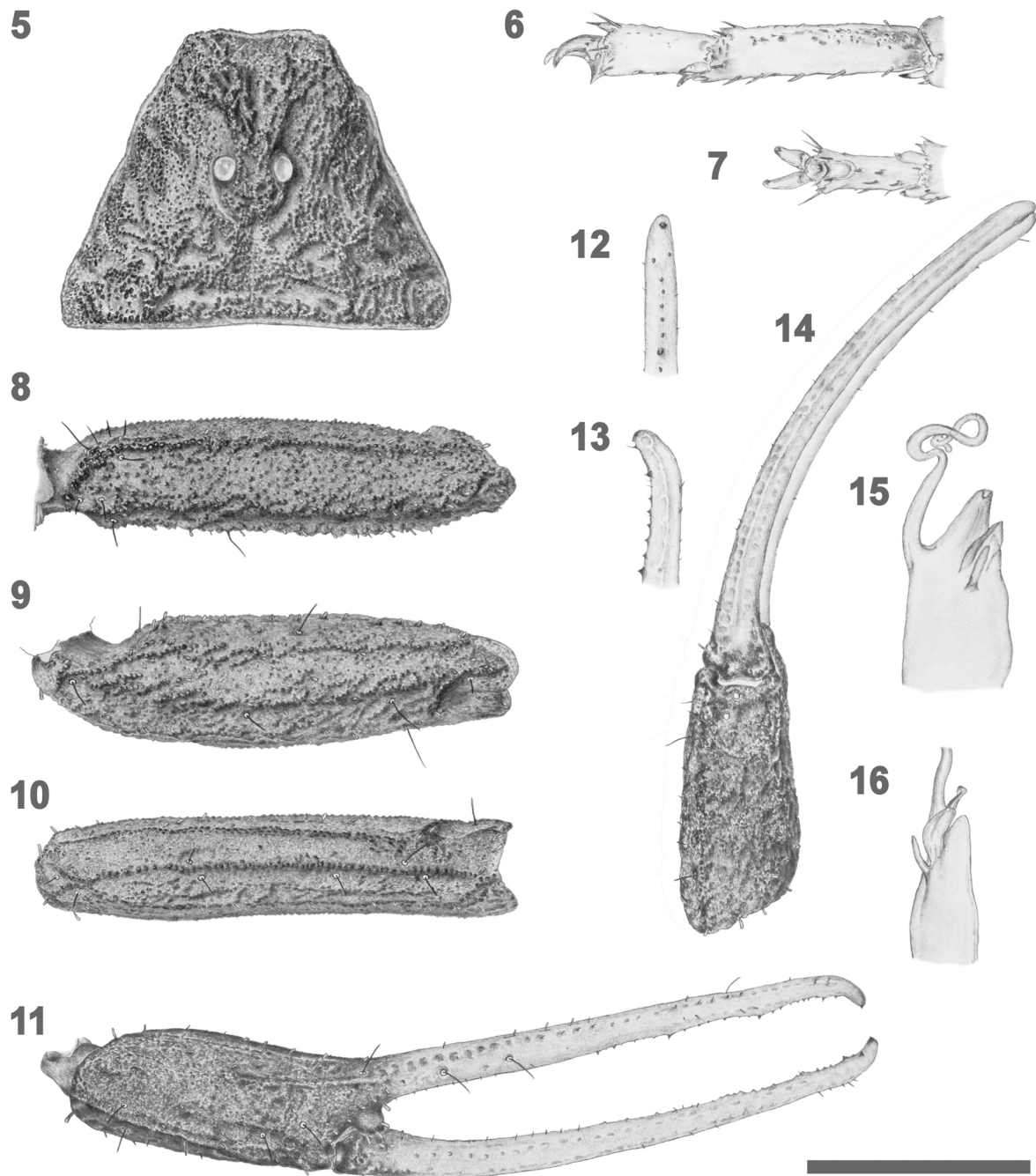
**Carapace** (Figs. 1, 3, 5). Strongly trapezoidal, W/L 1.31, posterior W/anterior W 2.50; anterior margin very weakly emarginate; surface densely, coarsely granular, with most carinae indistinct; anterior median carinae granular, divergent, becoming indistinct less than halfway towards anterior marginal shelf; median ocular tubercle prominent, raised, with large ocelli; lateral eyes with 3 ocelli, posterior ocellus very small; superciliary carinae indistinct, top of ocular tubercle flat, with curved row of granules above each eye; central median and posterior median carinae irregular, coarsely granulate, fused into reticular grid enclosing four smooth, oval depressions; posterior median furrow a wide, shallow, granular depression; posterior marginal furrow a shallow smooth transverse depression; anterior median furrow shallow, coarsely granular; sides of carapace steeply sloped, densely granular, lateral margins with finely granulated rim.

**Coxosternal area** (Figs. 2, 4). All coxae densely, coarsely granular, lacking macrosetae; coxa II endites with granulation reduced, nearly smooth on medial and antero-lateral surfaces; coxa IV narrow, elongate, with moderately developed, granular marginal carinae, an-

terior carina extending entire length of segment, posterior marginal carina confined to proximal half; sternum almost triangular, coarsely granular, with deep, transverse postero-median sulcus; genital opercula smooth, rounded triangular, lateral surfaces roughened, with 2–4 lateral macrosetae; genital papillae present; pectines (Fig. 17) with 3 marginal lamellae, 5–6 middle lamellae; fulcra bearing two short reddish setae; anterior margin of basal piece v-shaped, deeply notched, bordered by dark, granular labia; pectine teeth: left 16, right 14.

**Mesosoma** (Figs. 1–4). Pretergites with rough, matte surface bearing scattered microgranules, posterior borders minutely granular; border of pretergite nearly straight on tergites I–III, gently bisinuate on IV–VII; tergites I–VI densely granular, granulation fine on anterior half, coarse on posterior half; carinae indistinct on tergites I–III; tergites IV–VI with three short, longitudinal, granular carinae, very weak on IV, weak on V–VI; carinae confined to posterior half of tergites; tergites IV–VI with median and lateral carinae partially bridged by transverse row of granules; tergite VII with 5 broad, granular ridges; sternite III roughened medially, coarsely shagreened near lateral margins, densely microshagreened on anterolateral concavities above pectines; sternites IV–V densely shagreened, more coarsely along lateral margins, posteromedial area nearly smooth on IV, smooth transverse triangular patch on V; sternite VI densely, coarsely shagreened, posteromedial area rugose-granulate, sternite VII with dense granulation, granules finer anteriorly; sternites IV–VI with weak median sulcus, VI with weak median carinae, VII with strong, granular median carinae extending over posterior 2/3 of surface, and short, very weak lateral carinae; lateral margins of all sternites finely crenulate; sternites with posterior margins microdenticulate on III–V, granulate-crenulate on VI–V.

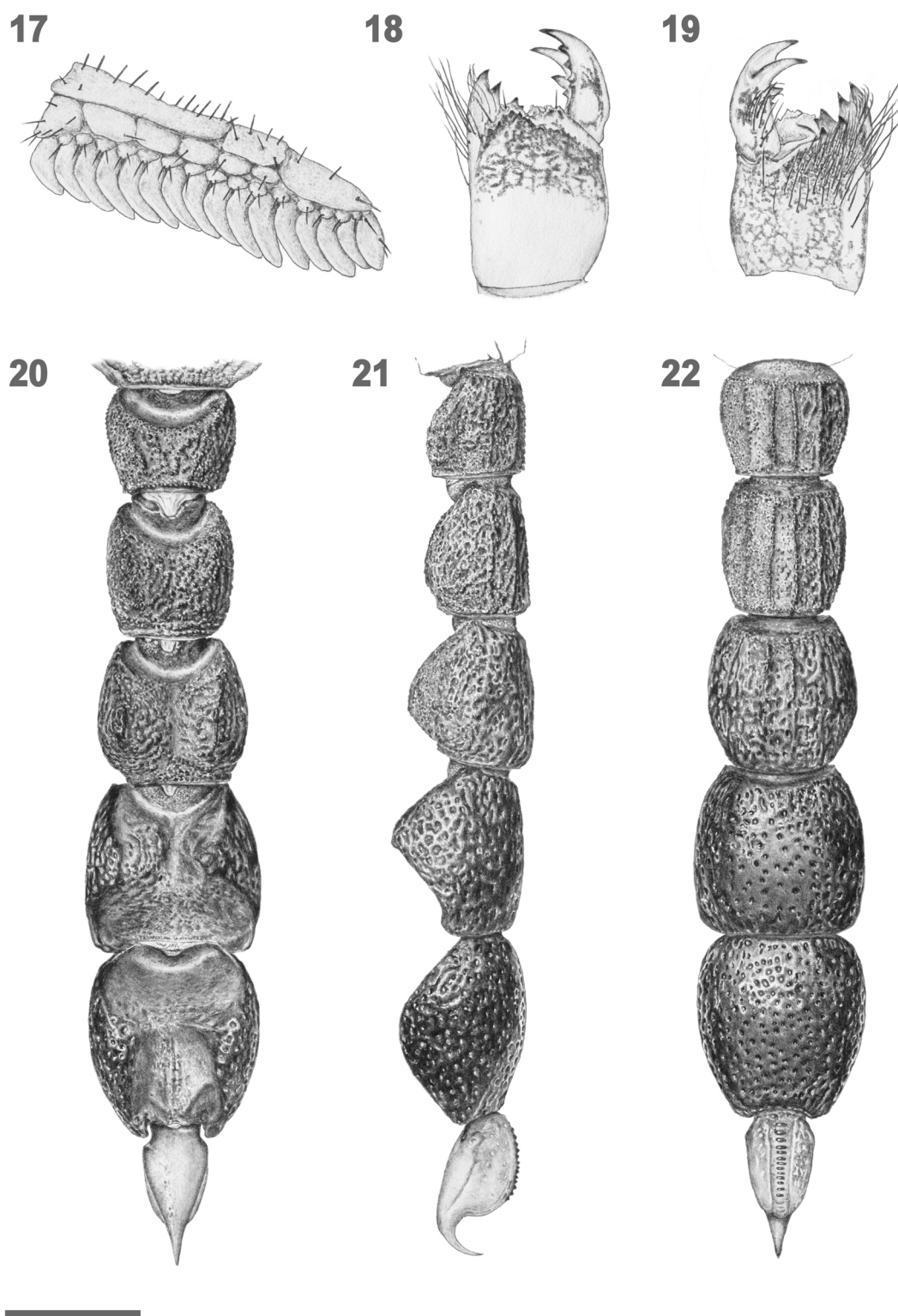
**Metasoma** (Figs. 1–4, 20–22). Segment I with 10 carinae, ventrosubmedian carinae strong, granulate-crenulate, ventrolateral carinae moderate, crenulate, median lateral carinae weak, barely distinguished from reticular granulation, dorsolateral carinae irregular, masked by reticular granulation, dorsosubmedian carinae distinct but weak, crenulate; segment II with 6 carinae, ventrosubmedian carinae moderate, crenulate, ventrolateral and dorsosubmedian carinae weak, crenulate, dorsolateral and median lateral carinae masked by heavy reticular granulation; dorsal and lateral intercarinal surfaces of I–II coarsely reticulo-granulate, ventral surfaces of II coarsely granular, of I more finely granular; segment III wider and taller than I and II, with 6 carinae, ventrosubmedian and ventrolateral carinae weak, smooth, ventrolaterals becoming indistinct posteriorly, dorsosubmedian carinae blunt, rugose;



**Figures 5–16:** *Microbuthus gardneri*, sp. nov. 5–14, holotype male; 15–16, paratype male (Jabal Bani Jabir). 5. Carapace, dorsal aspect. 6. Left basitarsus and telotarsus III, retrolateral aspect. 7. Left telotarsus III, ventral aspect. 8. Right pedipalp femur, dorsal aspect. 9. Right pedipalp patella, dorsal aspect. 10. Right pedipalp patella, external aspect. 11. Right pedipalp chela, dorsoexternal aspect. 12–13, right pedipalp chela movable finger terminus. 12. Dorsal aspect. 13. External aspect. 14. Right pedipalp chela, ventral. 15–16, right hemispermatophore. 15. Distal portion, convex aspect. 16. Lobes at base of flagellum, outer aspect. Scale bar: 5: 2 mm; 6, 7, 12, 13: 1 mm; 8, 9, 10, 11, 14: 1.56 mm; 15, 16: 0.70 mm.

dorsal and anterior lateral surfaces of segment III granulate to rugose-reticulate, ventromedian and posterior lateral surfaces rugose to smooth with scattered shallow

depressions; segments IV–V strongly swollen, ventral and lateral surfaces convex, smooth, with numerous shallow depressions or indentations, each giving rise to a



**Figures 17–22:** *Microbuthus gardneri*, **sp. nov.** 17, 20–22, holotype male; 18–19, paratype male (Jabal Bani Jabir). 17. Left pectine, ventral aspect. 18–19, right chelicera. 18. Dorsal aspect. 19. Ventral aspect. 20–22, metasoma and telson. 20. Dorsal aspect. 21. Right lateral aspect. 22. Ventral aspect. Scale bar: 17: 1 mm; 18, 19: 0.70 mm; 20, 21, 22: 2 mm.

very short, filiform microseta; dorsosubmedian and dorsolateral carinae indistinct, forming smooth blunt lips bordering dorsal anterior and posterior concavities; metasoma V with weak, crenulate ventrolateral carinae, confined to posterior 1/5 of segment; other carinae of IV–V obsolete; anterior half of dorsal surface of segment IV forming deep, rugose, anteriorly sloped, v-shaped trough fitting the aculeus; posterior half a wide, granular, nearly flat slope; anterior part of dorsal surface of segment V smooth, irregular, strongly sloped, base concave with longitudinal striae; posterior slope of segment V deeply concave, smooth, with only faint median sulcus; lateral anal lobe smooth; ventral anal arch bordered by slightly elevated margin.

**Telson** (Figs. 20–22). Vesicle slightly tapered, widest basally, narrowing distally; dorsal surface smooth, weakly convex; upper lateral surface with distinct longitudinal sulcus; ventral surface smooth with scattered depressions anterolaterally, bearing prominent, serrulate ventromedian carina with 13 polished, widely transverse granules; ventromedian carina flanked on either side by weak furrow; ventral surface with scattered microsetae; subaculear tubercle absent; aculeus short, stout, bent sharply downward perpendicular to plane of dorsal surface of vesicle; tip of aculeus not lower than deepest part of vesicle.

**Pedipalp** (Figs. 8–14, 125–126, 135–140). Femur, patella, and chela very slender, elongate. *Femur* (Fig. 8): with 5 moderate, granular carinae; external carina broad, heavily granulated, encircling trichobothria  $e_1$  and  $e_2$ ; intercarinal surfaces roughened, shagreened to densely, finely granular. *Patella* (Figs. 9–10): with 8 carinae; external carina strong, granular; dorsoexternal, dorso-median, dorsointernal, internal and ventrointernal carinae moderate, irregularly granulated; ventromedian and ventroexternal carinae weak, finely granulate; intercarinal surfaces roughened with dense, fine granulation dorsally, scattered fine granulation ventrally. *Chela* (Figs. 11–14): manus with ventroexternal, digital and dorsal marginal carinae weak to moderate, weakly granulose, dorsal secondary carina weak, external carina moderate but discontinuous; weak secondary carina present below ventroexternal carina, converging at external articular condyle of movable finger; internal and ventrointernal carinae obsolete; digital, dorsal secondary and dorsal marginal carinae moderate and distinct on fixed finger, dorsal interior carina very weak on apical end of fixed finger, obsolete on more proximal fixed finger and manus; external surfaces roughened, with weak reticulate granulation, ventral and internal surfaces smoother, matte; chela fingers elongate, smooth, vertically arched, leaving clear gap when closed; fixed finger deflected strongly upward at base, flanked externally and internally by rounded lobes

bearing three elongate clavate microsetae; six additional, less elongate, clavate setae in row along external margin of manus at base of movable finger; fixed finger with external apical groove at base of enlarged terminal tooth; both fingers bearing enlarged, erect, spinoid denticles dividing dentate margins into weakly scalloped subrows of fine, widely spaced microdenticles; fixed finger with subdistal pair of denticles plus 3 additional enlarged denticles on margin; fixed finger subrows with 5–6, 6, 3, 1–2 microdenticles (distal to proximal); movable finger with subdistal pair of denticles and two enlarged denticles along margin, subrows with 4, 5–6, 9 microdenticles; fixed finger with external groove at base of enlarged terminal tooth, receiving terminal tooth of movable finger. *Trichobothriotaxy* (Figs. 135–140): type A $\beta$ , neobothriotaxi minorante (Vachon, 1974, 1975), as diagnosed for the genus.

**Legs** (Figs. 3–4, 6–7). Inferior carinae of femur and patella on all legs crenulate to serrate; intercarinal surfaces granular; legs III–IV with tibial spurs; inferior margins of basitarsi with two rows of 4–6 stout, spiniform setae; soles of telotarsi with two rows of several short setae; unguis short, stout; legs with two tarsal spurs, prolateral tarsal spurs basally bifurcate, retrolateral tarsal spurs simple.

**Measurements of holotype male (adult) (mm)**. Total L 21.50; carapace L 2.71, preocular L 1.25; metasoma and telson L 12.80; metasomal segment (L/W/D): I 1.52/1.83/1.42, II 1.92/1.77/1.42, III 2.17/2.08/1.68, IV 2.50/2.46/1.88, V 2.75/2.39/1.73; telson vesicle L 1.50, W 0.93, D 1.04; leg III patella L 1.94, D 0.61; pedipalp chela L 5.25, manus ventral L 1.73, chela W 0.84, chela D 0.78, fixed finger L 3.33, movable finger L 3.42; pedipalp femur L 3.00, W 0.71; pedipalp patella L 3.15, W 0.86; pectine L 2.33. *Morphometrics*: pedipalp femur L/W 4.23; pedipalp patella L/W 3.66; chela L/W 6.25; chela movable finger L/manus ventral L 1.98; leg III patella L/D 3.18.

**Chelicera (paratype males)** (Figs. 18–19). Dark reticulated pigmentation on movable finger, and distal dorsal and distal ventral areas of manus; fingers with normal buthid dentition (Vachon, 1963; Sissom, 1990): movable finger with dorsal distal tine and ventral distal tine of equal size, dorsal margin with 4 denticles (subdistal, medial, two small basal), ventral margin with 2 denticles (large subdistal, small basal); fixed finger with large subdistal denticle and basal bicuspid; ventral aspect of fixed finger with two prominent denticles, distal denticle slightly larger than proximal denticle; dense brush of long setae on ventral and internal aspect of fixed finger, and ventral aspect of movable finger.

**Hemispermatorphore (paratype male)** (Figs. 15–16). Flagelliform, trunk elongate, flagellum relatively short, nearly half as long as trunk; 4 lobes at base of flagellum; inner lobe largest, triangular, tapered to a blunt curled tip; median lobe smaller, outer lobe smallest, both broadly laminate; basal lobe a narrow digitate hook, nearly as long as median lobe.

**Measurements of paratype female (adult).** Total L 24.50; carapace L 3.08, preocular L 1.31; metasoma and telson L 13.00; metasomal segment L/W/D: I 1.73/2.00/1.67, II 2.08/2.06/1.69, III 2.15/2.40/1.92, IV 2.48/2.67/2.17, V 2.88/2.58/2.04; telson vesicle W 0.99, D 1.06; leg III patella L 2.07, D 0.69; pedipalp chela L 5.83, manus ventral L 1.98, chela W 0.95, chela D 0.85, fixed finger L 3.75, movable finger L 3.96; pedipalp femur L 3.33, W 0.81; pedipalp patella L 3.63, W 1.06; pectine L 1.92, pectine teeth: left 12, right 11. *Morphometric ratios*: pedipalp femur L/W 4.11; pedipalp patella L/W 3.42; pedipalp chela L/W 6.14; chela movable finger L/manus ventral L 2.00; leg III patella L/D 3.00.

**Variation.** *Sexual dimorphism*: adult females ( $n = 8$ ) differed from adult males ( $n = 10$ ) as follows: larger size, total L (mm) 20.5–26.0 (females), 17.0–22.5 (males), carapace L (mm) 2.76–3.54 (females), 2.38–2.92 (males); wider carapace, W/L 1.29–1.41 (females), 1.19–1.33 (males) ( $p = 0.004$ ); mesosoma wider; pectines shorter, pectine L/carapace L 0.55–0.63 (females), 0.79–0.87 (males) ( $p = 0.0004$ ); fewer pectine teeth: 10–13 (females), 14–16 (males); basal piece of pectines wider and narrower, anterior margin wide, nearly straight, without median notch; ventrolateral carinae of metasoma V more strongly developed, crenulate. *Morphometrics* (Figs. 121–124) ( $n = 18$  adults unless otherwise stated): carapace W/L 1.19–1.41, posterior W/anterior W 2.14–2.61; pedipalp femur L/W 3.62–4.23; pedipalp patella L/W 3.17–3.83; pedipalp femur L/carapace L 1.03–1.15; pedipalp chela L/W 5.47–6.35; pedipalp chela movable finger L/manus ventral L 1.86–2.41; leg III patella L/D 2.94–3.23; metasoma L/W: I 0.77–0.90, II 0.97–1.12, III 0.90–1.19, IV 0.93–1.07, V 1.09–1.20; metasoma L/D: I 0.97–1.16, II 1.20–1.36, III 1.07–1.40, IV 1.13–1.33, V 1.41–1.68; metasoma W ratios: II/I 0.95–1.03, III/I 1.11–1.20, IV/I 1.30–1.41, V/I 1.25–1.40; telson L/vesicle D 1.77–2.13 ( $n = 11$ ), vesicle W/metasma V W 0.33–0.43. *Meristics* (including juveniles): pectine teeth: males, 11 combs with 14 teeth, 2 with 15, 9 with 16; females 2 combs with 10 teeth, 10 with 11, 3 with 12, 3 with 13; granules on ventromedian carina of telson 11–16 (2 vesicles with 11 denticles, 4 with 12, 1 with 13, 3 with 15, 10 with 16). *Trichobothriotaxy*: on the pedipalp patella,  $d_3$  in some cases split the dorsomedian carina (Fet, Soleglad &

Lowe, 2005: 6, fig. 12), in other cases was external to an unbroken dorsomedian carina (Figs. 9, 133, 137).

A juvenile male (carapace L 1.77) and female (carapace L 1.50) differed from adults in lacking strongly swollen metasomal segments III–V. *Morphometrics*: metasoma L/W: III 1.25–1.36, IV 1.24–1.37, V 1.43; metasoma W ratios: III/I 0.90–0.96 IV/I 1.10–1.05, V/I 1.08–1.12; telson vesicle W/metasma V W 0.51–0.55. There were far fewer punctuations on metasoma IV–V and the pits were much shallower. The telson vesicle of juveniles was more elongated and not as bulbous as in adults: telson L/vesicle D 2.29–2.43. The shape of the metasoma and telson of juveniles was similar to that seen in adult *Picobuthus wahibaensis*, **sp. nov.**

**Distribution** (Fig. 114). This new species is known only from the Al Hajar Mountains of Northern Oman, and represents the most eastern limit of the distribution of the genus *Microbuthus*.

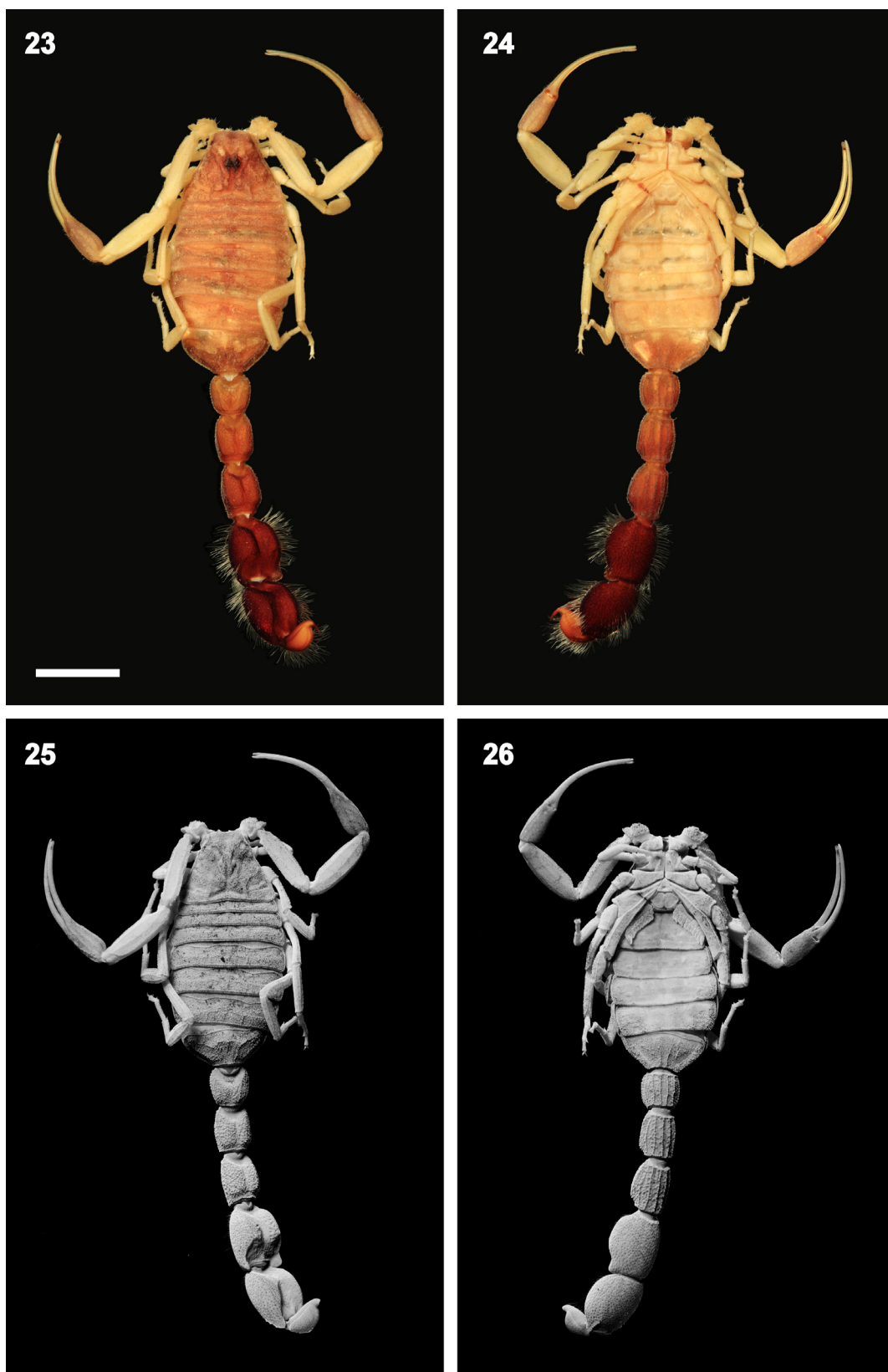
**Ecology.** All known specimens come from xeric rocky terrain with sparse vegetation. The collection site near the campus of Sultan Qaboos University is on a hot, open plain at low elevation (< 100 m a.s.l.), lying at the foothills of the southeastern end of the Al Hajar Al Gharbi. This area was strewn with loose rock and stones, receives drainage from numerous small wadis, and supports scattered *Euphorbia larica*, *Acacia* sp. and *Cyperus* sp. Other scorpions found at this site were *Hottentotta jayakari* (Pocock, 1895) and *Orthochirus glabrifrons* (Kraepelin, 1903). The species is also found on the limestone plateau of Jabal Bani Jabir in the eastern Al Hajar Mountains, above 1,600 m a.s.l. This is also a dry exposed area, littered with broken rock (Fig. 115). Other scorpions collected at this site included *Compsobuthus maindroni* (Kraepelin, 1900), *Hemiscorpius flagelliraptor* Lowe, 2009, *Hottentotta* sp., and *Nebo omanensis* Francke, 1980. Most samples of *M. gardneri* have been found at night by ultraviolet detection, but a few were collected under stones by day. They were relatively difficult to detect due to their small size and weak fluorescence of their black cuticle under UV light.

