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Holocene Ostracods from the Hang Hau Formation in Lei Yue Mun, Hong Kong, and their palaeoenvironmental implications

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The Holocene Hang Hau Formation is the youngest part of the Quaternary succession in Hong Kong and yields abundant and diverse ostracods. This study of ostracod assemblages from two cores in Lei Yue Mun identifies eight genera and nine species of marine Ostracoda that were previously unreported from the Hang Hau Formation, increasing the known diversity from 67 to 76 species. Among these species, *Neocyprideis timorensis* (Fyan 1916) is reported for the first time in China. The recovery of abundant juvenile and adult specimens has facilitated illustration and discussion of an ontogenetic series for *Neomonoceratina delicata* Ishizaki & Kato, 1976, extending from the A-5 instar (fourth moult after hatching) to the sexually dimorphic A (adult) instar. Palaeoenvironmental analysis of the ostracod assemblages supports and strengthens previous interpretations indicative of a warm, shallow, nearshore-marine environment.

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Key words: Hong Kong, Hang Hau Formation, ostracods, ontogeny, palaeoenvironment

HONG KONG lies on the northern fringe of the South China Sea, at the mouth of the Pearl River. Quaternary sediments in Hong Kong provide a record of deposition for the middle Pleistocene and Holocene, spanning 200000 years or more (Fyfe *et al*. 2000). The Quaternary stratigraphy in Hong Kong is usually divided into two parts: onshore and offshore (Fyfe *et al*. 2000). In ascending order, the onshore succession consists of the Chek Lap Kok and Fan Ling formations, whereas the offshore area contains the Tung Chung, Chek Lap Kok, Sham Wat, Waglan and Hang Hau formations (Fyfe *et al*. 2000). The Hang Hau Formation, the uppermost part of the Quaternary offshore succession in Hong Kong, yields abundant ostracods.

Ostracods from Hong Kong have been studied for a long time. Brady (1869) reported the first ostracod fauna from Hong Kong, material which was later revised by Whatley & Zhao (1988). Yim *et al*. (1988) also studied Holocene ostracods from Hong Kong and discussed their palaeoenvironmental significance. Since then, few studies have focused on the fossil ostracods of Hong Kong. Cao (1998) reported (in Chinese) on ostracods in two boreholes from the Hang Hau Formation in Lei Yue Mun (the channel; Fig. 1), describing 41 genera and 67 species from two cores. Hong *et al*. (2017) reported some ostracods in a hand-push piston corer from the east coast of the Plover Cove Reservoir, Hong Kong.

Here, we restudy the samples of Cao (1998) and add new specimens recently prepared from the same two cores.

Geological setting

The two boreholes, VB1 and VB6, are located in a shallow sea northeast of Lei Yue Mun, on the Kowloon side of the bay. The boreholes are located at 22°17′1.49″N 114°150′18.73″E, and 22°17′21.38″N 114°14′55.26″E, respectively (Fig. 1; Tables 1, 2).

The Hang Hau Formation can be subdivided into three members: in ascending order, the Tung Lung, Pok Liu and Tseung Kwan O members (Fyfe *et al*. 1997). The Tung Lung Member is composed mainly of

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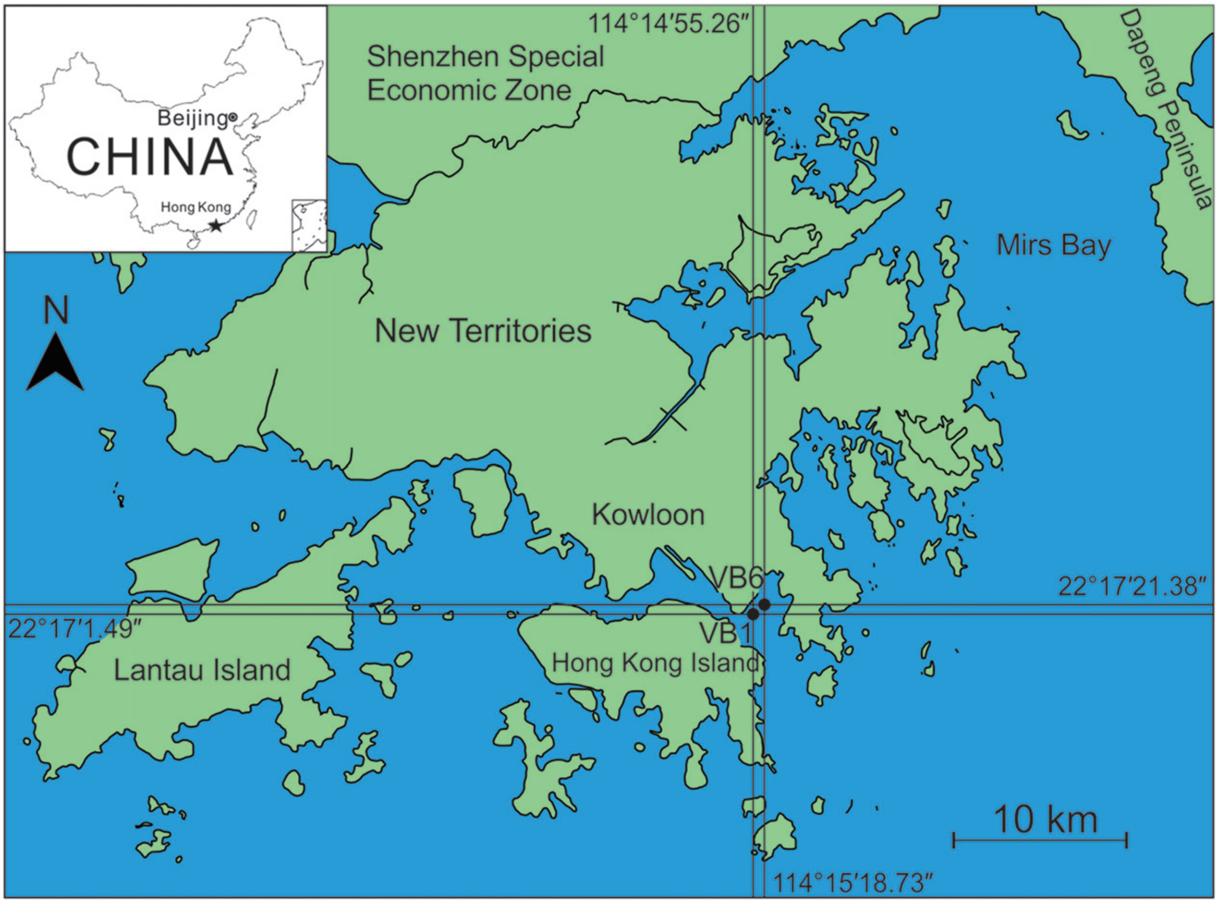

