THE EARLY SILURIAN ATRYPID BRACHIOPOD *ALISPIRA* FROM WESTERN CANADA

by JISUO JIN *and* B. S. NORFORD

ABSTRACT. *Alispira gracilis* and *Alispira tenuicostata* previously have been known only from early Silurian rocks of the Siberian Platform and the eastern Baltic region. Here they are described from early Silurian (Llandovery) rocks of Canada, from the Beaverfoot Formation in the southern Rocky Mountains, the Nonda Formation in the northern Rocky Mountains (both British Columbia), and the Mount Kindle Formation in the District of Mackenzie. A third species, *Alispira lowi*, is described from the Severn River Formation in northern Manitoba. Other doubtful species of *Alispira* have been reported from southwestern and eastern Siberia and from northwestern China. In Siberia, *Alispira* has been reported to range from the early Llandovery to Wenlock. In Canada, associations of *Alispira* with *Virgiana* indicate a late Rhuddanian age for its earliest occurrence; the genus ranges up into the Aeronian and possibly into the Telychian but occurrences of *Alispira* with *Pentamerus* have not been documented. The distributions of *Alispira gracilis* and *Alispira tenuicostata* indicate close links between the early Silurian shelly faunas of the Siberian Platform and those of the cratonic regions of western North America.

ALISPIRA was established by Nikiforova (*in* Nikiforova and Andreeva 1961) as a subgenus of *Zygospira*, and included two new species, *A. gracilis* and *A. tenuicostata*, both from the early Silurian (Llandovery) of the Tunguska River area, southern Siberia. Boucot *et al.* (1965) elevated *Alispira* to generic status. Because of its dorsally to dorso-medially directed spiralia, *Alispira* later was transferred from the Zygospiridae (characterized by medially directed spiralia) to the Atrypidae (Nikiforova and Modzalevskaya 1968; Copper 1977).

Initially, *Alispira* was thought to be confined to the Siberian Platform but Rubel (1970) reported *Alispira gracilis* from the Juuru horizon (Rhuddanian) of Estonia (Text-fig. 1, locality 5). The internal structures of the Estonian specimens, however, were not well described, except for the 'complete hinge plates' (that is, medially connected hinge plates) mentioned by Rubel (1970, p. 26). A third species, *Alispira praegracilis*, was described by Severgina (1978) from the late Ordovician (uppermost Ashgill) of the northwestern Altai Mountains, but its affinity to *Alispira* later was questioned (Kulkov and Severgina 1989). Fu (1982, 1985) reported another new species, *Alispira testudinaria*, from the early Silurian of Ningxia, northwestern China, remarking that 'the hinge plates in the brachial valve are discrete, approaching each other only at their anterior margins' (Fu 1982, p. 149). In comparison, typical *Alispira* has hinge plates entirely connected by a horizontal plate.

In North America, reports of *Alispira* have been scarce and there are no formal descriptions. Norford (1969, 1970), Norford *et al.* (1967), and Norford and Macqueen (1975) mentioned *Alispira* in faunal lists for the Nonda, Mount Kindle, and Severn River formations of Canada but did not describe or illustrate any specimens. The only other probable occurrence of *Alispira* was reported by Amsden (1974), who assigned, with reservation, four specimens to '*Homoeospira*' *fiscellostriata*? Savage, 1913. The four specimens are from the Noix Limestone (latest Ashgill) and the Bryant Knob Formation (earliest Llandovery) of Missouri, USA, and later were assigned to *Alispira gracilis* by Kulkov *et al.* (1985), although Amsden (1974, p. 78) had stated 'nothing is known of their internal structure'. The North American genus *Clintonella* Hall and Clarke, 1893 is similar to *Alispira* in external morphology (Copper 1977), and it is very likely that some representatives of *Alispira* in North America have been identified as *Clintonella*.

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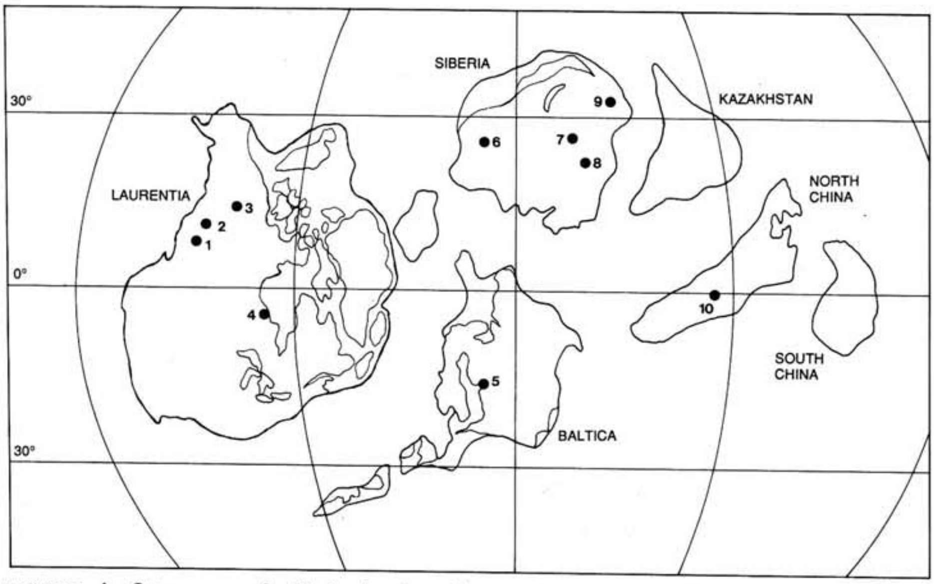


TEXT-FIG. 1. Occurrences of *Alispira* in the palaeocontinents of early Silurian equatorial regions. Palaeogeographical reconstruction adapted from Scotese and McKerrow (1990). 1, southern Rocky Mountains, Canada; 2, northern Rocky Mountains, Canada; 3, Mackenzie Valley, Canada; 4, Hudson Bay Lowlands, Canada; 5, Estonia; 6, Sette-Daban Range, Siberia; 7, 8, Tunguska, Siberia: 9, northern Altai Mountains, Siberia; 10, Ningxia, North China.

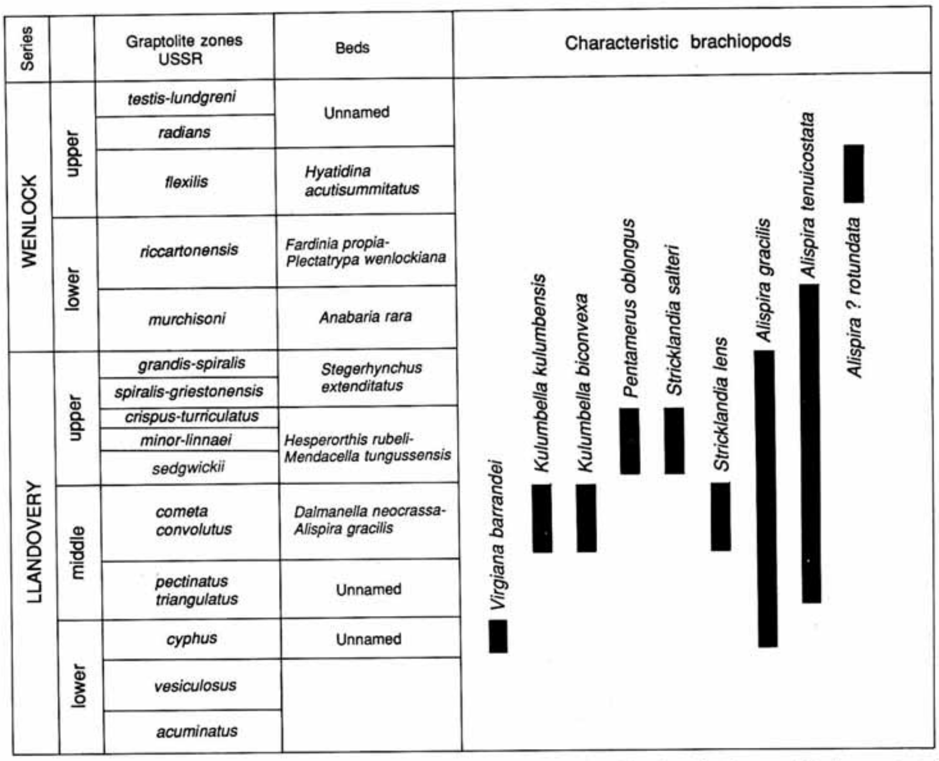
BIOSTRATIGRAPHY AND PALAEOGEOGRAPHY OF *ALISPIRA*

The two most common and best known species, *Alispira gracilis* and *A. tenuicostata*, are early Silurian (predominantly Llandovery) in age and can be used for dating rocks at this broad scale. Their widespread distribution in Western Canada and in the Siberian Platform may indicate biogeographical ties between these two regions in early Silurian time.

