THE AMMONITES *CRIOCERATITES* (*PARACRIOCERAS*) AND *SHASTICRIOCERAS* FROM THE BARREMIAN OF SOUTHWEST JAPAN

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ABSTRACT. *Crioceratites* (*Paracrioceras*) *asiaticum*, *Shasticrioceras nipponicum*, *Shasticrioceras patricki* and *S. intermedium* sp. nov. are described from Barremian strata of southwest Japan. The occurrence of these ammonites in southern Japan provides important evidence for the existence of a cold water current originating in the Arctic and separating northeast Japan from the Asian continent. The lineage of crioceratids from Japan is discussed. *Crioceratites* (*C.*) *ishiwarai*, *C.* (*Emericiceras*) *emerici* and *C.* (*P.*) *asiaticum* from Japan are interpreted as immigrant species from the Tethyan Sea or their descendants.

THE heteromorph ammonites *Crioceratites* (*Paracrioceras*) and *Shasticrioceras* were distributed principally in the northwest European and north Pacific faunal provinces respectively during the Barremian, though two species of *Shasticrioceras* have been recorded from the Lower Hauterivian of Speeton and from the Barremian of Bulgaria (Koenen 1902; Anderson 1938; Doyle 1963; Dimitrova 1967; Jeletzky 1971; Rawson 1975; Murphy 1975; Immel 1978; Kemper *et al.* 1981). Both of these genera have been recognized in Barremian strata of Japan and two species of *Shasticrioceras* have either been listed or briefly described in Japanese (Matsumoto 1947; Obata and Ogawa 1976; Obata and Matsukawa 1984, 1988; Matsukawa and Eto 1987). Furthermore, the occurrence of these typical NW European and north Pacific genera in the Barremian has generated much discussion, because Barremian faunas in Japan are mostly of Tethyan affinity (Eto 1987; Matsukawa 1988; Obata and Matsukawa 1988). However, several problems still remain: (1) the need for full descriptions of the four Japanese species belonging to *Crioceratites* (*Paracrioceras*) and *Shasticrioceras*; (2) determination of the causal relationship between the occurrences of these ammonites and the Barremian palaeogeography of Japan; and (3) interpretation of the lineage of crioceratids from Japan. This paper provides a taxonomic description of the Japanese species and discusses these outstanding problems.

LOCALITIES

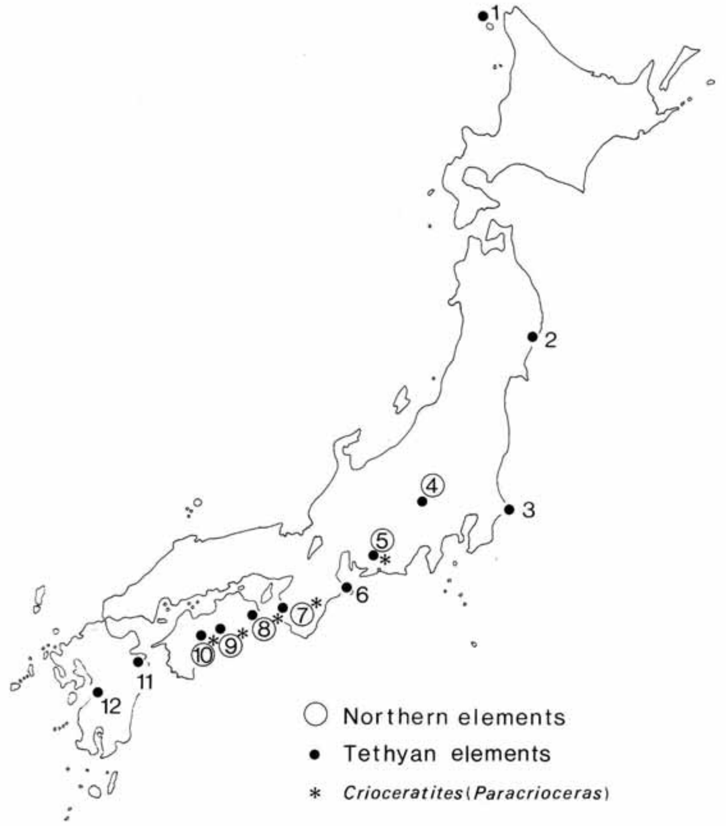
All localities mentioned in the text are shown in Text-figure 1. Below we give brief stratigraphical information on all those from which we have examined specimens.

Idaira: Akasaka, Inasa-cho, Inasa-county, Shizuoka Prefecture (locality 5 in Text-fig. 1). This locality was discovered by Hayashi *et al.* (1981), but ammonite species were not identified by them. Recent collecting from the brown mudstone in the lower part of the Idaira Formation has yielded the ammonites *Crioceratites* (*Paracrioceras*) *asiaticum* and *Shasticrioceras nipponicum*.

Arida: Yuasa, Yuasa-cho, Arida-county, Wakayama Prefecture (locality 7 in Text-fig. 1). This is the type area of the Arida Series in Japan (approximately corresponding to Barremian). The lithostratigraphy and biostratigraphy of this area were reviewed by Obata and Ogawa (1976), and ammonites from this area were figured by Matsumoto (1947) and Obata and Ogawa (1976).

Katsuuragawa: Nakagoya, Katsuura-cho, Katsuura-county, Tokushima Prefecture (locality 8 in Text-fig. 1). The littoral to shallow neritic facies of the Hanoura Formation consists of muddy sandstone which yielded the ammonites figured by Matsukawa and Eto (1987).

[Palaeontology, Vol. 36, Part 2, 1993, pp. 249–266, 3 pls.]



TEXT-FIG. 1. Occurrences of Barremian ammonites in Japan. Key to localities: 1, Rebun; 2, Kitakami; 3, Choshi; 4, Sanchu; 5, Idaira; 6, Shima; 7, Arida; 8, Katsuuragawa; 9, Monobe-Ryoseki; 10, Kochi; 11, Ohita; 12, Yatsushiro.

Monobegawa: Yunoki, Kahoku-cho, Kami-county, Kochi Prefecture (locality 9 in Text-fig. 1). The deltaic facies of the Ryoseki Formation consists of muddy sandstone containing the ammonite *Shasticrioceras patricki*.

For descriptions of the localities yielding these specimens see Matsumoto (1947), Obata and Ogawa (1976), Hayashi *et al.* (1981) and Matsukawa and Eto (1987).

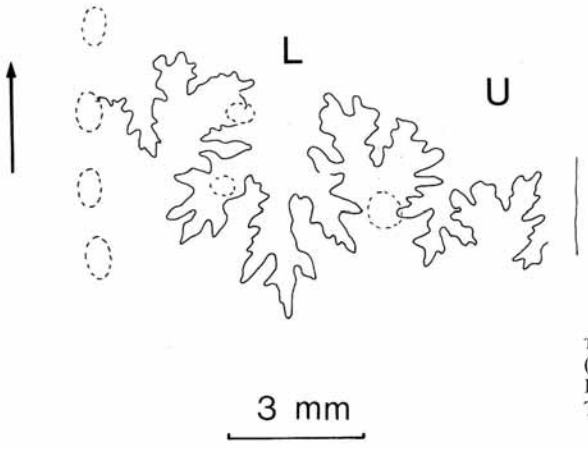
Repositories. Material has been examined from the following collections (abbreviations used in the text are shown in parenthesis): National Science Museum, Tokyo (NSM-PM); Department of Earth Sciences, Faculty of Science, Ehime University, Matsuyama (EE-AM); Collection of Mizuno Fossil Museum, Nagoya (YM).