Fig. 1. Location of the boreholes VB1 and VB6, within Lei Yue Mun, Hong Kong, China.

very fine to fine sand, whereas the Pok Liu and Tseung Kwan O members consist mainly of greenish-grey to dark-grey argillaceous ooze (Fyfe *et al*. 1997). Shells and shell debris can be found thoughout the formation (Fyfe *et al*. 1997). The oldest radiocarbon dating ages obtained from the Hang Hau Formation, from the Pok Liu Member, are between 9500 and 9000 years BP; basal sediments of the overlying Tseung Kwan O Member have been dated at 7990 ± 70 years BP (Fyfe *et al*. 1997).

Based on the petrographic characteristics of the two cores (VB1 and VB6; Tables 1, 2), we consider that these sediments represent the middle to upper part of the Hang Hau Formation.

Material and methods

The two boreholes studied, VB1 and VB6, were drilled for engineering purposes in 1997 by the Bachy Soletanche Group, with each borehole being about 10 m deep. Select samples from the two cores were sent to the Nanjing Institute of Geology and Palaeontology of the Chinese Academy of Sciences (NIGPAS) by Prof. Li Zuoming of the Hong Kong Polytechnic University; nine of these samples subsequently yielded ostracods after processing.

The samples were disaggregated in water, then washed and sieved through three table sieves (850 µm, 150 µm and 75 µm). Ostracods were picked under a binocular microscope. Unclean ostracode carapaces were cleaned with a fine wet brush. Selected specimens were placed on stubs, gold coated and then photographed using a LEO 1530VP scanning electron microscope, located at NIGPAS. All specimens illustrated in this article are housed and catalogued at NIGPAS storage facilities (catalogue numbers beginning with NGIP).

Abbreviations. H: height; L: length; W: width; LV: left valve; RV: right valve.

Systematic palaeontology

Class OSTRACODA Latreille, 1806

Order PODOCOPIDA Sars, 1866

Superfamily CYTHEROIDEA Baird, 1850

Family BYTHOCYTHERIDAE Sars, 1866

Pseudocythere Sars, 1866

Type species. *Pseudocythere caudata* Sars, 1866

Pseudocythere frydli Yajima, 1982 (Fig. 2A, B)

Table 1. Petrographic description of core VB1, revised from Cao (1998), Lan (1998), Pan (1998) and Wang (1998).

Core depths	Sample	Petrographic description	Fossils
0–1.40 m	Unsampled	–	–
1.40–2.40 m	–	Grey, argillaceous to silty, fine to coarse sand	Marine shell debris
2.40–4.00 m	–	Grey, argillaceous to silty, fine to coarse sand; containing lots of angular to subrounded, granular to pebble, quartz gravels	Shell and coral debris
4.00–7.75 m	4.00–4.40 m, 5.00–5.20 m, 7.00–7.20 m	Soft, greenish-grey, sandy clay	Foraminifers, bivalves, gastropods and ostracods
7.75–8.50 m	–	Dark grey to grey, argillaceous to silty, fine to coarse sand	Marine shell debris
8.50–9.75 m	8.60–8.80 m	Soft to hard, yellowish-brown and grey with white patches, silty to sandy clay	Foraminifers, bivalves, gastropods and ostracods
9.75–10.30 m	10.00–10.30 m	Soft, greenish-grey, sandy clay	Foraminifers, bivalves, gastropods and ostracods

Table 2. Petrographic description of core VB6, revised from Cao (1998), Lan (1998), Pan (1998) and Wang (1998).

Core depths	Sample	Petrographic description	Fossils
0–2.00 m	–	Soft to very soft, greenish-grey, silty to sandy clay	Marine shell debris
2.00–5.50 m	2.40–2.60 m, 5.00–5.20 m	Soft, greenish-grey, silty to sandy clay	Foraminifers, bivalves, gastropods and ostracods
5.00–8.20 m	7.00–7.20 m	Soft, greenish-grey, silty clay	Foraminifers, bivalves, gastropods and ostracods
8.20–8.55 m	–	Hard, black and grey, sandy to silty clay	Plant debris
8.55–10.00 m	–	Compacted to hard, light-brown and yellow, silty to sandy clay, intercalated with grey and red stripes	–

1982 *Pseudocythere frydli* sp. nov., Yajima (1982), p. 215, pl. 13, fig. 15; text-figs 16 (7, 8).

1986 *Pseudocythere frydli* Yajima, 1982, Hu (1986), p. 149, pl. 23, figs 11, 12, 14, 15, 17, 18; text-fig. 6c.

1988 *Pseudocythere frydli* Yajima, 1982, Ruan & Hao (1988), p. 261, pl. 42, figs 7, 8.

1990 *Pseudocythere frydli* Yajima, 1982, Ruan (1990), pl. 1, fig. 7.

2003 *Pseudocythere frydli* Yajima, 1982, Yasuhara & Kumai (2003), pl. 3, fig. 8.

Material. Two well-preserved left valves (NIGP166002, 166003).

Dimensions. NIGP166002: L = 562 µm, H = 276 µm; NIGP166003: L = 625 µm, H = 310 µm.

Occurrence. VB1, 4.00–4.40 m.

Remarks. The two specimens can be attributed to *P. frydli* Yajima, 1982 based on the following features: carapace elongate ovate in lateral view; a fine sulcus running along the anterior margin; posterior margin straight or slightly concave; more than 16 subparallel striae in the posterior part, converging at the posterior margin.

Pseudocythere frydli is widely distributed in Japan, Taiwan, the South China Sea, the Okinawa Trough and Hong Kong, and has an age ranging from the late Pliocene to Holocene (Hou & Gou 2007, Hu & Tao 2008).

Family HEMICYTHERIDAE Puri, 1953

Coquimba Ohmert, 1968

Type species. *Coquimba hermi* Ohmert, 1968

Coquimba lianpui Hu & Tao, 2008 (Fig. 2C)

2008 *Coquimba lianpui* sp. nov., Hu & Tao (2008), p. 239–240, pl. 90, fig. 15; pl. 178, fig. 21; pl. 198, figs 2, 4, 13, 18; pl. 222, fig. 10.