Siberian Platform

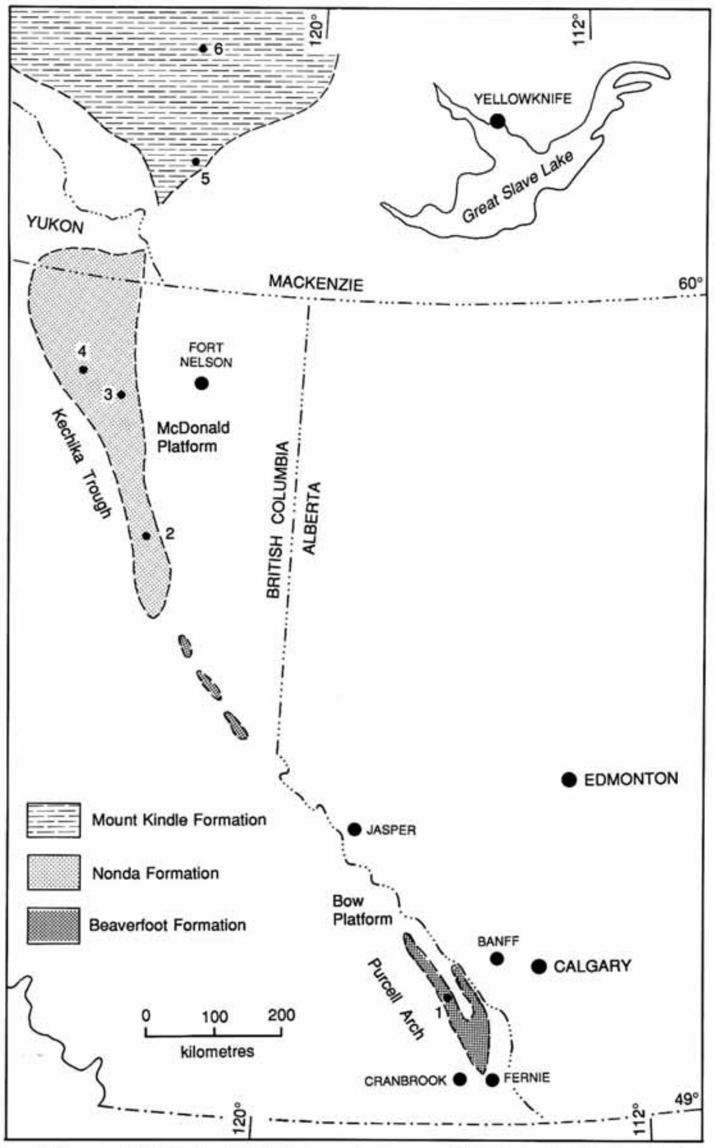
Nikiforova and Andreeva (1961) provided comprehensive description and tabulation of the abundant and highly diverse brachiopod faunas in the Ordovician and Silurian rocks of the Siberian Platform. Their record of the Siberian occurrences of the large-shelled pentamerids of Llandovery age, such as *Virgiana barrandei* (Billings, 1857), *Pentamerus oblongus* J. de C. Sowerby, 1839, *Stricklandia lens* (J. de C. Sowerby, 1839), *Kulumbella kulumbensis* Nikiforova, 1961, and *Kulumbella biconvexa* Nikiforova, 1961, formed the basis for intercontinental correlations of the early Silurian shelly faunas of Siberia with those of Europe and North America. They also recorded the presence of the rhynchonellid *Eocoelia* in the same faunas and Ziegler's (1966) later description of the *Eocoelia* lineage provided an additional tool for intercontinental correlation of the Siberian early Silurian faunas.

Compared to the rather short stratigraphical ranges recorded for most species of *Virgiana*, *Pentamerus*, *Stricklandia*, *Kulumbella*, and *Eocoelia*, the two atrypoid species, *Alispira gracilis* and *A. tenuicostata*, are reported to extend from the late Rhuddanian to the early Wenlock of northern Siberia (Lopushinskaya 1976). The oldest occurrence of *Alispira*, *A. gracilis*, is reported in the upper

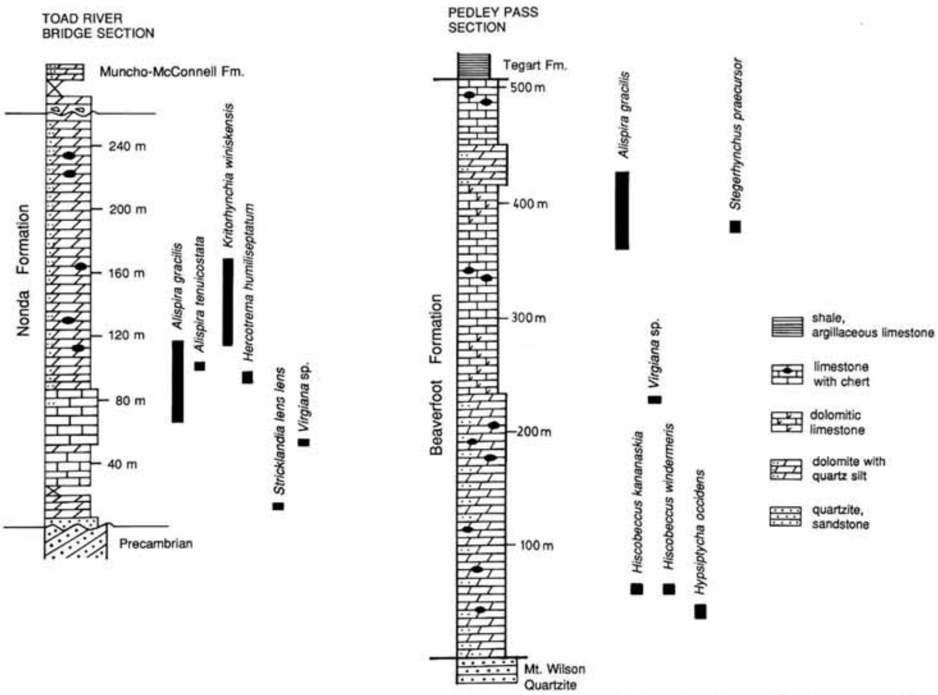


TEXT-FIG. 2. Stratigraphical ranges of the three species of *Alispira* in the Siberian Platform and their associated pentamerid brachiopods (data from Lopushinskaya 1976).

beds of the Rhuddanian Stage together with *Virgiana barrandei* (Text-fig. 2). These beds were correlated by Lopushinskaya (1976, table 1) with the *Coronograptus cyphus* Biozone recognized in both the Soviet and British graptolite zonal schemes. In the Aeronian, both *Alispira gracilis* and *A. tenuicostata* are present, associated with the aberrant stricklandiid pentamerids, *Kulumbella kulumbensis* and *K. biconvexa* (considered as index species of the Aeronian), and with the oldest species of *Eocoelia*, *E. hemisphaerica* (J. de C. Sowerby, 1839). Lopushinskaya correlated these beds with the Siberian graptolite biozones from *Monograptus triangulatus* to *Cephalograptus cometa*. The two species of *Alispira* persist through the Telychian, together with *Pentamerus oblongus* and *Stricklandia salteri* (Billings, 1868). These occurrences of the two species were considered coeval with the *Monograptus sedgwickii* to *Stomatograptus grandis* Biozones in the Soviet scheme, equivalent to biozones from *M. sedgwickii* to *M. crenulatus* (late Aeronian to latest Telychian) in Britain. In the early Wenlock, Lopushinskaya (1976) only recorded *Alispira tenuicostata* within her table 1 (as shown in our Text-figure 2) but both *A. gracilis* and *A. tenuicostata* in her text (p. 63). The doubtful species *Alispira*? *rotundata* Nikiforova and Modzalevskaya, 1968 has been recorded from the late Wenlock, which is probably the highest horizon suggested for the genus.



TEXT-FIG. 3. Localities (small black dots) of *Alispira* and pentamerids in the early Silurian of the Mount Kindle, Nonda, and Beaverfoot formations, Canada. 1, Pedley Pass (GSC Locs 47400, C-164513-164519); 2, Guilbault Creek (GSC Loc. 64473); 3, Mount Mary Henry (GSC Loc. 64537); 4, Toad River Bridge (GSC Locs 64548-64555); 5, near 'Red Rock Pass' section (GSC Loc. 42027); 6, Mount Kindle (GSC Locs 69800, 69801, 69803, 69804).