***Microbuthus kristensenorum*, sp. nov.**

Figs. 23–41, 114, 121–124, 134, 141–147, Tab. 2

*Microbuthus pusillus*: Finnegan, 1932: 92; Birula, 1937: 101; Vachon, 1949: 393–396, figs. 469, 471, 476; Vachon, 1951: 256; Vachon, 1952: 317, 321, 323, figs. 469, 471, 476; Vachon, 1966: 213; El-Hennawy, 1992: 102, 128 (part); Kovařík, 1998: 115 (part); Fet & Lowe, 2000: 182 (part); Lourenço, 2002: 165, 168, 169, figs. 5, 20; Fet, Soleglad &





**Figures 23–26:** *Microbuthus kristensenorum*, sp. nov., holotype female. Habitus viewed under reflected white light (23, 24) and UV fluorescence (25, 26). 23, 25. Dorsal aspect. 24, 26. Ventral aspect. Scale bar: 4 mm.



Lowe, 2005: 12 (part); Lourenço & Duhem, 2007: 444.

### Type material

**Holotype:** adult ♀, **Oman**, Jabal Qamr, 3 km. East of Ardit (F/14), UV detection, windswept plateau with rocky wadis, between stones under shrubs, 16°50.87'N 53°23.77'E, 1067 m a.s.l., 19 December 2001, 21:00–22:15 h, leg. A. Winkler, AW39 (NHMB).

**Paratypes:** **Oman:** 1 ♀, same locality as holotype (NHMB); 1 ♀, Dhofar Province, Milwah al 'Aud, ca. 17°8.13'N 54°17.6'E, Jabal Qara, 30 October 1930, 220 ft a.s.l., leg. B.S. Thomas, No. 15, 1931.6.2.17 (BMNH); 1 ♀, Dhofar Province, Wadi Shuwaymiyah, 17°55.81'N 55°32.98'E, 45 m a.s.l., 25 September 1995, 21:30 h, UV detection, small rocky wadi, rocky wall at edge of narrow side wadi, perched on rock, at eye level, leg. G. Lowe & M.D. Gallagher (NHMB); 1 ♀, 2 juvenile ♂, 1 juvenile ♀, Jabal Qamr, 2 km E of Ardit, N of Rakhyut (site F/10), windswept plateau with small rocky wadis, under little rock under small tree, 16°50.7'N 53°23.69'E, 1060 m a.s.l., 1 January 1999, 11:00–16:30 h, leg. A. Winkler & B. Winkler (ONHM); 4 ♀, Jabal Qamr; 2 km E of Ardit (site F/15II); windswept plateau with small rocky wadis, under small rocks & between rock on lee side, 16°50.70'N 53°23.69'E, 1060 m a.s.l., 31 January 2000, 16:00–21:00 h, leg. B. Winkler (GL, NHMB).

**Diagnosis.** A member of the genus *Microbuthus* differentiated as follows: adult females 23–26 mm long; base color pale yellow, with variable fuscous pigmentation on carapace, tergites, pedipalp manus and metasoma (Figs. 23–24); metasomal segments (Figs. 40–41) not very stout, metasoma L/W ratios, I > 0.95, II > 1.15, III > 1.2, IV > 1.15, V > 1.22; ventral and lateral surfaces of metasoma III granulate, not rugose-reticulate, with distinct ventrosubmedian carinae; ventral and lateral surfaces of metasoma IV–V densely clothed in numerous long translucent setae, each arising from a cuticular pit; metasoma V with ventrolateral carinae distinct, crenulate, confined to posterior 1/3 of segment; telson narrow, vesicle uniform in width, deepest posteriorly, abruptly truncated; ventral surface of vesicle bearing numerous long translucent setae; serrulate ventromedian carina extending over anterior 3/5 of vesicle; leg III patella L/D 3.2–3.8; legs III–IV with well developed tibial spurs; retrosuperior margins of basitarsi I–III without bristle combs (Fig. 28); pedipalps tenuous (Figs. 30–36), L/W ratios: femur > 3.8, patella > 3.4; chela fixed finger with *dt* at 1/5 of length from tip; pectine teeth: males 14–16, females 10–12.

**Etymology.** This species is named in honor of Charles and Anita Kristensen of Yarnell, Arizona, professional collectors and arachno-culturists who have promoted

science education and research into the pharmacology and toxicology of spider and scorpion venoms.

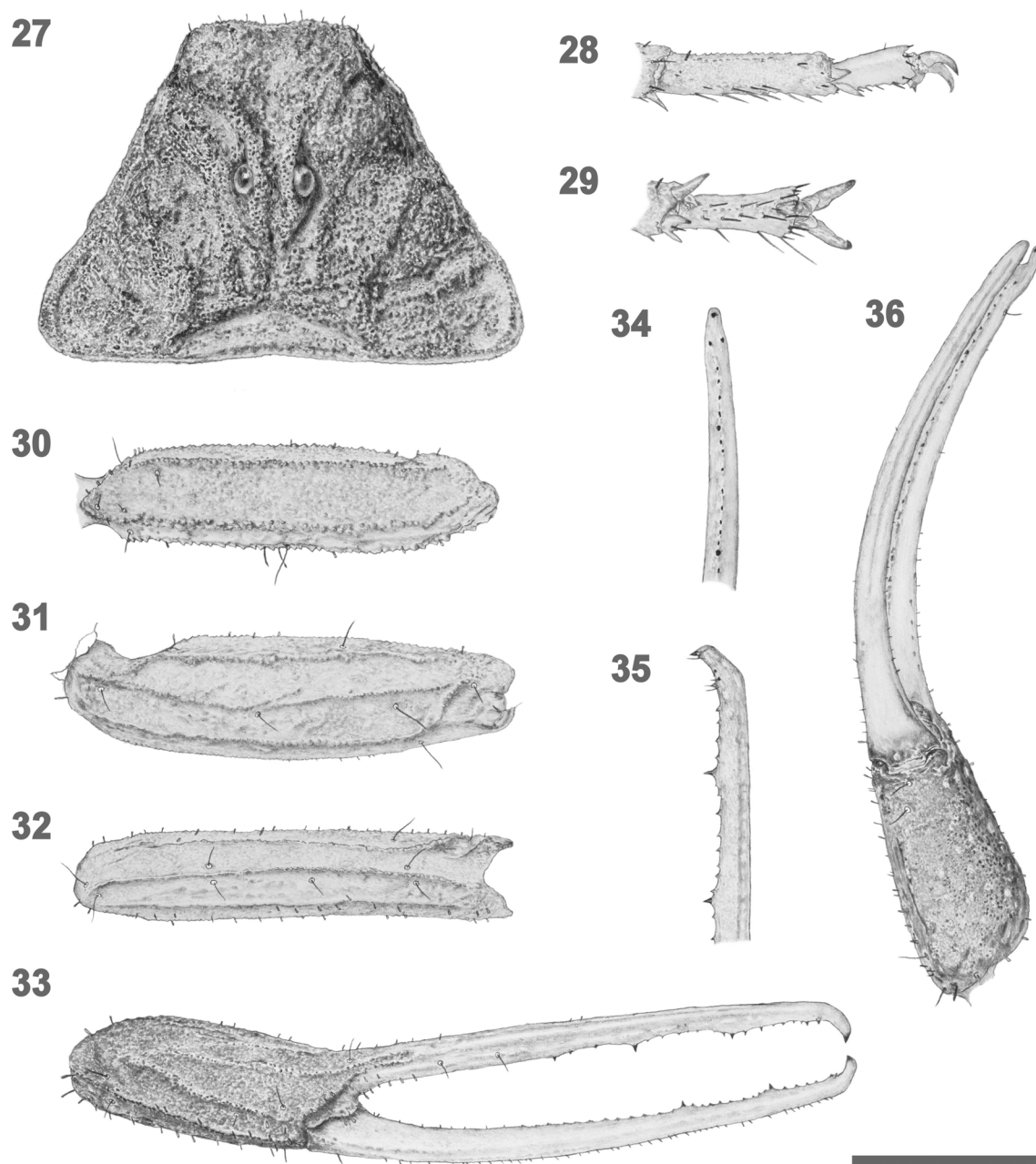
**Comparisons.** *Microbuthus kristensenorum* is easily distinguished from other *Microbuthus* by the dense pilosity on metasoma IV–V and telson (Figs. 23–24, 40–41). In addition, *M. kristensenorum* differs from *M. gardneri* by having less stout metasomal segments and more densely pitted metasomal segments IV–V. However, these segments are more swollen in *M. kristensenorum* compared to *M. fagei*, *M. maroccanus*, *M. flavorufus* and *M. pusillus* (see Table 2).

### Description of holotype female

**Coloration** (Figs. 23–24). Carapace, tergites and metasoma I–III ferruginous to rufofuscous, with underlying dark pigmentation pattern; metasoma IV–V castaneous to rufopiceous; telson bright orange to reddish brown, darker proximally; sternites III–VI ochraceous, sternite VII fuscous; pedipalp with fuscosity on manus and base of both fingers, otherwise light yellow; legs pale yellow.

**Carapace** (Figs. 23, 25, 27). Strongly trapezoidal, 1.36 times wider than long, posterior W/ anterior W 2.59; entire surface roughened, with dense granulation; clavate microsetae scattered over surface and margins; anterior median carinae granulate, posteriorly distinct, anteriorly expanded into broad ridges, sloping down to anterior marginal shelf; lateral eyes with 3 ocelli, posterior ocellus very small; ocular tubercle prominent, median eyes large, superciliary carinae granular, separated by median trough; central median and posterior median carinae weak, granular, well separated; posterior median furrow moderately deep, finely granulate; posterior marginal furrow deep, smooth; anterior median furrow wide, shallow, coarsely granular; lateral flanks of carapace steeply sloped; posterior margin of carapace bordered by granulate carina, margin minutely denticulate.

**Coxosternal area** (Figs. 24, 26). Coxae finely granular or shagreened, with scattered short reddish macrosetae; coxa II endites medially and laterally smooth; coxa III with heavily granulate anterior marginal carina; coxa IV narrow, elongate, with strong, granular anterior marginal carina extending over entire length of segment, weak posterior marginal carina confined to proximal half; sternum almost triangular, weakly granular, with deep, wide postero-median excavation, bearing two short reddish macrosetae; genital opercula rounded triangular, laterally rimmed, with 3 short macrosetae; basal piece wide, densely shagreened; pectines small, short (Fig. 39); left comb with 5 middle lamellae, right with 6; fulcrum bearing 1–2 reddish macrosetae; numerous short

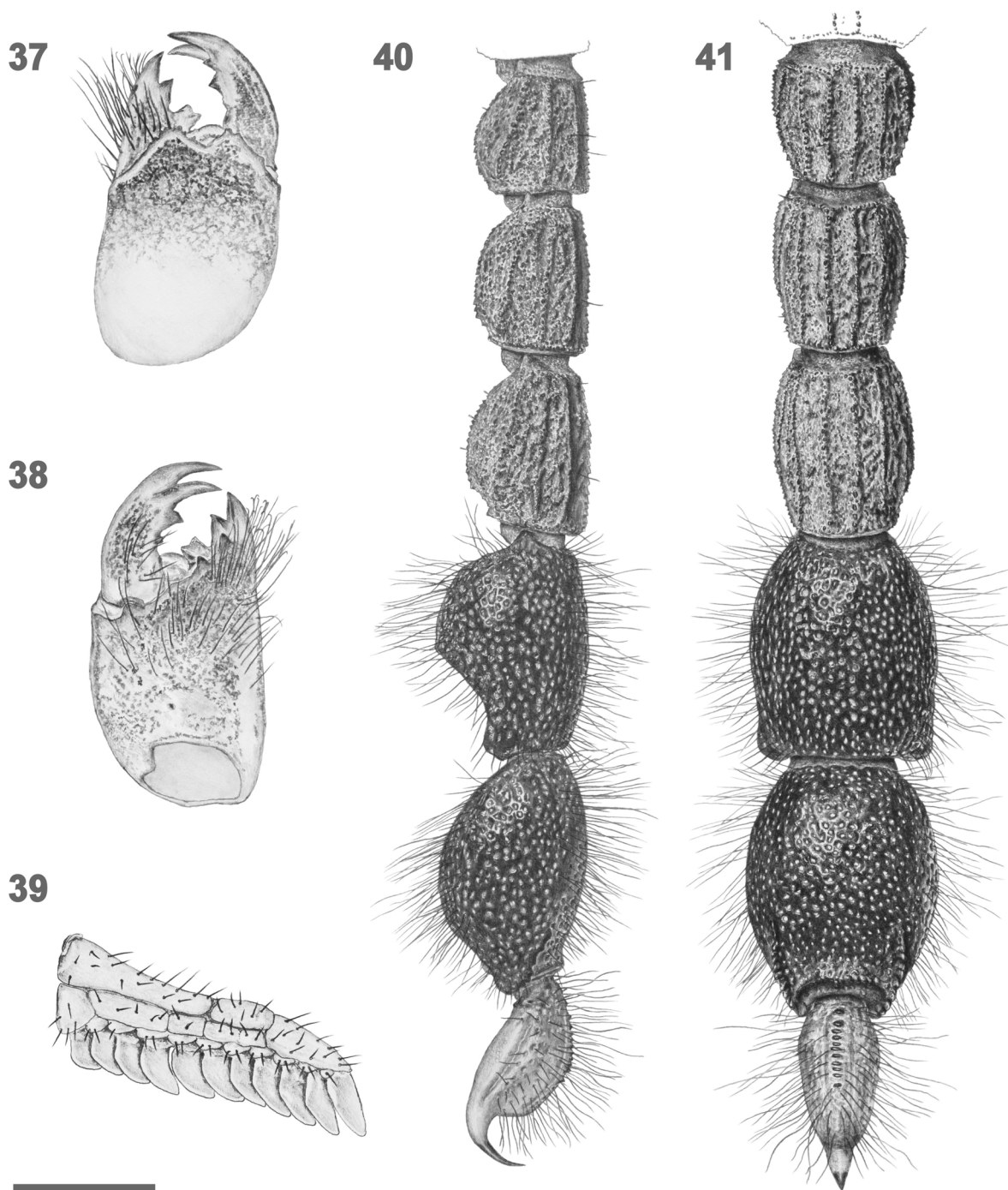


**Figures 27–36:** *Microbuthus kristensenorum*, **sp. nov.**, holotype female. **27.** Carapace, dorsal aspect. **28.** Right basitarsus and telotarsus III, retrolateral aspect. **29.** Right telotarsus III, ventral aspect. **30.** Right pedipalp femur, dorsal aspect. **31.** Right pedipalp patella, dorsal aspect. **32.** Right pedipalp patella, external aspect. **33.** Right pedipalp chela, dorsoexternal aspect. **34–35,** right pedipalp chela movable finger terminus. **34.** Dorsal aspect. **35.** External aspect. **36.** Right pedipalp chela, ventral aspect. Scale bar: 27, 30, 31, 32, 33, 36: 2 mm; 28, 34, 35: 1.26 mm; 29: 0.86 mm.

reddish macrosetae on lamellae; pectine teeth: left 11, right 10.

**Mesosoma** (Figs. 23–26). Pretergites densely, finely granular, rimmed posteriorly by minute granules; border

of pretergite nearly straight on tergite I, bisinuate on II–VII; all tergites with dense, coarse granulation and scattered clavate microsetae, bordered postero-medially by linear series of granules; margins of I–VI with regular microdenticulation; tergite I without lateral carinae,



**Figures 37–41:** *Microbuthus kristensenorum*, **sp. nov.** 37–38, paratype female (Jabal Qamr); 39–41, holotype female. 37–38, right chelicera. 37. Dorsal aspect. 38. Ventral aspect. 39. Left pectine, ventral aspect. 40–41, metasoma and telson. 40. Right lateral aspect. 41. Ventral aspect. For clarity, long macrosetae of metasoma IV–V were not rendered on the lateral surfaces in Fig. 40 and the ventral surfaces in Fig. 41). Scale bar: 37, 38: 0.66 mm; 39: 1 mm; 40, 41: 2 mm.

weak trace of median carina, II–III with weak traces of lateral carinae, weak median carina, IV–VI with 3 weak granular carinae on posterior half; VII with 5 weak, granular carinae; lateral margins of all tergites finely denticulate; sternites III–V anterolaterally shagreened, posteromedially smooth, matte; V laterally granular, VI

heavily shagreened, laterally granular, VII densely granular; III–VI with shallow median sulcus, posterior margins with minute, regular denticulation; VI with weak post-spiracular lateral carinae, joined with granular postero-median marginal carina; VII with strong, granular median carinae extending over posterior 2/3 of segment, and weak, granular lateral carinae limited to middle 1/4 of segment.

**Metasoma** (Figs. 23–26, 40–41). Segments I–III with 10 granulo-crenulate or granulo-denticulate carinae; ventro-submedian and ventrolateral carinae strong; median lateral carinae moderate; dorsosubmedian and dorsolateral carinae weak; median lateral carinae complete on I–II, confined to posterior 2/3 of segment on III; ventrosubmedian and ventrolateral carinae with dentate granules; intercarinal surfaces on metasoma I–III densely, coarsely granular; lateral and dorsal surfaces of III reticulo-granulate; metasoma IV–V swollen, heavily sclerotized, ventral, lateral and dorsolateral surfaces convex, smooth, lustrous, with numerous rounded depressions each giving rise to single long, pale, gently curved seta; anterior half of dorsal surface of metasoma IV a deep, rugose trough, posterior half a wide slope with fine median granulation, bounded by prominent posterolateral lobes; anterior slope of dorsal surface of segment V smooth, moderately concave, with shallow depressions; posterior part of V deeply excavated, longitudinally rugose; dorsosubmedian carinae of IV and dorsolateral carinae of V indistinct, rounded; ventrolateral carinae of V strongly developed on posterior 1/3 of segment, crenulate, with enlarged rounded granules; other carinae of IV–V obsolete; lateral anal lobe smooth; ventral anal arch strongly curved, smooth, bordered by elevated granulose ridge.

**Telson** (Figs. 40–41). Vesicle elongate, narrow, width almost uniform, only slightly tapered, asymmetric in lateral profile, posterior end deepest, abruptly truncate; ventral surface with broad serrulate ventromedian carina with 11 widely transverse granules, extending over anterior 3/5 of vesicle; carina bordered laterally by longitudinal sulci; ventral surface pitted, with numerous long, pale, curved setae emerging from pits; dorsal surface smooth, convex, separated from ventral surface by lateral sulcus; subaculear tubercle absent; aculeus short, stout, bent sharply downward perpendicular to plane of dorsal surface of vesicle; tip of aculeus lower than deepest part of vesicle.

**Pedipalp** (Figs. 30–36, 141, 143–147). *Femur* (Fig. 30): slender, 4 times longer than wide, strongly compressed dorsoventrally, with proximal ventroposterior surface concave; 5 carinae present; ventrointernal, internal, dorsointernal and dorsoexternal carinae well developed, granulo-denticulate; external carina weak, marked by

linear formation of granules; surfaces of femur roughened with dense fine granulation, bearing scattered clavate microsetae. *Patella* (Figs. 31–32): 3.6 times longer than wide, with 8 finely granulo-denticulate carinae; internal, dorsointernal, dorsomedian, dorso-external and external carinae moderate; ventroexternal, ventromedian and ventrointernal carinae weak; intercarinal surfaces finely roughened, shagreened, with scattered clavate microsetae. *Chela* (Figs. 33, 36): manus elongate, slightly wider at base; manus with ventroexternal, external and dorsal marginal carinae strong, digital carina moderate, dorsal secondary carina weak; moderate secondary carina present below ventro-external carina, converging at external articular condyle of movable finger; all carinae on manus finely granulose; digital, dorsal secondary and dorsal marginal carinae smooth, extending onto fixed finger; dorsal internal carinae obsolete on manus and fixed finger; surface of manus finely roughened, bearing numerous short clavate microsetae; fingers smooth, fixed finger deflected upward at base, flanked internally and externally by rounded lobes bearing several longer clavate setae on margins; 6 additional clavate setae arrayed in row along external margin of manus at base of movable finger; chela fingers long, tenuous, curved inward, vertically arched to leave wide gap with tips of fingers closed; both fingers bearing enlarged, erect, spinoid primary denticles dividing dentate margins into gently scalloped subrows of fine, widely spaced microdenticles; fixed finger with subdistal pair of denticles plus 3 additional enlarged denticles along margin; fixed finger subrows with 1, 6, 6, 4, 1 microdenticles (distal to proximal); movable finger with subdistal pair of denticles and two enlarged denticles along margin, subrows with 4, 8, 11 microdenticles; fixed finger with external groove at base of enlarged terminal tooth, receiving terminal tooth of movable finger. *Trichobothriotaxy* (Figs. 141, 143–147): type AB, neobothriotaxic minorante (Vachon, 1974, 1975), as diagnosed for the genus; right femur with 3 internal trichobothria ( $i_2$  missing, Fig. 141), left femur with 4 internal trichobothria;  $d_3$  on pedipalp patella positioned slightly external relative to dorsomedian carina (Figs. 31, 144).

**Legs** (Figs. 25–26, 28–29). All legs slender, inferior carinae of femur and patella denticulate to serrate; legs III–IV with small, well developed tibial spurs; ventral margins of basitarsi I–III with two rows of medium length macrosetae, not forming bristle combs; soles of telotarsi with two rows of short macrosetae; ungues short, stout, strongly curved; prolateral tarsal spurs basally bifurcate, retrolateral tarsal spurs simple.

**Measurements of holotype female (adult) (mm).** Total L 26.50; carapace L 3.50, anterior W 1.83, posterior W

4.75, preocular L 1.43; metasoma and telson L 16.50; metasomal segment (L/W/D): I 2.00/1.92/1.58, II 2.50/1.77/1.67, III 2.67/1.88/1.75, IV 3.33/2.58/2.29, V 3.42/2.58/2.13; telson L 2.58, telson vesicle L 2.04, W 1.08, D 1.15; leg III patella L 1.14, D 0.71; pedipalp chela L 6.96, manus ventral L 2.25, chela W 1.08, chela D 1.00, fixed finger L 4.38, movable finger L 4.92; pedipalp femur L 3.96, W 1.00; pedipalp patella L 4.17, W 1.17; pectine L 2.04. *Morphometrics*: pedipalp femur L/W 3.96; pedipalp patella L/W 3.57; chela L/W 6.42; chela movable finger L/manus ventral L 2.19; leg III patella L/D 3.39.

**Chelicera (paratype female)** (Figs. 37–38). Dark reticulated pigmentation on movable finger, and distal dorsal and distal ventral surfaces of manus; fingers with normal buthid dentition (Vachon, 1963; Sissom, 1990): movable finger with dorsal distal tine and ventral distal tine of equal size, dorsal margin with 3 large denticles (subdistal, medial, basal) and very small proximal denticle adjacent to basal denticle; ventral margin with 2 denticles (large subdistal, small basal); fixed finger with large subdistal denticle and basal bicuspid; ventral aspect of fixed finger with two prominent denticles, distal denticle only slightly larger than proximal denticle; dense brush of long setae on ventral and internal aspect of fixed finger, and ventral aspect of movable finger.

**Variation.** Adult females ( $n = 8$ ) from Jabal Qamr and Jabal Qara (Milwah Al Aud) were similar in form and coloration. Measurements (mm): total L 20–26; carapace L 2.76–3.54, metasoma and telson L 11.5–15.50. *Morphometrics* (Figs. 121–124): carapace W/L 1.29–1.41, carapace posterior W/anterior W 1.93–2.59; pedipalp femur L/W 3.82–4.35; pedipalp patella L/W 3.44–3.88; pedipalp femur L/carapace L 1.09–1.22; pedipalp chela L/W 6.00–6.52; pedipalp chela movable finger L/manus ventral L 2.04–2.23; leg III patella L/D 3.18–3.40; metasoma L/W: I 0.95–1.04, II 1.18–1.41, III 1.22–1.42, IV 1.17–1.33, V 1.24–1.48; metasoma L/D: I 1.15–1.26, II 1.35–1.50, III 1.37–1.59, IV 1.38–1.62, V 1.52–1.65; metasomal segment width ratios: II/I 0.92–0.96, III/I 0.95–1.00, IV/I 1.21–1.35, V/I 1.16–1.35; telson L/vesicle D 2.24–2.77, vesicle W/metasma V W 0.39–0.48. *Meristics*: Pectine teeth 10–13 (1 comb with 10 teeth, 10 with 11, 4 with 12, 1 with 13), ventromedian carina of telson with 11–15 granules. *Trichobothriotaxy*: subtractive neobothriotaxy (3 trichobothria, Fig. 141) on the internal right pedipalp femur of the holotype female was atypical, the normal complement of 4 internal trichobothria (Fig. 142) was present in 11 other femora (left femur of holotype, and bilaterally in femora of 5 paratype females).

One smaller, presumably immature female from Wadi Shuwaymiyah differed from adults of Jabal Qamr and Jabal Qara by its pale tan colored body with only

faint fuscous markings on the carapace and base of pedipalp fingers; only metasoma IV–V, and telson were dark reddish brown. It also differed in its bilateral loss of trichobothrium *esb*<sub>2</sub> on the pedipalp patella, and in having a more slender pedipalp patella and more slender metasoma I–IV. This does not appear to be an ontogenetic difference because juveniles ( $n = 3$ ) from Jabal Qamr are darkly pigmented, and have *esb*<sub>2</sub> present and the pedipalp patella and metasoma II–IV significantly less slender than in adults.

Measurements of Wadi Shuwaymiyah female (mm): total L 19.5; carapace L 2.34, ocular tubercle to anterior margin 1.10; carapace W 2.92; metasomal segments (L/W/D): I 1.41/1.28/1.22, II 1.63/1.14/1.22, III 1.82/1.18/1.06, IV 2.23/1.47/1.00, V 2.24/1.51/1.03; telson vesicle W 0.70, D 0.72; leg III patella L 1.76, D 0.48; pedipalp chela L 5.21, manus ventral L 1.76, chela W 0.79, D 0.69, fixed finger L 3.29, movable finger L 3.42; pedipalp femur L 2.9, W 0.67; pedipalp patella L 3.13, W 0.76; pectine L 1.55, pectine teeth: left 11, right 10. *Morphometric ratios*: pedipalp femur L/W 4.33, pedipalp patella L/W 4.12, metasoma L/W, I 1.10, II 1.43, III 1.54, IV 1.52, V 1.48, carapace L/W 1.25, carapace anterior W/posterior W 1.71.

Adult males were not represented in the samples examined. Two juvenile males had greater numbers of pectine teeth (14–16) compared to females (10–13). Juveniles (1 female, 2 males; total length 8.5–10 mm) were similar to adults in general form and color, but differed as follows: carapace lacking carinae; carapace and tergites with much reduced granulation, metasoma and pedipalps smooth; pedipalps without carinae; carination on metasoma I–III very weak; metasoma IV–V much less swollen, more elongate, smooth; surfaces of metasoma IV–V with only a small number of shallow depressions, completely lacking the long curved macrosetae found in adults. *Morphometrics of juveniles* ( $n = 3$ ): carapace W/L 1.26–1.30, carapace anterior W/posterior W 2.00–2.05, pedipalp femur L/W 3.33–3.62, pedipalp patella L/W 3.09–3.35, metasomal segment L/W: I 0.99–1.00, II 1.31–1.37, III 1.39–1.51, IV 1.53–1.60, V 1.69–1.73, metasoma V W/metasma I W 0.98–1.00, telson L/W 2.27–2.48, telson W/metasma V W 0.65–0.67.