Material. A well-preserved right valve (NIGP166004).

Dimensions. L = 512 µm, H = 269 µm.

Occurrence. VB1, 7.00–7.20 m.

Remarks. This specimen shares some features with Hu & Tao's (2008) type specimens: carapace subquadrate in lateral view; anterior end evenly rounded with a sulcus along it; posterior end centrally obtuse, slightly concave posterodorsally; a round tubercle situated anterocentrally; prominent angular massive tubercle present at the posteroventral with a ridge above it.

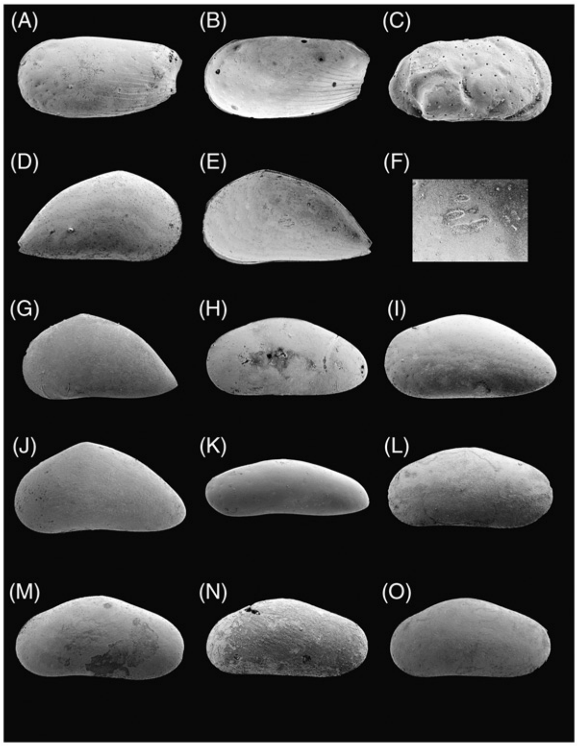

Fig. 2. SEM images of ostracod species from the Hang Hau Formation, Lei Yue Mun, Hong Kong, China. **A, B,** *Pseudocythere frydli* Yajima, 1982: **A,** NIGP166002, LV; **B,** NIGP166003, LV. **C,** *Coquimba lianpui* Hu & Tao, 2008, NIGP166004, RV. **D–G,** *Pontocypris subtriangulata* (Hu 1984): **D,** NIGP166005, RV; **E,** Internal view of NIGP166005; **F,** muscle scars of NIGP166005; **G,** NIGP166006, LV. **H, I,** *Propontocypris bengalensis* Maddocks, 1969: **H,** NIGP166013, LV; **I,** NIGP166014, LV. **J,** *Propontocypris crocata* Maddocks, 1969, NIGP166007, LV. **K,** *Argilloecia lunata* Frydl, 1982, NIGP166008, LV. **L–O,** *Aglaiocypris pellucida* Mostafawi, 2003: **L,** NIGP166009, LV; **M,** NIGP166010, LV; **N,** NIGP166011, LV; **O,** NIGP166012, LV. Scale =100 µm.

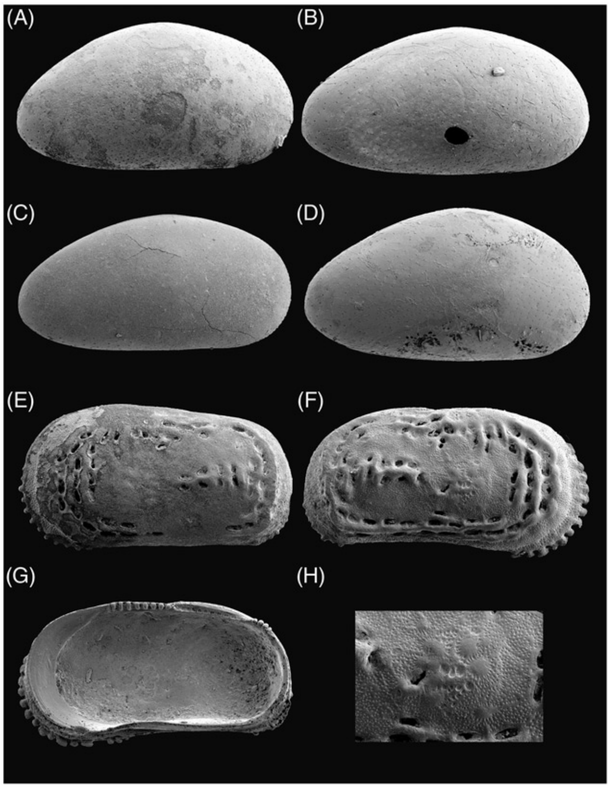

Fig. 3. SEM images of ostracod species from the Hang Hau Formation, Lei Yue Mun, Hong Kong, China. **A–D,** *Propontocypris clara* Zhao, 1988: **A,** NIGP166015, RV; **B,** NIGP166016, RV; **C,** NIGP166017, RV; **D,** NIGP166018, RV. **E–H,** *Neocyprideis timorensis* (Fyan 1916): **E,** NIGP166019, LV; **F,** NIGP166020, RV; **G,** internal view of NIGP166020; **H,** External muscle scars of NIGP166020. Scale =100 µm.

This species was previously reported from the Pleistocene and Holocene of Taiwan, Matsu and Fujian in China (Hu & Tao 2008). It is found from the Holocene of Hong Kong for the first time.

Family CYTHERIDEIDAE Sars, 1925

Neocyprideis Apostolescu, 1956

Type species. *Cyprideis (Neocyprideis) durocortoriensis* Apostolescu, 1956

Neocyprideis timorensis (Fyan 1916) (Fig. 3E–H)

1916 *Cytheridea timorensis* sp. nov., Fyan, p. 1211, fig. 9.

1976 *Bishopina mozarti* sp. nov., Bonaduce, Masoli & Pugliese, p. 397, pl. 12, figs 1–7.

1977 *Cytherelloidea* sp., Hughes (1977) MS, pl. 70, fig. 10.

1980 *Neocyprideis timorensis* (Fyan 1916), Williams (1980) MS, p. 57, pl. 3, figs 6–8.

1986 *Bishopina timorensis* (Fyan 1916), Malz & Ikeya (1986), pl. 3, figs 1–3.