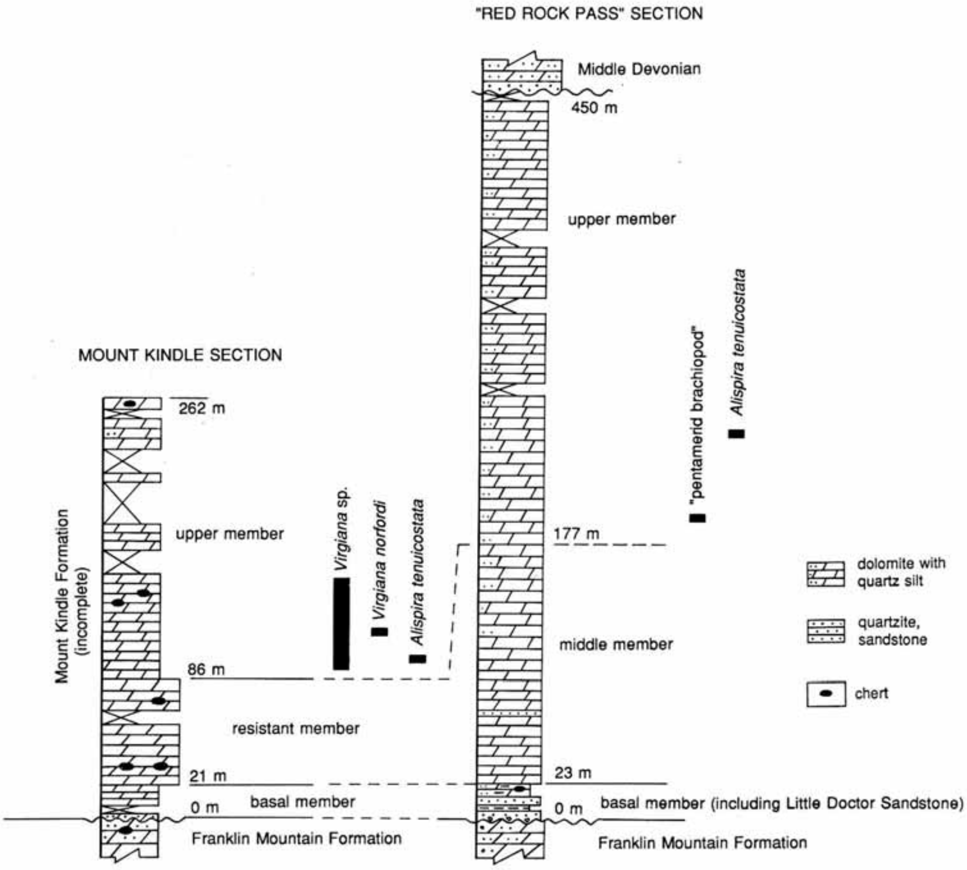


TEXT-FIG. 4. Stratigraphical ranges of *Alispira gracilis*, *A. tenuicostata* and other brachiopods in the type section of the Nonda Formation, near Toad River Bridge (Text-fig. 1, loc. 4), northern Rocky Mountains, Canada and in the standard section of the Beaverfoot Formation, Pedley Pass (Text-fig. 1, loc. 1), southern Rocky Mountains, Canada (data partly from Jin *et al.* 1989).

Western Canada

In the southern Rocky Mountains (Text-fig. 3, locality 1), the Beaverfoot Formation (Ashgill to Telychian) consists of dolomite, dolomitic limestone and limestone and is overlain by the Tegart Formation that includes the *Monograptus spiralis* Biozone at its base (Norford 1962, 1969; Jin *et al.* 1989). In the standard section (506 m thick) at Pedley Pass, *Alispira gracilis* is present at several horizons from 358·8 to 425·2 m above the base of the Formation (Text-fig 4). The late Rhuddanian *Virgiana* sp. and *Nondia* sp. are known at 222·2 to 222·8 m (Buttler *et al.* 1988). The *Alispira* horizons are within the *Eostropheodonta* Biozone of Norford (1962, 1969) that probably is mainly Aeronian in age but could be as early as late Rhuddanian.

In the northern Rocky Mountains (Text-fig. 3, localities 2–4), the Nonda Formation (Rhuddanian to Telychian) consists of dolomites, dolomitic limestones, limestones, and quartz sandstones. Four faunal assemblages in the formation were recognized by Norford *et al.* (1967). Subsequently the uppermost assemblage (with *Pentamerus*) was found to underlie the *Monograptus spiralis* Biozone at one locality (Davies 1966). Later, Boucot and Chiang (1974) discovered a virgianid brachiopod faunule, including *Virgiana norfordi* and *Nondia canadensis*, within the lower part of the formation but did not relate it to these assemblages. *Alispira gracilis* and *A. tenuicostata* are present in the type section (295 m thick) of the Nonda Formation near Toad River Bridge (Text-fig. 4) at 65·5 to

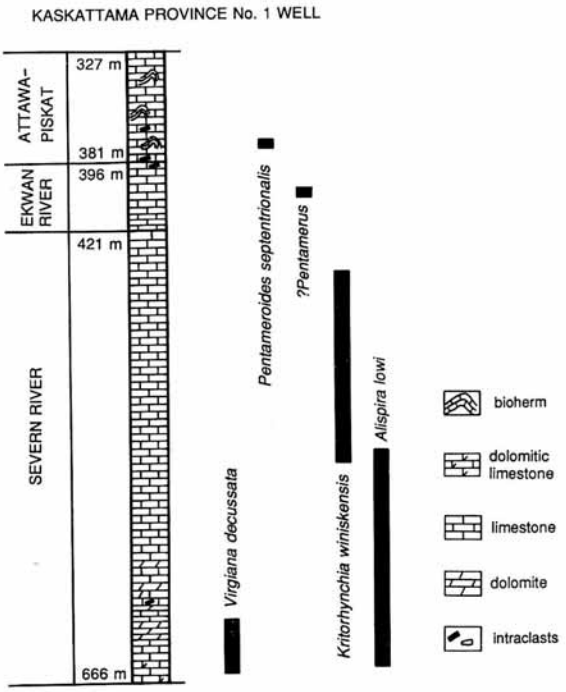


TEXT-FIG. 5. Stratigraphical ranges of *Alispira tenuicostata* and pentamerids in the type section (63° 21′ N, 123° 12′ W) and 'Red Rock Pass' section (61° 42′ N, 123° 18′ W) of the Mount Kindle Formation, District of Mackenzie, Northwest Territories, Canada. Data from Norford and Macqueen (1975), Shell Canada Limited, and Meijer-Drees (1975*a*, 1975*b*).

117 m above its base, within and below the second assemblage but above the occurrences of the lowest assemblage at 40 to 48 m. The virgianid faunule was reported by Boucot and Chiang (1974) from 79 m above the base of the Nonda Formation at a locality about 50 km from the type section. In the type section, only one broken pedicle valve of *Virgiana* sp. (with a relatively short, shallow spondylium supported by a high median septum) has been found at 50·6 to 53·3 m above the base. Thicknesses of the lower part of the Nonda Formation are irregular because of erratic distributions of quartz sandstone. If *Virgiana* sp. in the type section is a correlative of the *Virgiana* faunule of Boucot and Chiang, it can be inferred that the lowest *Alispira* is about as old as, or slightly younger than, the *Virgiana* faunule. *Stricklandia lens lens* Williams, 1951, which occurs 10·7 to 11·9 m above the base (Pl. 5, figs 11–12), was identified by comparing the form index (A/B; length of outer plate/length of inner plate) of the Nonda specimens with that provided by Baarli (1986) for Welsh,

Norwegian, and Estonian specimens. In Wales and Norway, the range of *S. lens lens* is confined to the *cyphus* Biozone (Cocks *et al.* 1984, p. 173; Baarli 1986, p. 201). Elsewhere, *Pentamerus oblongus* (Pl. 5, figs 3–10) is present in the assemblage at the Guilbault Creek section (474 to 485 m above the base of the Nonda), indicating an Aeronian to early Telychian age; *Alispira gracilis* occurs at 140·2 to 147·8 m above the base of the same section, being considerably older than *P. oblongus*. Based on the available data, *Alispira* in the Nonda Formation seems to range from latest Rhuddanian to early Aeronian.

Dolomites of the Mount Kindle Formation (Ashgill to Telychian and possibly younger) are widely distributed in the western part of the District of Mackenzie and are bounded by regional unconformities (Text-fig. 3; see also Norford and Macqueen 1975; Meijer-Drees 1975*a*, 1975*b*). Three informal members are recognized in the type section (more than 262 m thick; Text-fig. 5). The lower two are Late Ordovician in age. In the 'upper member' (at least 176 m thick), *Alispira tenuicostata* occurs at 9 m above its base (GSC Loc. 69801). Pentamerids were recorded by Norford and Macqueen (1975) from three intervals in the member: pentamerid? at 6 m (GSC Loc. 69800), *Virgiana* sp. at 29 to 30 m (GSC Loc. 69803), and *Pentamerus*? sp. at 61 to 66 m (GSC Loc. 69804) from its base. Re-examination of the collections shows that the shells from all three horizons are characterized by a shallow, broad spondylium supported by a high median septum and should all be assigned to *Virgiana*. The two internal moulds from GSC Loc. 69800 cannot be identified to the specific level. A few of the specimens from GSC Loc. 69803 show fine costae and can be assigned



TEXT-FIG. 6. Stratigraphical ranges of *Alispira lowi* and other brachiopods of the Severn River, Ekwan River, and Attawapiskat Formations, Kaskattama Province No. 1 Well, northern Manitoba, Canada. Data from Norford (1970) and Jin *et al.* (in press).

to *Virgiana norfordi* (Pl. 5, figs 1–2; see also Norford and Macqueen 1975, pl. 9, figs 1–6, 8). The shells from GSC Loc. 69804 are intensely dolomitized and recrystallized, with no surface sculpture preserved. About 200 km to the south, at a stratigraphic section (453 m thick) measured by Shell Canada Ltd in the Nahanni Range (Text-fig. 3, locality 5) near 'Red Rock Pass' of Meijer-Drees (1975*a*, 1975*b*), the base of the upper member is about 177 m above the base of the formation (Text-fig. 5). Pentamerid brachiopods occur at 188 m and an early Silurian coral faunule occurs at 240 m. *Alispira tenuicostata* is abundant at GSC Loc. 42027, an isolated locality within 2 km of the section measured by Shell, and thought to be at a stratigraphical position low in the upper member. *Alispira tenuicostata* in GSC Loc. 42027 may be coeval with the occurrence of the same species in the type section, where it is documented within the lower part of the *Virgiana* Biozone. The species in the Mount Kindle Formation may well be the oldest representative of the genus in western Canada.