SYSTEMATIC PALAEONTOLOGY

Order AMMONOIDEA Zittel, 1884
Suborder ANCYLOCERATINA Wiedmann, 1966
Superfamily ANCYLOCERATACEA Gill, 1871
Family ANCYLOCERATIDAE Gill, 1871
Genus CRIOCERATITES Léveillé, 1837
Subgenus PARACRIOCERAS Spath, 1924

Type species. Ammonites (*Crioceras*) *occultum* Seeley, 1865, from the middle Barremian of England (subsequent designation by Rawson 1975).

Remarks. Differing opinions have been presented concerning the taxonomic status of *Paracrioceras*. Based on the arguments of Rawson (1975), who regarded *Emericiceras* as a junior subjective synonym of *Paracrioceras*, Kemper *et al.* (1981) proposed that *Paracrioceras* is a subgenus of *Crioceratites*. On the other hand, Immel (1978) concluded that *Paracrioceras* is better considered as a synonym of the subgenus *Crioceratites* (*Crioceratites*). This latter interpretation is based on the minor morphological differences which exist between the type species of *Paracrioceras*, *Emericiceras* and *Crioceratites*.



TEXT-FIG. 2. Suture line of *Crioceratites* (*Paracrioceras*) *asiaticum* (Matsumoto). External suture, the fifth last suture of TI-1; locality 2505, Kumaiguchi in the Yuasa area (see Pl. 1, fig. 1).

As far as the Japanese Barremian material is concerned, *Crioceratites* (*Paracrioceras*) *asiaticum* Matsumoto (described below) is characterized by trituberculate major ribs in the mature stage, whereas *Crioceratites* (*Emericiceras*) *emerici* Léveillé has minor ribs lacking tubercles. The characters of both species are considered to satisfy at least the generic definition of *Crioceratites*. Under such circumstances, the authors are inclined to follow the classification of Kemper *et al.* (1981).

Crioceratites (*Paracrioceras*) *asiaticum* (Matsumoto, 1947)

Plate 1, figs 1–17; Plate 2, figs 3–5; Text-fig. 2

1947 *Australiceras asiaticum* Matsumoto, p. 13, pl. 1, fig. 1; text-fig. 1.
1976 *Paracrioceras* aff. *elegans* (Koenen); Obata and Ogawa, pl. 1, figs 2, 4; text-figs 6–2, 7.

Material. Lectotype: GK.H8301, chosen here, the original of Matsumoto (1947, pl. 1, fig. 1), from the Arida Formation at locality YU-103, Yuasa-Fujinami in the Yuasa area (T. Matsumoto Colln). Paralectotypes: GK.H8311 and GK.H8312 from the same formation and locality (T. Matsumoto Colln). GK.H8302 from the same formation at locality Ys-8, Yuasa-Suhara, in the Yuasa area (T. Matsumoto Colln). GK.H8303 from the same formation at locality Yu-5, Yuasa town, in the same area (Aiba, Kutsuna and Matsumoto Colln). NSM-PM 7447, a slightly deformed specimen from the same formation at locality 1703, Suhara in the Yuasa area (Y. Ogawa Colln). NSM-PM 7449 from the Arida Formation but probably derived from locality 2505, Kumaiguchi in the Yuasa area (T. Ishibashi Colln). NSM-PM 7629 (locality 1703), NSM-PM 7640 (locality 1703), NSM-PM 7632 (locality 1405), NSM-PM 7633 (locality 1703) and NSM-PM 7634 (locality 1403), all from the Arida Formation at Suhara in the Yuasa area (Y. Igawa Colln). NSM-PM 7638 and NSM-PM 7639, plaster casts of YM-1001 and YM-1002 respectively, from locality 2505 of the Arida Formation at Kumaiguchi in the Yuasa area (Y. Mizuno Colln). YM-1003 (locality 1507) of the Arida Formation at Suharazaka in the Yuasa area (Y. Mizuno Colln). EE-AM 1001, from the upper part of the Hanoura Formation at locality 4052, Nakagoya in the Katsuuragawa area (F. Eto Colln). NSM-PM 7641 from the lower part of the Idaira Formation at locality 03, Akasaka in the Idaira area (T. Komatsu Colln).

Diagnosis. Whorls compressed, subquadrangular to subhexagonal in section, with flattened dorsum and venter. Umbilical bullae, lateral and ventro-lateral spines present from middle stage on major ribs. Lateral spines are located at one-half to two-thirds the distance from umbilical shoulder to venter. A few minor and shorter ribs with weak tubercles or non-tubercles are intercalated between major ribs.

Description. The shell is of medium size, less than 60 mm in diameter in most specimens, but one specimen (YM-1003) is very large, about 340 mm in diameter. The whorl is crioceratid with tightly coiled early stage (e.g. in NSM-PM 7447 less than 17·1 mm in diameter, in NSM-PM 7449 less than 9·6 mm in diameter) and loosely coiled later stage. The whorl section is subquadrangular to subhexagonal and fastigate with narrow and flat venter, becoming high and more compressed with growth. Flanks are almost flat in the central region and gently convergent towards the ventro-lateral shoulder from a point at about one-half to two-thirds the distance from the umbilical margin. The ventro-lateral shoulder is rather subangular. The whorls are ornamented with tuberculate major ribs and generally non-tuberculate minor ones. The ribs number 55 per whorl on NSM-PM 7449 (43 mm in maximum diameter of loosely coiled whorls).

Four stages are recognized in the morphologic development of *C.* (*P.*) *asiaticum*:

1. *Early growth, less than 9·6 mm.* Whorls tightly coiled and almost completely covered with fine ribbing only.
2. *9·6–14·5 mm.* Whorls have only trituberculate major ribs. The tubercles are the site of ventro-lateral and lateral spines and umbilical bullae.
3. *Later growth, 14·5–270 mm.* Whorls consist of trituberculate major ribs characterized by ventro-lateral and lateral spines and umbilical bullae, with a few intercalated, non-tuberculate minor ribs.
4. *Latest growth, greater than 270 mm.* Whorls have only trituberculate major ribs, separated by narrow interspaces of the same width or half as wide as the ribs. The major ribs are radial, strong and broad, forming a triangle in section. They spring from the umbilical margin and continue over the venter where they decrease