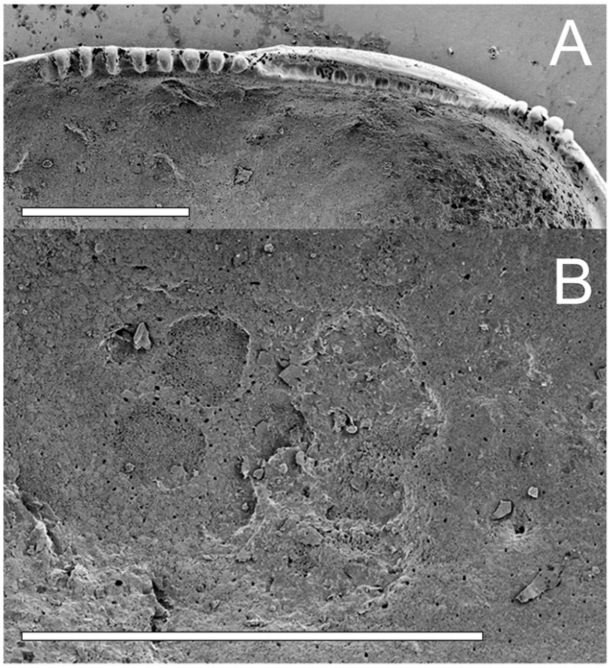

Fig. 4. Morphological details of *Neocyprideis timorensis* (Fyan 1916) (NIGP166020): **A,** Hinge; **B,** Muscle scars. Scale =100 µm.

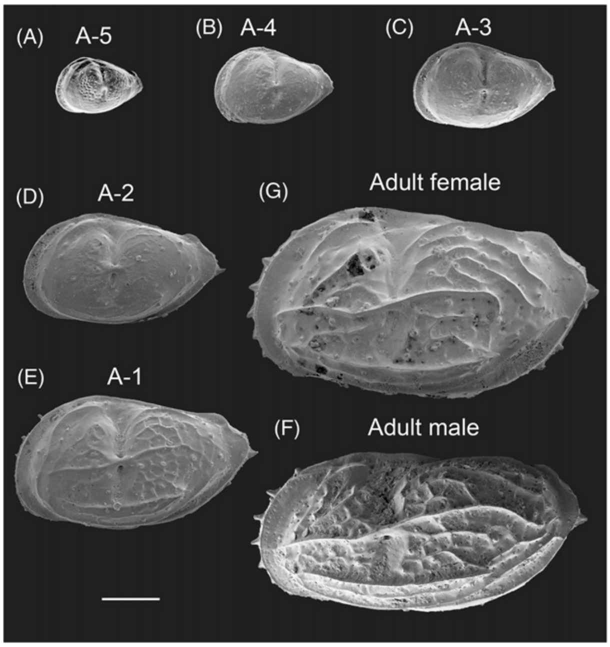

Fig. 5. SEM images of *Neomonoceratina delicata* Ishizaki & Kato, 1976, from the Hang Hau Formation, Lei Yue Mun, Hong Kong, China: **A,** NIGP166021, LV; **B,** NIGP166022, LV; **C,** NIGP166037, LV; **D,** NIGP166038, LV; **E,** NIGP166039, LV; **F,** NIGP166040, LV; **G,** NIGP166041, LV. Scale = 100 µm.

1988 *Neocyprideis timorensis* (Fyan 1916), Watson (1988) MS, p. 110, pl. 22, figs 10–18.

1988 *Neocyprideis timorensis* (Fyan 1916), Taylor (1988) MS, p. 42, pl. 2, figs 22, 23.

2001 *Neocyprideis timorensis* (Fyan 1916), Titterton *et al*. (2001), p. 37–38, pl. 2, figs 6–10.

2012 *Bishopina timorensis* (Fyan 1916), Munef *et al*., p. 156, pl. 2, fig. 23.

Material. A well-preserved left valve (NIGP166019) and a well-preserved right valve (NIGP166020).

Dimensions. NIGP166019: L = 511 µm, H = 268 µm; NIGP166020: L = 528 µm, H = 263 µm.

Occurrence. NIGP166019: VB1, 4.00–4.40 m; NIGP166020: VB1, 5.00–5.20 m

Diagnosis. Carapace medium-sized, thick-shelled and subrectangular in lateral view, with greatest height just anterior of mid-length. Surface of valves densely pitted, punctae large, deep around periphery and posterior central.

Description. Carapace laterally subrectangular; dorsal margin almost straight, ventral outline slightly concave; few marginal denticles in the anteroventral and posteroventral regions. Surface of valves densely pitted, punctae large, deep around periphery and posterior central area. Wide anterior vestibula. Entomodont hinge (Fig. 4A). The anterior tooth of the right valve is very long with nine small fine toothlets. The posterior tooth is crenulate and composed of four toothlets. Between the terminal teeth in the right valve is an undivided finely crenulate groove, which is the deepest in the middle. Vertical row of four undivided adductor muscle scars; frontal muscle scars prominent (Fig. 4B).

Remarks. The relationship between the three genera *Miocyprideis* Kollmann, 1960, *Bishopina* Bonaduce, Masoli & Pugliese, 1976 and *Neocyprideis* Apostolescu, 1956 is unclear. Titterton *et al*. (2001) tried to unify *Miocyprideis* and *Bishopina* under *Neocyprideis*, but Munef *et al*. (2012) thought they were different genera. Yasuhara *et al*. (2018) also abstain from separating these genera and further discussed their morphological differences and environmental preferences. This study follows Titterton *et al*. (2001) and Yasuhara *et al*. (2018), who considered the differences among the three genera to be insufficient to allow *Miocyprideis* and *Bishopina* generic status.

It should be noted that *N. timorensis*, found in VB1, is reported here for the first time in China. This species has previously been found in Recent sediments of the Red Sea, Singapore, Phuket Island, West Malay Peninsula, Thailand, Australia, Kenya, Java Sea and Northern Socotra Island (Indian Ocean, Yemen), as well as the upper Pliocene of Timor, and Miocene–Quaternary of the Solomon Islands (Titterton *et al*. 2001, Munef *et al*. 2012).

Family CANDONIDAE Kaufmann, 1900

Aglaiocypris Sylvester-Bradley, 1947

Type species. *Aglaiocypris pulchella* (Brady, 1868a) Sylvester-Bradley, 1947

Aglaiocypris pellucida Mostafawi, 2003 (Fig. 2L–O)

2003 *Aglaiocypris pellucida* sp. nov., Mostafawi, p. 71, figs A–C

Material. Four well-preserved left valves (NIGP166009–166012).