In the Hudson Bay region, limestones, dolomitic limestones, dolomites, and anhydrites of the Severn River Formation (about 250 m thick) are dated as late Rhuddanian to earliest Telychian (Norford 1970, 1972; Jin *et al.* in press). *Virgiana decussata* is widespread in the basal beds of the formation in northern Manitoba and has been documented at 10 to 56 m above the base of the formation in the Kaskattama Province No. 1 Well (Text-fig. 6). Norford (1970) initially reported *Alispira* sp. from 7 to 11 m above the base. Detailed examination of the core samples, with the help of serial sectioning, identifies the species as *Alispira lowi* (Pl. 4, figs 1–10, 13, 14). It has a much wider stratigraphic range than previously reported, from 9 m (GSC Loc. C-783) to 126 m (GSC Loc. C-922) above the base of the formation. The lowermost occurrence of *Alispira* overlaps the *Virgiana* Biozone and can be dated as late Rhuddanian; the uppermost occurrence extends into the middle Severn River Formation and is approximately mid Aeronian in age.

In summary, the lower range of *Alispira* in western Canada is well dated as late Rhuddanian by association with *Virgiana* faunules. The genus may range up through the Aeronian (above *Stricklandia lens lens*) but probably not into the Telychian (below *Pentamerus oblongus*).

Palaeogeographical implications

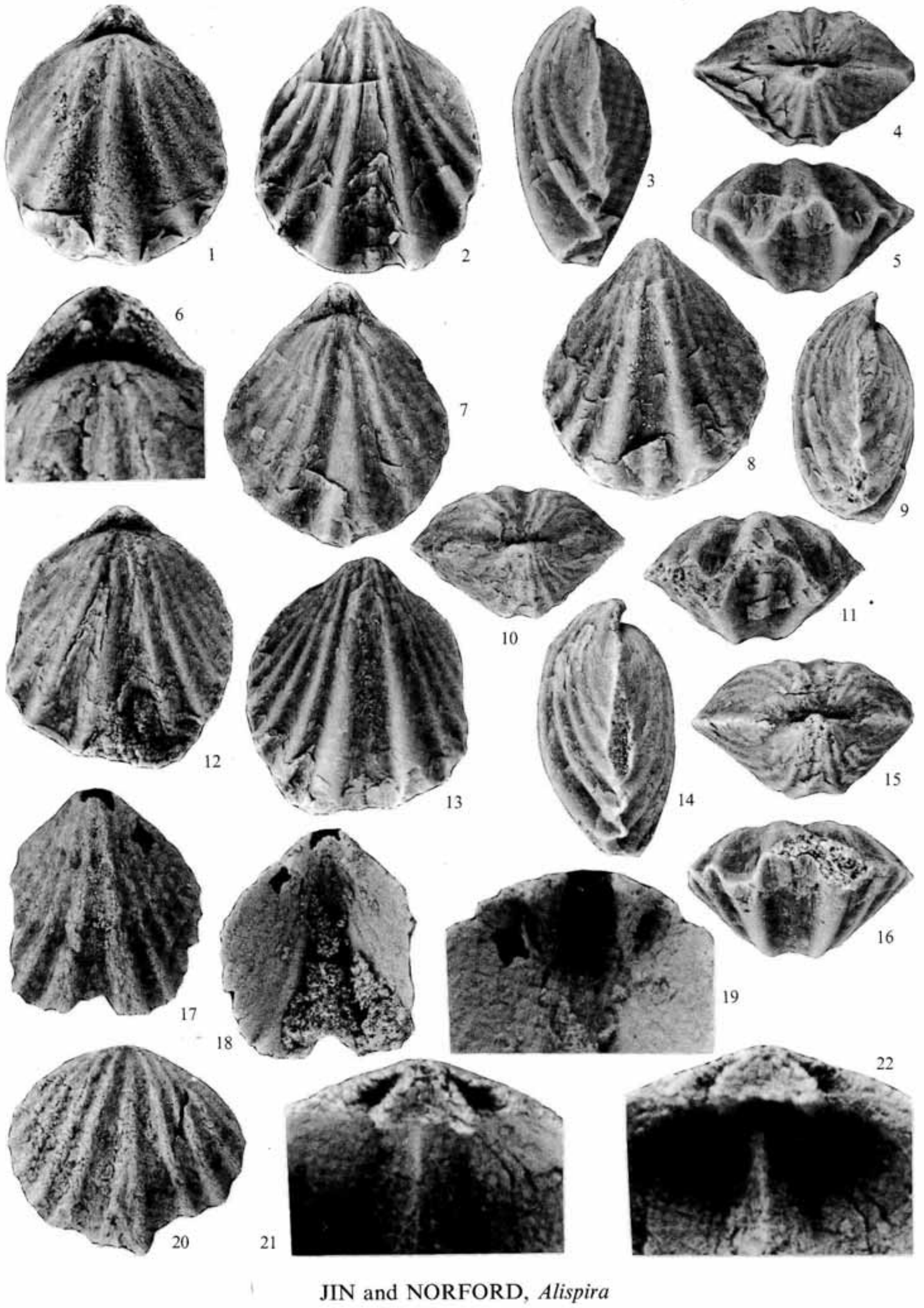
Disregarding the questionable species of *Alispira* from the northern Altai Mountains, Siberia (Severgina 1978; Kulkov and Severgina 1989) and northwestern China (Fu 1982, 1985), reliable records of *Alispira* are confined to the Siberian Platform, Estonia (Rubel 1970), and western Canada. *Alispira gracilis* and *A. tenuicostata* are among the most common and most abundant early Silurian brachiopods in the Siberian Platform. Their scarcity outside Siberia may have been, at least partly, due to the fact that these small atrypids are difficult to identify and may be hidden in other genera homoeomorphic to *Alispira*, such as *Homoeospira* and *Clintonella*.

The common association of *Alispira* with the large-shelled pentamerids implies that the genus preferred relatively shallow marine environments of normal salinity. The early Silurian *Virgiana* and *Pentamerus* generally occupied intertidal and subtidal zones and spread over all the equatorial palaeocontinents. The common occurrence of *A. gracilis* and *A. tenuicostata* in Siberia and western Canada probably indicates a close faunal link between the two respective palaeocontinents. Such

EXPLANATION OF PLATE 1

Figs 1–22. *Alispira gracilis* Nikiforova, 1961. 1–6, GSC 98103, partly exfoliated calcareous shell with inflated costae on fold and flanking sulcus, and well-developed deltidial plates, Beaverfoot Formation, Pedley Pass section (GSC Loc. C-164517). 7–11, GSC 98104, same locality as Figs 1–6. 12–16. GSC 98105, calcareous shell with fine growth lines preserved near anterior margin (Fig. 16), Beaverfoot Formation, Pedley Pass section (GSC Loc. C-164518). 17–19, GSC 98106, silicified pedicle valve showing well-developed dental plates, Nonda Formation, Hoole Creek section (GSC Loc. 45524). 20–22, GSC 98107, brachial valve with low median septum and horizontal plate connecting hinge plates, same locality as Figs 17–19.

Magnifications: 1–5, 7–16, ×6; 6, ×15; 17–18, 20, ×7; 19, 21–22, ×16.



JIN and NORFORD, *Alispira*

a faunal connection can be traced back even to Late Ordovician (late Ashgill) time. For many years, the unique rhynchonellid genus, *Lepidocycloides* Nikiforova (*in* Nikiforova and Andreeva 1961), has been reported widely from the Siberian Platform but was virtually unknown from other continents or regions. However, *Lepidocycloides rudicostatus* Jin *et al.* 1989, has been described from the lower part of the Beaverfoot Formation (Ashgill) of the southern Rocky Mountains, British Columbia. Given the high degree of provincialism characteristic of the Late Ordovician shelly faunas (Sheehan 1988), the common occurrence of *Lepidocycloides* accentuates the affinity of the brachiopod faunas of the two continents.