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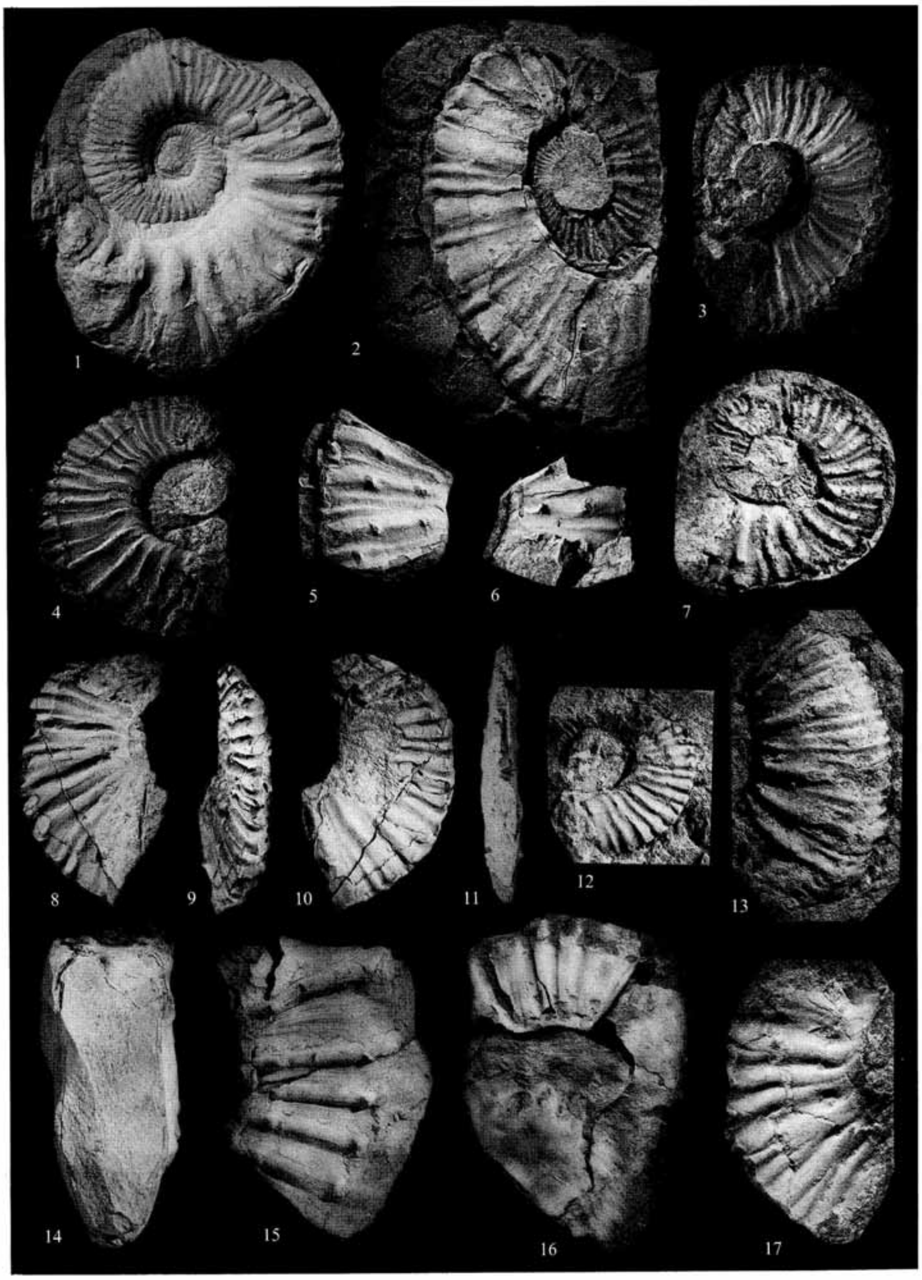
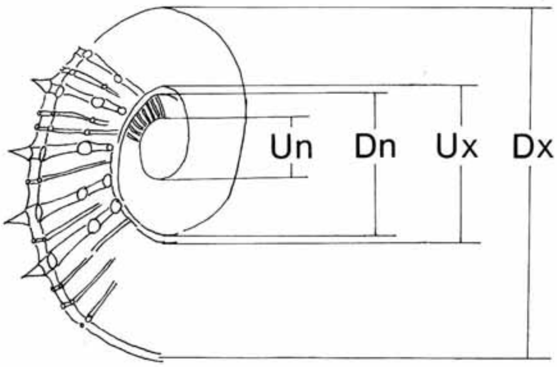
EXPLANATION OF PLATE 1

Figs 1–17. *Crioceratites* (*Paracrioceras*) *asiaticum* (Matsumoto). 1–16, Lower Barremian, upper part of the Arida Formation. 1, NSM-PM 7449; locality 2505; lateral view, × 1·3. 2, NSM-PM 7447; locality 1703; lateral view, × 1·3. 3, YM-1001; locality 2505; lateral view, × 1. 4, YM-1002; locality 2505; lateral view, × 1. 5, NSM-PM 7632; locality 1405; lateral view, × 1·0. 6, NSM-PM 7623; locality 1711; lateral view, × 1·2. 7, NSM-PM 7633; locality 1703; lateral view, × 1·0. 8–11, NSM-PM 7629; locality 1703; lateral (8, 10), ventral (9) and front (11) views, × 1·2. 12, NSM-PM 7624; locality 1403; lateral view, × 1·2. 13, NSM-PM 7634; locality 1403; lateral view, × 1·0. 14–16, YM-1003; locality 1507; front (14) and lateral (15, 16) views, × 0·5, × 0·3, × 0·2 respectively. 17, EE-AM 1001; Lower Barremian, upper part of the Hanoura Formation; locality 4052; lateral view, × 1·2.



MATSUKAWA and OBATA, *Crioceratites*

in strength. The minor ribs are fine and narrow, originating at the umbilical margin or at mid-flank, and continuing over the venter where they decrease in strength. The tubercles are the sites of stout and cone-like ventro-lateral and lateral spines and umbilical bullae. Two rows of lateral spines are found, in the ventral and the umbilical regions, but change their position with growth; the lateral spines near the ventral side are located at one-half to two-thirds the distance from the umbilical shoulder, whereas the lateral spines near the umbilical side are at one-quarter to one-sixth the distance. The dorsum is flat and without ornamentation. The suture line consists of the elements of E, L, U, and I (see Text-fig. 2). The ventral saddle is bifid and slightly asymmetric. Lateral lobe (L) is deep, showing symmetrically trifid lobules. Umbilical lobe (U) is smaller than lateral ones. The first lateral saddle is as broad as the second lateral one, but the third one is rather narrow.



TEXT-FIG. 3. Dimensions measured on shells of *Crioceratites* (*Paracrioceras*) *asiaticum* (Matsumoto). Dx, diameter of loose spire; Ux, maximum umbilical gap; Dn, maximum diameter of tight spire; Un, umbilicus of tight spire.

Measurements. (in mm; see Text-fig. 3 for explanation of symbols used).