**Distribution** (Fig. 114). This species occurs in the coastal region around the Dhofar Mountains of Oman. In Oman, it was first collected by Bertram Thomas in 1930 from a site known as Milwah al 'Aud (Finnegan, 1932). The precise coordinates of this site are not known (Arnold, 1980), but it is thought to be on the Salalah coastal plain, within a days walk of Ayn Arzat (Ain ar Rizat) in the Jabal Qara Mountains (M.D. Gallagher, 1994, personal communication). According to Thomas (1932: 39), the 'stream of Rizat rises two miles above the tree garlanded Milwah al 'Aud', and the coordinates

cited here are estimated from the location labeled 'Milwah Al Aud' on the map in Arabia Felix, showing Dhofar and the Qara Mountains (Thomas, 1932: 101). The material examined in this study shows that the species occurs throughout the coastal mountains and wadis of Dhofar, from lower foothills to above 1,000 m a.s.l. In his treatise on African scorpions, Vachon (1952: 320, fig. 469, 471) illustrated a female *Microbuthus* specimen from Aden with densely pilose metasoma IV–V and telson, that compares favorably with the material from Oman. The Aden population is herein provisionally assigned to *M. kristensenorum*. The species might also be distributed throughout the intervening mountains of the Hadhramaut along the southern coast of Yemen.

**Ecology.** Found in mesic to xeric rocky microhabitats along the coast and mountains of Dhofar Province, ranging from vegetated coastal wadis to windswept rocky plateaus (Figs. 119–120). A female with 3 juveniles was collected from under a rock at the base of a small tree.

**Remarks.** In the past, this species has been misidentified as *Microbuthus pusillus* Kraepelin, 1898, the type species of the genus. Borelli (1915: 461) cited a specimen of *M. pusillus* from 'Aden' in the museum in Milan. Finnegan (1932) determined the specimen collected by Bertram Thomas from Dhofar (examined here) as *M. pusillus*, and Vachon (1949, 1952) also applied this name to *Microbuthus* specimens from Aden (Yemen) with dense pilosity on metasomal segments IV–V and the telson vesicle. There is no indication that any of these authors analyzed the type of *M. pusillus*, which originates from Tadjourah Bay, Djibouti (deposited in Zoologisches Museum der Universität Hamburg). The holotype was recently studied by Kovařík (2003), who furnished detailed photomicrographs of the specimen (Kovařík, 2005, personal communication). Although Kraepelin (1898) listed it as male, the holotype appears to be female, judging from the short pectines, low number of pectine teeth (9 + 9), and wide mesosoma. Compared to material of *M. kristensenorum* from Dhofar, the holotype of *M. pusillus* differs as follows: dense pilosity absent on metasoma IV–V and telson, cuticular depressions without visible setae; metasoma IV–V less swollen; telson vesicle more symmetrically ovoid in lateral profile, with ventro-median carina extending over more (anterior 0.86) of the length of the vesicle; pedipalp femur and patella less slender (L/W 3.28 and 2.9 respectively, cf. Table 2), and patella darkly pigmented, not pale. The most obvious difference is the complete lack of long setation on metasoma IV–V and telson, a prominent diagnostic character of *M. kristensenorum*. The holotype of *M. pusillus* is in poor condition and disarticulated, so it is possible that its metasoma IV–V and telson once bore a

dense cover of macrosetae, and that these have all detached during long museum storage. However, in his original description Kraepelin (1898) does not mention any conspicuous, dense setation on these segments. Kraepelin (1901) cited further African records of *M. pusillus* from Abyssinia (Ethiopia), Goubet Al-Kharab (shore of Lake Ghoubet, adjacent to Tadjourah Bay, Djibouti), and Obock (Djibouti), but none from the Arabian Peninsula.

According to Kovařík (2003), *M. pusillus* is likely to be synonymous with *M. litoralis* (Pavesi, 1885), although this could not be formally verified because the type of the latter species is lost. This hypothesis is plausible because the locality where the type of *M. litoralis* was collected (Aseb, Eritrea) is only about 120 km northwest of Tadjourah Bay, and likely to have similar shoreline habitat along the Red Sea coast of the Horn of Africa. Birula (1905) redescribed *M. litoralis* based on a specimen from Asab (= Aseb), Eritrea. His illustrations of the metasoma, telson and pedipalps of *M. litoralis* are morphometrically similar to the holotype of *M. pusillus*. The characters that he proposed to differentiate the two species, i.e. the degree of granulation on the sternites and dorsal surfaces of metasoma IV–V, and the strength of carination on tergites I–II, are subjective, and can be variable and age-dependent in other *Microbuthus*. Lourenço (2002) published an illustration of a female *M. litoralis* that also compares favorably with the holotype of *M. pusillus* in the morphometrics of pedipalps and metasoma, and in the color pattern (darkly pigmented carapace, tergites, metasoma, pedipalp patella and pedipalp chela manus, with lighter legs and pedipalp femur). However, the provenance of this specimen was not mentioned. It is notable that neither Pavesi nor Birula describe any dense pilosity on the metasoma or telson of *M. litoralis*, which suggests that this character is not present in the African populations.

Determinations of specimens from Aden with hirsute metasomal segments as *M. pusillus* might have been based on the geographic proximity of Aden to the type locality of that species. However, Aden is separated from the African coast by the straits of Bab el-Mandeb, a significant marine barrier to scorpion dispersal. These straits opened up when the Arabian Peninsula separated from the African continent by axial rift of the Red Sea trough in the early Pliocene, ca. 5 Mya (Coleman, 1993). Since then, *Microbuthus* populations of Aden would have been isolated from those of northeast Africa, providing ample time for species divergence (Fernandes, Rohling & Siddall, 2006). Vachon (1952: 323) referred to "Aden" as the type locality of *M. pusillus*, and may have misinterpreted the "Gulf of Aden" cited by Kraepelin for Tadjourah Bay in Djibouti. Vachon (1952: 317) also mentioned specimens of *Microbuthus* in the collection of Muséum National d'Histoire Naturelle,

Paris, from 'Obock, Djibouti', which he classified as *M. litoralis* (Vachon, 1952, fig. 476), and which could be the same as those studied by Kraepelin (1901) who determined them as *M. pusillus*. Collection of additional *Microbuthus* material from Yemen, and comparison with material from Djibouti, is needed to determine whether *M. pusillus* actually occurs on the Arabian Peninsula.

Genus *Femtobuthus*, gen. nov.

**Type species.** *Femtobuthus shutuae*, sp. nov.

**Diagnosis.** A member of the picobuthoid group (see diagnosis above), differentiated as follows: very small scorpions, adults < 18 mm; metasoma (Figs. 51–52) with segments I–III stout, ventral and ventrolateral carinae well developed, median lateral carinae weak, dorsal and dorsolateral carinae obsolete; ventrosubmedian carinae on II–III armed with enlarged dentate granules, lobate in females; metasoma IV–V wider, more robust than I–III; anterior ventral margins of metasoma III–IV rimmed by arcs of large rounded granules; metasoma V robust, dorsolateral carinae strong, ventrolateral carinae and ventral surface armed posteriorly with large, lobate granules; ventral and lateral surfaces of metasoma IV–V granular, not smooth, weakly pitted with shallow depressions; telson vesicle moderately swollen, ovoid; tibial spurs usually present on leg IV, sometimes present but often reduced or absent on leg III; fixed finger of chelicera armed ventrally with two denticles, distal denticle large, proximal denticle very small (Fig. 54); pedipalps (Figs. 47–50, 62) with weak or obsolete carination, chela fixed finger weakly deflected upward at base, moderately curved, not strongly arched vertically (Fig. 50); trichobothria (Figs. 47–50, 163–168): femur: 2 external, 2 dorsal ( $d_2$ ,  $d_3$  and  $d_5$  absent), 2 internal ( $i_2$  and  $i_4$  absent); patella: 5 external ( $esb_2$  and  $em$  absent), 4 dorsal ( $d_2$  absent), 1 internal; manus: 4 external ( $eb_3$  and  $Esb$  absent), 2 ventral; fixed finger: 6 ( $esb$  absent).

**Comparisons.** This monotypic genus is created for one of the smallest known scorpions. The morphology of *Femtobuthus* is intermediate between *Picobuthus*, **gen. nov.**, and *Microbuthus*. Characters shared with *Picobuthus* include: very small size, cheliceral fixed finger with proximal ventral denticle much smaller than distal ventral denticle, absence of smooth, pitted metasomal segments IV–V, stout pedipalp segments, lack of strongly arched pedipalp fingers, 5 external patellar trichobothria, and basitarsal bristle combs; characters shared with *Microbuthus* include: strongly trapezoidal carapace, relatively short, deep telson vesicle, and presence of tibial spurs on leg IV. It is distinguished from both *Picobuthus* and *Microbuthus* by subtractive neobothriotaxy of the pedipalp femur (2 dorsal, 2

internal trichobothria). Comparisons are summarized in Table 1.

**Etymology.** The name is derived from the prefix '*femto*' which signifies a factor of  $10^{-15}$  in SI units, a reference to the very small size of these scorpions.

*Femtobuthus shutuae*, sp. nov.

Figs. 42–62, 111, 114, 121–124, 163–168

#### Type material

**Holotype:** adult ♂, **Oman**, between Shalim & Ash Shuwaymiyah, open rocky windswept plateau, sparse shrubs, ground with bare rock, patches of soil, UV detection, active on ground near bases of small shrubs, 18°02.44'N 55°36.91'E, 265 m a.s.l., 26 September 1995, 1:32 h, leg. G. Lowe & M.D. Gallagher (NHMB).

**Paratypes:** **Oman**. 3 ♂, same locality as holotype (GL, NHMB); 5 ♀, Wadi Shuwaymiyah, near Farrah (site F/6), UV detection, mouth of burrows in hard sandy soil, 17°54.33'N 55°41.28'E, 7 m a.s.l., 29 December 2002, 19:00–20:30 h, leg. A. Winkler (GL, NHMB, ONHM).

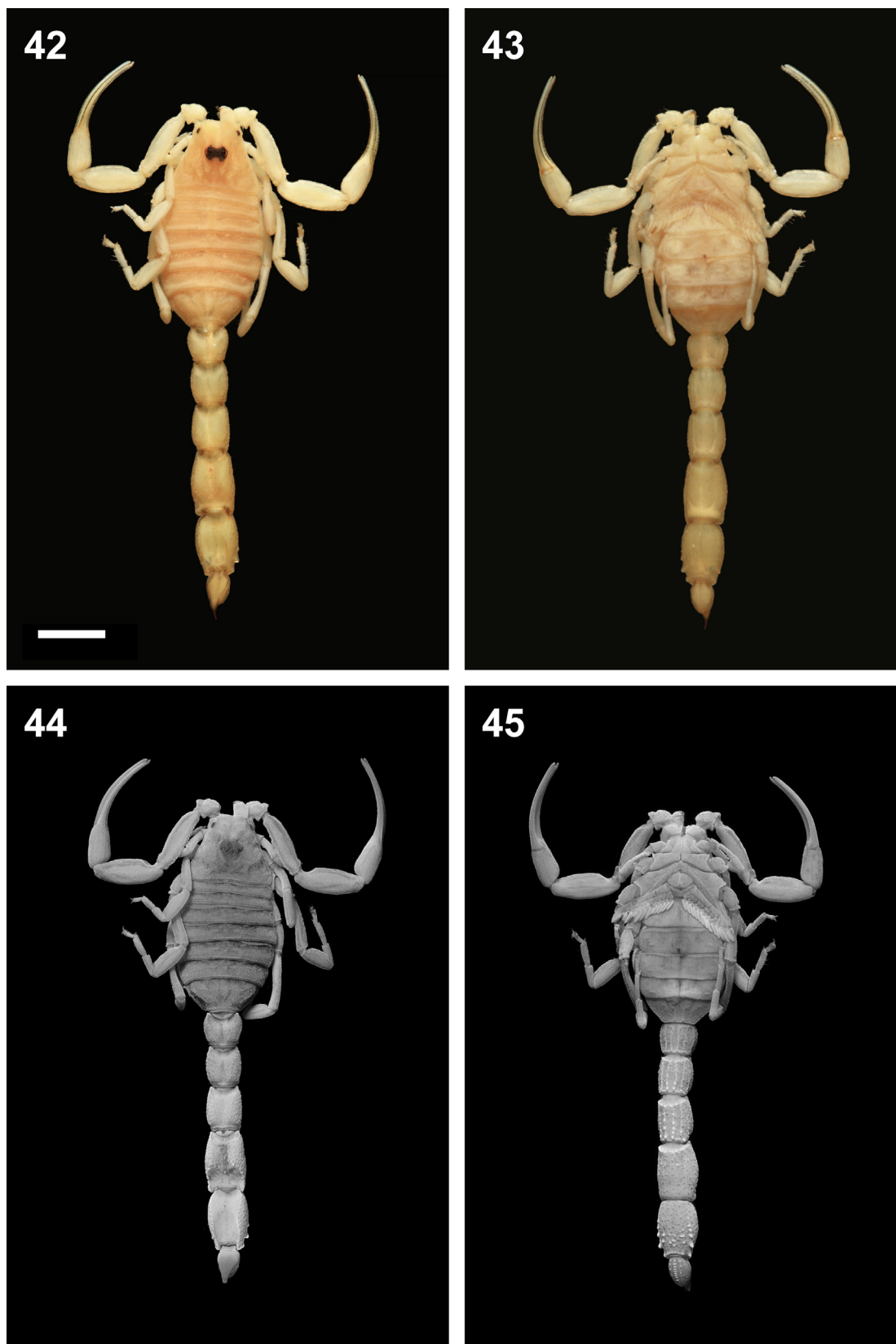
**Diagnosis.** A member of the genus *Femtobuthus* further differentiated as follows: very small scorpions, adult males 13.5–15 mm, adult females 16–18 mm; color uniform pale yellow, sometimes with faint brown marbling on carapace (Figs. 42–43); metasomal segments (Figs. 51–52) stout, segments IV–V wider than I–III, heavier, with ventral and lateral surfaces weakly convex, finely granular, segment V uneven, slightly rugose, dimpled, with microsetae arising from depressions, pustulose with enlarged lobate granules on posterior ventral surface; ventrolateral carinae extending over posterior 3/4 of metasoma V, armed with 4–5 rounded or lobate denticles; ventrosubmedian carinae of metasoma II–III with 3–5 enlarged, tuberculate denticles; retrosuperior margins of basitarsi of legs I–III with bristle combs (Fig. 55).

**Etymology.** The specific epithet derives from *Shutu*, Babylonian goddess of the South Wind, a reference to the intense southerly night winds experienced by the collectors while camping at the type locality.

#### Description of holotype male (adult)

**Coloration** (Figs. 42–43, 111). Entire body pale straw color, with faint ferruginous pattern on carapace; median eyes, median ocular tubercle, and lateral eyes black; aculeus reddish brown.

**Carapace** (Figs. 42, 44, 46). Trapezoidal, W/L 1.27, posterior W/anterior W 2.35; anterior margin weakly



**Figures 42–45:** *Femtobuthus shutuae*, sp. nov., holotype male. Habitus viewed under reflected white light (42, 43) and UV fluorescence (44, 45). 42, 44. Dorsal aspect. 43, 45. Ventral aspect. Scale bar: 2 mm.



incurved; entire surface densely granular, carinae indistinct; anterior ocular triangle with shallow median furrow, sloped downwards towards anterior margin; lateral eyes with 3 ocelli, most posterior ocellus smallest; ocular tubercle large, with broad, flat top and scattered granules; median eyes large in proportion to carapace; area of central median and posterior median carinae with irregular reticulated granulation; posterior median and posterior marginal furrows shallow; lateral flanks of carapace steeply sloped, bordered posteriorly by transverse granular ridge; posterior margin minutely denticulate.

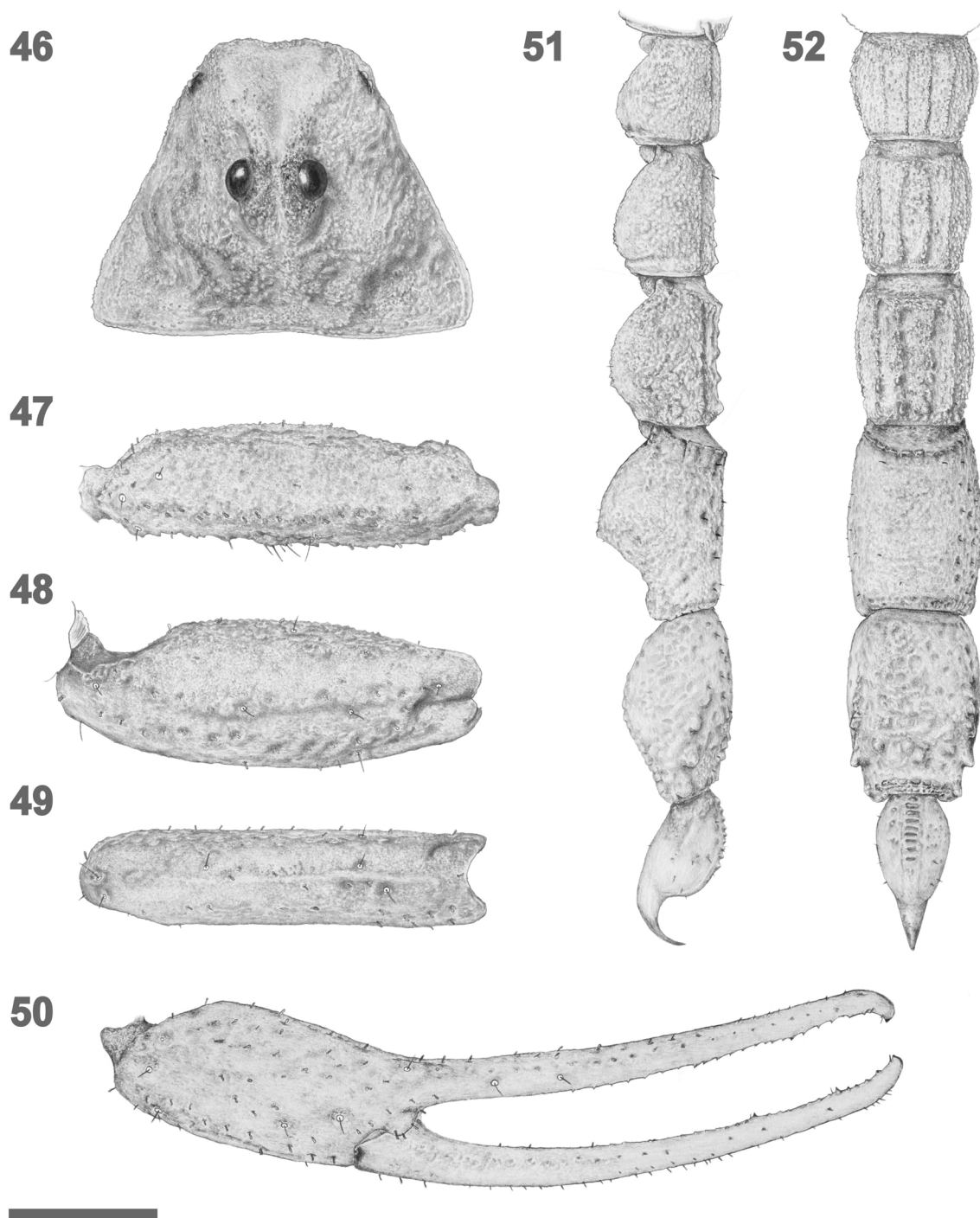
**Coxosternal area** (Figs. 43, 45). Coxae smooth or very finely roughened, with sparse, scattered reddish macrosetae; coxa III weakly shagreened on anterior margin; coxa IV elongate, narrow, weakly finely shagreened; marginal carinae of coxae obsolete; sternum almost triangular, smooth, with deep, postero-median excavation, bearing two short reddish macrosetae; genital operculum rounded triangular, smooth; pectines with 3 marginal lamellae, 5–6 middle lamellae, all with numerous long reddish macrosetae (Fig. 57); fulcra present, each bearing two long reddish macrosetae; basal piece anteriorly emarginate, with deep anterior median sulcus; pectine teeth: left 13, right 13.

**Mesosoma** (Figs. 42–45). All pretergites with matte surface, posterior border regularly microgranulate; border nearly linear on pretergite I, slightly bilobate on II–III, more strongly bilobate on IV–VII; all tergites roughened, coarsely granular; tergites I–II lacking distinct carinae; median carina on tergite III obsolete, lateral carinae reduced to short rows of granules; tergites IV–VI tricarinate, all carinae weak, granular; median and lateral areas of tergites III–VI with small numbers of separated granules arranged in roughly transverse rows; tergites I–VI with posterior border bounded by transverse ridge of smaller contiguous granules, with posterior margins minutely denticulate, pleural margins denticulate; tergite VII with granular median prominence, and two pairs of granular lateral carinae; outer lateral carinae strong, inner lateral carinae weak; lateral margins of tergite VII denticulate, posterior margin smooth; sternites III–VI smooth, with scattered reddish macrosetae, posterior margins finely denticulate; sternite VII finely granular, with pair of weak, granular median carinae and faint granular traces of obsolete lateral carinae.

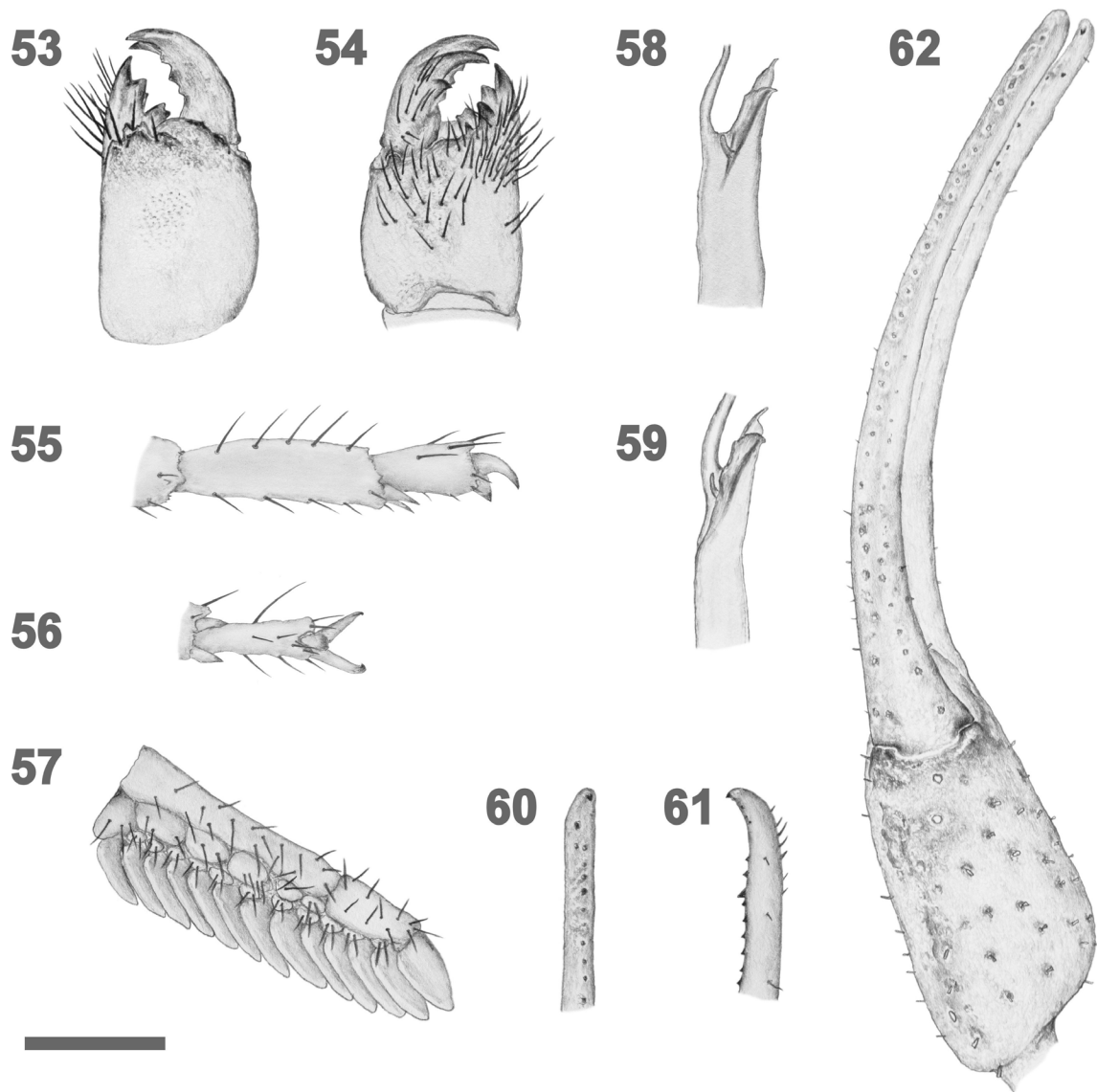
**Metasoma** (Figs. 42–45, 51–52). Segment I with ventrosubmedian, ventrolateral, and median lateral carinae moderate, crenulate, dorsolateral and dorso-submedian carinae weak, indistinct, marked by series of granules; median lateral carinae complete; segment II with ventrosubmedian carinae strong, crenulate, with 4–

5 enlarged, rounded dentate granules, posterior two granules largest; ventrolateral carinae strong, crenulate, with slightly enlarged, rounded dentate granules; median lateral carinae moderate, crenulate, confined to posterior 1/2 of segment; dorsolateral and dorsosubmedian carinae weak, indistinct, marked by series of small granules; segment III with ventrosubmedian carinae strong, extending from anterior to posterior margin, bearing five well separated, enlarged tuberculate denticles; ventrolateral carinae moderate, with slightly enlarged, blunt denticles; median lateral carinae weak, crenulate, confined to posterior 1/3 of segment; dorsolateral and dorsosubmedian carinae weak, indistinct, marked by series of granules, dorsal series terminating posteriorly with slightly enlarged, blunt denticle; segment III with anterior ventral margin rimmed by transverse arc of enlarged blunt denticles; segments I–III with ventral intercarinal surfaces finely granular, dorsolateral and dorsal surfaces more coarsely granular; dorsal median furrow shallow on I–II, moderate on III; segment IV with moderate, crenulate dorsosubmedian carinae terminating posteriorly in enlarged denticle, other carinae absent; anterior ventral margin of IV with arc of enlarged, transversely elongated, tuberculate denticles; ventrolateral surface of IV weakly convex, coarsely roughened, with small number of short, truncate microsetae arising from scattered shallow dimples; anterior dorsal surface of IV with deep v-shaped median furrow, posterior dorsal surface wide, steeply sloped, smooth; segment V with 4 carinae; dorsolateral carinae strong, crenulate; ventrolateral carinae weak in anterior half, strong in posterior half with 4 enlarged, truncate, tuberculate denticles increasing in size posteriorly; lateral anal lobe smooth; anal arch smooth, bordered by curved row of 7 enlarged granules; ventral surface of segment V weakly convex, anterior half thickened with several shallow depressions containing short, truncate microsetae, posterior half pustulose with large blunt denticles; lateral surfaces weakly convex, coarsely roughened, with numerous shallow depressions with microsetae; dorsal surface smooth, lustrous, with short, wide anterior slope, and long, deep posterior concavity fitting the telson; concavity with single, weak, median sulcus.