Links between the shelly faunas of the two continents in early Silurian time are also demonstrated by occurrences of other brachiopods. *Virgiana barrandei* is one of the most common and diagnostic species in the late Rhuddanian rocks of Anticosti Island. Despite the close proximity between North America (Laurentia) and Europe (Baltica) in that time, the species has not been found in Britain or the Baltic region. In the Siberian Platform, however, *V. barrandei* appears to be quite common (see Lopushinskaya 1976). The aberrant stricklandiid *Kulumbella*, with extremely flat shells and criss-cross surface sculpture, was discovered initially in the mid Llandovery rocks of Siberia by Nikiforova (*in* Nikiforova and Andreeva 1961) and subsequently reported from rocks of similar age in Estonia (Rubel 1970). *Kulumbella* also is common in the upper Gun River (mid Aeronian) rocks of Anticosti Island, Quebec. Apart from a single shell of *Kulumbella* sp. reported from South China (Rong and Yang 1981), the pattern of geographic distribution of *Kulumbella* is very similar to that of *Alispira* in early Silurian time; that is, both occur commonly in equatorial regions of the three neighbouring palaeocontinents: Siberia, Baltica, and Laurentia (Text-fig. 1).

LOCALITIES AND PRESERVATION

Sample GSC Loc. 42027 was collected by B. S. Norford in 1960; GSC Loc. 45524 and 47400 in 1961; GSC Loc. 64473, 64537-64533 in 1964; and GSC Loc. C-164513-164519 by B. S. Norford and J. Jin in 1987. The specimens from the Nonda and Mount Kindle formations are intensely silicified, as are their internal matrices, but a few separated valves show relatively well-preserved internal structures. In contrast, collections from the Pedley Pass section of the Beaverfoot Formation are predominantly calcareous, making possible detailed examination of internal structures by serial sectioning.

GSC Loc. 42027. Mount Kindle Formation, near 'Red Rock Pass' section of Meijer-Drees (1975*a*), District of Mackenzie, Northwest Territories, 61° 42′ N, 123° 18′ W, about 259 m above base of formation.

GSC Loc. 45524. Nonda Formation, Hoole Creek section, northern British Columbia, 59° 18′ N, 126° 12′ W, 176·8 to 179·8 m above base of formation.

GSC Loc. 47400. Beaverfoot Formation, Pedley Pass section, southeastern British Columbia, 50° 25′ N, 115° 46′ W, 380 to 420·6 m above base of formation.

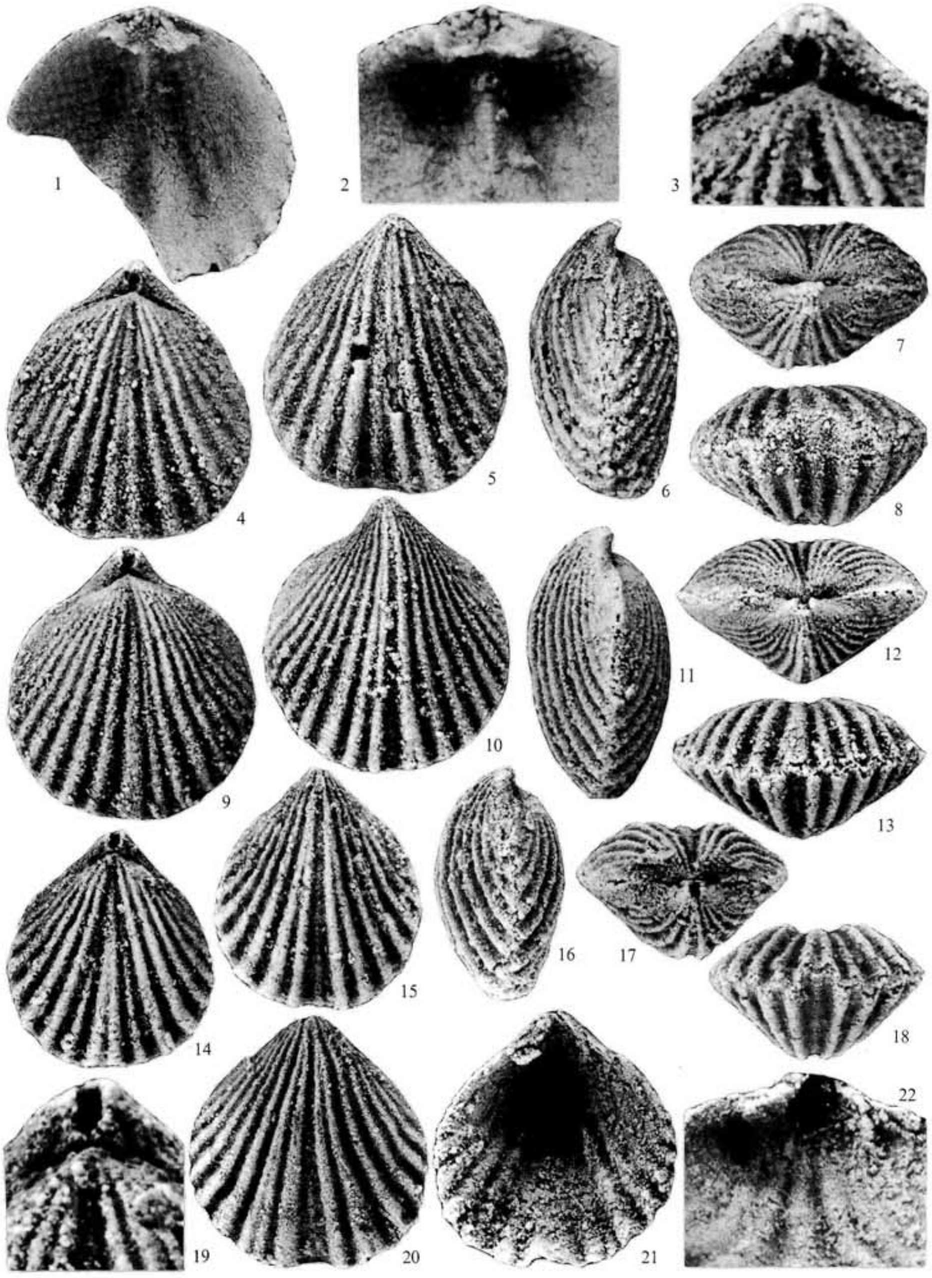
GSC Loc. 52169. Beaverfoot Formation, Hatch Creek section, southwestern British Columbia, 50° 00′ N, 116° 24′ W, 318 m above base of formation.

EXPLANATION OF PLATE 2

Figs 1–2. *Alispira gracilis* Nikiforova, 1961. GSC 98108, silicified brachial valve with well-defined horizontal plate connecting hinge plates, Nonda Formation, Hoole Creek section (GSC Loc. 45524).

Figs 3–22. *Alispira tenuicostata* Nikiforova, 1961. Four silicified specimens from the Nonda Formation, Mount Mary Henry section (GSC Loc. 64537). 3–8, GSC 98111, complete shell with deltidial plates nearly coalescing medially. 9–13, GSC 98112, deltidial plates poorly preserved. 14–19, GSC 98113, relatively small shell with medially conjunct deltidial plates. 20–22, GSC 98114, pedicle valve with relatively large teeth and short dental plates.

Magnifications: 1, ×10; 2, ×15; 3, 19, ×18; 4–18, 20–21, ×6; 22, ×12.



JIN and NORFORD, *Alispira*

GSC Loc. 64473. Nonda Formation, Guilbault Creek section, northern British Columbia, 56° 34′ N, 123° 35′ W, 478 to 485 m above base of formation.
GSC Loc. 64483. Nonda Formation, Guilbault Creek section, northern British Columbia, 56° 34′ N, 123° 35′ W, 140·2 to 147·8 m above base of formation.
GSC Loc. 64537. Nonda Formation, Mount Mary Henry section, northern British Columbia, 58° 28′ N, 124° 30′ W, 59·4 to 59·7 m above base of formation.
GSC Loc. 64548. Nonda Formation, Toad River Bridge section, northern British Columbia, 58° 48′ N, 125° 37′ W, 112·2 to 117·0 m above base of formation.
GSC Loc. 64549. Nonda Formation, same section, 98·8 to 102·7 m.
GSC Loc. 64550. Nonda Formation, same section, 88·7 to 98·8 m.
GSC Loc. 64553. Nonda Formation, same section, 65·5 to 67·7 m.
GSC Loc. 64554. Nonda Formation, same section, 50·6 to 53·3 m.
GSC Loc. 64555. Nonda Formation, same section, 10·7 to 11·9 m.
GSC Loc. 69800. Mount Kindle Formation (upper member), Mount Kindle, District of Mackenzie, Northwest Territories, 63° 21′ N, 123° 12′ W, 6·1 to 6·4 m above base of member.
GSC Loc. 69801. Mount Kindle Formation (upper member), same section, 9·1 m.
GSC Loc. 69803. Mount Kindle Formation (upper member), same section, 29·2 to 29·9 m.
GSC Loc. 69804. Mount Kindle Formation (upper member), same section, 61·2 to 66·1 m.
GSC Loc. C-783. Severn River Formation, core section from Kaskattama Province No. 1 Well, northern Manitoba, 57° 15′ N, 90° 10′ W, depth 540 m.
GSC Loc. C-922. Severn River Formation, same section, depth 657 m.
GSC Loc. C-164513. Beaverfoot Formation, Pedley Pass section, southeastern British Columbia, 50° 25′ N, 115° 46′ W, 358·8 m above base of formation.
GSC Loc. C-164517. Beaverfoot Formation, Pedley Pass section, 403·6 to 404·5 m above base of formation.
GSC Loc. C-164518. Beaverfoot Formation, Pedley Pass section, 406·7 to 407·6 m above base of formation.
GSC Loc. C-164519. Beaverfoot Formation, Pedley Pass section, 425·2 m above base of formation.