	Dn	Dx	H	B	B/H	Un	Ux
Gk.H8301 (lectotype)	15·9		6·4	4·5	0·70	5·7	
		26·5	11·6				9·5 (0·36)
MSM-PM 7447	42·1					16·6 (0·39)	
		50·0	18·7				21·3 (0·43)
NSM-PM 7449	32·8		15·4			9·6 (0·29)	
		37·5	17·6				12·5 (0·33)
NSM-PM 7638			39·3	15·0			13·5 (0·34)
NSM-PM 7640				91·7	34·5	0·38	

Comparisons. The present species is closely similar to *Paracrioceras elegans* (Koenen 1902, p. 295, pl. 24, figs 1–3; pl. 29, fig. 3) from the Barremian of the Hoheneggelsen, near Hannover, Germany, in the nature of its coiling, its narrow flat venter and unornamented flat dorsum, and the alternating trituberculate major ribs and fine minor ones. The whorl section of the latter is, however, more rounded or oval at middle to late stage than *C.* (*P.*) *asiaticum*. Furthermore, the lateral spines near the ventral side are situated at one-half to two-thirds the distance from the umbilical shoulder on later growth stage of *C.* (*P.*) *asiaticum*, whereas in *C.* (*P.*) *asiaticum* they are located three-quarters the distance from the umbilical shoulder.

C. (*P.*) *asiaticum* is also distinct from *Paracrioceras occultum* (Seeley), the type species of the genus (Rawson 1975, p. 275. text-fig. 1; pl. 43, figs 1–6). In *P. occultum* the ribs are almost all equal in strength and the lateral tubercles disappear at the late growth stage, whereas in *C.* (*P.*) *asiaticum* the ribbing includes both major and minor ribs, with the major ribs exhibiting three tubercles through the middle to late growth stages.

The present species is readily distinguished from *Crioceratites* (*C.*) *ishiwarai* (Yabe and Shimizu), described as *Crioceras ishiwarai* by Yabe and Shimizu (1926, p. 85, text-figs 1–2; pl. 4) from the Oshima Formation of northeast Japan. In the latter species, the shell consists of tightly coiled whorls showing five to eight minor ribs intercalated between major ribs in the adult stage. In *C.* (*P.*) *asiaticum*, the shell exhibits loosely coiled whorls at later stages, and only a few minor, shorter ribs are intercalated between major ones.

Crioceras yagii Yabe and Shimizu (1926, p. 72, pl. 15, figs 16–19), from the Ishido Formation of central Japan, differs from the present species in having a subcircular whorl section, three to six minor ribs between major ribs, and three long spines on each major rib.

Occurrence. Lower Barremian. Upper Arida Formation, upper Hanoura Formation and lower Idaira Formation.

Genus SHASTICRIOCERAS Anderson, 1938

Type species. Shasticrioceras poniente Anderson, 1938, from Barremian deposits of California (subsequent designation by Arkell *et al.*, 1957, p. L208).

Shasticrioceras nipponicum Matsumoto, 1947

Plate 2, figs 1–2, 6–7; Plate 3, figs 1–14

1947 *Shasticrioceras nipponicum* Matsumoto, p. 19, pl. 1, fig. 3; text-fig. 2.
1976 *Shasticrioceras nipponicum* Matsumoto; Obata and Ogawa, pl. 1, fig. 1; pl. 4, fig. 6; text-fig. 6–1.

Material. Lectotype: GK.H8305, chosen here, the original of Matsumoto (1947, pl. 1, fig. 3), from the Arida Formation at Yu-103, Yuasa-Fujinami in the Yuasa area (T. Matsumoto Colln). Paralectotypes: GK.H8306, H8307 and H8313 from the same formation and locality (T. Matsumoto Colln). Other specimens include NSM-PM 7635, NSM-PM 7636 and YM-1004, all from the Arida Formation at locality 1711, Yada in the Yuasa area (NSM-PM 7635 was collected by Y. Ogawa, NSM-PM 7635 by Y. Kotake and YM-1004 by Y. Mizuno). NSM-PM 7637 and NSM-PM 7444, casts and moulds, from the Arida Formation at locality 2505, Kumaiguchi in the Yuasa area (Y. Ogawa and S. Higashiyama Colln). EE-AM 1002, casts and moulds, from the upper part of the Hanoura Formation at locality 4052, Nakagoya in the Katsuuragawa area (F. Eto and M. Matsukawa Colln). NSM-PM 7700, from the lower part of the Idaira Formation at locality 03, Akasaka in the Idaira area (T. Komatsu, T. Kitamura and M. Matsukawa Colln).

Diganosis. A compressed and loosely coiled species of *Shasticrioceras* with radial or slightly sinuous ribs, on which strongly pronounced clavate tubercules present. Ribs arise between umbilical margin and mid-flank, cross flank to ventral shoulder, but are interrupted on venter.

Description. The shell is of medium size, less than *c.* 140 mm in diameter, and the whorl is slightly uncoiled. The whorl section is compressed planulate, oblong and somewhat swollen at mid-flank and gradually convergent towards the venter. The venter is rather narrow in comparison with the dorsum and both are flat. Flanks are ornamented with radial to slightly sinuous major ribs and intercalated straight or branching minor ones. The ribs are sharpened near the venter, forming a nearly triangular ridge separated by narrow interspaces. Most ribs start at the umbilical margin but some of the minor ribs arise at mid-flank; all reach to the ventral shoulder and exhibit the ventro-lateral clavi, being interrupted on the venter. Umbilical bullae are found only on the major ribs. In the inner whorls of the early growth-stage (e.g. in NSM-PM 7635, about 30 mm in diameter) the ribs are rather rectiradiate and uniform in strength. In contrast, the outer volution of the middle to late growth-stage (e.g. in NSM-PM 7635, more than 30 mm in diameter, and in YM-1004, more than 35 mm in diameter) exhibits ribbing consisting of stout major and somewhat weaker minor ribs, often quite similar in appearance and often difficult to distinguish. The minor ribs, however, arise higher on the flanks than the major ones.

Measurements. (in mm; see Text-fig. 3 for explanation of the symbols used).

	Dx	H	B	B/H	Ux	Ux/Dx
GK.H8305 (lectotype)	22·7	10·6	5·6	0·53	8·3	0·37
NSM-PM 7635	67·6	31·5			17·9	0·26
NSM-PM 7444		33·4				
NSM-PM 7636	45·7	20·2			13·8	0·30
YM-1004	133·1	51·9			47·4	0·36

Comparisons. The present species is distinct from *Shasticrioceras* sp. aff. *S. patricki* Murphy (Obata and Matsukawa 1984, p. 18, pl. 5, fig. 2; pl. 6, fig. 2) from the Barremian of the Ishido Formation. In *S. nipponicum*, the venter is narrow, the clavate tubercles at the ventral shoulder are more strongly pronounced, and the ribs are coarser and more frequently branched at the umbilical margin. In contrast, *S.* sp. aff. *S. patricki* shows a broader venter, weaker clavi, and more numerous and crowded ribs.

Shasticrioceras poniente, the type species of the genus from the upper part of the Lower Barremian of California, described by Anderson (1938, p. 204, pl. 57, figs 1–3; pl. 67, figs 4–5) and Murphy (1975, p. 41, pl. 10, figs 1–2, 6; pl. 11, figs 5, 7), somewhat resembles the present species in its tightly coiled crioceratid whorl and in its branching or intercalated ribbing. *S. poniente* can be distinguished from *S. nipponicum*, however, by its continuous ribs which are sigmoidal and biconcave in adult stage, and rounded on the lower half of the flank.

Occurrence. Lower Barremian. Middle Arida Formation, upper Hanoura Formation and lower Idaira Formation.