Dimensions. NIGP166009: L = 562 µm, H = 274 µm; NIGP166010: L = 602 µm, H = 298 µm; NIGP166011: L = 560 µm, H = 270 µm; NIGP166012: L = 578 µm, H = 283 µm.

Occurrence. NIGP166009: VB1, 4.00–4.40 m; NIGP166010, 166011: VB1, 5.00–5.20 m; NIGP166012: VB6, 7.00–7.30 m.

Remarks. These specimens share the following diagnostic features with the type specimens: carapace obtuse triangular in lateral view; both ends evenly rounded; maximum height in the middle; dorsal margin convex, and ventral margin concave in anterior half; numerous normal pores on the carapace. This discovery is the first record from Hong Kong.

Superfamily PONTOCYPRIDOIDEA Müller, 1894

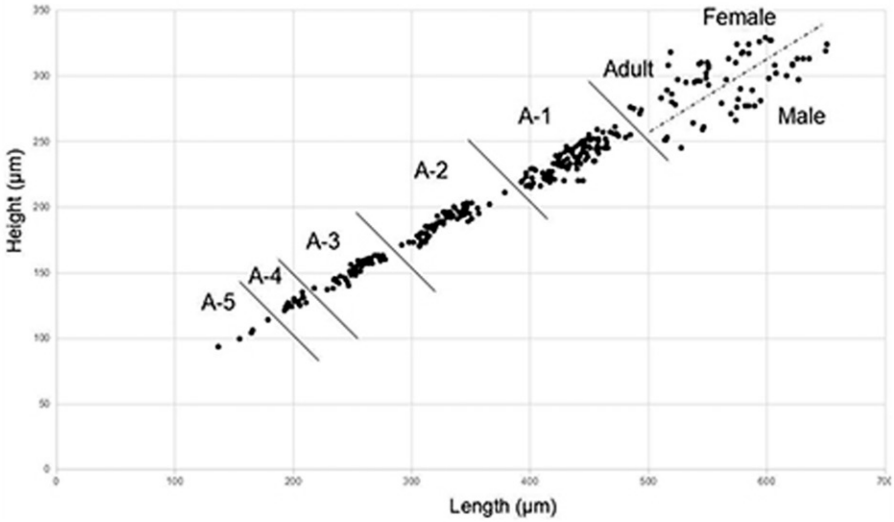

Fig. 6. Plot of carapace length versus height of specimens of *Neomonoceratina delicata* Ishizaki & Kato, 1976 from the Hang Hau Formation, Lei Yue Mun, Hong Kong, China.

Family PONTOCYPRIDIDAE Müller, 1894

Pontocypris Sars, 1866

Type species. *Cythere (Bairdia) mytiloides* Norman, 1862

Pontocypris subtriangulata (Hu 1984) (Fig. 2D–G)

1984 *Propontocypris subtriangulata* sp. nov., Hu, p. 74, pl. 8, figs 3–6, 10; text-figs 5 a, b, d.

1988 *Propontocypris* cf. *crocata* Maddocks, 1969, Ruan & Hao (1988), p. 245, pl. 36, fig. 8.

2008 *Pontocypris subtriangulata* Hu, 1984, Hu & Tao, p. 97, pl. 109, figs 13, 18; pl. 184, fig. 11, text-figs 66 A, B, C.

Material. A right valve with posterior margin broken (NIGP166005) and a well-preserved left valve (NIGP166006).

Dimensions. NIGP166005: L = 691 μm, H = 375 μm; NIGP166006: L = 833 μm, H = 460 μm.

Occurrence. NIGP166005: VB1, 5.00–5.20 m; NIGP166006: VB1, 7.00–7.20 m.

Remarks. The two specimens can be attributed to *Pontocypris subtriangulata* (Hu 1984) based on the following features: carapace medium-sized; subtriangular in lateral view; maximum height anteriorly; anterior margin rounded; posterior margin acute; ventral margin concave; numerous normal pores on the carapace.

Apart from this new record in the Holocene of Hong Kong, the species is only known from the upper Pleistocene of Taiwan (Hu & Tao 2008).

Propontocypris Sylvester-Bradley, 1947

Type species. *Pontocypris trigonella* Sars, 1866

Propontocypris bengalensis Maddocks, 1969 (Fig. 2H, I)

1969 *Propontocypris* (*Schedopontocypris*) *bengalensis* sp. nov., Maddocks, p. 38, figs 31 A, C, F.

2003 *Propontocypris bengalensis* Maddocks, 1969, Mostafawi, p. 71, figs 48 A, B.

Material. Two well-preserved left valves (NIGP166013, 166014).

Dimensions. NIGP166013: L = 466 μm, H = 228 μm; NIGP166014: L = 479 μm, H = 232 μm.

Occurrence. NIGP166013: VB1, 4.00–4.40 m; NIGP166014: VB1, 7.00–7.20 m.

Remarks. The two specimens possess the following features: carapace subtriangular in lateral view; rounded anteriorly, subacute posteriorly; maximum height in the middle; dorsal margin convex, ventral margin slightly concave; numerous normal pores on the carapace. On this basis, they can be attributed to *Propontocypris bengalensis* Maddocks, 1969. This species is here reported for the first time from Hong Kong.

Propontocypris crocata Maddocks, 1969 (Fig. 2J)

1969 *Propontocypris crocata* sp. nov., Maddocks, p. 11, text-figs 11B, D–F, I–M.

1988 *Propontocypris crocata* Maddocks, 1969, Ruan & Hao (1988), p. 245, pl. 36, figs 7–11.

2008 *Propontocypris crocata* Maddocks, 1969, Hu & Tao (2008), p. 104, pl. 98, fig. 18; pl. 110, figs 4, 21; pl. 184, figs 3, 6, text-fig. 67.

Material. A well-preserved left valve (NIGP166007).

Dimensions. L = 580 μm, H = 305 μm.

Occurrence. VB6, 7.00–7.30 m.

Remarks. *Propontocypris crocata* Maddocks, 1969 has the following diagnostic features: carapace medium-sized, subtriangular in lateral view; maximum height anteriorly or in the middle; anterior margin narrowly rounded; posterior margin subacute; ventral margin concave; carapace with numerous normal pores. These features are all found in the new specimen, and so we attribute it to *P. crocata*.