All figured specimens used in the present study are deposited in the type collections of the Geological Survey of Canada (GSC), Ottawa.

SYSTEMATIC PALAEONTOLOGY

Superfamily ATRYPOIDEA Gill, 1871
Family ATRYPIDAE Gill, 1871
Subfamily CLINTONELLINAE Poulsen, 1943
Genus ALISPIRA Nikiforova, 1961

Type species. *Zygospira* (*Alispira*) *gracilis* Nikiforova (*in* Nikiforova and Andreeva), 1961, p. 244, pl. 53, figs 1–8, early Silurian (early to late Llandovery), Siberian Platform.

Age. (?latest Ashgill) Llandovery to Wenlock.

Diagnosis. Shell small, with carina in ventral umbo and median furrow in dorsal umbo; dorsal fold developed anteriorly; dental plates present; hinge plates connected by horizontal plate to form cardinal cavity.

Remarks. Detailed discussion on the taxonomic position of *Alispira* can be found in Copper (1977). The following additional species is assigned without doubt: *Zygospira* (*Alispira*) *gracilis* forma *tenuicostata* Nikiforova (*in* Nikiforova and Andreeva), 1961, p. 247, pl. 53, figs 9–17. Early Silurian (early Llandovery-earliest Wenlock; see also Lopushinskaya 1976), Siberian Platform.

The following species are questionably assigned: *Alispira*? *rotundata* Nikiforova and Modzalevskaya, 1968, p. 59, pl. 2, figs 1–7). Wenlock, eastern Siberia. *Alispira* (?) *deplanata* Oradovskaya, 1975, p. 103, pl. 31, figs 1–6. Anikin horizon, late Llandovery, Kolyma River, Siberia. *Alispira praegracilis* Severgina, 1978, p. 34, pl. 6, fig. 2. Dorozhnin beds, latest Ashgill, northwest Altai Mountains, Siberia. (Quoted as '?*Alispira praegracilis*', by Kulkov and Severgina 1989). *Alispira* *testudinaria* Fu, 1982, p. 149, pl. 40, fig. 4. Lower Ningqiang Group, early Silurian, Ningxia, northwest China. Fu (1985) reported the same species again as a new species, '*Alispira testudinaria* sp. nov.' but did not explain why he did not recognize his 1982 description. The type locality and type stratum were given by Fu (1985, p. 90) as Tongxin County, Ningxia, lower Limestone Member, Zhaohuajing Group, mid Llandovery.

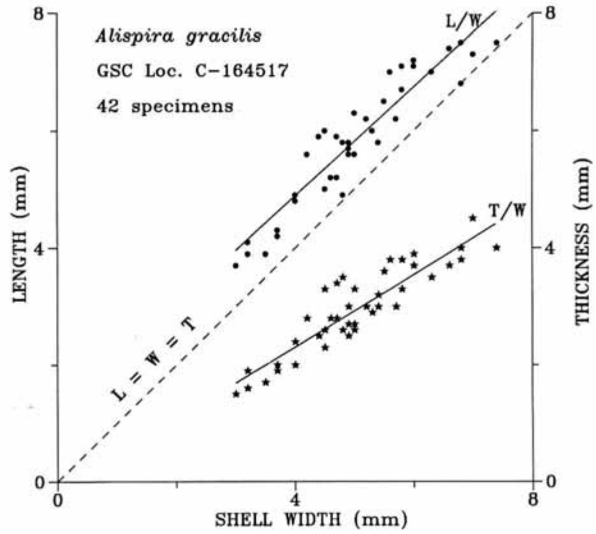
Alispira gracilis Nikiforova, 1961

Plate 1, figs 1–22; Plate 2, figs 1–2; Plate 4, figs 11–12; Text-figs 7–9

1961 *Zygospira* (*Alispira*) *gracilis* Nikiforova (*in* Nikiforova and Andreeva), 1961, p. 244, pl. 53, figs 1–8.
1965 *Alispira gracilis* Nikiforova; Boucot *et al.*, p. H634, fig. 518, 4*a–c*.
1968 *Alispira gracilis* Nikiforova; Nikiforova and Modzalevskaya, pp. 58, 60.
1970 *Alispira gracilis* Nikiforova; Rubel, p. 25, pl. 13, figs 16–22.
1975 *Alispira gracilis* Nikiforova; Oradovskaya, p. 102, pl. 67, figs 8–14.
1976 *Alispira gracilis* Nikiforova; Lopushinskaya, p. 63, pl. 11, figs 1–2.
1977 *Alispira gracilis* Nikiforova; Copper, pl. 40, figs 14–18.
1982 *Alispira gracilis* Nikiforova; Kulkov and Rybkina, pl. 8, figs 1–2.
1985 *Alispira gracilis* Nikiforova; Kulkov *et al.*, p. 144, pl. 17, fig. 9.

Type specimens. The holotype and paratypes illustrated by Nikiforova (*in* Nikiforova and Andreeva 1961) were collected from the Tunguska River area, Siberia. The type horizon was given as 'Lower Silurian (Llandovery)' by Nikiforova. Lopushinskaya (1976) determined that the range of *A. gracilis* in the Siberian Platform is from the *Virgiana barrandei* Biozone (*Coronograptus cyphus* Biozone, latest Rhuddanian) to the latest Llandovery.

Description (based on collections from western Canada). Shell small, elongate, with average length 5·9 mm, width 5·1 mm, thickness 3·0 mm (Text-fig. 7), somewhat rhomboidal or subelliptical in outline, nearly plano-

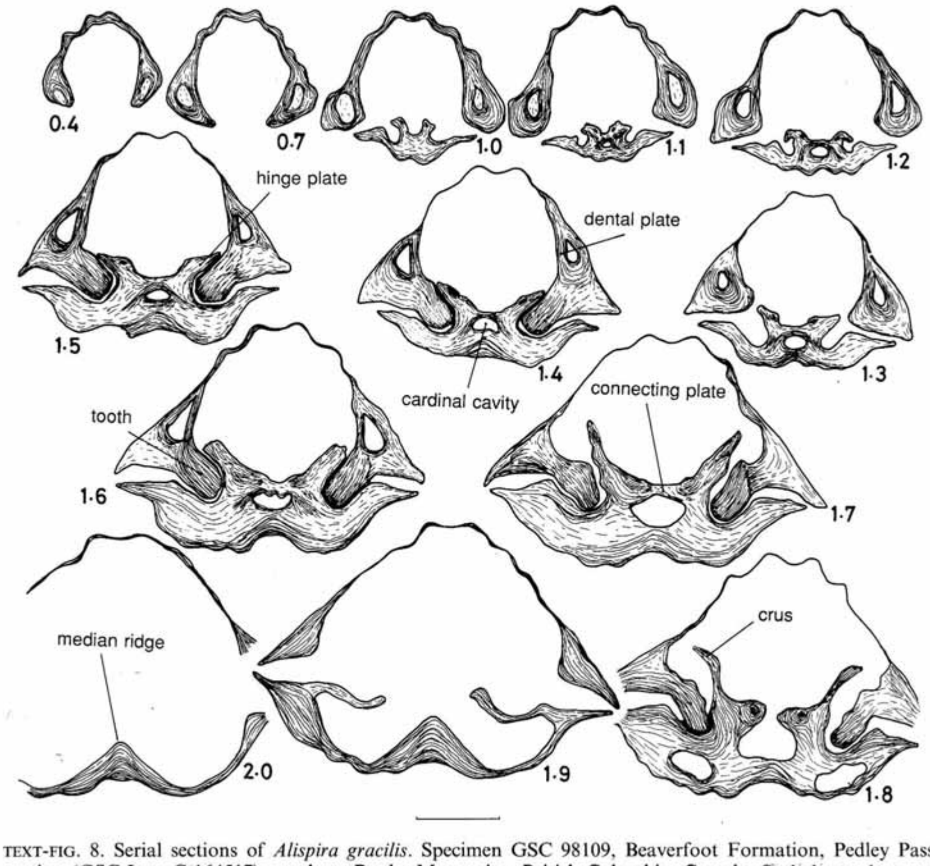


TEXT-FIG. 7. Shell dimensions of *Alispira gracilis*. GSC Loc. C-164517, Beaverfoot Formation, Pedley Pass, southern Rocky Mountains, British Columbia, Canada. Note that the shell length/width ratio remains nearly constant whereas the thickness/width ratio decreases through ontogeny. Refer to text for statistical data.