Shasticrioceras patricki Murphy, 1975

Plate 2, figs 8–9; Text-fig. 4

1975 *Shasticrioceras patricki* Murphy, p. 46, text-fig. 26; pl. 7, figs 1–2; pl. 10, figs 3–5; pl. 13, fig. 4.

Material. EE-AM 1003, from the Monobe Member of the Ryoseki Formation at locality R2, Yunoki in the Monobegawa area, Kochi Prefecture (T. Okada and M. Matsukawa Colln).

Description. The shell is large, about 110 mm in diameter. The whorl is crioceratid and loosely coiled below about 62 mm in diameter. The whorl-section is compressed, planulate and oblong with more-or-less swollen flanks which are gently convergent toward the venter from a point at about three-quarters of the distance from the umbilical margin. The ventro-lateral shoulder is rather subangular and the venter is narrow and flat. Flanks

EXPLANATION OF PLATE 2

Figs 1–2, 6–7. *Shasticrioceras nipponicum* Matsumoto. 1–2, NSM-PM 7700; Lower Barremian, lower part of the Idaira Formation; locality 03; internal mould (1) and external mould (2); lateral views, × 1·2. 6–7, GK H8305, lectotype; Lower Barremian, upper part of the Arida Formation; locality Yu-103; ventral (6) and lateral (7) views, × 1·2.

Figs 3–5. *Crioceratites* (*Paracrioceras*) *asiaticum* (Matsumoto). 3, NSM-PM 7449; Lower Barremian, lower part of the Idaira Formation; locality 03; lateral view, × 0·8. 4–5, GK H8301; lectotype; Lower Barremian, upper part of the Arida Formation; locality Yu-103; ventral (4) and lateral (5) views, × 1·2.

Figs 8–9. *Shasticrioceras patricki* Murphy. EE-AM 1003; Lower Barremian, Monobe Member of the Ryoseki Formation; locality R2; ventral (8) and lateral (9) views, × 0·8.

MATSUKAWA and OBATA, *Shasticrioceras*, *Crioceratites* are ornamented with straight and coarse ribs in early growth-stages (less than *c.* 27·6 mm in diameter), which become biconcave and finer in later stages (more than *c.* 34·8 mm in diameter). Most of the ribs originate at the umbilical margin and cross the venter in a straight line; some of them arise on the flank or bifurcate at about three-quarters of the distance from the umbilical margin. Ribs are sharpened at the top, forming a nearly triangular ridge in cross-section, and are separated by interspaces of equal width. A small pointed clavus is found on each rib at the periphery of the venter. The suture line is not completely preserved but shows trifid lobes (see Text-fig. 4). The saddles are broader than the lobes and show an asymmetrically divided top. Ventral lobe (E) is shallow. Lateral lobe (L) is narrow and deep, showing subsymmetrically trifid lobules. The umbilical lobe (U) is broadest, but is rather shallow.

Measurements. (in mm; see Text-fig. 3 for explanation of the symbols used).

	Dx	Dn	H	Ux	Un
EE-AM 1003	*c.* 110·0		40·0	*c.* 64·0	
		c. 27·6	7·4		*c.* 20·2

Remarks. The shell is considered to be discoidal with successive whorls just in contact with each other. The present specimen is closely similar to the illustrated specimens of *Shasticrioceras patricki* Murphy, 1975 (pl. 7, figs 1–2; pl. 10, figs 3–5), from the upper part of the Lower Barremian of California. Japanese and Californian specimens show a similar shell form with fine, biconcave ribs most of which traverse the entire flank, rarely arising or branching on the flank, and possessing a small clavus at the ventral shoulder.

The present specimen is different from the specimen of *S.* sp. aff. *S. patricki* Murphy (Obata and Matsukawa 1984, pl. 5, fig. 2; pl. 6, fig. 2) from the Lower Barremian of the Sanchu area, Japan. The latter specimen exhibits nearly radial, straight ribs which are rather fine in early growth-stages and gradually increase in coarseness with growth. *S. patricki* possesses straight ribs which are rather coarse in the early growth-stage, becoming fine and biconcave in the later stage.

Shasticrioceras nipponicum Matsumoto has some similarity to the present species in the general features of shell form and ornamentation, but differs in its remarkable clavate tubercles and coarse ribs which are frequently branched at the umbilical margin.

Occurrence. Lower Barremian, Monobe Member of the Ryoseki Formation.

Shasticrioceras intermedium sp. nov.

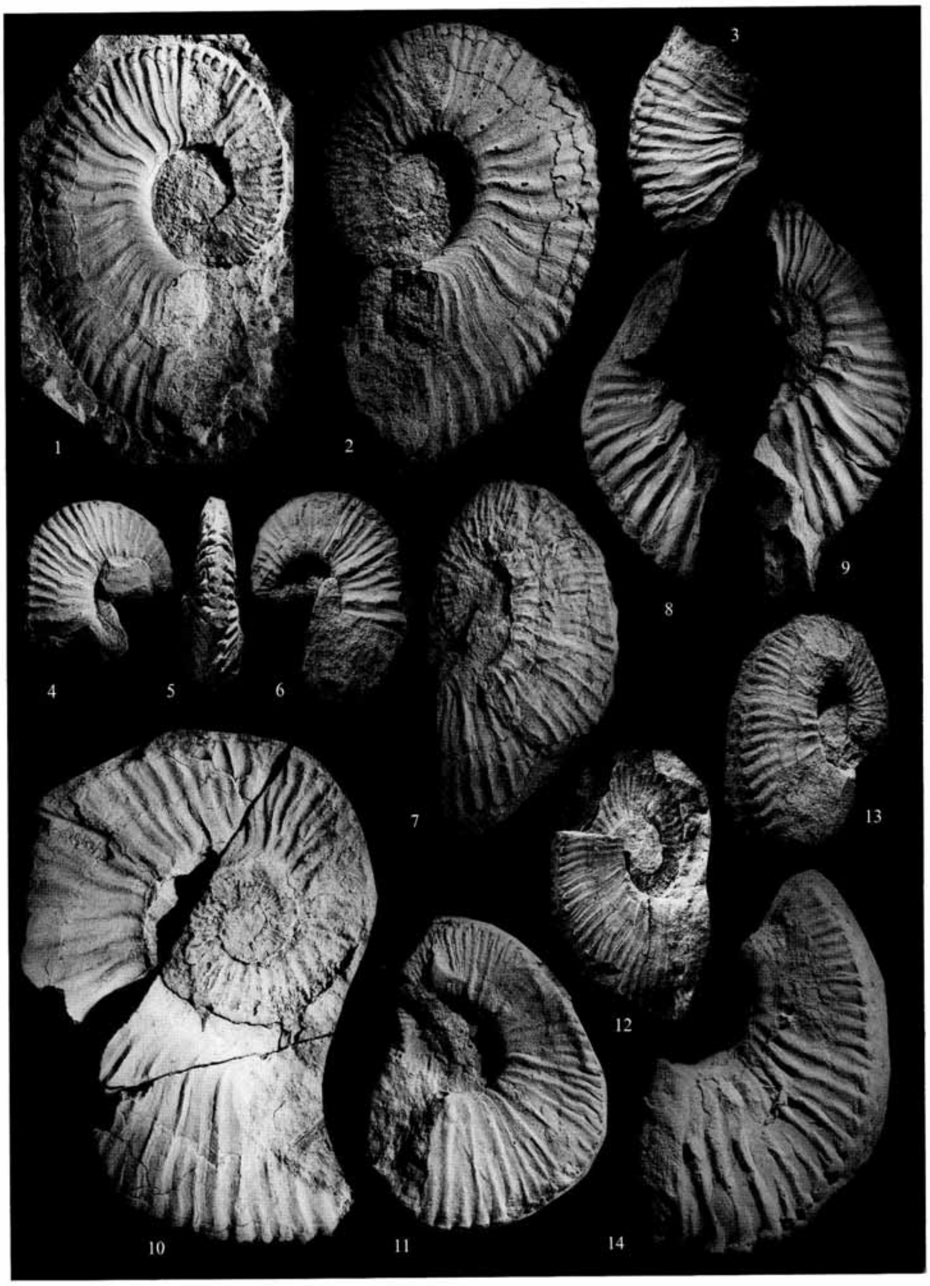
Derivation of name. The present species has lateral tubercles on the major ribs although other species of the *Shasticrioceras* do not have them. Therefore, the species possesses generic characters of both *Shasticrioceras* and *Paracrioceras*.