**Telson** (Figs. 42–45, 51–52). Vesicle ovoid, bulbous, widest at base, tapered posteriorly; dorsal surface smooth, glabrous; lateral surface smooth, with weak longitudinal sulcus; ventral surface with prominent ventromedian carina armed with 9 transverse granules on anterior half of vesicle, not bordered by longitudinal sulci, flanked by longitudinal series of 4 polished granules; ventral surface with scattered, elongate, blunt-tipped, reddish macrosetae; posterior ventral aspect of vesicle rounded, steeply sloped, without subaculear tubercle; aculeus short, stout, bent sharply downward



**Figures 46–52:** *Femtobuthus shutuae*, **sp. nov.**, holotype male. **46.** Carapace, dorsal aspect. **47.** Right pedipalp femur, dorsal aspect. **48.** Right pedipalp patella, dorsal aspect. **49.** Right pedipalp patella, external aspect. **50.** Right pedipalp chela, dorsoexternal aspect. **51–52,** metasoma and telson. **51.** Right lateral aspect. **52.** Ventral aspect. Scale bar: 46: 1 mm; 47, 48, 49, 50: 0.70 mm; 51, 52: 1.37 mm.



**Figures 53–62:** *Femtobuthus shutuae*, sp. nov. 53–54, 58–59, paratype male from type locality; 55–57, 60–62, holotype male. 53–54, right chelicera. 53. Dorsal aspect. 54. Ventral aspect. 55. Right basitarsus and telotarsus III, retrolateral aspect. 56. Right telotarsus III, ventral aspect. 57. Left pectine, ventral aspect. 58–59, right hemispermatophore, lobes at base of flagellum. 58. Convex aspect. 59. Outer aspect. 60–61, right pedipalp chela movable finger terminus. 60. Dorsal aspect. 61. External aspect. 62. Right pedipalp chela, ventral aspect. Scale bar: 53, 54, 58, 59: 0.357 mm; 57: 0.76 mm; 55, 56, 60, 61, 62: 0.5 mm.

perpendicular to plane of dorsal surface of vesicle; tip of aculeus approximately level with ventromedian carina of vesicle.

**Pedipalp** (Figs. 47–50, 60–62, 163–168). Femur, patella and chela elongated, with numerous short, clavate microsetae. *Femur* (Fig. 47): with 4 carinae, external carina broad with dentate granules, including 3 enlarged granules proximal to trichobothrium  $e_2$ , bearing enlarged

clavate microsetae; dorsoexternal and dorsointernal carinae weak, granulate, with very shallow dimples ringed by fine granules; internal carina distinct, irregular, granulated; other carinae indistinct; intercarinal surfaces roughened. *Patella* (Figs. 48–49): 6 carinae present; ventroexternal, dorsoexternal, dorsomedian, dorsointernal carinae very weak, almost smooth; dorsoexternal, dorsomedian, dorsointernal carinae with series of very shallow dimples ringed by microgranules;

external and internal carinae moderate, smooth; intercarinal surfaces smooth, matte. *Chela* (Figs. 50, 60–62, 159–164): ventroexternal carina faint, smooth on distal half of manus, other carinae obsolete; surface of manus matte; chela fingers elongate, nearly linear, not strongly arched vertically, leaving almost linear gap when closed; fixed finger distinctly upwardly bent at base; base of fixed finger flanked externally and internally by rounded lobes bearing one short clavate microseta; fixed finger with external subapical groove at base of enlarged terminal tooth; dentate margin of fixed finger armed with two external subdistal microdenticles, and three slightly enlarged erect spiniform denticles separating 3 gently scalloped subrows of (apical to proximal) 5, 7, 7 well spaced microdenticles; movable finger with enlarged apical tooth (Figs. 60–61) and three slightly enlarged, erect spiniform denticles (one internal subapical) defining three gently scalloped subrows of (apical to proximal) 4, 7, 7 non-contiguous microdenticles. *Trichobothriotaxy* (Figs. 163–168): type A, neobothriotaxitic minorante (Vachon, 1974, 1975), as diagnosed for the genus.

**Legs** (Figs. 44–45, 55–56). Segments relatively stout; inferior carinae of femur and patella on all legs crenulate to serrate; intercarinal surfaces finely roughened; tibial spurs present bilaterally on legs IV, present on left leg III, absent on right leg III; all legs with 2 tarsal spurs; basal bifurcation on prolateral tarsal spurs small on III–IV, minute on II, absent on I; retrolateral tarsal spurs simple; basitarsi I–III moderately compressed, retrosuperior margins finely denticulate, equipped with sparse bristle combs of elongate macrosetae with formula 3/4 3/4: 4/4 4/4: 5/4 5/3; setae along retro-inferior margins all much shorter than those along retrosuperior margins; telotarsi with ventromedian row of 1–3 short, stout macrosetae; unguis short, stout.

**Measurements of holotype male (mm).** Total L 14.24; carapace L 2.03, W 2.58, preocular L 0.93; metasoma and telson L 8.43; metasomal segment (L/W/D): I 1.01/1.18/0.98, II 1.22/1.08/0.98, III 1.37/1.08/1.00, IV 1.83/1.25/1.14, V 1.78/1.22/1.01; telson L 1.49, vesicle L 1.06, W 0.67, D 0.67; pedipalp chela L 3.75, manus ventral L 1.22, chela W 0.71, D 0.65, fixed finger L 2.42, movable finger L 2.67; pedipalp femur L 2.05, W 0.61; pedipalp patella L 2.12, W 0.76; pectine L 1.73, leg III patella L 1.38, D 0.52. *Morphometrics*: carapace W/L 1.27; carapace posterior W/anterior W 2.35, pectine L/carapace L 0.85, pedipalp femur L/carapace L 1.01, pedipalp femur L/W 3.36, pedipalp patella L/W 2.79, pedipalp chela L/W 5.28, pedipalp chela movable finger L/manus ventral L 2.19, chela manus L/W 1.72, patella III L/W 2.65, leg III patella L/D 2.65, metasomal segment L/W I 0.86, II 1.13, III 1.27, IV 1.46, V 1.46,

metasoma V W/metasoma I W 1.03, telson L/W 2.22, telson W/metasoma V W 0.55.

**Chelicera (paratype male)** (Figs. 53–54). Color uniform pale yellow; fingers with normal buthid dentition (Vachon, 1963; Sissom, 1990); movable finger with distal dorsal tine and distal ventral tine of equal size, dorsal margin with 3 denticles (larger subdistal and medial, smaller basal); ventral margin with single large subdistal denticle; fixed finger with large subdistal denticle and basal bicuspid; ventral aspect of fixed finger with two denticles, distal denticle large, prominent, proximal denticle very small; dense brush of long setae on ventral and internal aspect of fixed finger, and ventral aspect of movable finger.

**Hemispermaphore (paratype male)** (Figs. 58–59). Flagelliform, trunk elongate, flagellum thin, tapering, almost as long as trunk uncoiled; inner lobe largest, tapering at apex; basal lobe a thin, hook-like projection.

**Variation.** *Sexual dimorphism*: adult females ( $n = 5$ ) differed from adult males ( $n = 4$ ) as follows: larger size, total L (mm) 16–18 (females), 13.5–15.0 (males), carapace L (mm) 2.42–2.60 (females), 1.80–2.04 (males); wider mesosoma; pectines shorter, pectine L/carapace L 0.48–0.62 (females), 0.84–0.98 (males) ( $p = 0.014$ ); fewer pectine teeth: 7–9 (females), 12–14 (males); basal piece of pectines wider with anterior margin weakly curved, without deep median furrow, larger tuberculate denticles on ventrosubmedian carinae of metasoma II–III and anterior ventral arcs of metasoma III–IV; larger lobate dentition on ventrolateral carinae of metasoma V; metasoma III–V deeper, L/D: III 1.18–1.31 (females), 1.34–1.48 (males) ( $p = 0.014$ ); IV 1.43–1.58 (females), 1.48–1.73 (males) ( $p = 0.050$ ); V 1.58–1.72 (females), 1.76–1.98 (males) ( $p = 0.014$ ); metasoma V broader, L/W: 1.37–1.42 (females), 1.46–1.55 (males) ( $p = 0.014$ ); telson vesicle narrower relative to metasoma V, vesicle W/metasma V W: 0.47–0.53 (females), 0.53–0.57 (males) ( $p = 0.027$ ). *Morphometrics* (Figs. 121–124) ( $n = 9$  adults): carapace W/L 1.22–1.33, posterior W/anterior W 2.29–2.58; pedipalp femur L/carapace L 0.97–1.09; pedipalp femur L/W 3.23–3.47; pedipalp patella L/W 2.70–3.05; pedipalp movable finger L/manus ventral L 2.17–2.39; pedipalp chela L/W 5.28–5.95; leg III patella L/D 2.63–2.90; metasoma L/W: I 0.82–0.91, II 1.12–1.22, III 1.19–1.36, IV 1.43–1.57; metasoma L/D: I 1.03–1.10, II 1.19–1.40; metasoma W ratios: II/I 0.89–0.93, III/I 0.89–0.93; IV/I 1.01–1.07, V/I 1.03–1.12; telson L/vesicle D 2.02–2.32. *Meristics*: pectine teeth: males, 2 combs with 12 teeth, 5 with 13, 1 with 14; females, 2 combs with 7 teeth, 6 with 8, 2 with 9; ventromedian carina of telson with 8–10 granules (2 vesicles with 8 granules, 2 with 10). Development of tibial spurs was variable: among males, spurs were

absent on left leg IV of one paratype; absent on left leg III and vestigial on right leg III of a second paratype; and absent on left leg III and reduced on right leg III of a third paratype; among females, there were 2 paratypes with all spurs on legs III and IV, 2 paratypes with a spur only on one leg IV, 1 paratype with spurs on one leg III, two legs IV (other leg III truncated). *Trichobothriotaxy*: among 18 femora, all (100 %) had 2 dorsal trichobothria, 17/18 (94.4 %) had 2 internal trichobothria, and 1/18 (5.6%) had a single internal trichobothrium; among 18 patellae, 16 (88.9 %) had 5 external trichobothria (*esb*<sub>2</sub> and *em* absent), and 2 (11.1 %) had 4 external trichobothria (1 case of *est* absent, 1 case of *esb*<sub>1</sub> absent). Thus, subtractive neobothriotaxy was very stable on both femur and patella.

**Measurements of paratype female (mm).** Total L 14.24; carapace L 2.03, W 2.58, preocular L 0.93; metasoma and telson L 8.43; metasomal segment (L/W/D): I 1.01/1.18/0.98, II 1.22/1.08/0.98, III 1.37/1.08/1.00, IV 1.83/1.25/1.14, V 1.78/1.22/1.01; telson L 1.49, vesicle L 1.06, W 0.67, D 0.67; pedipalp chela L 3.75, manus ventral L 1.22, chela W 0.71, D 0.65, fixed finger L 2.42, movable finger L 2.67; pedipalp femur L 2.05, W 0.61; pedipalp patella L 2.12, W 0.76; pectine L 1.73, leg III patella L 1.38, D 0.52. *Morphometrics*: carapace W/L 1.27; carapace posterior W/anterior W 2.35, pectine L/carapace L 0.85, pedipalp femur L/carapace L 1.01, pedipalp femur L/W 3.36, pedipalp patella L/W 2.79, pedipalp chela L/W 5.28, pedipalp chela movable finger L/manus ventral L 2.19, chela manus L/W 1.72, leg III patella L/D 2.65, metasomal segment L/W I 0.86, II 1.13, III 1.27, IV 1.46, V 1.46, metasoma V W/metasma I W 1.03, telson L/W 2.22, telson W/metasma V W 0.55.

**Distribution** (Fig. 114). Known only from the locality of the holotype, in a plateau region at the southern end of the Jiddat al Harasis, and from nearby Wadi Shuwaymiyah.

**Ecology.** The locality of the holotype was situated on an open windswept plateau just inland and north of the coastal village of Ash Shuwaymiyah. The ground was bare limestone with isolated patches of sandy soil, some loose rock, and sparse, scattered shrubs. Specimens were collected by ultraviolet detection after midnight (> 6 h after sunset), under strong gusting wind. The scorpions were running on the ground near the bases of small shrubs. Although collected off a mostly rocky substrate, the metasomal dentition, stout legs and tarsal bristle combs of this minuscule species suggest a fossorial existence in fine aeolian deposits accumulated around shrubs or packed into rock fissures. A series of paratype females was collected by Alex Winkler at the mouths of small burrows in Wadi Shuwaymiyah (Fig. 119). Other

scorpions found in the vicinity of the collection sites of *F. shutuae* were *Leiurus* sp. (at the type locality), *Hottentotta salei* (Vachon, 1980), *Compsobuthus acute-carinatus* (Simon, 1882), *Nebo* sp., *Butheolus anthracinus* (Pocock, 1895), and *Microbuthus kristensenorum*, **sp. nov.** (in Wadi Shuwaymiyah).

#### Genus *Picobuthus*, gen. nov.

**Type species.** *Picobuthus wahibaensis*, **sp. nov.**

**Diagnosis.** A member of the picobuthoid group (see diagnosis above), differentiated as follows: small scorpions, adults < 20 mm; metasoma (Figs. 83–86, 107–109): all segments finely granular; metasoma I–III with distinct carinae, IV with carinae reduced or obsolete, V only with dentate ventrolateral carinae; metasoma IV–V elongate, width equal to or narrower than metasoma I, ventral and lateral surfaces neither strongly convex nor smooth, lacking conspicuous pits or depressions; telson vesicle elongate, pyriform, not posteriorly truncate; pedipalp fixed finger weakly deflected upward at base, gently curved (Figs. 75, 99); tibial spurs absent on legs III–IV; retrosuperior margins of basitarsi I–III with bristle combs (Figs. 68, 92); fixed finger of chelicera armed ventrally with two denticles, distal denticle large, proximal denticle small (Figs. 78, 102); trichobothria (Figs. 148–162): femur: 2 external, 3 dorsal (*d*<sub>2</sub> and *d*<sub>5</sub> absent) in  $\beta$  configuration (Vachon, 1975), 2–4 internal (either *i*<sub>4</sub>, or *i*<sub>2</sub> and *i*<sub>4</sub> absent); patella: usually 5 external (*esb*<sub>2</sub> and *em* usually absent), 4 dorsal (*d*<sub>2</sub> absent), 1 internal; manus: 4 external (*Eb*<sub>3</sub> and *Esb* absent), 2 ventral; fixed finger: 6 (*esb* absent).

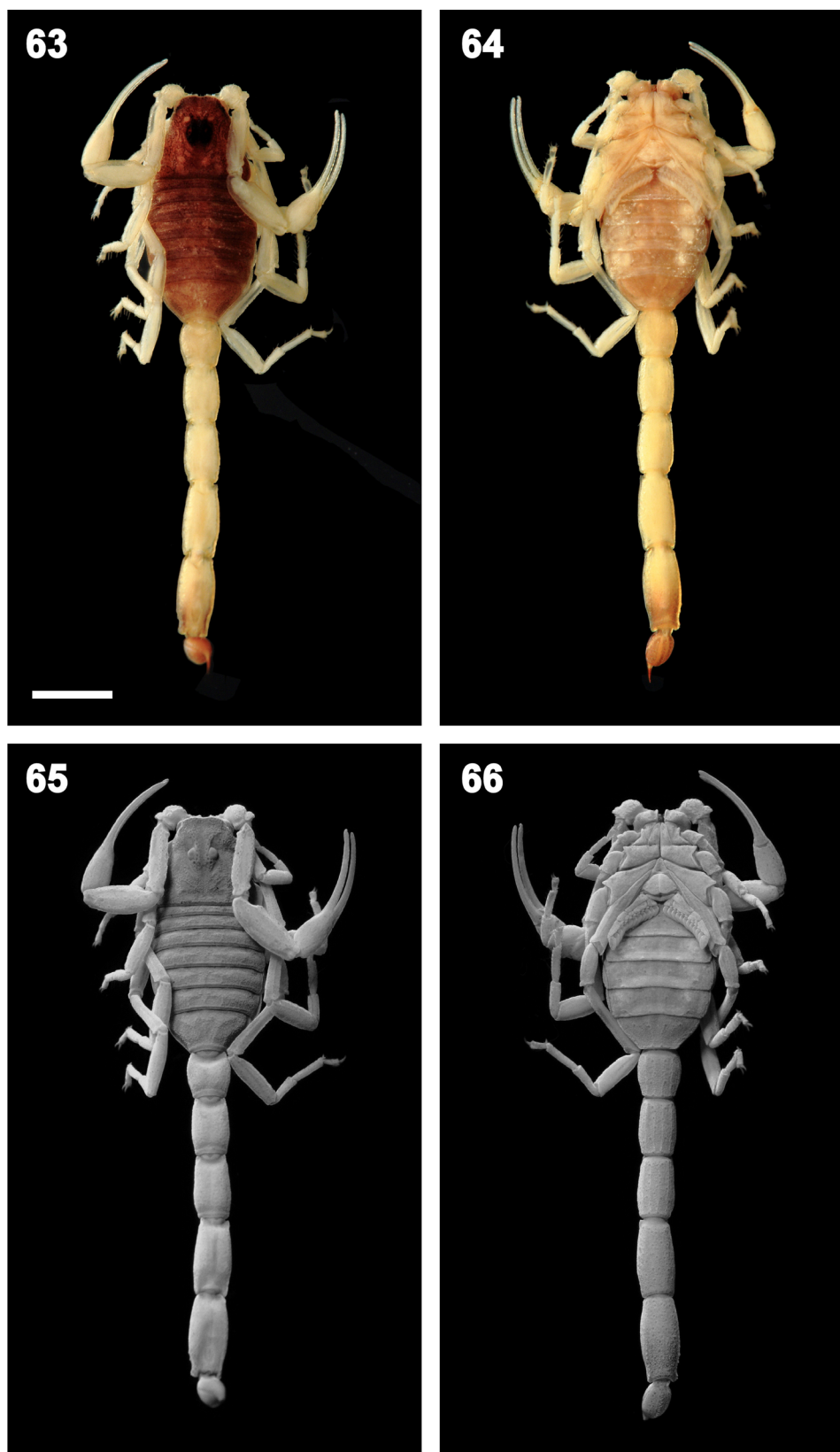
**Subordinate taxa.** *P. dundoni*, **sp. nov.**, *P. wahibaensis*, **sp. nov.**

**Comparisons.** *Picobuthus* differs from *Microbuthus* in all characters used to diagnose genera within the picobuthoid group, with the exception that both have relatively slender leg segments that contrast with the more robust legs of the fossorial *Femtobuthus*. See under *Femtobuthus* for characters shared with that genus. *Picobuthus* is distinguished from both *Femtobuthus* and *Microbuthus* by the more elongate, pyriform telson, more slender metasomal segments, and narrower, less trapezoidal carapace. Comparisons are summarized in Table 1.

**Etymology.** The name is derived from the prefix ‘*pico*’ meaning ‘small’, in reference to the very small size of the scorpions.

#### *Picobuthus wahibaensis*, sp. nov.

Figs. 63–86, 113–114, 121–124, 148–155



**Figures 63–66:** *Picobuthus wahibaensis*, **sp. nov.**, holotype male. Habitus viewed under reflected white light (**63, 64**) or UV fluorescence (**65, 66**). **63, 65.** Dorsal aspect. **64, 66.** Ventral aspect. Scale bar: 2 mm.

**Type material.**

**Holotype:** adult ♂, **Oman**, S of An Nuqdah (site F/21), UV detection, humpy dunes, at base of and between dry shrubs on ground, 20°45.48'N 58°35.42'E, 40 m a.s.l., 5 February 2000, 19:00–21:00 h, leg. A. & B. Winkler (NHMB).

**Paratypes:** **Oman:** 1 adult ♀, Mintirib, dunes 8 km W, 22°23'N 58°47'E, 290 m a.s.l., 8 February 1986, leg. W. Büttiker, Oman Eastern Sands Project (ONHM); 2 ♀, Oman, 4 km N An Nuqdah, sand & grass & *Heliotropium* hummocks, 20°53'N 58°44.53'E, 10 m a.s.l., 29 January 1997, leg. I.D. Harrison & M.D. Gallagher, MDG 8844 (GL, NHMB); 1 ♂, 1 ♀ (dismembered), Oman, same locality as holotype, NHMB; 2 ♂, 1 ♀, Oman, East Wahiba Sands (site F/7), *Prosopis* woodland, UV detection, on sand dunes in and under small shrubs, 21°39.43'N 59°18.22'E, 37 m a.s.l., 16 December 2001, 18:15–20:15 h, leg. A. Winkler (NHMB); 8 ♂, 2 ♀, Oman, East Wahiba Sands (site F/8), *Prosopis* woodland, UV detection, on sand dunes in and under small shrubs, 21°39.55'N 59°18.15'E, 41 m a.s.l., 16 December 2001, 20:30–21:30 h, leg. A. Winkler (BMNH, GL, NHMB, MNHN, ONHM).

**Diagnosis.** A member of the genus *Picobuthus* differentiated as follows: adults up to 21 mm in length; body fuscous or black, metasoma yellow to fuscous, legs and pedipalps yellow with variable fuscosity on chela manus (Figs. 63–64, 113); metasoma (Figs. 83–86) with 10 carinae on segments I–III, segment IV with all except dorsosubmedian carinae obsolete, V with all except ventrolateral and dorsolateral carinae obsolete; ventro-submedian carinae on II–III with weak or obsolete dentition; ventrolateral carinae of metasoma V dentate on posterior half of segment, larger denticles alternating with smaller denticles; lateral anal lobe with 3–4 small crenulations; intercarinal surfaces of all metasomal segments with dense, fine granulation; metasoma IV–V both 2.0–2.1 times longer than wide.

**Etymology.** The specific epithet refers to Ramlat Al Wahiba (Wahiba Sands), where all known specimens have been collected.

**Comparisons.** *Picobuthus dundoni* is similar in form and coloration to *P. wahibaensis*. Both are sand-adapted species with variable melanic pigmentation on the body and pedipalp chela. However, *P. dundoni* is readily distinguished by the enlarged dentition on the ventro-submedian carinae of metasoma II–III (Figs. 107–108), the fewer, larger denticles on the ventrolateral carinae of metasoma V, the tuberculate ventral, intercarinal denticles on metasoma V in females, and less elongate metasoma IV–V and telson.

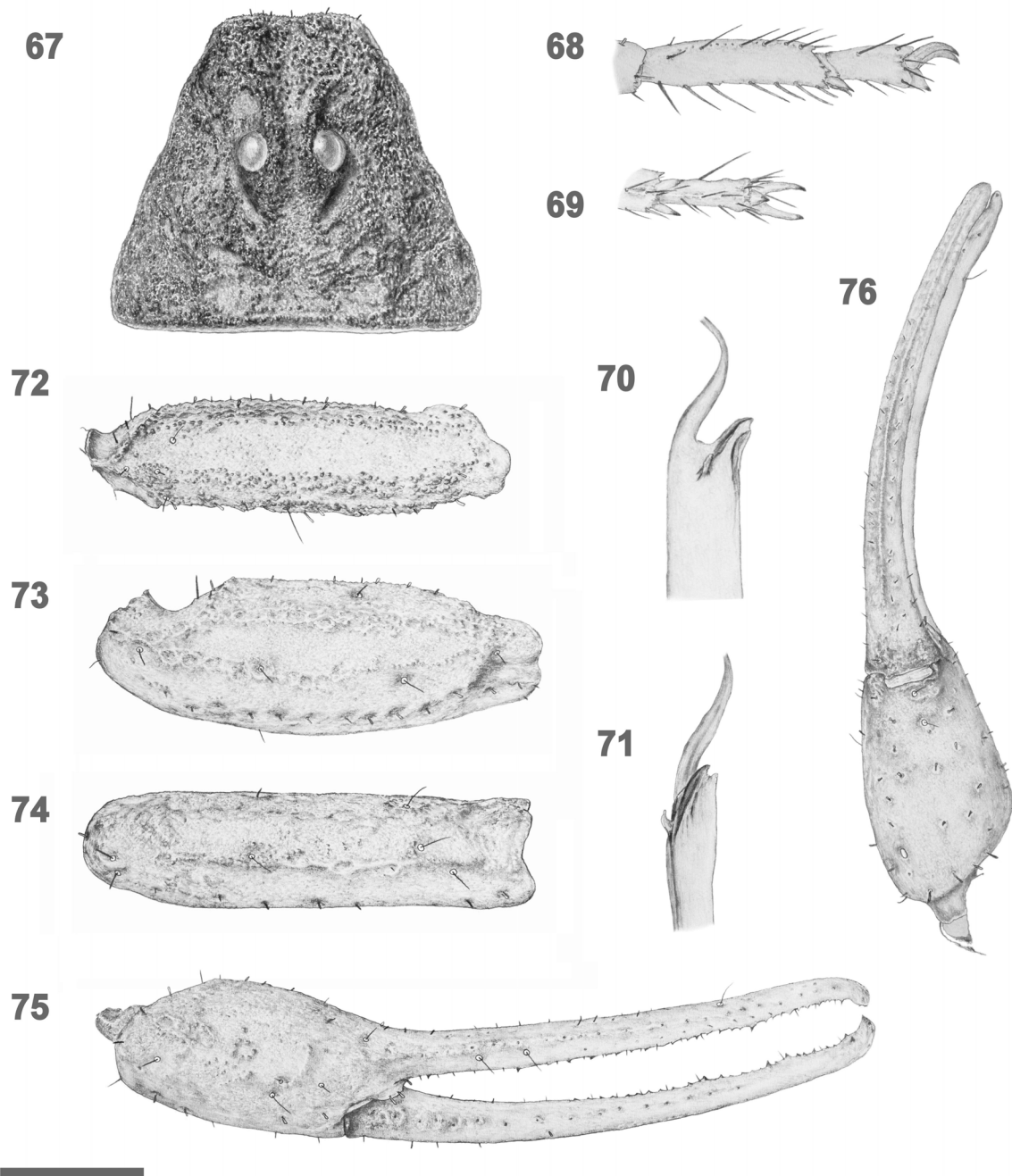
**Description of holotype male (adult)**

**Coloration** (Figs. 63–64, 113). Carapace, tergites and manus of chelicera fuscous, with darker underlying patterns; ocular tubercle black; metasoma I–IV dirty yellow, metasoma V yellow proximally, fuscous distally; telson rusty orange-brown, with darker longitudinal bands ventrally, and pale spots around microsetal insertion sockets; aculeus red; ventral surface of body, legs, and pedipalps light yellow, with faint underlying fuscosity on chela manus.

**Carapace** (Figs. 63, 65, 67). Trapezoidal, W/L 1.16, posterior W/anterior W 2.21; anterior median carinae distinct only in posterior half of ocular triangle, granular and diverging distally; all other carinae obsolete; entire surface of carapace densely granular; preocular triangle sloped downward towards wide anterior marginal shelf; anterior margin weakly convex, micro-denticulate or crenulate, with 5 short microsetae; ocular tubercle large with prominent, bulbous median eyes separated by more than their diameter; superciliary carinae granular, continuous with anterior median carinae, with regular series of 6–7 dimples ringed by fine granules; lateral eyes with 2 ocelli on right side, 3 on left side with anterior left ocellus smallest; anterior median furrow shallow, with irregular coarse granulation; central median and posterior median furrows shallow, finely granular; posterior marginal furrow shallow, irregularly granulate; lateral borders of carapace finely crenulate, posterior border smooth.

**Coxosternal area** (Figs. 64, 66). Coxae weakly granular, with scattered short reddish macrosetae; coxa II endites smooth; marginal carinae obsolete on coxae I–III; coxa IV with weak, granulate anterior marginal carina, posterior marginal carina obsolete; sternum sub-triangular, almost smooth, with deep, postero-median excavation, bearing few short macrosetae; genital opercula large, rounded triangular, smooth; pectines (Fig. 79) relatively short, anterior margins not attaining distal ends of coxae IV, extending past distal ends of trochanter III; 3 marginal lamellae, 5 middle lamellae; inner fulcra present, without setae; basal piece with weak anteromedian depression; pectine teeth: left 12, right 12.