This species was distributed in Taiwan, the Okinawa Trough, Indian Ocean and Hong Kong from the late Pleistocene to Holocene (Maddocks 1969, Ruan & Hao 1988, Hu & Tao 2008, this study).

Propontocypris clara Zhao, 1988 (Fig. 3A–D)

1988 *Propontocypris clara* sp. nov., Zhao in Wang *et al*. (1988), p. 230, pl. 36, figs 3–5.

1989 *Propontocypris clara* Zhao, 1988, Ruan (1989), p. 118, pl. 20, fig. 24.

2009 *Propontocypris clara* Zhao, 1988, Tanaka *et al*. (2009), pl. 1, fig. 1.

Material. Four well-preserved right valves (NIGP166015–166018).

Dimensions. NIGP166015: L = 526 µm, H = 280 µm; NIGP166016: L = 497 µm, H = 256 µm; NIGP166017: L = 504 µm, H = 252 µm; NIGP166018: L = 512 µm, H = 274 µm.

Occurrence. NIGP166015, 166016: VB1, 5.00–5.20 m; NIGP166017, 166018: VB1, 7.00–7.20 m.

Remarks. The four specimens share the following features with *Propontocypris clara* Zhao, 1988: carapace elongate subtriangular in lateral view; rounded anteriorly, narrowly rounded posteriorly; maximum height anteriorly; dorsal margin convex, ventral margin slightly convex; numerous normal pores on the carapace. Based on these features, they can be attributed to this species.

The species was widely distributed in the Northern Xisha Trench, East China Sea, South China Sea, Vietnam and Hong Kong from the middle Pleistocene to Holocene (Hou & Gou 2007, Tanaka *et al*. 2009, this study).

Argilloecia Sars, 1866

Type species. *Argilloecia cylindrica* Sars, 1866

Argilloecia lunata Frydl, 1982 (Fig. 2K)

1982 *Argilloecia lunata* sp. nov., Frydl (1982), p. 127, pl. 8, figs 3–7, text-fig. 319.

1988 *Argilloecia lunata* Frydl, 1982, Wang *et al*. (1988), p. 231, pl. 36, figs 9, 10, text-fig. 5.69.

1988 *Argilloecia lunata* Frydl, 1982, Ruan & Hao (1988), p. 240, pl. 37, figs 18–20.

1989 *Argilloecia lunata* Frydl, 1982, Ruan (1989), p. 117, pl. 20, fig. 11.

1993 *Argilloecia* cf. *lunata* Frydl, 1982, Dewi (1993), p. 112, figs 35, 36.

1994 *Argilloecia lunata* Frydl, 1982, Zheng *et al*. (1994), pl. 45, fig. 19.

2008 *Argilloecia lunata* Frydl, 1982, Tanaka (2008), fig. 2e.

2014 *Argilloecia lunata* Frydl, 1982, Iwatani *et al*. (2014) fig. 3.1.

Material. A well-preserved left valve (NIGP166008).

Dimensions. L = 553 µm, H = 184 µm.

Occurrence. VB1, 4.00–4.40 m.

Remarks. This specimen is attributed to *Argilloecia lunata* Frydl, 1982 based on the following features: elongate in lateral outline, subrounded anteriorly and subacute posteriorly; dorsal margin convex, ventral margin sinuate.

This species was widely distributed in Japan, the Okinawa Trough, Northern Xisha Trench, East China Sea, South China Sea and Hong Kong from the late Pleistocene to Holocene (Hou & Gou 2007, this study).

Discussion

The main purpose of this paper is to record ostracod taxa that were previously unrecognized in the Hang Hau Formation; detailed palaeoenvironmental analysis must await the results of further study. Nevertheless, some useful comments about palaeoenvironmental aspects of the fauna as a whole may be made at this early stage of the research.

Ontogeny of Neomonoceratina delicata Ishizaki & Kato, 1976

Neomonoceratina delicata is widely distributed in the inner bays of the Ryukyu Islands, the southwestern part of the East China Sea, the northern part of the South China Sea, and southeastern Asia (Irizuki *et al*. 2009).

In VB6 (5.00–5.20 m), we found more than 500 specimens attributed to *N. delicata* (Fig. 5). The carapace lengths and heights for all these specimens were measured, and an ontogenetic growth series plotted for this species based on left valves only (Fig. 6). Ostracod growth occurs by moulting, with an increase in the valve length of 1.18–1.35 times per moult (Anderson 1964). Ostracod moult stages are expressed as: A (adult), A-1, A-2, A-3, etc., in order of decreasing size and younger ages (Yamaguchi *et al*. 2015). Podocopid ontogeny usually constitutes nine instars (eight juvenile stages and one adult stage; e.g., Horne *et al*. 2002), with instars forming data-point clusters on an L–H scatter plot (Yamaguchi *et al*. 2015). In our study, six instars are identifiable, with clear gaps separating each set from one another. The mean height and length of these instars are: A = 566.2 µm and 294.9 µm; A-1 = 437.0 µm and 237.8 µm; A-2 = 328.3 µm and 188.6 µm; A-3 = 254.6 µm and 152.7 µm; A-4 = 202.8 µm and 127.7 µm; and A-5 = 160.4 µm and 103.4 µm. The increase in the valve length observed in this dataset is 1.26–1.33 times, which is consistent with both Anderson (1964) and Brooks' rule, the latter of which suggests that with each moult, crustaceans double their volume and increase their linear dimensions by approximately the cube root of two (1.26) (Brooks 1886). The specimens of *N. delicata* figured were chosen to represent the six distinct instars.

In many cases, the male forms of these podocopids have relatively longer and narrower carapaces than the females (Ozawa 2013), and female adults can be distinguished from male specimens in the *N. delicata* material from Hong Kong (Fig. 5). For the female adults, the mean height and length are 548.8 µm and 302.8 µm, respectively, being 586.2 µm and 284.7 µm for the adult males. As a result, the carapace length is more than twice the height in the male adults but less than twice the height in the female adults.

Diversity

Previous research (Cao 1998) recorded 67 species of ostracods, within 41 genera, from the Holocene Hang Hau Formation in Lei Yue Mun; the present study raises the diversity to 76 species within 49 genera (Appendix 1). Most of the taxa reported by Cao (1998) belong to the Podocopina, with fewer belonging to the Platycopina; all of the additional taxa reported herein belong to the Podocopina.