Text-fig. 5

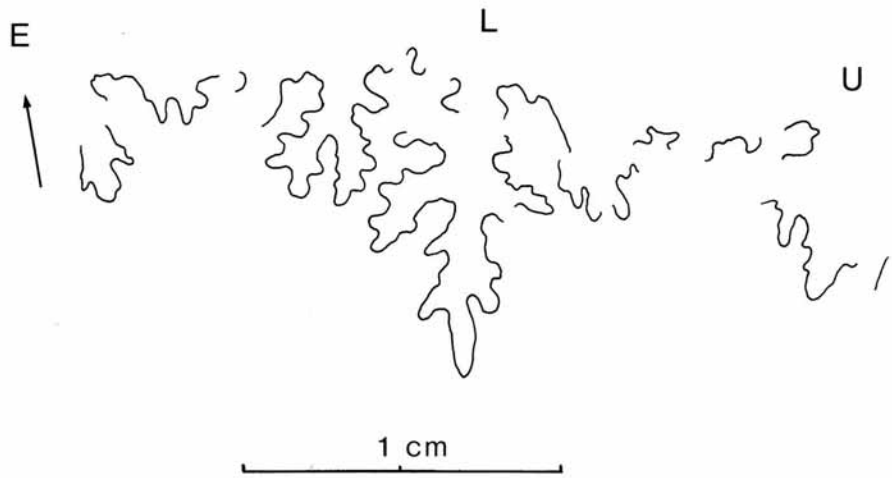
1976 *Shasticrioceras* sp. Obata and Ogawa, pl. 1, fig. 5.

EXPLANATION OF PLATE 3

Figs 1–14. *Shasticrioceras nipponicum* Matsumoto. 1–6, 8–14, Lower Barremian, upper part of the Arida Formation. 1–2, NSM-PM 7635; locality 1711; internal mould (1) and rubber cast from the same external mould (2); lateral views, × 1. 3, NSM-PM 7625; locality 1703; lateral view, × 1. 4–6, NSM-PM 7626; locality 2505; lateral (4 and 6) and ventral (5) views, × 1·2. 8–9, NSM-PM 7637; locality 2505; lateral views, × 1·2. 10, YM-1004; locality 1711; lateral view, × 0·6. 11, NSM-PM 7627; locality 1711; lateral view, × 1. 12, NSM-PM 7628; locality 1919; lateral view, × 1·2. 13, NSM-PM 7636; locality 1711; lateral view, × 1. 14, NSM-PM 7444; locality 2505; lateral view, × 0·8. 7, EE-AM 1002; Lower Barremian, upper part of the Hanoura Formation; locality 4052; lateral view, × 1·2.



MATSUKAWA and OBATA, *Shasticrioceras*



TEXT-FIG. 4. Suture line of *Shasticrioceras patricki* Murphy. External suture, the second last suture of EE-AM 1003; locality R2, Yunoki, Monobegawa area (see Pl. 2, fig. 5).

Material. Holotype: NSM-PM 7446. Paratypes: NSM-PM 7630 and NSM-PM 7631. All from locality 1405 in the Arida Formation (Y. Ogawa Colln).

Diagnosis. Very compressed species of *Shasticrioceras* with one, two, or three tubercles on major ribs in the adult stage.

Description. The shell attains large size (120 mm in maximum diameter). The whorl is of ancyloceratid type with an openly coiled whorl even at the early growth-stage (e.g. in NSM-PM 7446, less than 18 mm in diameter). The whorl section is compressed, planulate, and oblong with slightly flattened flanks and flattened venter. The ventro-lateral shoulder is angular, but the dorsal shoulder is rather rounded. The whorl is ornamented with numerous nearly radial, but very slightly sinuous, ribs which are sometimes tuberculated. Ribs arise at the umbilical margin and become weaker on the venter. Both major and minor ribs are present, but sometimes it is difficult to distinguish between them. In early growth-stages the ribs are crowded and equal to the interspaces in width. They gradually increase in coarseness and become one-third as wide as the interspaces in the adult growth-stage. Mono- to trituberculate major ribs appear irregularly at the latest stage. Distinctly clavate tubercles are found on the periphery of the venter of the major ribs and umbilical bullae and lateral spines are weak. The top of each clavus is rather flattened. The suture line is unknown.

Measurements. (in mm; see Text-fig. 3 for explanation of the symbols used).

	Dx	H	B	B/H	Ux
NSM-PM 7446 (holotype)	195+	27+	11·1	0·41	54·3
NSM-PM 7630		14·6	4·1	0·28	
NSM-PM 7631		17·4	6·0+	0·34+	

TEXT-FIG. 5. *Shasticrioceras intermedium* sp. nov., Lower Barremian, upper part of the Arida Formation. A–B, NSM-PM 7446; holotype; locality 1405; lateral and ventral views, respectively, × 1. C, NSM-PM 7630; paratype; locality 1405; lateral view, × 1·2. D, NSM-PM 7631; paratype; locality 1405; lateral view, × 1·3.

Comparisons. The present species is closely related to *Shasticrioceras nipponicum* Matsumoto in having a planulate and oblong whorl section, flat venter, and major and minor ribs which are interrupted on the venter and show ventro-lateral clavi. The two species are distinguished by the presence of one, two or three lateral tubercles on the major ribs of *S. intermedium*.

Shasticrioceras poniente Anderson, the type species of *Shasticrioceras*, from the upper part of the Lower Barremian of California, has a much more swollen whorl than the present species. The ribs of *S. poniente* are continuous around the whorl, but on *S. intermedium* are interrupted on the venter. Furthermore, some major ribs in the latter have lateral tubercles.

Remarks. The presence of lateral tubercles on the major ribs of *S. intermedium* might lead to a revised definition for the genus *Shasticrioceras*.