**Mesosoma** (Figs. 63–66). Pretergites matte or finely shagreened, with microgranulate posterior border; all tergites densely granular; tergites I–II with carinae indistinct, tergite III–IV with faint trace of lateral carinae, tergites V–VI weakly tricarinate, with weak, granular lateral carinae and faint trace of median carina on posterior halves of segment; tergite VII with carinae indistinct; sternites III–VI smooth, matte, slightly roughened around stigmata, with microsetate posterior



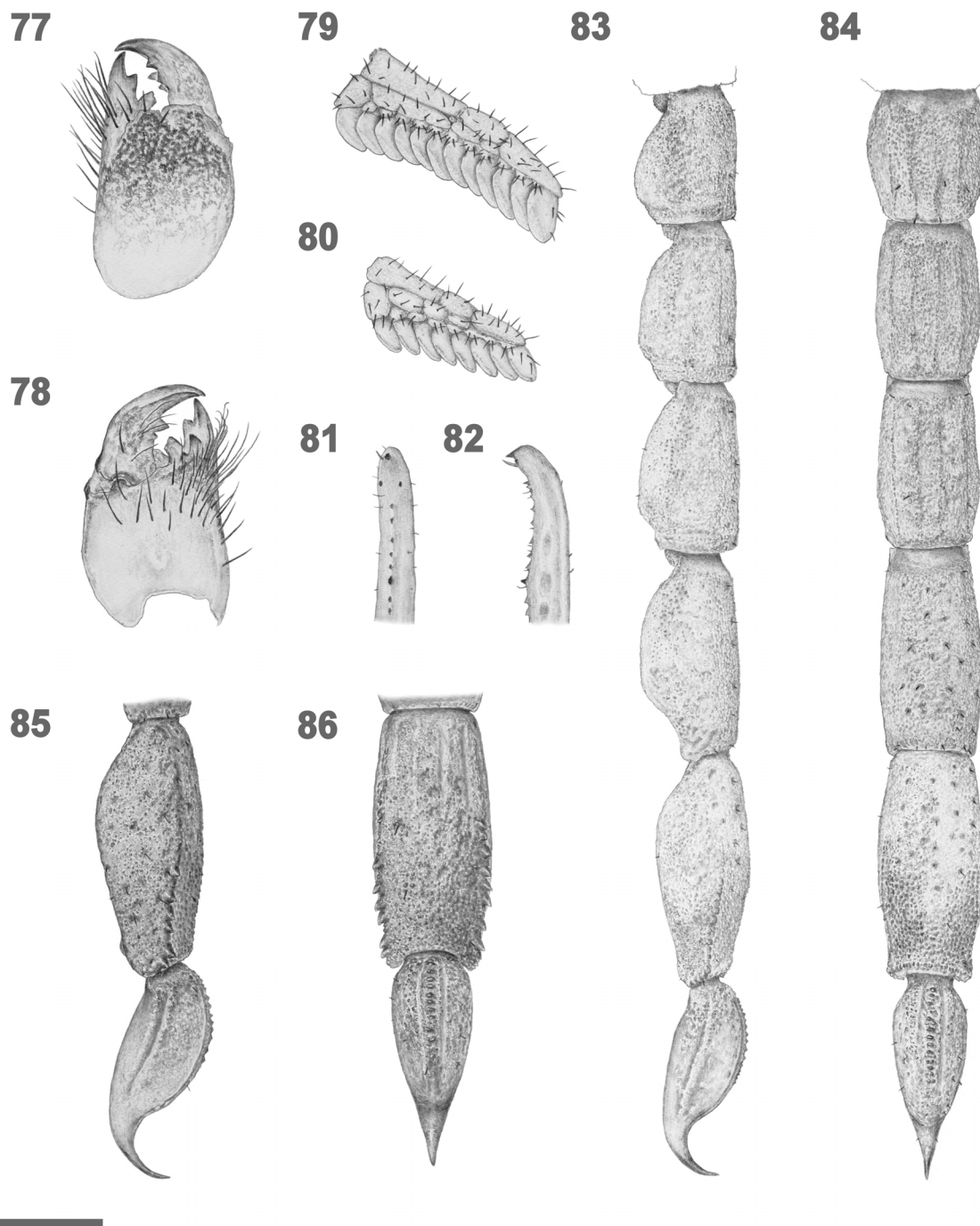
**Figures 67–76:** *Picobuthus wahibaensis*, sp. nov. 70–71, paratype male (An Nuqdah); 67–69, 72–76, holotype male. 67. Carapace, dorsal aspect. 68. Right basitarsus and telotarsus III, retrolateral aspect. 69. Right telotarsus III, ventral aspect. 70–71, right hemispermatophore, lobes at base of flagellum. 70. Convex aspect. 71. Outer aspect. 72. Right pedipalp femur, dorsal aspect. 73. Right pedipalp patella, dorsal aspect. 74. Right pedipalp patella, external aspect. 75–76, right pedipalp chela. 75. Dorsoexternal aspect. 76. Ventral aspect. Scale bar: 67: 1 mm; 68, 69, 72, 73, 74, 75, 76: 0.70 mm; 70, 71: 0.55 mm.

margins; sternite VII roughened, finely granular, median carinae very faint, granular, lateral carinae indistinct.

**Metasoma** (Figs. 63–66, 83–86). All segments with rounded convex surfaces, carination greatly reduced;

segments I–III with ventrosubmedian, ventrolateral and median lateral carinae very faint, granular, other carinae obsolete; IV lacking carinae; V with carinae obsolete except for ventrolateral carinae on posterior half bearing small denticles of varying sizes; ventral and lateral





**Figures 77–86:** *Picobuthus wahibaensis*, sp. nov. 77–78, paratype male (An Nuqdah); 80, 85–86, paratype female (An Nuqdah); 79, 81–84, holotype male. 77–78, right chelicera. 77. Dorsal aspect. 78. Ventral aspect. 79. Left male pectine, ventral aspect. 80. Left female pectine, ventral aspect. 81–82, right pedipalp chela movable finger terminus. 81. Dorsal aspect. 82. External aspect. 83–84, metasoma and telson of male. 83. Right lateral aspect. 84. Ventral aspect. 85–86, metasoma V and telson of female. 85. Right lateral aspect. 86. Ventral aspect. Scale bar: 77, 78, 81, 82: 0.347 mm; 79, 80: 0.72 mm; 83, 84, 85, 86: 1 mm.

surfaces densely, finely shagreened on segments I–IV, more coarsely granular on V, with small depressions around microsetal insertion points; dorsal surface shagreened on segments I–III, matte on VI, smooth on V; dorsal median furrow shallow on I–III, deep on IV; dorsal surface of IV with wide, gentle posterior slope; dorsal surface of V with shallow anterior slope, deep concavity on posterior 7/10 of segment; sides of V not straight, with gentle posterior waist; lateral anal lobe with 4 small crenulations; ventral anal arch finely granular, without enlarged granules or dentition; all metasomal segments with sparsely scattered, short microsetae.

**Telson** (Figs. 83–86). Vesicle slender, pyriform, gently tapered posteriorly; dorsal surface smooth, weakly convex; upper lateral surface with distinct longitudinal sulcus; lateral and ventral surfaces granulated on proximal half, smooth on distal half; ventromedian carina with 12 transverse denticles or granules, flanked laterally by parallel series of fine granules and weak longitudinal sulcus; ventral surface with scattered microsetae; aculeus short, stout, with thick base, curved abruptly downward; tip of aculeus slightly lower than deepest part of vesicle; subaculear tubercle absent.

**Pedipalps** (72–76, 81–82, 148, 151–155). *Femur* (Fig. 72): 5 carinae present, external carina a broad, irregularly granulated ridge; dorsoexternal, dorsointernal and internal carinae weak, finely granular; ventrointernal carina weak, broadly granulated; dorsointernal and dorsoexternal carinae with series of shallow dimples ringed by fine granules; intercarinal surfaces smooth to finely roughened. *Patella* (Figs. 73–74): 5 carinae present, external, dorsoexternal, dorsomedian and dorsointernal carinae faint, with irregular, partially fused, fine granulation; internal carina weak, lightly granular; dorsointernal and dorsomedian and dorsoexternal carinae with series of shallow dimples ringed by fine granules; intercarinal surfaces smooth to finely roughened. *Chela* (Figs. 75–76): manus with carinae obsolete; dorsal marginal and dorsal secondary carinae on fixed finger very weak, smooth; surface of manus smooth, matte, with shallow dimples at microsetal insertion points; fingers long, slender, without strong vertical deflection and curvature, leaving gap of nearly constant width when closed; base of fixed finger flanked externally and internally by rounded lobes bearing three short clavate microsetae; fixed finger with external apical groove at base of enlarged terminal tooth, and two spinoid subdistal denticles; movable finger with two spinoid subdistal denticles below enlarged terminal tooth; dentate margins of both fixed and movable fingers armed with linear series of noncontiguous spinoid microdenticles divided into three subrows by two slightly enlarged, erect spiniform denticles; subrow

counts, from apical to proximal: fixed finger 5–6, 7–8, 8–9, movable finger 5, 6, 10–12; denticles in proximal row of movable finger progressively reduced to minute granules; margins of fingers gently scalloped between enlarged denticles; all pedipalp segments bearing scattered short, clavate microsetae. *Trichobothriotaxy* (Figs. 148, 151–155): type A $\beta$ , neobothriotaxic minor-ante (Vachon, 1974, 1975), as diagnosed for the genus; right femur with 2 internal trichobothria, left femur with 3; external surface of patella with 5 trichobothria (*em* and *esb*<sub>2</sub> absent).

**Legs** (Figs. 63–66, 68–69). Femur and patella of all legs with weak to obsolete carinae, inferior carinae finely crenulate; intercarinal surfaces matte or finely roughened; tibial spurs absent; all legs with two tarsal spurs; retrolateral spurs simple, prolateral spurs basally bifurcate; basitarsi I–III compressed, margins micro-crenulate, equipped with series of reddish macrosetae; all retrosuperior setae elongate, forming bristle combs; retroinferior setae much shorter than retrosuperior setae on basitarsus I, about half as long on II, and equally long on III; setation formula: 3/4 4/3: 5/5 5/5: 6/8 5/6; soles of all telotarsi with ventral median series of short reddish setae, 1 seta on I, 2 setae on II–IV; unguis moderately elongated, gently curved.

**Measurements of holotype male (mm)**. Total L 16.14; carapace L 2.23, W 2.58, anterior W 1.17; preocular L 0.96, metasoma and telson L 10.24, metasoma L/W/D: I 1.21/1.10/0.96, II 1.50/0.99/0.92, III 1.63/0.95/0.94, IV 1.92/0.96/0.96, V 2.10/1.00/0.92; telson L 1.83, vesicle L 0.92, W 0.67, D 0.67; pedipalp chela L 3.58, manus ventral L 1.17, chela W 0.71, D 0.67, fixed finger L 2.17, movable finger L 2.58, pedipalp femur L 2.00, W 0.54, pedipalp patella L 2.17, W 0.77; pectine L 1.50; leg III patella L 1.71, D 0.53. *Morphometrics*: carapace W/L 1.16, pectine L/carapace L 0.67, pedipalp femur L/carapace L 0.90, pedipalp femur L/W 3.69, pedipalp patella L/W 2.83, pedipalp movable finger L/manus ventral L 2.21, pedipalp movable finger L/carapace L 1.16, pedipalp chela L/W 5.06, pedipalp manus ventral L/chela W 1.65, chela manus L/W 1.65, leg III patella L/D 3.23, metasomal segment L/W I 1.09, II 1.51, III 1.71, IV 2.00, V 2.10, metasoma V W/metasma I W 0.91, telson L/W 2.74, telson W/metasma V W 0.67.

**Chelicera (paratype male)** (Figs. 77–78). Dark reticulated pigmentation on distal dorsal surface of manus; fingers with normal buthid dentition (Vachon, 1963; Sissom, 1990), movable finger with dorsal distal tine and ventral distal tine of equal size, dorsal margin with 2 denticles, ventral margin with single large subdistal denticle; fixed finger with large subdistal denticle and basal bicuspid; ventral aspect of fixed finger with two denticles, distal denticle large, prominent,

proximal denticle small, about 1/4 size of distal denticle; numerous long setae on ventral and internal aspect of fixed finger, and ventral aspect of movable finger.

**Hemispermatorphore (paratype male)** (Figs. 70–71). Flagelliform, trunk long, slender, flagellum short; 4 lobes at base of flagellum; inner, median and outer lobes laminate; inner lobe broadest, triangular, outer lobe narrower, tapering apically, median lobe smallest, acuminate; basal lobe an elongate, narrow hook-like process.

**Variation.** *Coloration:* specimens from *Prosopis* woodlands in the East Wahiba Sands (Fig. 113) were more darkly pigmented than specimens from An Nuqdah, i.e. nearly black on carapace and mesosoma, carapace with pair of white preocular spots, pedipalp fuscous on trochanter, distal patella and chela manus, and metasoma and telson fuscous, darkest on metasoma V. *Sexual dimorphism:* females differed from males as follows: larger size, total L (mm): 16.0–20.5 (females), 14.5–16.1 (males); carapace L: 2.46–2.67 (females), 2.00–2.23 (males) ( $n = 3$  adult males, 5 adult females); carapace more strongly sculpted, with deeper furrows, ocular tubercle located further back from anterior margin, preocular L/carapace L, 0.43–0.48 (females), 0.42–0.43 (males) ( $p = 0.044$ ); fewer pectine teeth: 6–8 ( $n = 7$  females), 10–12 ( $n = 12$  males); pectines much shorter, not reaching distal ends of trochanter III, pectine L/carapace L, 0.42–0.48 (females), 0.63–0.67 (males) ( $p = 0.006$ ); metasoma I–III with more distinct carination, each segment with 10 weak carinae; median lateral carinae complete on metasoma I, extending over posterior 4/5 of metasoma II, faint and limited to posterior 1/3 of metasoma III; ventrosubmedian carinae on metasoma II posteriorly crenulate; ventrolateral carinae of metasoma V with series of 5–7 enlarged blunt denticles on posterior half of segment; manus of pedipalp chela more densely granulated, with weak, faintly granular ventroexternal, dorsal secondary and dorsal marginal carinae, fixed finger with smooth, moderate to strong digital, dorsal secondary, and dorsal marginal carinae. *Morphometrics* (Figs. 121–124) ( $n = 11$  unless otherwise stated): carapace W/L 1.13–1.29, carapace posterior W/anterior W 2.03–2.31, pedipalp femur L/carapace L 0.83–0.95, pedipalp femur L/W 3.35–3.96, pedipalp patella L/W 2.79–3.41, pedipalp movable finger L/manus ventral L 1.99–2.44, pedipalp movable finger L/carapace L 1.09–1.28, pedipalp chela L/W 5.00–5.71, pedipalp manus ventral L/chela W 1.52–1.83, leg III patella L/D 3.06–3.60; metasomal segment L/W: I 1.00–1.13, II 1.45–1.65, III 1.64–1.91, IV 2.00–2.29, V 2.08–2.29; L/D: I 1.26–1.43, II 1.54–1.80, III 1.64–2.00, IV 2.00–2.31, V 2.30–2.98; metasoma W ratios: II/I 0.82–0.90, IV/I 0.79–0.88, V/I 0.83–0.93, telson L/W ( $n = 10$ ) 2.63–3.00, telson W/metasma V W 0.56–0.72.

*Meristics* (including sub-adults): pectine teeth: males, 3 combs with 10 teeth, 12 combs with 11, 9 with 12; females, 1 comb with 6 teeth, 5 combs with 7, 8 with 8; granules on ventromedian carina of telson vesicle, 9–14 ( $n = 6$  males, 6 females); retrolateral setae of basitarsus, leg I 2–5, leg II 4–6, leg III 5–8 ( $n = 12$  males, 7 females). *Trichobothriotaxy:* subtractive neobothriotaxy was variable on the internal surface of the pedipalp femur (Figs. 148–150) and external surface of the pedipalp patella: among 36 femora, there were 7 (19.4 %) with 2, 7 (19.4 %) with 3, and 22 (61.2 %) with 4 internal trichobothria (Figs. 138–140), including 5/18 (28 %) cases of bilateral reduction, and 4/18 (22 %) cases of unilateral reduction from the normal count of 4; however, all 36 femora bore 3 dorsal trichobothria; among 36 patellae, *em* was always absent, *esb*<sub>2</sub> was absent in 34 (94.4 %) cases and present in 2 (5.6 %) cases (bilaterally in the same animal), *esb*<sub>1</sub> was absent in only 1 (2.8 %) case. Thus, neobothriotaxy was very stable on the patella, but showed considerable variability on the internal surface of the femur.

**Measurements of paratype female (An Nuqdah) (mm).** Total L 20.50; carapace L 2.67, W 3.17, anterior W 1.51; preocular L 1.25; metasoma and telson L 11.50; metasomal segment L/W/D: I 1.39/1.39/1.10, II 1.71/1.18/1.10, III 1.90/1.16/1.16, IV 2.32/1.12/1.16, V 2.51/1.15/1.06; telson L 1.96, vesicle L 1.43, W 0.73, D 0.76; pedipalp chela L 4.38, manus ventral L 1.47, chela W 0.86, D 0.82, fixed finger L 2.63, movable finger L 2.92, pedipalp femur L 2.38, W 0.71; pedipalp patella L 2.63, W 0.91; pectine L 1.26; leg III patella L 2.12, D 0.63. *Morphometrics:* carapace W/L 1.16, carapace posterior W/anterior W 2.22, pectine L/carapace L 0.44, pedipalp femur L/carapace L 0.90, pedipalp femur L/W 3.35, pedipalp patella L/W 2.89, pedipalp movable finger L/manus ventral L 1.99, pedipalp movable finger L/carapace L 1.09, pedipalp chela L/W 5.09, pedipalp manus ventral L/chela W 1.63, chela manus L/W 1.63, leg III patella L/D 2.89, metasomal segment L/W I 1.04, II 1.46, III 1.70, IV 2.08, V 2.19, metasoma V W/metasma I W 0.84, telson L/W 2.68, telson W/metasma V W 0.67.

**Distribution** (Fig. 114). Known only from Ramlat Al Wahiba (Wahiba Sands) in northeast coastal Oman. The Wahiba Sands are dominated by a major zone of *high sands*, composed of north-south linear mega-ridges (Al Hibal) and meso-ridges (Al Dhil). A minor zone of *low sands* includes a complex of smaller transverse or irregular dunes, stretching along northern, eastern and southern margins of the high sands, some facing the Arabian Sea (Warren, 1988). All collection sites of *P. wahibaensis* are distributed in these *low sands*.

**Ecology.** Along the eastern margins of the Wahiba Sands, this species occurs in low *nabkhah* dunes

(coppice dunes, formed around the base of vegetation) and *Prosopis cineraria* (ghaf) woodlands (Fig. 116). It probably inhabits burrows in sand at the bases of shrubs. The compressed basitarsi with bristle combs on legs I–III are consistent with psammophilous adaptation (Fet, Polis & Sissom, 1998; Polis, 1990; Prendini 2001a).

***Picobuthus dundoni*, sp. nov.**

Figs. 87–109, 112, 114, 121–124, 156–162

**Type material**

**Holotype:** adult ♂, **Oman**, near Wadi Andam, road south of Sinaw, UV detection, moving on soft sand at base of shrub, 21°19.35'N 58°15.55'E, 90 m a.s.l., 19 September 1995, 23:00 h, leg. G. Lowe & M.D. Gallagher (NHMB).

**Paratypes:** **Oman:** 1 ♀, near Wadi Andam, road south of Sanaw, UV detection, stationary on soft sand at base of small shrub, 21°19.48'N 58°15.24'E, 90 m a.s.l., 19 September 1995, 23:30 h, leg. G. Lowe & M.D. Gallagher (NHMB); 1 ♂, 30 km S. of Adam, sandy wadi, 22°05.9'N 57°31.12'E, 23:30–01:00 h, 19 March 1996, leg. J. Dundon (GL); 1 ♂, Wadi Qitbit, dry sandy desert and shrubs & small trees, strong new moon, no breeze, 19°07'N 54°31'E, 100 m a.s.l., 6 December 1997, leg. I.D. Harrison & M.D. Gallagher, MDG 8923 (ONHM); 1 ♀, Wadi Qitbit, (site F/12) UV detection, dunes near spring, on sand between shrubs, 19°9.33'N 54°30.47'E, 20:00–21:00 h, ca. 210 m a.s.l., leg. A. Winkler (NHMB).

**Diagnosis.** A member of the genus *Picobuthus* differentiated as follows: adults up to 18 mm in length; base color pale yellow, carapace and tergites dark brown to black, or pale yellow; metasoma I–III with 10 weak carinae, IV with all except dorsosubmedian carinae obsolete, V with only ventrolateral and dorsolateral carinae developed; ventrosubmedian carinae of metasoma II–III armed with 4–8 enlarged denticles; anterior ventral margin of metasoma IV in female with curved rows of 3–5 tubercles; ventrolateral carinae of metasoma V with 3–5 enlarged lobate denticles increasing in size posteriorly; lateral anal lobe with blunt, lobate denticle; intercarinal surfaces of metasomal segments with dense, fine granulation; metasoma IV–V both 1.75–2.0 times longer than wide.

**Etymology.** The specific epithet is a patronym honoring Jim Dundon, who has collected and contributed much important material to the study of scorpions in Oman.

**Comparisons.** See under *P. wahibaensis*.

**Description of holotype male (adult)**

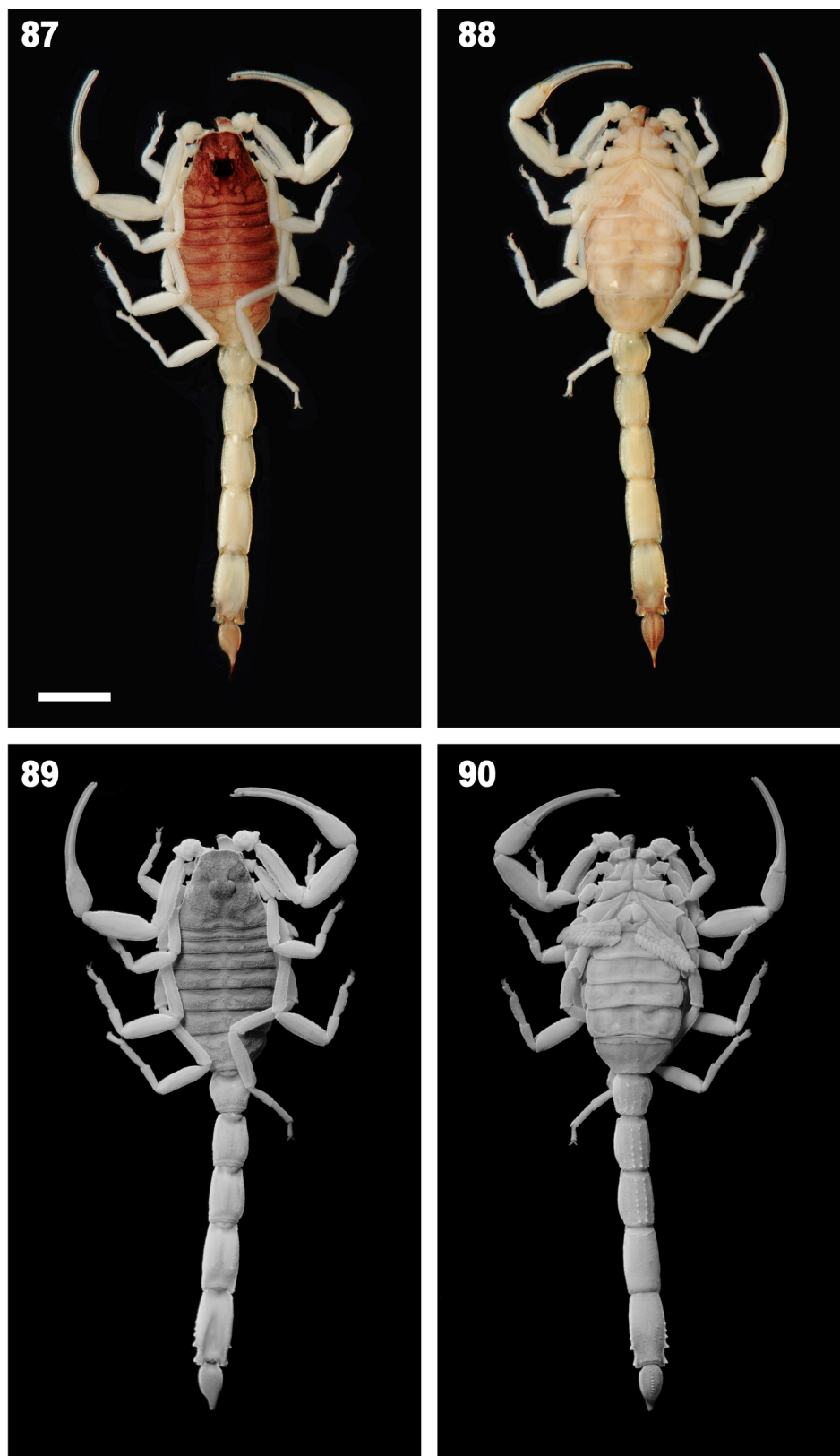
**Coloration** (Figs. 87–90). Carapace and tergites dark brown to black, the fuscocity on the carapace forming

characteristic pattern; ocular tubercle black; moderate fuscocity also present on chelicerae, pedipalp coxae, and posterior ventral and lateral surfaces of metasomal segment V; manus of chelicera fuscous distally, fusco-reticulate more proximally; telson vesicle moderately fuscous, with pair of lighter stripes on its ventral surface; aculeus reddish brown; remaining segments of pedipalps, metasoma, legs and ventral body segments pale yellow.

**Carapace** (Figs. 87, 89, 91). Trapezoidal, W/L 1.11, posterior W/anterior W 2.07; anterior median carinae confined to posterior half of ocular triangle, granular, weakly divergent; other carinae indistinct; entire surface of carapace densely granular; ocular triangle gently sloped downward to wide marginal shelf; preocular region with numerous clavate microsetae; anterior margin micro-denticulate, weakly convex with very shallow median emargination, bearing 8 short microsetae; median ocular tubercle very prominent, median eyes large, bulbous, widely separated by more than their diameter; superciliary carinae granular, continuous with anterior median carinae, without regular dimples ringed by granules; lateral eyes with 3 ocelli, equal in size on left, becoming smaller posteriorly on right; anterior median furrow wide, shallow, coarsely granular posteriorly, smooth anteriorly; central median and posterior median furrows shallow, granular; posterior marginal furrow shallow, granular medially, smooth in lateral ovoid depressions; posterior furrows surrounded by coarse, heavy granulation; lateral borders of carapace finely denticulate; posterior margin of carapace rimmed with smooth, pale, emarginate border.

**Coxosternal area** (Figs. 88, 90). Coxae weakly, finely granular to finely shagreened, with scattered reddish macrosetae; coxa II endites smooth on medial and lateral margins; coxae II–III with stronger anterior granulation, anterior margins with dentate granules; marginal carinae obsolete on coxae I–III; coxa IV with weak, granulate anterior marginal carina, posterior marginal carina obsolete; sternum sub-triangular, almost smooth, with deep, postero-median excavation, bearing few macrosetae; genital opercula large, rounded triangular, smooth, bearing 4–5 long, reddish macrosetae, margins not incised; pectines elongate, tips of anterior margins just short of distal ends of coxa IV; pectines (Fig. 105) with 3 marginal lamellae, 5 middle lamellae; outer fulcra with 2–3 elongate reddish macrosetae; inner fulcra present, without setae; basal piece wide, strongly sculpted with deep anteromedian pit, thick anterolateral labiae; pectine teeth: left 12, right 11.