Taphonomy

The recognition of six instars of *N. delicata* in sample VB6 (5.00–5.20 m) leads us to suggest that this represents an *in situ* assemblage with little or no post-mortem transport, size sorting or mixing (Boomer *et al.* 2003), although it must be noted that an assemblage from a 20 cm-thick sample is likely to be time-averaged. Our conclusion is supported to some extent by the observation that the ostracods in borehole VB6 include many delicate valves, which are unlikely to have survived transportation over long distances. The ostracods from borehole VB6 can therefore be treated as parautochthonous or autochthonous elements, directly representative of the local environment.

Most ostracods from borehole VB1 are well preserved but disarticulated, which indicates that these ostracods can be regarded as parautochthonous elements transported only short distances and preserved under moderate-energy hydrodynamic conditions.

Palaeoecology and palaeoenvironments

A total of 26 genera and 35 species of ostracods have been found in borehole VB6 to date. Based on the observations of this study, combined with those of Cao (1998), this ostracod assemblage is dominated by *Sinocytheridea impressa* (Brady 1869), *Pistocythereis bradyi* (Ishizaki 1968) and *P. bradyformis* (Ishizaki 1968), with other common species including *Neomonoceratina delicata*, *Bicornucythere bisanensis* (Okubo 1975), *Cornucoquimba leizhouensis* Gou in Gou *et al*. 1983 and *Xestoleberis hanaii* Ishizaki, 1968. In Recent and Quaternary sediments along the coast of China, *Sinocytheridea impressa* is widely distributed in supratidal to upper shelf settings in water less than 20 m deep (Zhao & Wang 1988a, 1990, Liu *et al*. 2013). This well-known euryhaline species can tolerate salinity values as low as 2‰ (Zhao & Wang 1988a, 1990, Liu *et al*. 2013) and is especially abundant in brackish waters influenced by freshwater inflows (Irizuki *et al*. 2005, Liu *et al*. 2013). *Pistocythereis bradyi* lives abundantly in muddy inner to middle bays of 7–30 m water depths (Yasuhara *et al*. 2005, Irizuki *et al*. 2006, Yasuhara & Seto 2006). *Pistocythereis bradyformis* and *Bicornucythere bisanensis* prefer salinity values above 25‰ and water depths of 20–50 m, although they also occur in coastal conditions (Zhao & Wang 1988a, b, 1990, Liu *et al*. 2013). *Bicornucythere bisanensis* is dominant in warm-temperate to cool-temperate bays in Japan, the Bohai Sea, the Yellow and East China Seas and Russia (Irizuki *et al*. 2009). *Neomonoceratina delicata* is a typical shallow-water species living abundantly in the inner bays of the Ryukyu Islands, the southwestern part of the East China Sea, the northern part of the South China Sea and southeastern Asia, in water depths less than 20 m (Irizuki *et al*. 2009, Liu *et al*. 2013). *Xestoleberis hanaii* is known for its wide environmental tolerances and is widely distributed from subtropical to subarctic zones (Sato & Kamiya 2007). It lives on and around seaweeds, mainly in intertidal rocky shores and seagrass beds (Irizuki *et al*. 2006). In summary, the ostracod fauna from borehole VB6 must have lived in a warm, littoral to shallow sublittoral, tidally influenced marine environment.

Based on findings from this study and Cao (1998), ostracods are higher in diversity and abundance in borehole VB1 as compared with VB6, with 48 genera and 72 species recognized. Besides the dominant species found in VB6, this assemblage also includes many species widely distributed in Japan and the South China Sea, such as *Spinileberis quadriaculeata* (Brady, 1880), *Cythere omotenipponica* Hanai, 1959 and *Loxoconcha sinensis* Brady, 1869 (e.g., Malz & Ikeya 1983, Zhao & Wang 1988b, Hou & Gou 2007, Yasuhara & Seto 2006). Other characteristic species found in VB1 include *Bythoceratina* spp., *Macrocypris decora* (Brady, 1866) and *Cytherelloidea cingulata* Brady, 1869. *Spinileberis quadriaculeata* is abundant in similar environments to of *B. bisanensis*, which prefers to live on silty bottoms (Md = 5–8 phi) in brackish waters (salinity = 20–30 psu) at water depths of 2–7 m (Ikeya & Shiozaki 1993, Irizuki *et al*. 2006). *Loxoconcha sinensis* is a warm-water species typical of the South China Sea, which also occurs in the outer-shelf area of the East China Sea and can be brought northwards by warm water (Zhao & Wang 1988b). Individuals of the genus *Cytherelloidea* Alexander, 1929 are considered to live in a shallow-, warm-water marine environment (Vaziri *et al*. 2007). The deep-water genus *Bythoceratina* Hornibrook, 1952 has the highest species diversity in modern tropical seas (Savelieva 2014). *Macrocypris decora* has a wide distribution—Australia, Indonesia, East China Sea, Indian Ocean, South Atlantic Ocean, Malacca Strait Singapore and Richmond River valley, extending from the Miocene to Recent—and is typically found in middle- and outer-shelf areas of the present-day East China Sea and South China Sea, in euryhaline waters (Dewi 1993, Liu *et al*. 2013). The dominant ostracods in VB1 indicate that the ostracod fauna lived in warm, shallow-water, nearshore-marine conditions, although the occurrence of some deeper-water taxa (e.g., *Bythoceratina* spp.) suggests that the water was deeper in VB1 than in VB6 during the deposition of the Holocene Hang Hau Formation.

Conclusions

Restudy of the ostracods from the Hang Hau Formation, Lei Yue Mun, Hong Kong, China, reveals new specimens assigned to eight genera and nine species, raising the diversity of the ostracod fauna from 67 species within 41 genera to 76 species within 49 genera.

owing to the special location of Hong Kong between the East China Sea and the South China Sea, the ostracod fauna of Hong Kong has its own unique characteristics. The ostracods of the Hang Hau Formation contain the same euryhaline species (e.g., *Sinocytheridea impressa*) seen in the East China Sea, Japan, and related regions, and also have tropical species (e.g., *Cytherelloidea cingulata*) seen in the South China Sea and Indonesia. With the new evidence obtained from our recent studies, ostracod assemblages from the VB1 and VB6 cores indicate that the drilling area near Lei Yue Mun was located in warm, shallow, nearshore-marine waters during deposition of the Hang Hau Formation. These palaeoenvironmental conclusions are generally consistent with those of Cao (1998).