Occurrence. Lower Barremian. Arida Formation, Arida area.

DISCUSSION

Palaeogeography

Barremian ammonite faunas in Japan contain northern, high latitude elements including Boreal *Simbirskites* (*Milanowskia*), northwest European *Crioceratites* (*Paracrioceras*) and northern Pacific *Shasticrioceras*. The distribution of these ammonites in Japan has been explained by the presumed marine connections during a transgressive period (Matsukawa 1988; Obata and Matsukawa 1988). It is worthy of note that these northern ammonites, accompanied by Tethyan ones, are found at several localities in southwest Japan but not in northeast Japan (see Text-fig. 1). This is in contrast to the segregated northern and Tethyan ammonite faunas which are found in northern and southern localities, respectively, in the southern Caucasus and Crimea (Kakabadze 1981).

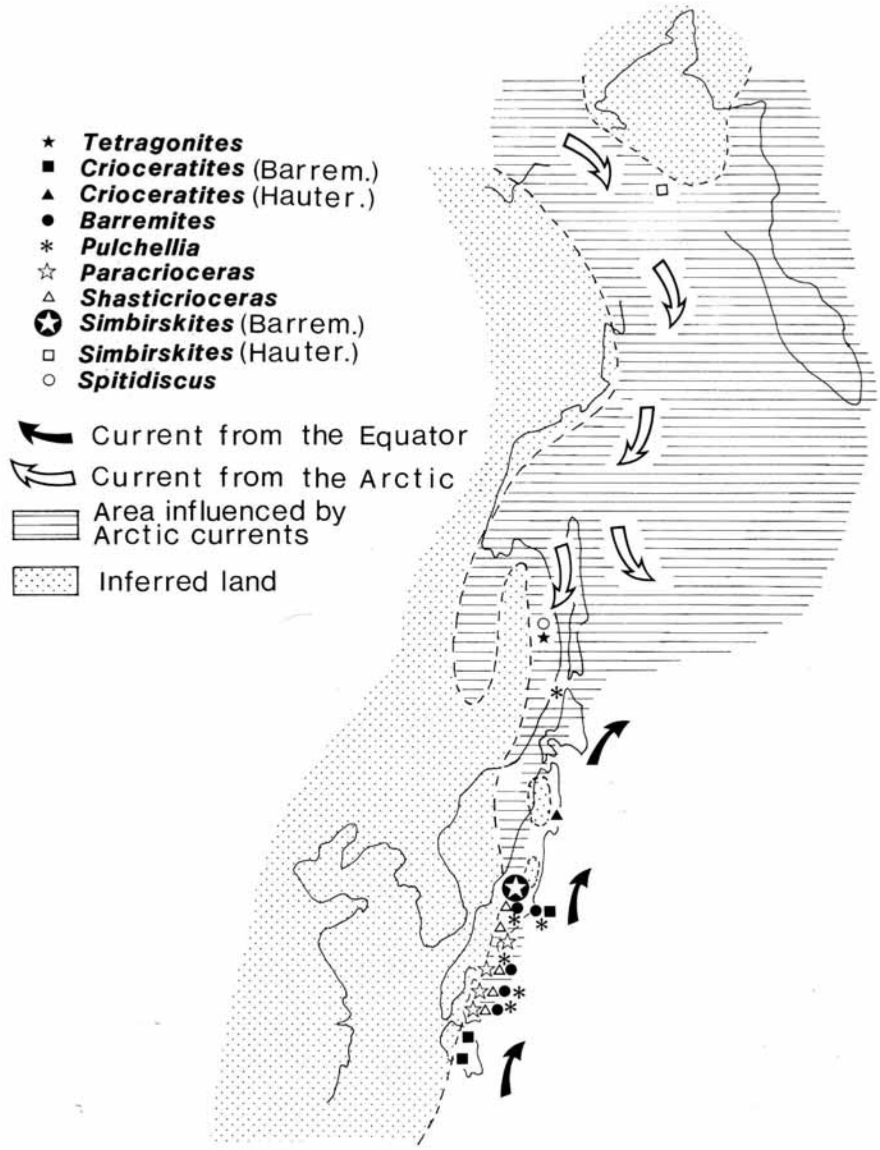
The presumed palaeocurrent directions (Obata and Matsukawa 1988) and palaeogeography of Japan during Barremian time provide an explanation. Oceanic circulation patterns are useful in explaining the global distribution of some Tethyan and Boreal ammonites in Barremian time (Obata and Matsukawa 1988). A warm current presumably passed northward from the equator, turning to the east near the position of present-day Hokkaido, whereas a cool current was directed southward from the Arctic, turning west by Coriolis force to reach near Kyushu. If northeast Japan was part of the eastern margin of the Asiatic continent, the area must have been influenced by the Arctic current. However, only Tethyan ammonites have been found in northeast Japan. As an explanation of the problem, a seaway for the cool current from the Arctic is considered to have existed between northeast Japan and the Asiatic continent. This seaway makes it possible to explain the occurrence of northern ammonites only in southwest Japan (see Text-fig. 6). In southern Sikhote-Alin, northwest European and Tethyan ammonites, including *Spitidiscus* sp. aff. *S. rotula*, have been reported from the Barremian, and Boreal bivalves, including *Aucella crassicolis*, *A. volgensis* and *A. okensis*, from the Valanginian (Avdeiko 1968). This occurrence suggests that both Equatorial and Arctic currents reached Sihotaryn during the Barremian. The southward current probably occurred at a greater depth as an undercurrent because the Arctic Ocean consisted of cool waters (e.g. Jeletzky 1971). This concurs with the common heteromorphs in the northern faunas from Japan because they are interpreted to have had a benthic mode of life (e.g. Klinger 1980). The occurrence of only one specimen of *Pulchellia*, a characteristic Tethyan genus, from Rebun in the northern part of northeast Japan, probably suggests that the current from the Equator reached northward at least that far.

Shasticrioceras patricki Murphy is found in middle Barremian strata of both California and Japan. This species is interpreted to have been carried to these widely separated areas by currents from the Arctic, or to have been a migrant via high latitudes from Japan to California, or vice-versa. Some species of the genus *Shasticrioceras* from Barremian strata of Arctic Canada were also likely to have been immigrants from the northern Pacific Ocean (Text-fig. 7). The occurrence of *S. bifurcatus* Dimitrova in the Barremian of Bulgaria (Dimitrova 1967) might support the hypothesis that the genus was derived from a Tethyan ancestor because *Shasticrioceras* is not known to occur between the Bulgarian and northern Pacific areas and where non-marine facies occur.