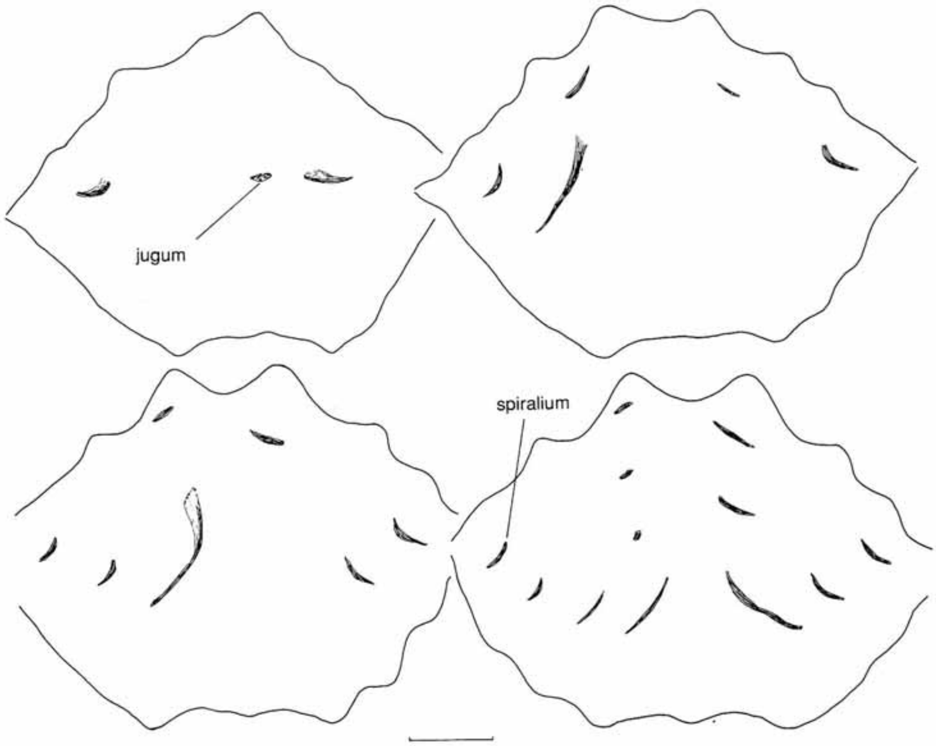
convex (with flattened brachial valve) in young forms but becoming equibiconvex in relatively large specimens. Hingeline short, curved, attaining about one-third of shell width. Anterior commissure uniplicate in adult forms.

Ventral umbo narrow, carinated, with erect to suberect beak extending about 1 mm beyond hingeline; delthyrium partly covered by small deltidial plates (Pl. 1, figs 1, 6); position of foramen submesothyridid; two costae forming umbonal carina, extending and prominently thickening toward anterior margin to define relatively narrow sulcus; median costa developed anteriorly in sulcus of some relatively large specimens. Dorsal umbo flattened or weakly convex, marked by median furrow; fold developed in anterior two-thirds of shell, formed by one coarse costa (bifurcating into two near anterior margin of relatively large shells), bounded on each side by conspicuous groove. Each flank of adult shells occupied by four to six simple, subrounded costae. Growth lines poorly developed.

Dental plates low, short, forming relatively small dental cavities (Pl. 1, fig. 19; Text-fig. 8), teeth large, rounded; muscle field poorly impressed. Hinge plates sessile on valve floor, connected by horizontal plate capping small, cardinal cavity between hinge plates (Pl. 1, figs 21–22); crura poorly preserved in serially sectioned specimens; jugal plates not coalesced medially; spiralia directed dorsally or dorso-medially, with three to five whorls (Text-fig. 9).



TEXT-FIG. 8. Serial sections of *Alispira gracilis*. Specimen GSC 98109, Beaverfoot Formation, Pedley Pass section (GSC Loc. C-164517), southern Rocky Mountains, British Columbia, Canada. Scale bar = 1 mm.



TEXT-FIG. 9. Random sections of *Alispira gracilis*. Specimen GSC 98110, a posteriorly broken shell, Beaverfoot Formation, Pedley Pass section (GSC Loc. C-164518), southern Rocky Mountains, British Columbia, Canada. Scale bar = 1 mm.

Remarks. The specimens from the Rocky Mountains are assigned to *Alispira gracilis* on the basis of their small, elongate shell (< 10 mm in length), low convexity, carinated ventral umbo, relatively sparse costae, and well-developed horizontal plate connecting the hinge plates. On average, specimens from the Rocky Mountains are slightly smaller and a little more elongate (maximum length 7·5 mm, width 7·4 mm, thickness 4·5 mm, average length/width ratio 1·17) than those from the Siberian Platform (maximum length 8·9 mm, width 8·9 mm, thickness 5·0 mm, average length/width ratio approximately 1·08). Typical specimens of *A. gracilis* from the Tunguska area of Siberia have 12–19 costae on each valve (Nikiforova and Andreeva 1961, p. 245), whereas the shells from the Rocky Mountains have only 10–14 costae. In general, the morphology of the Rocky Mountains specimens overlaps with that of the relatively small shells from the Siberian Platform. Throughout ontogeny, the shells of *Alispira gracilis* maintain a nearly constant length/width ratio, whereas the thickness/width ratio (convexity) decreases with age (Text-fig. 7).

Occurrence. (Total 280 specimens). Beaverfoot Formation. GSC Loc. 47400 (9 specimens); GSC Loc. 52169 (35); GSC Loc. C-164513 (13); GSC Loc. C-164517 (88); GSC Loc. C-164518 (80);

GSC Loc. C-164519 (4). Nonda Formation. GSC Loc. 45524 (26 specimens, mostly disjunct, silicified valves); GSC Loc. 64483 (13); GSC Loc. 64548 (11); GSC Loc. 64553 (1);

Alispira lowi (Whiteaves, 1906)

Plate 4, figs 1–10, 13–14; Text-fig. 10

1906 *Rhynchospira lowi* Whiteaves, 1906, p. 277, pl. 25, figs 8–9.
1915 *Rhynchospira lowi* (Whiteaves); Bassler, p. 1122.
1956 *Homoeospira lowi* (Whiteaves); Stearn, p. 107, pl. 12, figs 14–17.
1960 *Rhynchospira lowi* (Whiteaves); Bolton, p. 193.
1966 *Plectatrypa lowi* (Whiteaves); Bolton, p. 44, pl. 19, figs 5, 10.
1970 *Plectatrypa lowi* (Whiteaves); Norford, p. 5, 27–30.
1970 *Alispira* sp. Norford, p. 5, 24–26.

Type specimens. The type series was on two small limestone blocks (labelled GSC 4403 and 4403*a*) which had numerous specimens of *A. lowi*. The former block contained the two shells illustrated by Whiteaves (1906) and Bolton (1966). Both shells are partly damaged and were half-buried in the matrix; the drawings of the specimens as perfect in Whiteaves (1906, pl. 25, figs 8–9) are thus the result of artistic embellishment. For this study, these two shells were extracted from the matrix. The specimen of Whiteaves' plate 25 figure 8 (GSC 4403–1) is better preserved and is here selected as lectotype. Paralectotypes are GSC 4403–2, and four specimens from the other block (GSC 4403a–1–4).

The dimensions of the lectotype are (mm): length 8·0, width 7·5 and thickness 3·4.

Type locality and horizon. The two blocks are labelled as from the 'Limestone rapids, Fawn River'. At these rapids, the Severn River Formation is exposed, at a horizon to be correlated with the lower part of the formation in the Kaskattama Province No. 1 Well.

Description. Shell small, elongate, subelliptical in outline, nearly plano-convex or unequally biconvex (with flattened brachial valve). Hingeline short, curved, attaining about one-third of shell width. Anterior commissure weakly uniplicate in relatively large shells.

Ventral umbo narrow, carinate, with erect to suberect beak; delthyrium partly covered by small deltidial plates; foramen not well preserved; two costae forming umbonal carina, bifurcating anteriorly to define narrow sulcus; median costa intercalating anteriorly in sulcus. Dorsal umbo flattened or weakly convex, marked by median furrow; fold developed in anterior two-thirds of shell, formed by one coarse costa (bifurcating into two near anterior margin of larger shells), bounded on each side by conspicuous groove (anterior extension of median furrow). Each flank of adult shells occupied by four to six simple, subrounded costae. Growth lines present, poorly preserved.

Dental plates low, short, forming relatively small dental cavities (Pl. 4, fig. 7), teeth large, rounded; muscle field poorly impressed. Hinge plates attached to valve floor, medially connected to cap distinct cardinal cavity, with prominent median ridge (cardinal process) observed in one specimen (Text-fig. 10); crura emerging from ventral surfaces of hinge plates; jugal plates not preserved; spiralia directed dorsally or dorso-medially, with about three whorls.