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix 1

Taxonomic list of ostracods recovered from cores VB1 and VB6, Lei Yue Mun, Hong Kong, China (Cao 1998, this study).

Distribution	VB1 (m)					VB6 (m)		
Species	4.00–4.40	5.00–5.20	7.00–7.20	8.60–8.80	10.00–10.30	2.40–2.60	5.00–5.20	7.00–7.30
Taxa recorded by Cao (1998)								
Alocopocythere kendengensis (Kingma 1948)				+				+
Alocopocythere profusa Guan in Guan *et al.* 1978				+	+			+
Atjehella semiplicata Kingma 1948	+	+		+	+			
Argilloecia regulata Gou & Huang, in Gou *et al.* 1983							+	
Aurila cymba (Brady 1869)	+	+	+	+	+			+
Bicornucythere bisanensis (Okubo 1975)	+	+	+	+	+			+
Bythoceratina sheyangensis Chen, 1982 in Hou *et al.* 1982	+							
Bythoceratina callidictya Zhao in Wang *et al.* 1988			+		+			
Bythoceratina orientalis (Brady 1869)		+						
Bythoceratina hanaii Ishizaki 1968	+							
Bythoceratina cassidoidea Zhao in Wang *et al.* 1988	+		+					
Callistocythere asiatica Zhao 1984	+		+					
Callistocythere undulatifacialis Hanai 1957				+	+			
Callistocythere sp.				+	+		+	
Caudites scopulicolus jasonensis Zhao & Whatley 1989	+				+			
Copytus posterosulcus Wang 1985	+	+	+	+	+		+	
Cornucoquimba leizhouensis Gou in Gou *et al.* 1983	+	+	+	+	+	+	+	
Cornucoquimba gibboidea (Hu 1982)			+					
Cythere omotenipponica Hanai 1959	+	+	+			+		
Cytherelloidea cingulata Brady 1869					+			
Cytherois leizhouensis Gou & Huang in Gou *et al.* 1983	+	+	+	+	+	+		
Cytheromopha acupunctata (Brady 1880)					+			
Cytheropteron miurense Hanai 1957		+		+	+			
Hemikrithe taiwanensis Malz 1982	+	+		+	+	+	+	
Hemicytheridea reticulata Kingma 1948								+
Hemicytheridea cancellata (Brady 1868a)		+	+	+	+			+
Hemicytheridea sp.					+			
Hemicytherura bodjonegoroensis Kingma 1948				+	+			

(*Continued*)

(*Continued*).

Distribution Species	VB1 (m)					VB6 (m)		
	4.00–4.40	5.00–5.20	7.00–7.20	8.60–8.80	10.00–10.30	2.40–2.60	5.00–5.20	7.00–7.30
Hemicytherura cuneata Hanai 1957					+			
Javanella kendengensis Kingma 1948					+			
Keijia demissa (Brady 1868b)	+		+	+	+			
Keijella kloempritensis (Kingma 1948)					+	+		+
Lankacythere ? *euplectella* (Brady 1869)		+		+	+	+		
Leptocythere pulchra Zhao & Whatley 1989	+							
Loxoconcha taiwanensis Zhao in Wang *et al.* 1988		+	+		+			
Loxoconcha ocellata (Bold van den 1973)			+	+	+			
Loxoconcha tarda Guan in Guan *et al.* 1978		+	+					
Loxoconcha zhejiangensis Zhao 1984								+
Loxoconcha sinesis Brady 1869	+	+	+	+	+	+	+	
Loxoconcha japonica Ishizaki 1968	+	+	+	+				
Loxoconcha modesta Ishizaki 1968		+			+	+		
Macrocypris decora (Brady 1866)	+	+						
Mutilus salebrosa (Brady 1869)			+					
Neocytheretta faceta (Guan in Guan *et al.* 1978)	+				+	+		+
Neocytheretta snellii (Kingma 1948)	+	+			+	+		
Neocytheretta spongiosa (Brady 1870)	+		+	+	+		+	
Neocytheretta adunca (Brady 1880)				+		+		
Neomonoceratina delicata Ishizaki & Kato 1976	+	+	+	+	+	+	+	+
Neomonoceratina dongtaiensis Yang & Chen in Hou *et al.* 1982					+			
Neonesidea elegans (Brady 1869)	+	+	+	+	+			+
Nipponocythere obesa (Hu 1978)	+		+		+	+		
Paracytheridea tschoppi (Bold van den 1946)					+			
Parakrithella sp.	+							
Pistocythereis bradyi (Ishizaki 1968)	+	+	+	+	+	+	+	
Pistocythereis bradyformis (Ishizaki 1968)	+	+	+	+	+	+	+	
Pistocythereis guangdongensis Gou in Gou *et al.* 1983				+	+			
Semicytherura miurensis (Hanai 1957)					+		+	
Sinocytheridea impressa (Brady 1869)	+	+	+	+	+	+	+	+

(*Continued*)

(*Continued*).

Distribution Species	VB1 (m)					VB6 (m)		
	4.00–4.40	**5.00–5.20**	**7.00–7.20**	**8.60–8.80**	**10.00–10.30**	**2.40–2.60**	**5.00–5.20**	**7.00–7.30**
Spinileberis quadriaculeata (Brady 1880)	+	+	+	+	+	+		
Stigmatocythere kingmai Whatley & Zhao 1988	+			+	+			
Stigmatocythere roesmani (Kingma 1948)			+	+	+	+		
Tanella gracilis Kingma 1948		+	+		+			
Triebelina sertata Triebel 1948	+		+					
Xestoleberis kalibengensis Kingma 1948					+			
Xestoleberis hanaii Ishizaki 1968	+	+	+	+	+	+	+	
Xestoleberis variegata Brady 1880			+					
Additional taxa (this paper)								
Aglaiocypris pellucida Mostafawi 2003	+	+						+
Argilloecia lunata Frydl 1982	+							
Coquimba lianpui Hu & Tao 2008			+					
Neocyprideis timorensis (Fyan 1916)	+	+						
Pontocypris subtriangulata (Hu 1984)		+	+					
Propontocypris bengalensis Maddocks 1969	+		+					
Propontocypris crocata Maddocks 1969								+
Propontocypris clara Zhao in Wang *et al.* 1988		+	+					
Pseudocythere frydli Yajima 1982	+							