**Mesosoma** (Figs. 87–90). Pretergites finely roughened, posterior borders regularly micro-granulate; border nearly linear on pretergite I–II, gently sinuous on III–IV,



**Figures 87–90:** *Picobuthus dundoni*, sp. nov., holotype male. Habitus viewed under reflected white light (87, 88) and UV fluorescence (89, 90). 87, 89. Dorsal aspect. 86, 88. Ventral aspect. Scale bar: 2 mm.

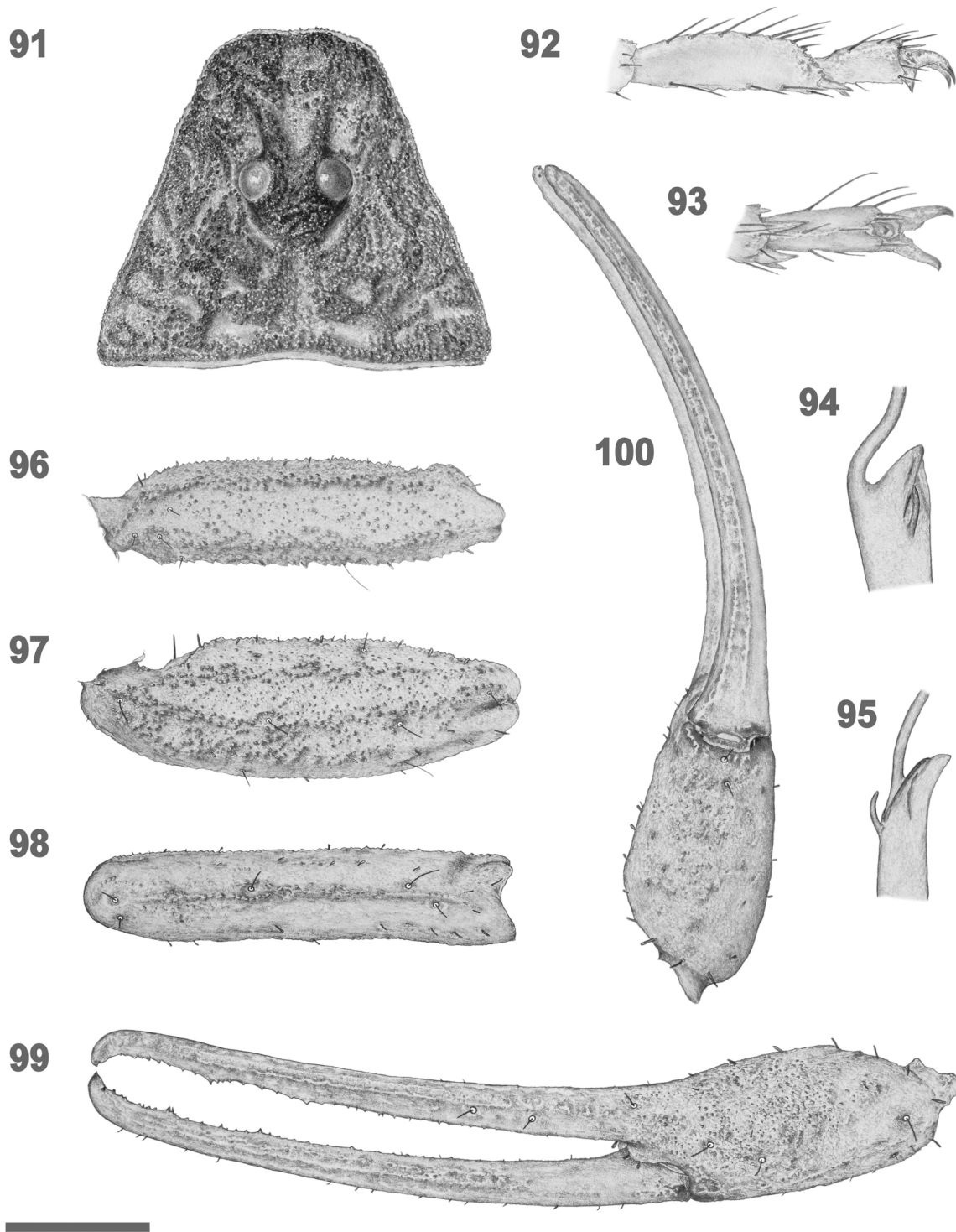
bilobate on V–VII; all tergites densely, granular, with granules coarser on posterior half; tergites I–II with carinae indistinct, tergites III–VI weakly tricarinate, with weak, granular carinae confined to posterior half of tergite; tergite VII with two pairs of weak, coarsely granular lateral carinae and granular central hump; posterior margins of tergites I–VI pale, non-granular, very weakly microdenticulate, almost smooth; sternites III–VI smooth; sternite IV–VI with shallow median furrow; posterior margins of sternites III–VI regularly microdenticulate; margin of sternite VI laterally microdenticulate, medially emarginate with much finer denticulation; sternite VII shagreened to finely granulose, carinae obsolete, positions of median carinae marked by short rows of 3 small granules.

**Metasoma** (Figs. 87–90, 108–109). Segment I with 10 carinae, ventrosulmedian carinae weak, granulose, with slightly enlarged posterior denticle, ventrolateral carinae weak, granulose, median lateral carinae weak, granulose, more distinct in posterior half of segment, dorsolateral carinae very weak, barely distinct from surrounding granulation, dorsosulmedian carinae weak, crenulate or granulate; segments II–III with 8 carinae, ventrosulmedian carinae well developed, armed with moderately enlarged, non-contiguous denticles separated by crenulations (II with 5–6, III with 7 enlarged denticles), ventrolateral carinae weak, granular, median lateral carinae weak, distinct only on posterior 1/2 of segment, dorsolateral carinae indistinct, dorsosulmedian carinae very faint, granular; segment IV with all carinae obsolete except for faintly granular dorsosulmedian carinae; anterior ventral margin of IV with pair of curved rows of 3–5 small tubercles; segment V with 4 carinae, ventrolateral carinae developed into series of 5–6 enlarged, non-contiguous tuberculiform denticles increasing in size posteriorly, last two widely separated; dorsolateral carinae blunt, finely granular; lateral anal lobe with blunt, lobate tooth contiguous with terminal enlarged tooth of ventrolateral carina; ventral anal arch finely granular, with adjacent curved ridge of medium to large granules; ventral and lateral surfaces of segments IV–V convex; all ventral and lateral surfaces of metasoma densely granular; dorsal surface of segment I densely coarsely granular with weak median furrow; of segment II rugose and granulate with weak to moderate median furrow; of segment III rugose with moderate, smooth median furrow; of segment IV smooth with deep v-shaped median furrow and wide, lightly shagreened posterior slope; of segment V smooth with abbreviated anterior slope and deep, elongate concavity occupying posterior 7/10 of segment.

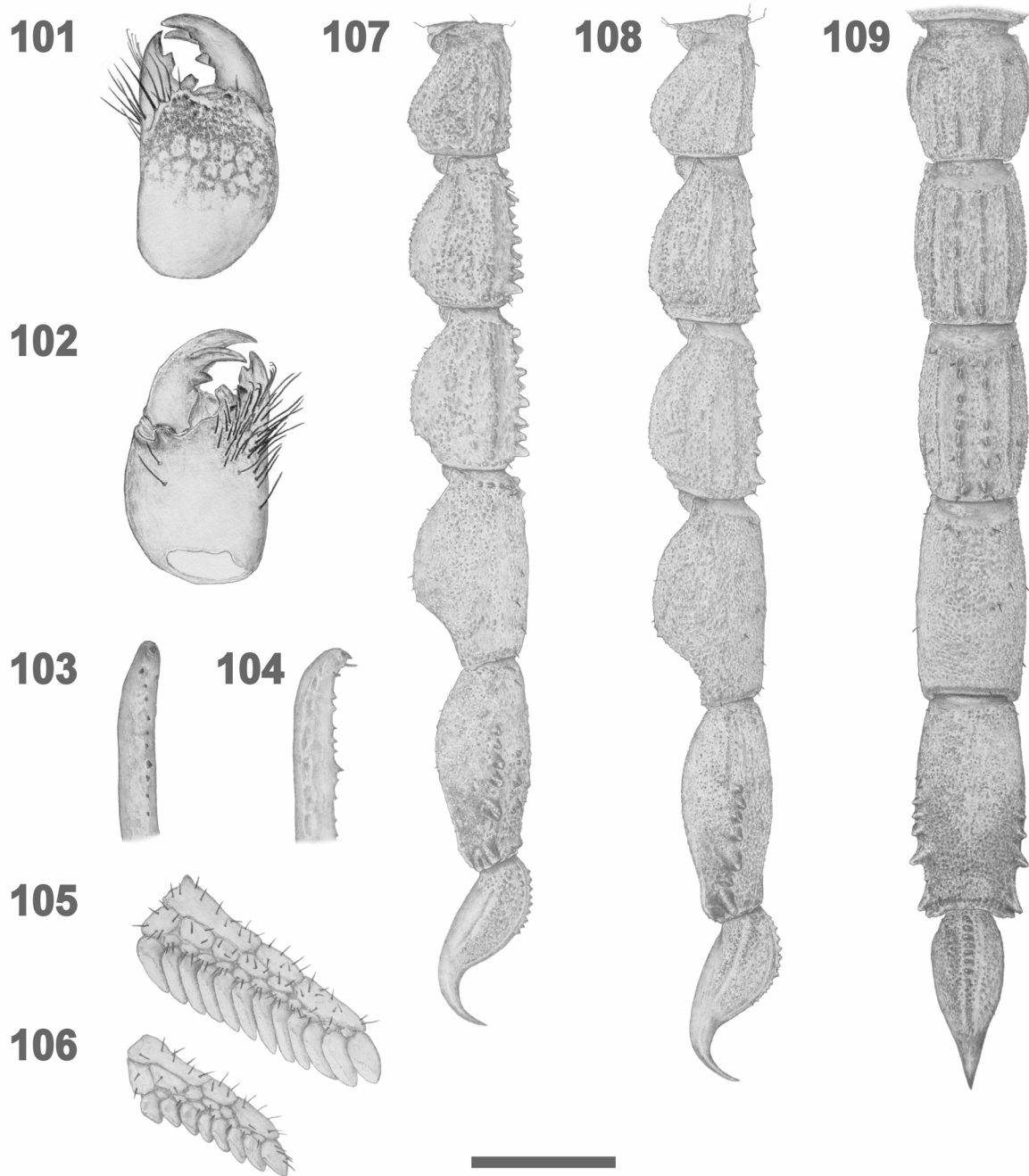
**Telson** (Figs. 108–109). Vesicle pyriform, nearly parallel sided anteriorly, gently tapered in width posteriorly; dorsal surface smooth, very slightly convex; upper

lateral surface with shallow longitudinal sulcus on distal half of vesicle; lateral and ventral surfaces granulated proximally, smooth distally, granules larger on ventral surface; ventral surface with ventromedian carina bearing 6 larger transversely elongated granules, and 5 smaller rounded granules (3 proximal, 2 distal); ventromedian carina flanked by parallel lateral rows of smaller granules, and pale, smooth stripe; few scattered microsetae; aculeus short, stout, thick and conical at base, abruptly curved downward distally; tip of aculeus not lower than deepest part of vesicle; subaculear tubercle absent.

**Pedipalps** (Figs. 96–100, 103–104, 156, 158–162). *Femur* (Fig. 96): with 5 carinae, external carina a broad ridge, irregularly studded with conical granules; dorsoexternal and dorsointernal carinae weak, granular; internal carina moderate, crenulate to serrate; ventrointernal carina weak, granular; dorsoexternal surface finely roughened, dorsal surface densely, finely granular, internal surface densely, coarsely granular, ventral surface shagreened. *Patella* (Figs. 97–98): with 5 carinae, dorsoexternal, dorsomedian and dorsointernal carinae weak, irregular, finely granulated; external carina strong, smooth to weakly crenulated; internal carina moderate, crenulated; ventrointernal carina obsolete, replaced by band of slightly enlarged granules; all intercarinal surfaces roughened, ventral surface lightly shagreened, dorsal, dorsointernal and dorsoexternal surfaces more heavily shagreened. *Chela* (Figs. 99–100, 103–104): manus with dorsal marginal carina weak, smooth, all other carinae obsolete; surface smooth to lightly shagreened; fixed finger with digital, dorsal secondary and dorsal marginal carinae weak, smooth; base of fixed finger flanked externally and internally by small lobes bearing three short clavate microsetae; fixed finger with external apical groove at base of enlarged terminal tooth, and two small spiniform subdistal denticles; movable finger with two small spiniform subdistal denticles below enlarged terminal tooth; dentate margins of both fixed and movable fingers armed with row of noncontiguous microdenticles divided into three subrows by two slightly enlarged, spiniform denticles; subrow counts, from apical to proximal: fixed finger 6, 7–8, 12, movable finger 5, 7, 14; denticles in proximal rows of fingers progressively reduced to minute granules; edges of fingers barely scalloped between enlarged denticles, almost linear; all pedipalp segments with scattered short, clavate microsetae. *Trichobothriotaxy* (Figs. 156, 158–162): type A $\beta$ , neobothriotaxic minorante (Vachon, 1974, 1975), as diagnosed for the genus; femur with 2 external, 3 dorsal, 3 internal trichobothria; dorsal surface of patella with 4 trichobothria ( $d_2$  absent); external surface of patella with 5 trichobothria ( $em$  and  $esb_2$  absent); chela palm with 4 external trichobothria ( $Eb_3$  and  $Esb$



**Figures 91–100:** *Picobuthus dundoni*, sp. nov. 94–95, paratype male (Adam); 91 – 93, 96 – 100, holotype male. 91. Carapace, dorsal aspect. 92. Right basitarsus and telotarsus III, retrolateral aspect. 93. Right telotarsus III, ventral aspect. 94–95, right hemispermatophore, lobes at base of flagellum. 94. Convex aspect. 95. Outer aspect. 96. Right pedipalp femur, dorsal aspect. 97. Right pedipalp patella, dorsal aspect. 98. Right pedipalp patella, external aspect. 99–100, left pedipalp chela. 99. Dorsoexternal aspect. 100. Ventral aspect. Scale bar: 91: 1 mm; 92, 96, 97, 98, 99, 100: 0.75 mm; 93, 94, 95: 1 mm.



**Figures 101–109:** *Picobuthus dundoni*, sp. nov. **101 – 102**, paratype male (Adam); **106 – 107**, paratype female (Wadi Andam); **103–105, 108–109**, holotype male. **101–102**, right chelicera. **101**. Dorsal aspect. **102**. Ventral aspect. **103–104**, left pedipalp chela movable finger terminus. **103**. Dorsal aspect. **104**. External aspect. **105**. Left male pectine, ventral aspect. **106**. Left female pectine, ventral aspect. **107**. Metasoma and telson of female, right lateral aspect. **108–109**, metasoma and telson of male. **108**. Right lateral aspect. **109**. Ventral aspect. Scale bar: 101, 102, 103, 104: 0.53 mm; 105, 106: 1 mm; 107, 108, 109: 1.5 mm.

absent); fixed finger of chela with 6 trichobothria (*esb* absent).

**Legs** (Figs. 87–90, 92–93). All legs with femora densely granular, with crenulate to serrate carinae; patellae

shagreened, with carinae weak except for serrate inferior carina; tibial spurs absent; all legs with two tarsal spurs; retrolateral spurs simple, prolateral spurs basally bifurcate, basal branch very small on leg I, becoming larger on more posterior legs; basitarsi I–III compressed,



retrosuperior margins dentate, with combs of elongate macrosetae; setation formula: 4/3 4/3: 6/4 7/4: 8/6 6/7; retrosuperior margins of telotarsi I–III with combs of 3 elongate macrosetae; soles of all telotarsi with single ventral median row of 2–3 slender bristles; unguis well developed, curved.

**Measurements of holotype male (mm).** Total L 16.00; carapace L 2.25, W 2.5, preocular L 1.00; metasoma and telson L 10.00; metasomal segment L/W/D: I 1.15/1.16/0.94, II 1.51/1.02/0.96, III 1.64/1.02/0.98, IV 1.96/1.01/1.02, V 2.08/1.02/0.85; telson L 1.63, telson vesicle W 0.67, D 0.67; pedipalp chela L 3.79, manus ventral L 1.12, chela W 0.65, D 0.59, fixed finger L 2.48, movable finger L 2.82; pedipalp femur L 2.08, W 0.57; pedipalp patella L 2.29, W 0.76; pectine L 1.67; leg III patella L 1.78, D 0.57. *Morphometrics:* carapace W/L 1.11, carapace posterior W/anterior W 2.07, pectine L/carapace L 0.74, pedipalp femur L/carapace L 1.25, pedipalp femur L/W 3.65, pedipalp patella L/W 3.01, pedipalp movable finger L/manus ventral L 2.52, pedipalp movable finger L/carapace L 1.25, pedipalp chela L/W 5.83, pedipalp manus ventral L/chela W 1.72, chela manus L/W 1.72, leg III patella L/D 3.12, metasomal segment L/W I 0.99, II 1.48, III 1.61, IV 1.94, V 2.04, metasoma V W/metasma I W 0.88, telson L/W 2.43, telson W/metasma V W 0.66.

**Chelicera (paratype male)** (Figs. 101–102). Dark reticulated pigmentation on distal dorsal surface of manus; fingers with normal buthid dentition (Vachon, 1963; Sissom, 1990); movable finger with dorsal distal tine and ventral distal tine of equal size, dorsal margin with 4 denticles (subdistal, medial, two small basal), ventral margin with single large subdistal, denticle; fixed finger with large subdistal denticle and basal bicuspid; ventral aspect of fixed finger with two denticles, distal denticle large, prominent, proximal denticle small, about 1/4 size of distal denticle; numerous long setae on ventral and internal aspect of fixed finger, and ventral aspect of movable finger.

**Hemispermaphore (paratype male, Adam)** (Figs. 94–95). Flagelliform, trunk long, slender, flagellum rather short, less than half as long as trunk; 4 lobes at base of flagellum; inner lobe a broad, apically rounded lamina; median lobe smaller, acuminate; outer lobe small, tapering apically; basal lobe slender, forming curved, pointed hook.

**Variation.** *Sexual dimorphism:* Adult females ( $n = 2$ ) differed from sub-adult or adult males ( $n = 3$ ) as follows: carapace with finer granulation, less distinct anterior median carinae; central and posterior median furrows shallower, posterior marginal furrow shallower, finely granular, lacking distinctive ovoid depressions; meso-

soma larger, tergites wider with finer granules; pectines shorter (Fig. 106), pectine L/carapace L 0.41–0.51 (females), 0.66–0.74 (males) ( $p = 0.08$ ); fewer pectine teeth: 6–8 (females), 11–12 (males); metasomal segments more coarsely granular, carinae more robust; segments II–III with more prominent enlarged non-contiguous lobate denticles on ventrosubmedian carinae, not separated by crenulations (Fig. 107), ventrolateral carinae moderate, armed posteriorly with enlarged dentate granules; tubercles on anterior ventral margin of segment IV much larger; metasomal segments II–IV less elongate; metasoma V with larger, more blunt ventrolateral dentate granules, ventral surface pustulose, studded with numerous polished, vesiculate granules and three pairs of larger tuberculate granules; vesicle of telson more heavily granulated, with 9–13 denticles on ventromedian carina. *Morphometrics* (Figs. 121–124) ( $n = 5$  sub-adults or adults): carapace W/L 1.11–1.22, posterior W/anterior W 2.07–2.23; pedipalp femur L/W 3.32–3.77; pedipalp patella L/W 2.78–3.10; pedipalp femur L/carapace L 0.87–0.92; pedipalp chela L/W 5.11–5.96; pedipalp chela movable finger L/manus ventral L 2.38–2.61; leg III patella L/D 2.89–3.28; metasoma L/W: I 0.95–1.04, II 1.32–1.48, III 1.49–1.68, IV 1.76–1.94, V 1.82–2.04; metasoma L/D: I 1.22–1.26, II 1.43–1.57, III 1.52–1.67, IV 1.77–2.00, V 2.21–2.45; metasoma W ratios: II/I 0.84–0.89, IV/I 0.85–0.93, V/I 0.83–0.95; telson L/vesicle W 2.43–2.71, vesicle W/metasma V W 0.56–0.66. *Meristics:* granules on ventromedian carina of telson vesicle, 9–11 (3 vesicles with 9 granules, 1 with 11, 1 with 13); setae in retrosuperior comb of basitarsus: I 4–6, II 4–8, III 6–8; pectine teeth: males, 1 comb with 10 teeth, 4 with 11, 1 with 12; females: 2 combs with 6 teeth, 2 with 8. *Trichobothriotaxy:* among 8 femora, internal trichobothria numbered 3 in 4 cases ( $i_4$  absent bilaterally in 2 males), and 4 in 4 cases (bilaterally orthobothriotaxic in 2 females) (Figs. 156–157). A larger sample size is required to determine if this represents significant sexual dimorphism. All 8 femora bore 3 dorsal trichobothria. Among 8 patellae, all had 5 external trichobothria ( $esb_2$  and  $em$  absent). *Geographic variation:* The paratype male from Wadi Qitbit was slightly smaller than the two northern males, and may be sub-adult. It was distinct in having uniform pale coloration, with only faint ferruginous pigmentation on the anterior half of the carapace. The female from Wadi Qitbit differs from the female from Wadi Andam as follows: dusky pigment absent from carapace and tergites, ventrosubmedian carinae on metasoma II–III with longer, dentate granules posteriorly; ventrolateral carinae on metasoma II–III with smaller granules anteriorly, larger posterior terminal granules, posterior ends of carinae bent more strongly in dorsolateral direction; smaller granules on ventro-posterior surface of metasoma V; telson with vesicle less pyriform, wider distally.



**Figures 110–113:** Habitus of new picobuthoid scorpions *in vivo*. **110.** *Microbuthus gardneri*, **sp. nov.**, female (Jabal Bani Jabir). **111.** *Femtobuthus shutuae*, **sp. nov.**, paratype female (Wadi Shuwaymiyah). **112.** *Picobuthus dundoni*, **sp. nov.**, paratype female (Wadi Qitbit). **113.** *Picobuthus wahibaensis*, **sp. nov.**, paratype male (East Wahiba Sands). Figs. 111–113 from Alex Winkler.

**Measurements of paratype female (Wadi Andam) (mm).** Total L 17.72; carapace L 2.36, W 2.71, preocular L 1.04; metasoma and telson L 9.46; metasomal segment L/W/D: I 1.16/1.22/0.94, II 1.43/1.08/0.98, III 1.55/1.04/1.02, IV 1.88/1.07/1.06, V 2.01/1.06/0.86; telson L 1.61, vesicle W 0.61, D 0.57; pedipalp chela L 3.92, manus ventral L 1.22, chela W 0.73, D 0.65, fixed finger L 2.50, movable finger L 2.92; pedipalp femur L 2.06, W 0.62; pedipalp patella L 2.33, W 0.78; pectine L 1.20, leg III patella L 1.76, D 0.60. **Morphometrics:** carapace W/L 1.15, carapace posterior W/anterior W 2.17, pectine L/carapace L 0.51, pedipalp femur L/carapace L 0.87, pedipalp femur L/W 3.32, pedipalp patella L/W 2.99, pedipalp movable finger L/manus ventral L 2.39, pedipalp movable finger L/carapace L 1.24, pedipalp chela L/W 5.37, pedipalp manus ventral L/chela W 1.67, chela manus L/W 1.67, leg III patella L/D 2.93, metasomal segment L/W I 0.95, II 1.32, III 1.49, IV 1.76, V 1.90, metasoma V W/metasma I W 0.87, telson L/W 2.64, telson W/metasma V W 0.58.

**Distribution** (Fig. 114). Known only from central Oman, where it was found in sandy wadis west of the Wahiba Sands, and Wadi Qitbit, at the edge of the Rubh Al-Khali (Empty Quarter).

**Ecology.** The collection sites in Wadi Andam were situated in a vegetated patch of an open sandy alluvial plain (Fig. 117). Areas of soft sand were intermingled with tracts of firmer ground littered with gravel and small stones. Small and large sand hummocks were accumulated around the bases of shrubs and small trees, including *Acacia tortilis*. The holotype male and a paratype female were found on soft sand at the bases of shrubs. The male was agile, running rapidly on sand with metasoma held over the body, and the female was stationary. The only other scorpion species at these sites was *Compsobuthus arabicus* Levy, Amitai & Shulov, 1973, which was collected on sand at the base of vegetation. The paratypes from Wadi Tarban, south of Adam, and Wadi Qitbit, at the edge of the Rubh Al-Khali, were also taken off sandy substrates. The

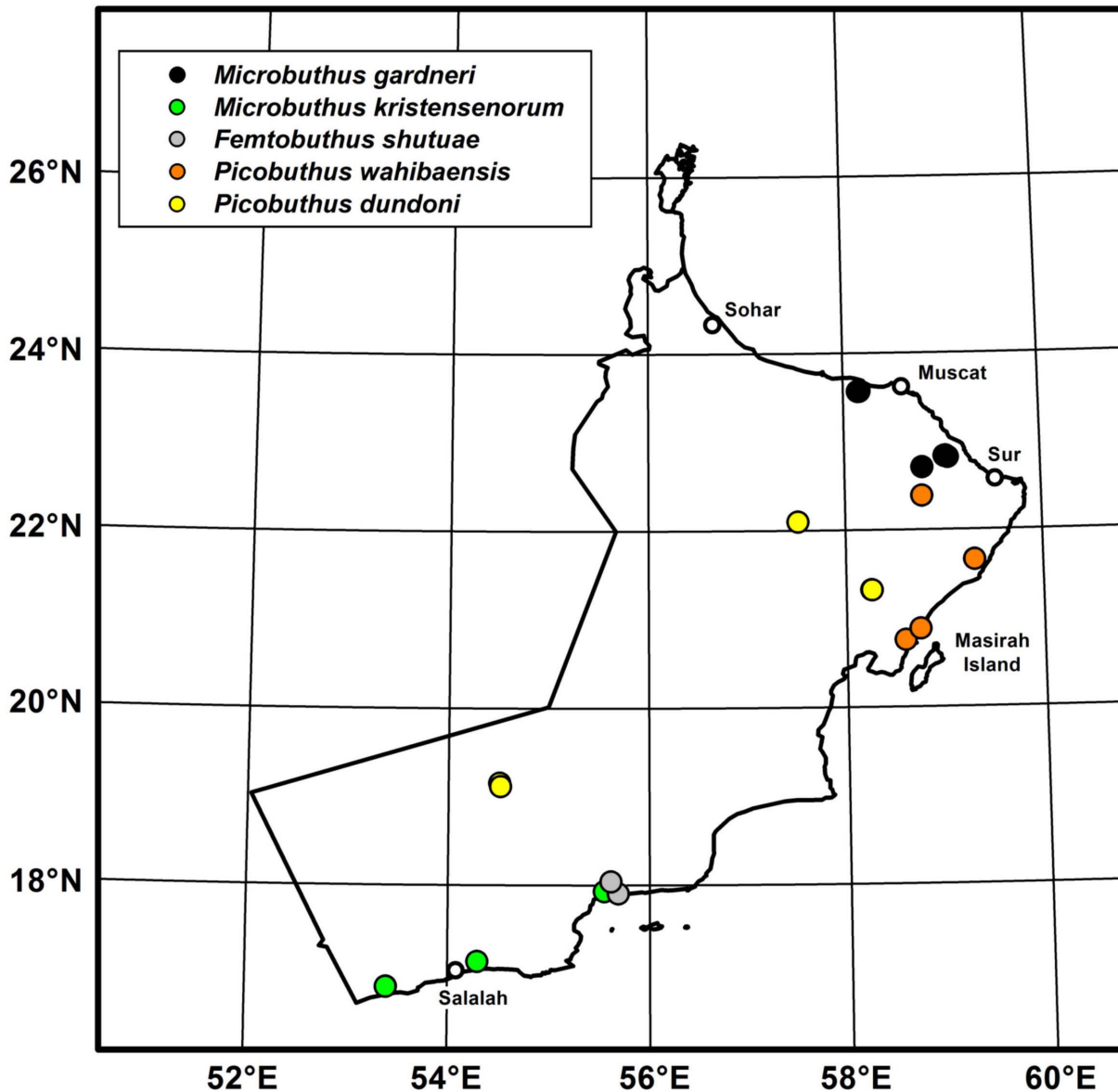
compressed basitarsi of these scorpions with bristle combs on legs I–III are consistent with their psammophilous habitat (Fet, Polis & Sissom, 1998; Polis, 1990; Prendini, 2001a). The enlarged dentition on the metasoma also suggests fossorial arenicolous adaptation.