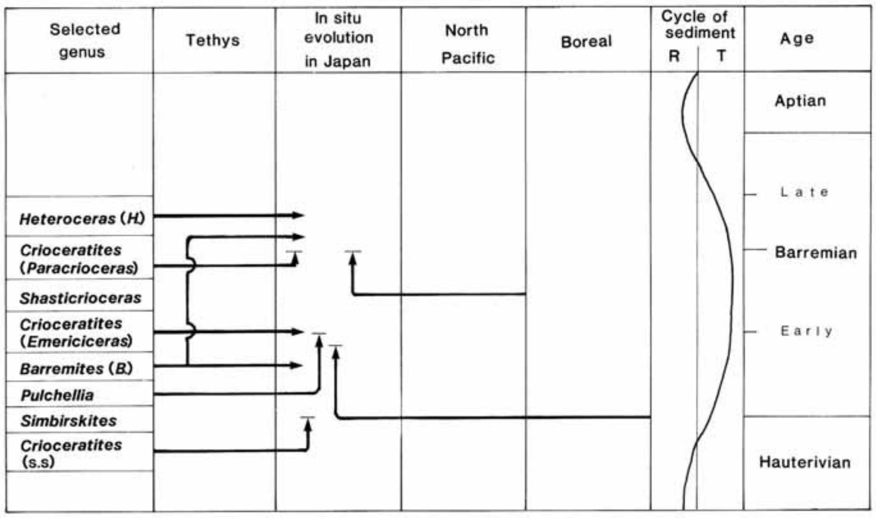
Evolution of Crioceratites *in Japan*

Three species of *Crioceratites*, *C.* (*C.*) *ishiwarai*, *C.* (*E.*) *emerici* and *C.* (*Paracrioceras*) *asiaticum*, are known to occur in statigraphical order in the mid-Hauterivian to early Barremian of Japan.

C. (*C.*) *ishiwarai* from the middle Hauterivian, allied to *C.* (*C.*) *nolani* or *C.* (*C.*) *duvali* of Europe, is characterized by having a tightly coiled whorl, trituberculate major ribs with five to eight minor ribs between them in the adult stage, and by a tendency to bifurcation of ribs near the ventral border (Yabe and Shimizu 1926). *C.* (*E.*) *emerici* from the Japanese lower Barremian is characterized by loose coiling, trituberculate major ribs and four continuous minor ribs between major ribs in the adult stage. *C.* (*P.*) *asiaticum* is distinguished by having tight to loose coiling as the shell grows, trituberculate major ribs and one to two minor ribs between major ribs in the adult stage.



TEXT-FIG. 6. Distribution of some Barremian ammonite genera and the presumed palaeogeography and palaeocurrents around Japan.



TEXT-FIG. 7. Origin of some Barremian and Hauterivian ammonite species from Japan.

Examining the Japanese material in its stratigraphical context, it is seen that the whorl changes successively from tightly coiled to loosely coiled, and back again to tightly coiled. Ribs consist of trituberculate major ribs and minor ribs. The number of minor ribs between major ribs decreases stratigraphically, from five or eight to one or two through four. Some minor ribs bifurcating near the ventral border in *C.* (*C.*) *ishiwarai* are not seen in other species. From the above characters, it can be seen that the number of minor ribs shows a tendency to decrease through time. Furthermore, *C.* (*P.*) *asiaticum* does not have similar morphological features to *C.* (*E.*) *emerici* and *C.* (*C.*) *ishiwarai* throughout its ontogeny. Thus, *C.* (*E.*) *emerici* seems not to be recognizably related to *C.* (*P.*) *asiaticum* in the same lineage.

Each of the Japanese species has a close resemblance to European forms: *C.* (*C.*) *ishiwarai* is similar to species of the *C. nolani* and *duvali* group; *C.* (*P.*) *asiaticum* resembles *C.* (*P.*) *elegans*; and specimens identified as *C.* (*E.*) *emerici* from Japan and Europe belong to one and the same species. According to Immel (1978), one of two crioceratid lineages including *C.* (*E.*) *emerici* (referred to as *C.* (*C.*) *emerici* by Immel) which developed in southern Europe (Tethyan province), is made up of *C.* (*C.*) *nolani*, *C.* (*C.*) *journoti*, *C.* (*E.*) *emerici*, and *C.* (*E.*) *barremense* in order, and is characterized by a decreasing number of minor ribs. Another lineage comprising *C.* (*P.*) *elegans* (referred to as *C.* (*C.*) *elegans* by Immel) is highly developed in northwest Europe (Boreal province) and is characterized by having no distinction between major and minor ribs and being loosely to tightly coiled as the shell grows.

Thus, morphological affinities are, as described above, not recognizable between the three species from Japan, but all of these species appear closely similar to some European species.

Crioceratites (*Paracrioceras*) in northwestern Europe is interpreted to have descended from southern European *Crioceratites* (*Crioceratites*) species migrating northward during mid-Hauterivian time (Immel 1978; Kemper *et al.* 1981).

According to P. F. Rawson (pers. comm. February 1991), by the Barremian northwest Europe had apparently lost contact with areas to the north: the Barents Shelf had become non-marine, and the Russian Platform and northern Siberia partly so. No heteromorphs are known from these areas in either the Barremian or the Hauterivian, with the exception of three specimens from the Russian

Platform. All the evidence suggests that the NW European heteromorphs came originally from western Tethys and never migrated farther into the Boreal Realm. Thus, it is suggested that the ancestor of *C.* (*P.*) *asiaticum* is more likely to have been derived from Tethys. *C.* (*P.*) *asiaticum* is interpreted to have evolved in parallel to the European crioceratid lineage and to have a common ancestor.

Consequently, it may be a reasonable interpretation that the three Japanese crioceratid species are immigrant species from the Tethys, and that *C.* (*C.*) *ishiwarai* and *C.* (*P.*) *asiaticum* developed in Japan (see Text-fig. 7).

CONCLUSIONS

Four species representing three genera of ammonites from four Barremian formations in southwest Japan are described in this paper. These genera were mainly distributed in the northwest European and northern Pacific provinces in Barremian time. They are interpreted to have migrated between these areas via high latitude seas.

The occurrence of only Tethyan ammonite faunas in northeast Japan and of mixed Tethyan and northern faunas in southwest Japan suggests that a Barremian seaway existed between northeast Japan and continental Asia. This is based on oceanic circulation patterns and concordant global distribution of ammonites during the Barremian.

Three species belonging to *Crioceratites* from Japan appear morphologically more closely related to some species from Europe than to each other. It may be reasonable to interpret these three species from Japan as immigrant species from the Tethys or their descendants.

Acknowledgments. We thank Drs J. W. Haggart (Geological Survey of Canada), P. F. Rawson (University College, University of London), E. Kemper (Bundesanstalt für Geowissenschaften und Rohstoffe), N. J. Mateer (University of California) and J. P. Thieuloy (Université de Grenoble) for critical reading of the manuscript. We are also indebted to Dr M. Futakami (Kawamura-gakuen Women's University, Chiba) for fruitful discussion on some of the problems. Thanks are extended to Dr T. Matsumoto (Kyushu University) and Messrs. Y. Ogawa (Manaus, Brazil), Y. Mizuno (Nagoya) and T. Komatsu (Tokyo Gakugei University) for their kind help in collecting the fossils described herein. The study was financially supported in part by the Science Research Fund of the Japanese Ministry of Education, Science and Culture (Monbushou) (Obata, no. 56340041 for Cooperative Research in 1981–1982; Matsukawa, no. 56740335 in 1981 and no. 61740463 in 1986).

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Typescript received 2 November 1990
Revised typescript received 10 August 1992