## Discussion

Endemic picobuthoid scorpions have adapted to diverse environments in all major biotic regions of Oman (Figs. 115–120): rocky habitats are occupied in the northern Al Hajar Mountains by *Microbuthus gardneri*, and in the southern Dhofar Mountains by *M. kristensenorum*; coastal dunes of the eastern Wahiba Sands are inhabited by a psammophile, *Picobuthus wahibaensis*; a second psammophile, *P. dundoni*, has colonized inland dunes ranging from the north-central plains to the margins of the Rubh Al-Khali sand system; and the south-central limestone plateau and southern coastal wadis are occupied by the fossorial, arenicolous *Femtbuthus shutuae*. The discovery of wide ecological radiation by these diminutive scorpions spurs a reassessment of current ideas regarding their bionomics and biogeography. Previously, the North African species of *Microbuthus* have been characterized as halophilic and associated with mesic or humid coastal habitats (Vachon, 1951; Lourenço, 2002). The apparent widely disjunct distribution of *Microbuthus* in eastern and western coastal locations of North Africa was proposed to reflect a fragmentation or regression of ancient mesic faunas that were unable to adapt to xeric conditions that accompanied advent of the Sahara Desert (Lourenço, 2002; Lourenço & Duhem, 2007; Qi & Lourenço, 2007). This ‘mesic model’ does fit the distributions of three of the picobuthoid species in Oman, i.e. *M. kristensenorum* in the lush, vegetated southerly slopes of the Dhofar Mountains and coastal ranges of the Hadhramaut; *F. shutuae* along the southern coast and plateau of Jiddat Al Harasis; and *P. wahibaensis* on the seaward side of the Wahiba Sands. These coastal regions receive substantial moisture as drizzle or dew condensed from humid air masses drawn inland from the Arabian Sea. During the summer months, a southwest monsoon generates a belt of dense coastal fog which sustains relatively mesic environments in the Jiddat Al Harasis and Dhofar Mountains (Gallagher & Woodcock, 1980; Sale, 1980). On the other hand, two other picobuthoids in Oman have successfully adapted to arid conditions in the Al Hajar Mountains (*M. gardneri*) and central desert plains extending to the edge of the Rubh Al-Khali (*P. dundoni*). The central desert of Oman is classified as hyper-arid with mean annual rainfall < 48 mm, and maximum temperatures > 50 °C (Ghazanfar, 2004). Although the finding of *M. flavorufus* in northern Egypt near the Gulf of Suez was interpreted as supporting a mesic model (Lourenço & Duhem, 2007), the

coordinates of the type locality place the collection site in a hot, arid valley with sparse vegetation, some 20 km inland from the Red Sea. Thus, modern picobuthoid scorpions are not necessarily restricted to mesic or humid habitats, and are capable of adapting to new environments. The fact that the few available museum specimens of *Microbuthus* were collected near coastal areas may reflect a bias in the sampling of small cryptic faunas for more densely populated and easily traveled coastal routes. The scorpion fauna of the interior of North Africa has not been intensively sampled by UV detection methods that facilitate the finding of small cryptic scorpions. If *Microbuthus* were found in the interior deserts far from coastal areas, it could mean that arid adapted forms evolved earlier, and mesic forms came later during Pleistocene pluvial periods. Alternatively, the mesic model may account for the large scale, relict coastal distributions of ancient picobuthoid faunas, and xerophilous adaptations evolved more recently in response to arid climates that prevailed during late cycles of Pleistocene glaciation.

The specialized morphology of the posterior metasomal segments in *Microbuthus* has provoked speculation about the affinities of these peculiar scorpions. Vachon (1952: 320) considered *Microbuthus* to be most closely allied to *Orthochirus*, another genus of buthids whose species have developed very heavy sclerotization of metasoma IV–V, with numerous cuticular pits or punctuations. This is presumably a derived trait, as the majority of other buthid and non-buthid scorpions, both extant and fossil, lack such specialization and have metasoma IV–V structurally similar to metasoma I–III. Some other buthid genera (e.g. *Butheoloides*, *Karasbergia*, *Isometroides*, *Orthochirus*) also exhibit a superficially similar structure of their posterior metasomal segments, and it has been suggested that the presence of pits containing certain sensillar structures with a potentially chemoreceptive function defines a distinct lineage of small buthids (Lourenço, 2001; Lourenço, 2003). However, all of these genera are unlikely to be descended from an immediate common ancestor with the same metasomal structures because: (i) structurally different sense organs arise from the pits of different genera or species, e.g. *Karasbergia* has microscopic bifurcated processes (Lourenço, 2001); *Orthochirus scrobiculosus* has short curved microsetae (Fet et al., 2003); *O. danielleae*, *O. monodi*, *O. fети*, *O. gromovi* and *O. heratensis* have longer macrosetae (Lourenço & Vachon, 1997; Kovařík, 2004); and *Microbuthus kristensenorum* has long curved macrosetae that are not present in the pits of other *Microbuthus* species; thus, the homology of pit sensilla across genera is not supported; (ii) in other respects, *Orthochirus* is closer to *Butheolus* Simon, 1882, and *Baloorthochirus* Kovařík, 1996, which lack the strongly modified metasoma IV–V; (iii) in other respects,

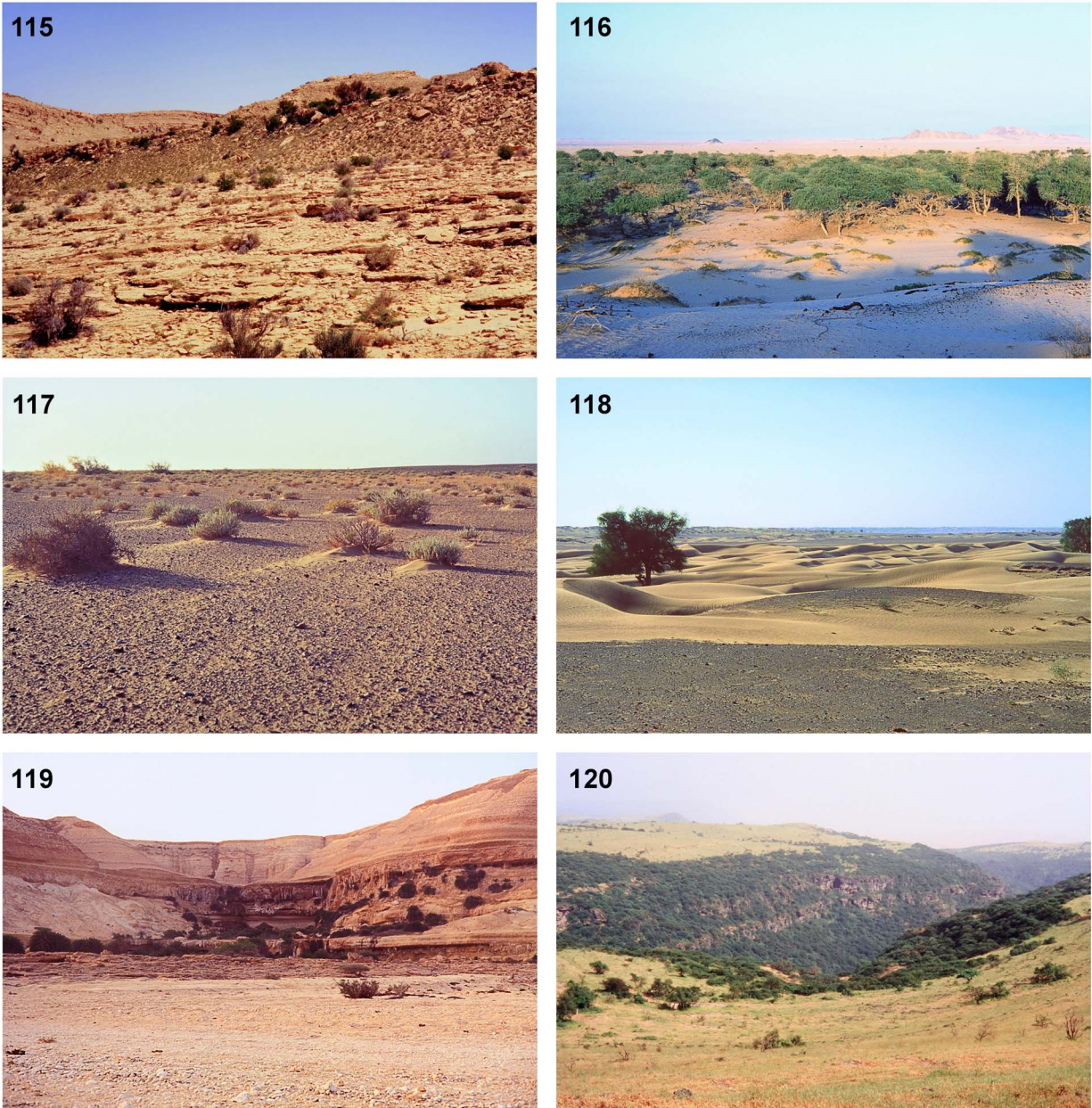


**Figure 114:** Distribution of new picobuthoid scorpions in Oman. Black circles, *Microbuthus gardneri*, **sp. nov.** Green circles, *Microbuthus kristensenorum*, **sp. nov.** Gray circles, *Femtobuthus shutuae*, **sp. nov.** Orange circles, *Picobuthus wahibaensis*, **sp. nov.** Yellow circles, *Picobuthus dundoni*, **sp. nov.**

*Microbuthus* is closer to *Picobuthus*, **gen. nov.**, and *Femtobuthus*, **gen. nov.**, which also lack such modification of metasoma IV–V; (iv) a cladistic analysis of the high level taxonomy of buthids based on trichobothrial patterns and presence or absence of tibial spurs placed various genera with sclerotized, pitted metasomal segments into different major lineages (Fet, Söglad & Lowe, 2005); in particular, *Butheoloides* and *Karasbergia* express the  $\alpha$ -configuration of trichobothria on the pedipalp femur, whereas *Isometroides*, *Microbuthus* and *Orthochirus* express the  $\beta$ -configuration.

The development of heavily sclerotized, pitted metasomal segments is more likely to be a case of convergent evolution of analogous structures dictated by common functional constraints. An important role of the posterior metasomal segments is to wield the telson, a primary offensive and defensive weapon of scorpions. Selective pressure would be expected to favor mechanical reinforcement of the exoskeleton of these segments. For example, a thickened metasoma would be especially useful to *Isometroides*, a specialized predator that attacks ctenizid and diplurid spiders within their burrows (Main, 1956; Main, 1957; Koch, 1977). Heavy



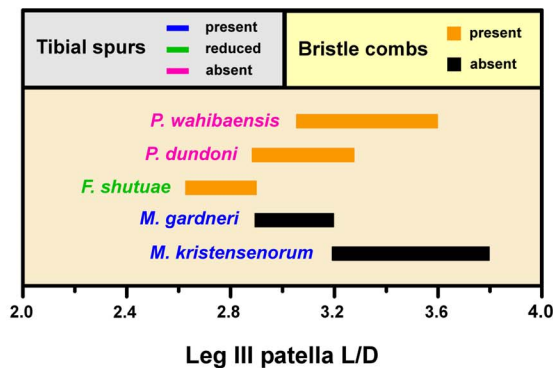


**Figure 115–120:** Habitats of new picobuthoid scorpions in Oman. **115.** Jabal Bani Jabir, rocky terrain and type locality of *Microbuthus gardneri*, **sp. nov.** **116.** East Wahiba Sands, *Prosopis* woodland, dune habitat of *Picobuthus wahibaensis*, **sp. nov.** **117.** Wadi Andam, sandy plain, type locality of *Picobuthus dundoni*, **sp. nov.** **118.** Wadi Muqshin, near Wadi Qitbit, edge of Rub Al-Khali, dune habitat of *Picobuthus dundoni*, **sp. nov.** **119.** Wadi Shuwaymiyah, habitat of *Femtobuthus shutuae*, **sp. nov.**, and *Microbuthus kristensenorum*, **sp. nov.** **120.** Jabal Qara, Dhofar Mountains, habitat of *Microbuthus kristensenorum*, **sp. nov.**

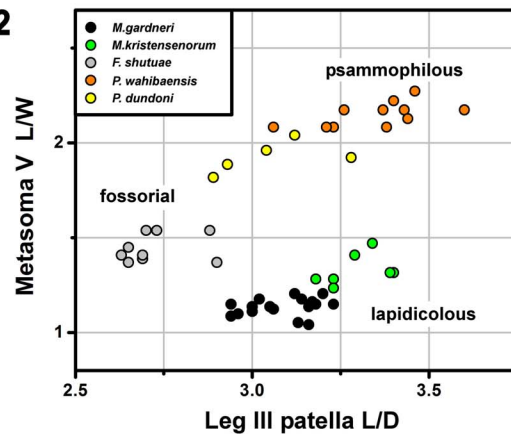
sclerotization of metasomal segments IV–V may be needed to withstand crushing by powerful chelicerae of mygalomorph spiders. However, excessive thickening of the cuticle creates a problem for the deployment of various sensillar organs. Sensory neuron dendrites must be able to receive and transduce signals from the external environment through the dense armor plating. This problem has been solved by localized thinning of

the exoskeleton at many small pits that facilitate the exit of diverse sensillar structures. The metasoma is thus able to serve as a versatile, multifunctional tool, i.e. as a weapon for combat, as a protective shield held over the mesosoma (Shulov & Amitai, 1960; Levy & Amitai, 1980; Lowe, 1993), and as a movable sensor array with potentially tactile or olfactory capabilities (Lourenço, 2001; Fet et al., 2003; Lourenço, 2003). In *Orthochirus*

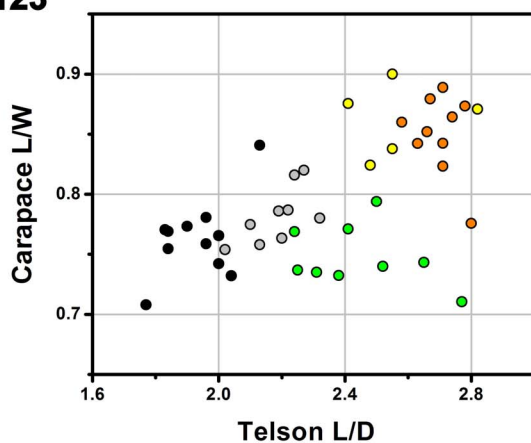
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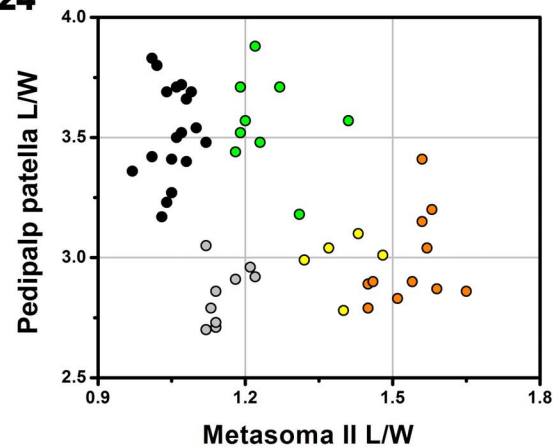
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**Figures 121–124:** Morphometric variation of picobuthoid scorpions in Oman (data from adults). **121.** Variation in characters correlated with substratum specialization: slenderness of legs (bar plots show range of variation of leg III patella L/D), and development of basitarsal bristle combs and tibial spurs. Psammophilous species (*Picobuthus* spp.) have more slender legs with bristle combs, without tibial spurs; lapidicolous species (*Microbuthus gardneri*, *M. kristensenorum*) have more slender legs without bristle combs, with tibial spurs; the fossorial *Femtothuthus shutuae* has stout legs with bristle combs, and reduced tibial spurs. **122.** Scatter plot of variation in slenderness of legs and metasoma V (leg III patella L/D vs. metasoma V L/D). Metasoma V is more slender in the psammophilous *Picobuthus*, and more stout in the lapidicolous *Microbuthus*, reflecting development of a heavily sclerotized telson sheath. **123.** Scatter plot of variation in telson L/D and carapace L/W. The telson is deeper in *M. gardneri* and *Femtothuthus*, and longer in *M. kristensenorum* and *Picobuthus*, the carapace more elongated in *Picobuthus*, and more trapezoidal in *Microbuthus* and *Femtothuthus*. **124.** Scatter plot of variation in slenderness of anterior metasoma and pedipalp (metasoma II L/W vs. pedipalp patella L/W). The anterior metasoma is more stout in *Microbuthus* and *Femtothuthus*, and more slender in *Picobuthus*, the pedipalp relatively more stout in *Femtothuthus* and *Picobuthus*, and more slender in *Microbuthus*. Data points in scatter plots represent individuals, with species membership color coded according to inset of Fig. 122.

and *Microbuthus*, the modified metasomal segments IV–V may perform another vital function. These two segments are laterally expanded and their dorsal surfaces deeply excavated (Fig. 20). When the metasoma is coiled, they fold together and interlock to form a shell or sheath that encapsulates the telson (Fig. 110). These two genera include species living in rocky habitats where the tip of an exposed aculeus would be vulnerable to abrasion or breakage. Enhanced protection of the aculeus may well be crucial to the survival of these scorpions, since they possess only small or weakly developed pedipalp chelae and probably rely more on their venom to quickly immobilize captured prey. A

distinctive feature of the picobuthoid telson is the serrulate ventromedian carina. This studded ornamentation may be useful for bracing the vesicle against sclerites of arthropod prey, to gain leverage for the aculeus to penetrate interscleritic membranes and deliver venom. The various subaculear tubercles or spines adorning the ventral surfaces of vesicles in many different scorpion taxa (e.g. Buthidae, Diplocentrinae, the vaejovid genus *Wernerius*) may play similar roles.

As very small scorpions with a highly modified pedipalp morphology, the picobuthoids exhibit unusual trichobothrial patterns that deserve special attention. All picobuthoids show subtractive neobothriotaxy of five

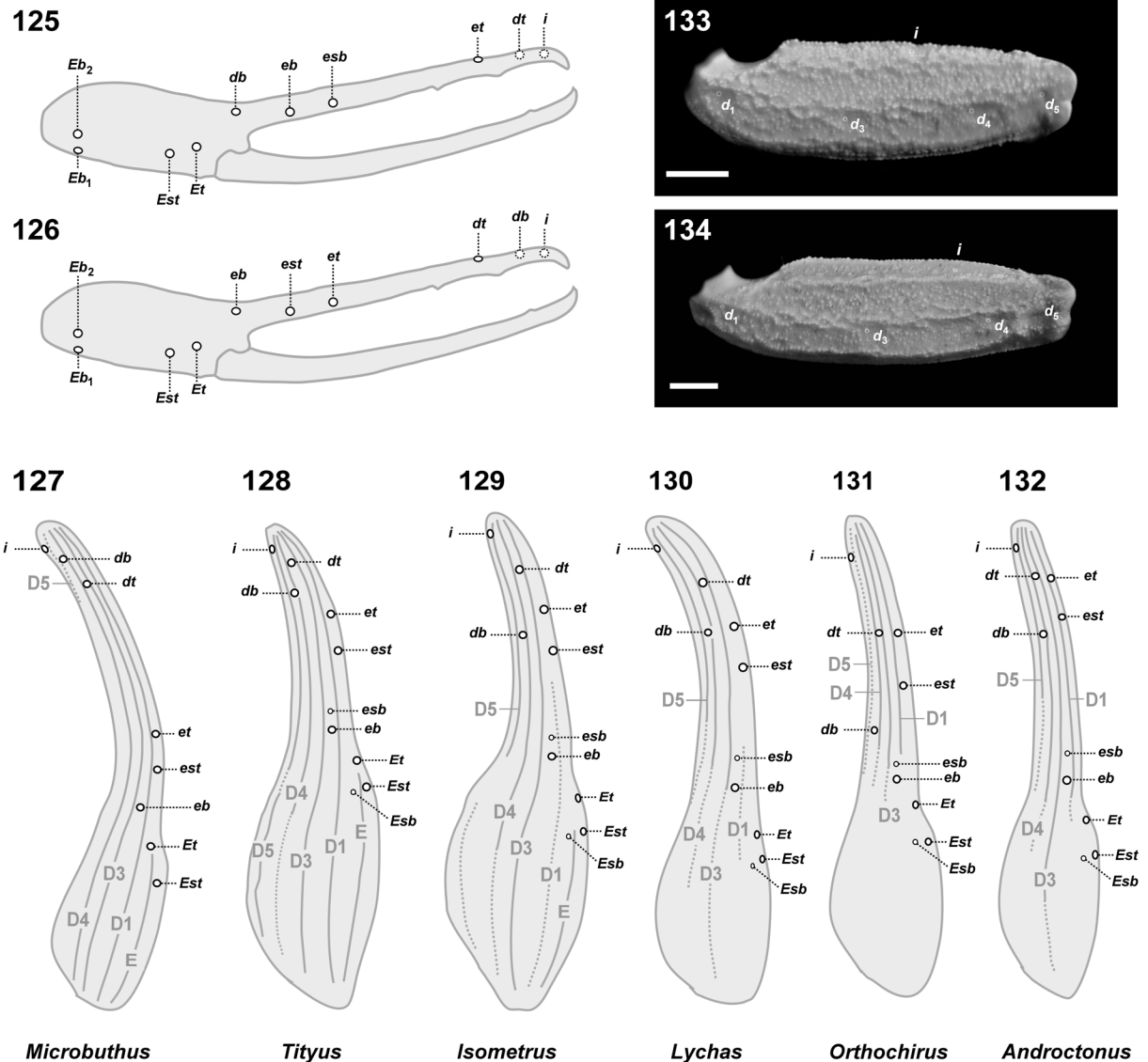
	<i>Microbuthus</i>	<i>Fentobuthus</i>	<i>Picobuthus</i>
carapace	strongly trapezoidal, posterior W/ anterior W > 2.3		moderately trapezoidal, posterior W/ anterior W < 2.3
metasoma I	granulate to rugose	granulate	granulate
metasoma II		granulate, large dentate granules on ventrosubmedian carinae	
metasoma III	convex, smooth and pitted	granulate	
metasoma IV		granulate, large lobate granules on ventrolateral carinae	
metasoma V			
telson vesicle	abbreviated, posteriorly truncate	abbreviated, ovoid	elongate, pyriform
leg III–IV tibial spurs	present	present on IV, reduced or lost on III	absent
leg I–III basitarsal bristle combs	absent	present	
chelicera fixed finger – ventral denticles	distal and proximal denticles nearly equal in size	proximal denticle distinctly smaller than distal denticle	
pedipalp chela fixed finger	strongly deflected upward	weakly deflected upward	
femoral trichobothria – internal	4	2	2–4
femoral trichobothria – dorsal	3, $\beta$ -configuration	2, degenerate $\beta$ -configuration	3, $\beta$ -configuration
patellar trichobothria – external	6 – 7	5	

**Table 1:** Distribution of diagnostic characters that differentiate between picobuthoid genera. In addition to these characters, shared diagnostic characters separating all three picobuthoid genera from other buthids include the following: small size; carapace trapezoidal; carapace and tergites densely granular; tergites weakly monocarinate or tricarinate; body and pedipalps with numerous short, clavate microsetae; telson vesicle with serrulate ventromedian carina, lacking subaculear spine or tubercle; pectine teeth < 16; fulcra and middle lamellae present; pedipalps slender, chela fingers long, narrow, curved, with gap when closed, denitition reduced to sparse series of minute granules and few large spiniform denticles; loss of petite trichobothria: femur  $d_2$ , patella  $d_2$ , chela  $Eb_3$ ,  $Esb$  and  $esb$ ; chela fixed finger with trichobothrium  $db$  on internal aspect, distal to  $dt$ . See under group and generic diagnoses in **Systematics** section for more details.

	<i>M. gardneri</i>	<i>M. kristensenorum</i>	<i>M. pusillus</i>	<i>M. flavorufus</i>	<i>M. fagei</i>	<i>M. maroccanus</i>
Coloration	Black	Ferruginous; pedipalp femur, patella & legs yellow	Black; pedipalp femur may be yellow	Yellow to reddish-yellow	Dark brown, pedipalps & legs lighter	Light brown
metasoma I L/W	0.77–0.90	0.95–1.04	0.88*	0.81	0.61–0.87	0.84–0.87
metasoma II L/W	0.97–1.12	1.18–1.41		1.00	0.72	
metasoma III L/W	0.90–1.19	1.22–1.42		1.06	1.00	
metasoma IV L/W	0.93–1.07	1.17–1.33	1.09*	0.95	1.10	
metasoma V L/W	1.04–1.20	1.24–1.48	1.19*	1.25	1.20–1.50	1.50–1.60
metasoma V L/D	1.41–1.68	1.52–1.65	1.72	1.79	2.00–2.45	2.25–2.46
metasoma V W/ metasoma I W	1.25–1.4	1.16–1.35	1.24*	1.25	1.1–1.2	1.05–1.13
telson L/vesicle D	1.77–2.04	2.24–2.77	2.06	2.00	2.33	
pedipalp femur L/W	3.6–4.2	3.82–4.35	3.28	3.38	3.14–3.67	3.00–3.14
pedipalp patella L/W	3.2–3.8	3.44–3.88	2.91	3.22	2.56–2.78	2.54–2.89
pedipalp patella – external trichobothria	7	7		7	6	6
species distribution	northern Oman, Al Hajar Mountains	southern Dhofar province of Oman, southern coast of Yemen	Djibouti, Eritrea (north-east African coast)	Red Sea coast of northern Egypt,	Mauritania (north-west Africa)	Morocco (north-west Africa)

**Table 2:** Comparison of coloration, morphometrics, trichobothriotaxy, and geographic distribution of different species of *Microbuthus*. Data for *M. pusillus* were obtained from photomicrographs of the holotype provided by F. Kovarik. Data for *M. flavorufus*, *M. fagei* and *M. maroccanus* were obtained from published information. \*Putative values inferred from data on *M. litoralis* given by Birula (1905), assuming synonymy with *M. pusillus*.

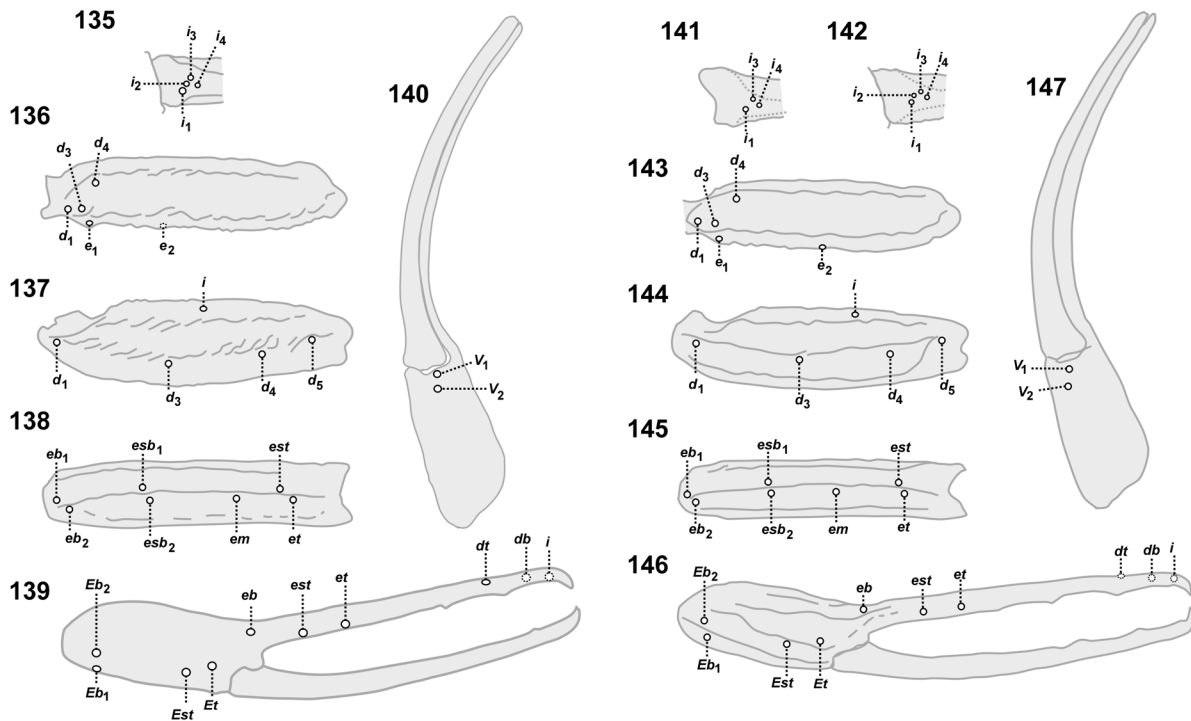




**Figures 125–134:** Picobuthoid trichobothriotaxy. **125.** Schematic showing trichobothrial nomenclature for right pedipalp chela (dorsoexternal aspect) of *Microbuthus* used by Vachon (1952, 1974). **126.** Schematic showing revised trichobothrial nomenclature for right pedipalp chela fixed finger (dorsoexternal aspect) of picobuthoids, including *Microbuthus*, based on homologies with other buthids derived from locations of trichobothria relative to landmark carinae. Trichobothrial sockets visible on dorsal and external surfaces are shown as circles with solid outline, those hidden on internal surfaces as circles with dotted outline. **125–126**, with holotype of *M. gardneri* as example. **127–132**, stylized schematics of upper sides of right pedipalp chelae of *Microbuthus* and representatives of five other buthid genera, comparing placements of fixed finger trichobothria with respect to landmark carinae. Carinal terminology after Soleglad & Sissom (2001), i.e. E = external, D1 = digital, D3 = dorsal secondary, D4 = dorsal marginal, D5 = dorsal internal. Solid lines indicate strong carination, dotted lines weak carination. **127.** *Microbuthus gardneri*, **sp. nov.**, adult female paratype from type locality (Jabal Bani Jabir). **128.** *Tityus ecuadorensis* Kraepelin, 1896, adult male. **129.** *Isometrus melanodactylus* (L. Koch, 1867). **130.** *Lychas marmoreus* (C.L. Koch, 1844). **131.** *Orthochirus scrobiculosus* (Grube, 1873). **132.** *Androctonus crassicauda* (Olivier, 1807). **133–134**, fluorescence images of the right pedipalp patella of *Microbuthus* species from Oman, dorsal aspect, showing positions of dorsal trichobothria, and the tendency for placement of  $d_3$  towards external side of dorsomedian carina (for illustrative purposes, fluorescence contrast of trichobothrial sockets was enhanced). **133.** *Microbuthus gardneri*, **sp. nov.**, female paratype (Al Khod). **134.** *Microbuthus kristensenorum*, **sp. nov.**, female paratype (Jabal Qamr). Scale bars in Figs. 129–130: 0.50 mm.

buthid petite trichobothria (Soleglad & Fet, 2001), specifically the loss of femoral  $d_2$ , patellar  $d_2$ , chela manus  $Eb_3$  and  $Esb$ , and chela fixed finger  $esb$  (see

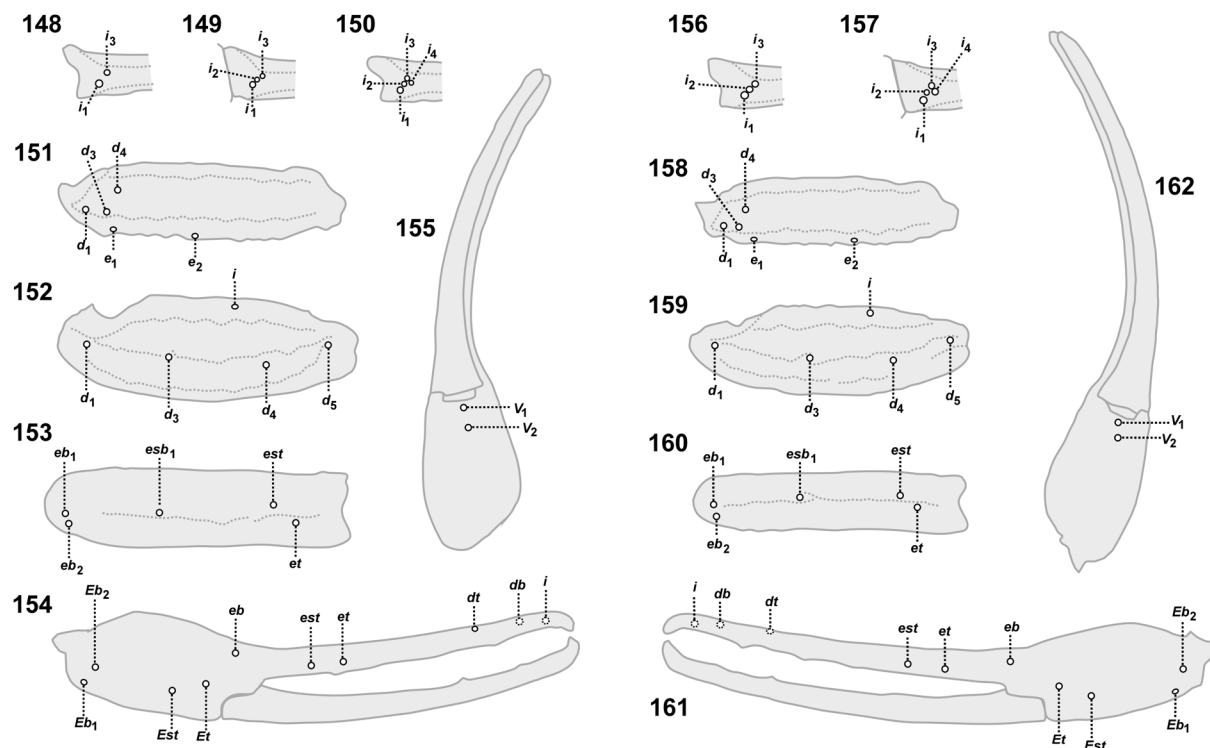
below). In larger buthids, these petite trichobothria are distinguishable from other trichobothria by having smaller diameter sockets (Navidpour et al. 2008). They



**Figures 135–147:** Trichobothrial maps of *Microbuthus* species in Oman. **135–140**, *M. gardneri*, **sp. nov.**, right pedipalp, holotype male. **135**. Base of femur, internal aspect. **136**. Femur, dorsal aspect. **137**. Patella, dorsal aspect. **138**. Patella, external aspect. **139**. Chela, external aspect. **140**. Chela, ventral aspect. **141–147**, *M. kristensenorum*, **sp. nov.**, right pedipalp, **141**, **143–147**, holotype female, **142**, topoparatype female. **141–142**. Base of femur, internal aspect. **143**. Femur, dorsal aspect. **144**. Patella, dorsal aspect. **145**. Patella, external aspect. **146**. Chela, external aspect. **147**. Chela, ventral aspect. Trichobothrial nomenclature after Vachon (1974), except for revised nomenclature in **Figs. 126–127**.

also have much shorter, finer shafts that are pale and fluorescent under ultraviolet illumination, in contrast to the longer shafts of other trichobothria that are dark and non-fluorescent. Fluorescence of these petite trichobothria can be clearly seen in high resolution images of pedipalps of *Akentrobuthus*, *Parabuthus*, *Pseudolychas* and *Rhopalurus* (Prendini, 2003; Prendini, 2004; Vignoli & Prendini, 2008; Prendini et al. 2009), and has been observed in many other buthids examined by the author, including those illustrated in Figs. 127–132 (i.e. *Androctonus*, *Isometrus*, *Lychas*, *Orthochirus* and *Tityus*), as well as representatives of the genera *Anomalobuthus*, *Apistobuthus*, *Babycurus*, *Buthacus*, *Butheolus*, *Centruroides*, *Compsobuthus*, *Hottentotta*, *Isometroides*, *Leiurus*, *Mesobuthus*, *Odontobuthus*, *Parabuthus*, *Uroplectes* and *Vachoniolus*. Although all picobuthoid trichobothria are relatively short compared to those of larger scorpions, no trichobothria with much shorter fluorescent shafts were present in any picobuthoid scorpion examined in this study. Therefore, homologies for observed picobuthoid trichobothria should be sought among the set of non-petite trichobothria identified in other buthids. On the pedipalp femur, patella and chela manus, positions of non-petite trichobothria correlate

well with those of other buthids, allowing unambiguous identification. Subtractive neobothriotaxy of non-petite trichobothria occurs on the internal surface of the femur (*Picobuthus* with 2–4, *Femtobuthus* with 2), dorsal surface of the femur (*Microbuthus* and *Picobuthus* with 3, *Femtobuthus* with 2), and external surface of the patella (*Femtobuthus* and *Picobuthus* with 5, losing *esb*<sub>2</sub> and *em*; *Microbuthus fagei* with 6, losing *em* (Vachon, 1949, 1952)). The high intraspecific variability in the number of internal trichobothria lost on the femur of *Picobuthus* (Figs. 148–150) shows the risk of basing new taxa solely on neobothriotaxic data obtained from small samples. The high degree of subtractive neobothriotaxy, both petite and non-petite, in *Picobuthus* and *Femtobuthus* may be correlated with the very small size of these two genera, which are significantly smaller than both species of *Microbuthus* found in Oman. The femoral trichobothrial count of *Femtobuthus* (total of 6, compared to the orthobothriotaxic 11) is the lowest of any known Recent buthid. With only 2 trichobothria on the dorsal surface of the femur, its pattern cannot be formally classified as either  $\alpha$ - or  $\beta$ -configuration (Vachon, 1975). However, the positions of the 2 trichobothria are well correlated with those of *d*<sub>1</sub> and *d*<sub>4</sub>



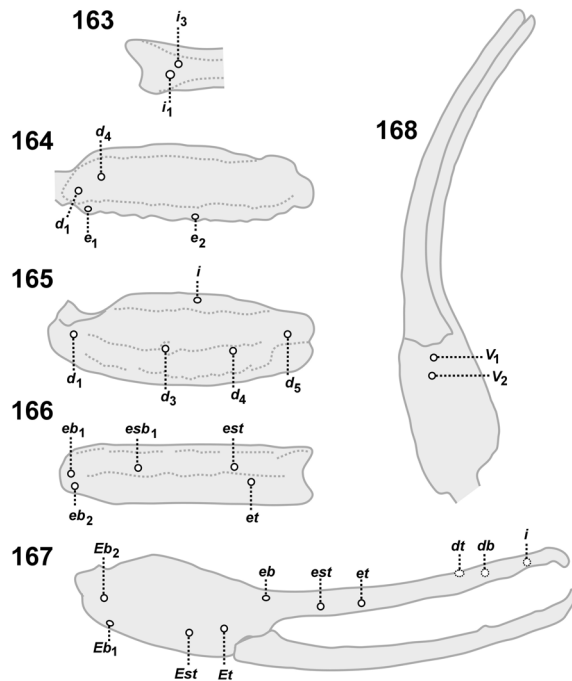
**Figures 148–162:** Trichobothrial maps of *Picobuthus* species. **148–155,** *P. wahibaensis*, **sp. nov.**, right pedipalp, **148, 151–155:** holotype male, **149–150:** paratype males (East Wahiba Sands). **148–150.** Femur, internal aspect. **151.** Femur, dorsal aspect. **152.** Patella, dorsal aspect. **153.** Patella, external aspect. **154.** Chela, external aspect. **155.** Chela, ventral aspect. **156–162,** *P. dundoni*, **sp. nov.**, right pedipalp femur and patella, left pedipalp chela, **156, 158–162:** holotype male, **157:** paratype female (Wadi Qitbit). **156–157.** Femur, internal aspect. **158.** Femur, dorsal aspect. **159.** Patella, dorsal aspect. **160.** Patella, external aspect. **161.** Chela, external aspect. **162.** Chela, ventral aspect. Trichobothrial nomenclature after Vachon (1974), except for revised nomenclature in **Figs. 126–127.**

in *Microbuthus* and *Picobuthus*, indicating that the *Femtobuthus* configuration is derived from the  $\beta$ -configuration of other picobuthoids by the loss of  $d_3$ . Thus, trichobothriotaxy of the picobuthoid group can be classified as type A $\beta$ , and the degenerate pattern of *Femtobuthus* can be interpreted as a synapomorphic condition.

In their description of *Microbuthus flavorufus*, Lourenço & Duhem (2007) reported the presence of 4 dorsal trichobothria on the pedipalp femur:  $d_1$ ,  $d_3$  and  $d_4$ , which also occur in other species of *Microbuthus* and in *Picobuthus*, and  $d_5$ , which is not seen in any other picobuthoid scorpion. They described  $d_5$  as “extremely reduced”, but it is unclear how it was distinguished from other socketed microsetae with areola diameters less than those of trichobothria  $d_1$ ,  $d_3$  and  $d_4$ . These microsetae are quite numerous on the pedipalp segments of other picobuthoids. They also indicated that the petite trichobothrium  $d_2$  was present on the pedipalp patella, and again characterized it as “extremely reduced”. Development of either of these two trichobothria would be unprecedented among picobuthoid scorpions, but their locations were not illustrated. Considering the

difficulty of visualizing small, reduced trichobothria in very small species of scorpions by light microscopy and clearly distinguishing them from other types of microsetae, these observations should be reassessed by electron microscopy (Navidpour et al. 2008).

The homologies of trichobothria on the pedipalp fixed finger of picobuthoids are less obvious. In *Microbuthus*, Vachon (1952: 319, figs. 463, 472; 1974: 910) identified the dorsoexternal trichobothrium located at the base of the fixed finger as  $db$ , the two external trichobothria on the proximal half of the finger as  $eb$  and  $esb$ , the third trichobothrium from the tip of the finger as  $et$ , the second from the tip as  $dt$ , and the most apical as  $i$ ;  $est$  was presumed missing (Fig. 125). These homologies were accepted by Lourenço (2002) and Lourenço & Duhem (2007). However, the labels applied by Vachon are inconsistent with the positions of corresponding trichobothria in other buthids relative to the standard landmark carinae on the chela. To resolve this conflict, first note that  $esb$  is a petite trichobothrium, and thus has most likely been lost in the picobuthoids along with the other petite trichobothria. The trichobothrium labeled by Vachon as ‘ $esb$ ’ has a socket diameter equal to that of



**Figures 163–168:** Trichobothrial map of *Femtobuthus shutuiae*, sp. nov., holotype male. **163.** Base of femur, internal aspect. **164.** Femur, dorsal aspect. **165.** Patella, dorsal aspect. **166.** Patella, external aspect. **167.** Chela, external aspect. **168.** Chela, ventral aspect. Trichobothrial nomenclature after Vachon (1974), except for revised nomenclature in Figs. 126–127.

the adjacent more proximal trichobothrium which he labeled as ‘*eb*’, and a shaft that is neither greatly reduced nor fluorescent. If the missing trichobothrium is in fact *esb*, not *est*, then one of the six trichobothria on the fixed finger must be *est*. It is proposed here that the trichobothrial homology of picobuthoids be determined by observing the positions of trichobothria of other buthids relative to standard landmark carinae (Soleglad & Sissom, 2001) on the chela fixed finger (Figs. 128–132): (i) both *est* and *et* are situated on the external surface of the fixed finger, external to and below the digital carina (D1), and directly adjacent to the dentate margin; (ii) *eb* and *esb* (if present) are situated internal to, or above D1, and external to or below the dorsal secondary carina (D3); (iii) *i*, *db* and *dt* are all situated internal to D3 on the fixed finger; (iv) *dt* is situated external to the dorsal marginal carina (D4) on the fixed finger; and (v) *db* is always situated internal to *dt*, either internal to, or interrupting D4; (vi) *i* is situated internal to the dorsal internal carina (D5). These considerations lead to the revised picobuthoid scheme shown in Figs. 126–127, in which *eb* (not *db*) is the dorsoexternal trichobothrium at the base of the fixed finger, *est* and *et* (not *eb* and *esb*) are the external trichobothria on the proximal half of the finger, *dt* (not *et*) is the third trichobothrium from the tip of the finger, and *db* (not *dt*) is the second from the tip.

The identification of the most apical trichobothrium as *i* is preserved, as it occupies the normal internal, sub-apical position. The homology that places *db* distal to *dt* in picobuthoids is unusual and not seen in other buthids, and was chosen to comply with the principle of avoiding traversal of trichobothria across landmark carinae. Carinal traversal is infrequent in buthid trichobothria, the shift of femoral *d2* across the dorsointernal carina, and of patellar *d3* across the dorsomedian carina being the only two well documented cases (Soleglad & Fet, 2001; Fet, Soleglad & Lowe, 2005). The reverse homology assignment for the second and third sub-distal trichobothria, with *db* proximal to *dt*, requires not one, but two traversals of trichobothria in opposing directions across D4 relative to the configuration in other buthids. Although *db* sometimes interrupts D4 on the buthid fixed finger, presumably as a result of lateral compression of the finger and reduction in the width of the D4–D5 intercarinal surface, there is no documented case of complete crossover of *db* onto the D3–D4 intercarinal surface. It is therefore more parsimonious to assume a proximal-distal shift of *db* independent of *dt*, that respects carinal boundaries. The original homology assignment of Vachon (1952, 1974) is much less parsimonious, its derivation from the prevalent buthid configuration requiring no less than 7 carinal traversals: *dt* across D4, *et* across D1 and D3, *esb* across D1, *eb* across D1, and *db* across D4 and D3. The unusual distal deployment of *db* might be correlated with the extreme extension, narrowing and warping of the pedipalp fingers of picobuthoids, a condition not found in other buthids. The proximal position of *et* in picobuthoids suggests that much of the chela finger elongation occurred distal to *et*, stretching the apical section of the finger between *est* + *et*, and *db* + *dt*. The strongly curved distal portion of the finger is too narrow to accommodate the carinae D3, D4 and D5, across its width. This apparently forced *db* to the internal aspect of the finger, and carina D5 has become nearly obsolete. Interestingly, displacement of *db* onto the internal surface also occurs in the very different genus *Pantobuthus*, apparently caused by broadening of the D4–D5 dorsal intercarinal surface of a very short, stout fixed finger (Lourenço & Duhem, 2009: 46, fig. 25). The far distal placement of *db* in picobuthoids might be dictated by mechanical constraints imposed on very slender fingers of small scorpions. The cuticle surrounding *db* is depressed or excavated in many larger buthids, often disrupting the D4 carina, and a localized excavation of the interior surface can also be seen around *db* of picobuthoids. A more proximal placement of *db* near the middle of the picobuthoid fixed finger may therefore weaken the finger at a point that probably experiences higher torque when the chela fingers are used to grasp prey.

In the revised picobuthoid trichobothrial scheme, the far apical deployment of *db* and *dt*, and the location

of *eb* at the base of the fixed finger or distal surface of the manus, is similar to patterns seen in the New World genera *Tityus* and *Centruroides* (González-Sponga, 1984; Francke & Stockwell, 1987), as well as in many Old World buthids belong to the genera *Lychas*, *Isometrus* and *Babycurus* (Vachon, 1972; Vachon, 1982; Tikader & Bastawade, 1983; Kovařík, 1997; Kovařík, 2000; Lowe, 2000) (Figs. 128–130). Another similarity to these genera is the tendency of patellar trichobothrium  $d_3$  to be situated external to the dorsomedian ( $DM_c$ ) carina. This was previously noted by Vachon (1952: 319, 322–323, figs. 470–471) for *M. fagei* and *M. kristensenorum* (= *M. pusillus* of Vachon). Fet, Soleglad & Lowe (2005) analyzed an example of *M. gardneri* in which  $d_3$  bifurcated the  $DM_c$  carina, and placed *Microbuthus* in the ‘Buthus’ group of scorpions characterized by having  $d_3$  internal to the  $DM_c$  carina. In very small scorpions, the continuity of carinae can be easily disrupted by nearby sensillar structures. This is seen, for instance, on the pedipalp patellae of *Picobuthus* and *Femtobuthus*, in which granules of the weakly developed dorsomedian carina detour around microsetal and trichobothrial insertion loci (Figs. 48, 73, 97). Examination of a larger sample of 64 patellae from 20 *Microbuthus gardneri* and 12 *M. kristensenorum* revealed a tendency for  $d_3$  to be located slightly external, but in close proximity to the dorsomedian carina (Figs. 133–134). A tendency for external placement of  $d_3$  does not strictly comply with the diagnosis of the ‘Buthus’ group. However, the  $DM_c$  carina of picobuthoids is irregular and discontinuous, following a trajectory that intersects all 4 dorsal patellar trichobothria ( $d_1$ ,  $d_3$ ,  $d_4$ ,  $d_5$ ), a unique condition in buthids. Fet, Soleglad & Lowe (2005) considered this an exceptional case within the ‘Buthus’ group. Biogeographically, the North African and Arabian distribution of picobuthoids is congruent with that of other members of this group. Alternatively, if picobuthoids were not members of the ‘Buthus’ group, then the  $\beta$ -configuration of the femoral trichobothria would imply membership in either the ‘Ananteris’ or ‘Isometrus’ groups (Fet, Soleglad & Lowe, 2005). Assignment to one of these two groups is not possible because they are defined by the dorsal or internal position of femoral  $d_2$ , which has been lost in the picobuthoids. It is interesting that the ‘Ananteris’ or ‘Isometrus’ groups mostly include scorpions with Afrotropical and Oriental distributions that favor mesic and humid, rather than arid habitats, which would be consistent with a mesic model of picobuthoid distribution. Analysis of additional taxonomic characters is needed to clarify the systematic position of these enigmatic scorpions.

The discovery in Oman of three new picobuthoid scorpions that appear to exhibit more plesiomorphic features, along with two new species of *Microbuthus*, suggests that this group of micro-scorpions might have

originated in the Arabian Peninsula. Of the known members of this group, *Picobuthus wahibaensis* exhibits the least specialized metasomal segments, most slender telson, and least trapezoidal carapace, all of which may be plesiomorphic traits. It may be the closest living approximation to an ancestral picobuthoid stem species. Two other species, *P. dundoni* and *Femtobuthus shutuae*, have more specialized metasomal segments with enlarged dentition that may be associated with fossorial lifestyles. The absence of tibial spurs on legs III–IV in *Picobuthus* may be a synapomorphy correlated with psammophilous adaptation (Navidpour & Lowe, 2009), and it is likely that tibial spurs were present in ancestral picobuthoids, and were retained by the non-psammophilous genera *Microbuthus* and *Femtobuthus*. Within the picobuthoids, *Microbuthus* appears to represent a distinct lineage defined by a unique synapomorphy, the highly modified form of metasomal segments IV–V and telson. The abbreviated form of the telson vesicle and the more strongly trapezoidal carapace in both *Femtobuthus* and *Microbuthus* could be synapomorphic traits indicating a closer relationship between these two genera. *Femtobuthus* may be a plesiomorphic sister genus to *Microbuthus*, descended from a picobuthoid with modified telson but lacking heavy fortification of metasoma IV–V. The more specialized hind metasoma and telson of *Microbuthus* might have been a key evolutionary innovation that liberated picobuthoids from more restrictive arenicolous or psammophilous niches, enabling them to expand into a greater variety of lapidicolous or epigeal habitats. This could have facilitated dispersal of *Microbuthus* out of the Arabian Peninsula into Africa. If such dispersal took place prior to separation of the Arabian plate from the African continent by rifting of the Red Sea, the picobuthoid lineage would date back to the Miocene or earlier (> ca. 5 Mya). This hypothesis predicts that the more plesiomorphic genera, *Picobuthus* and *Femtobuthus*, were not able to achieve wide dispersal and are restricted to the Arabian Peninsula. It will be interesting to see whether future surveys of scorpion faunas by ultraviolet detection will reveal any representatives of *Picobuthus* or *Femtobuthus* in Africa.

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## Appendix A

**Comparative material examined:** *Isometrus melano-dactylus*: 1 ♂, Queensland, Route 81, Rifle Creek, E of Mt Molloy, 17 March 1987, leg. G. Lowe (GL). *Lychas marmoreus*: 1 ♂, Australia, South Australia, pitfall, NE of Hahndorf, Millewa Road, Mt Lofty Ranges, 35.01° S 138.51° E, 30 January – 7 February 1999, leg. N. L. & S. J. Fargher (GL). *Tityus ecuadorensis*: 1 ♂, Ecuador, Vilcabamba, 1990, leg. S. D. Miller (GL). *Androctonus crassicauda*: 1 immature ♂, Oman, Batinah coast, 10–15 km W of Barka, Abyad pipeline road, 23°41.16'N 57°43.61'E, < 50 m a.s.l., 13 October 1993, leg. G. Lowe, A. S. Gardner & S. M. Farook (NHMB). *Orthochirus scrobiculosus*: 1 ♀, Turkmenistan, Bolshoi Balkhan Mt., 20 April 1993, leg. A. Feodorov (GL).

### Key to new species of picobuthoid scorpions in Oman.

- 1 Metasoma IV–V heavily sclerotized, ventral and lateral surfaces smooth with numerous cuticular pits or depressions (Figs. 21–22, 40–41) ..... 2  
     Metasoma IV–V not heavily sclerotized, granular, without cuticular pits ..... 3
- 2 Metasoma IV–V and telson densely pilose, numerous long curved macrosetae arising from cuticular pits (Figs. 40–41); metasoma V L/W 1.24–1.48 ..... *Microbuthus kristensenorum*  
     Metasoma IV–V and telson lacking dense pilosity, cuticular pits with very short microsetae (Figs. 21–22); metasoma V L/W 1.04–1.20 ..... *Microbuthus gardneri*
- 3 Pedipalp femur with 2 internal, 2 dorsal trichobothria (Figs. 163–164); metasoma V stout, L/W 1.3–1.6; telson vesicle moderately swollen, ovoid ..... *Femtoobuthus shutuae*  
     Pedipalp femur with 2–4 internal, 3 dorsal trichobothria; metasoma V slender, L/W 1.8–2.3; telson vesicle pyriform ..... 4
- 4 Metasoma II–III with enlarged, dentate granules on ventrosubmedian carinae; metasoma V with enlarged lobate granules on posterior ventrolateral carinae or posterior ventral intercarinal surface (Figs. 107–109); metasoma V L/W 1.82–2.04 ..... *Picobuthus dundoni*  
     Metasoma II–III without enlarged, dentate granules; metasoma V with small dentate granules on posterior ventrolateral carinae, posterior ventral intercarinal surface without enlarged granules (Figs. 83–86); metasoma V L/W 2.08–2.29 ..... *Picobuthus wahibaensis*