Remarks. *Alispira lowi* is similar to *Alispira gracilis* in its small, elongate, plano-convex shells, with fairly strong costae, presence of dental plates and medially connected hinge plates capping a distinct cardinal cavity. The median ridge (cardinal process) on the horizontal plate so far has been observed

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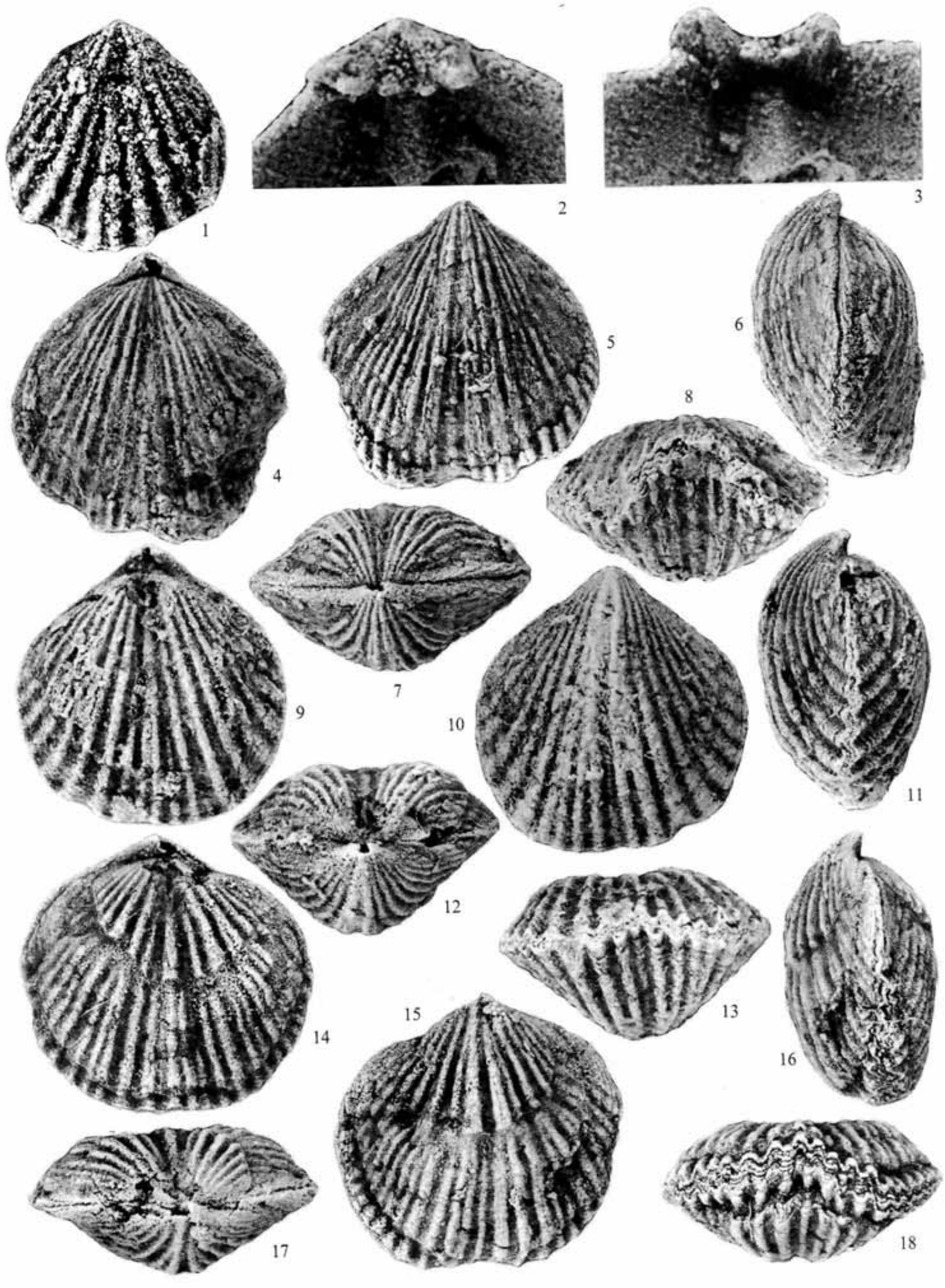
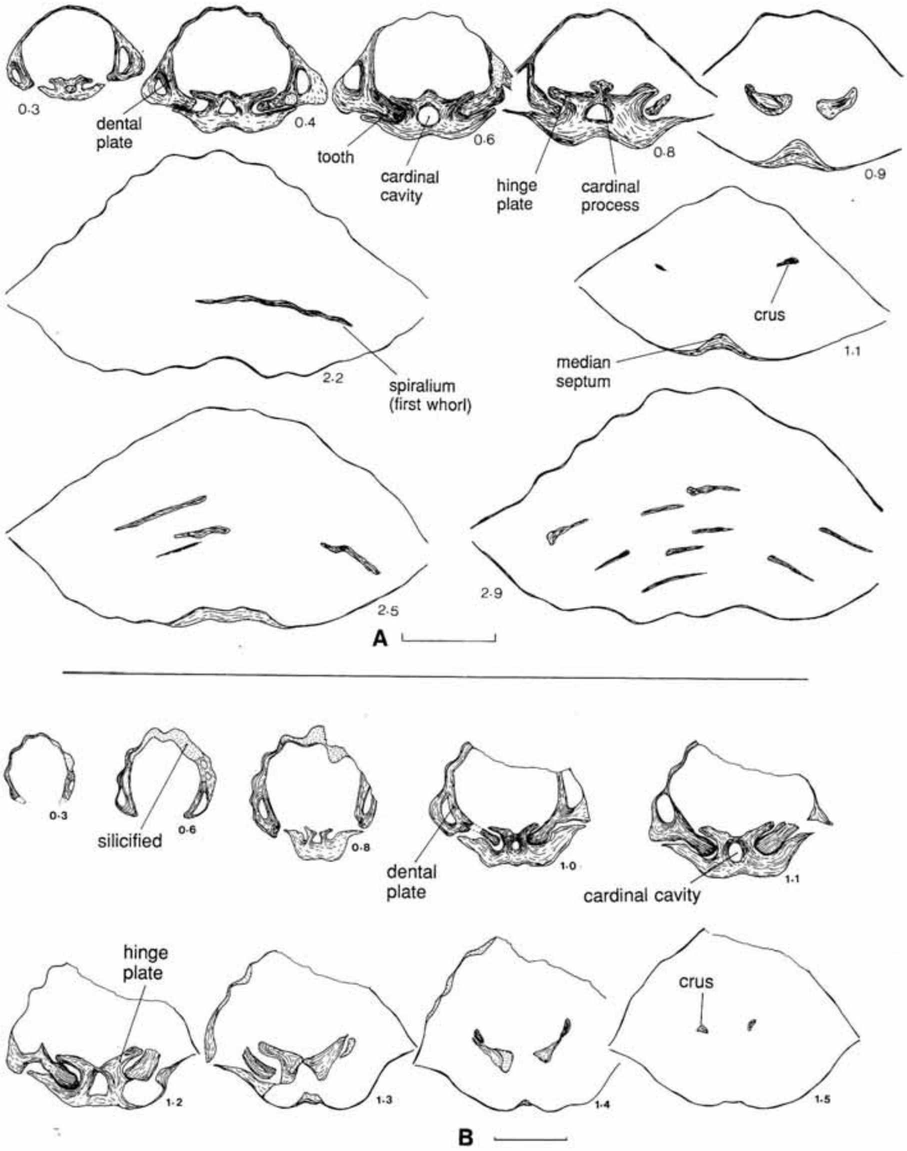
EXPLANATION OF PLATE 3

Figs 1–18. *Alispira tenuicostata* Nikiforova, 1961. 1–3, GSC 98115, silicified brachial valve showing median septum and horizontal plate connecting hinge plates, Nonda Formation, Mount Mary Henry section (GSC Loc. 64537). 4–18, three complete, silicified shells with fine, numerous costae, Mount Kindle Formation, near 'Red Rock Pass' section (GSC Loc. 42027); 4–8, GSC 98116; 9–13, GSC 98117, shell with fine growth lines near anterior margin; 14–18, GSC 98118.

Magnifications: 1, ×7; 2, ×14; 3, ×16; 4–8, ×5; 9–13, ×6; 14–18, ×5·5.



JIN and NORFORD, *Alispira*



TEXT-FIG. 10. Serial sections of *Alispira lowi*. A, specimen GSC 102532, Severn River Formation, Kaskattama Province No. 1 Well (GSC Loc. C-783), Hudson Bay Lowlands, Canada. Note the hinge plates medially connected by a ventrally convex plate with a median ridge (cardinal process). B, paralectotype, GSC 4403a-1, Severn River Formation, Fawn River, Hudson Bay Lowlands, Canada. Scale bar = 1 mm.

only in one of the Hudson bay specimens. Other congeneric species from the Siberian Platform and the Canadian Rocky Mountains invariably lack such a structure. The taxonomic value of the median ridge cannot be fully assessed due to the small number of specimens available for studying its variability.

Occurrence. Severn River Formation. GSC Loc. C-783 (6 loose shells, and about ten broken valves or shells buried in the same core sample). GSC Loc. C-922 (about ten broken valves buried in the core sample).

Alispira tenuicostata Nikiforova, 1961

Plate 2, figs 3–22; Plate 3, figs 1–18; Text-figs 11–12

1961 *Zygospira (Alispira) gracilis* forma *tenuicostata* Nikiforova (*in* Nikiforova and Andreeva), p. 247, pl. 53, figs 9–17.

?1970 *Zygospira (Alispira)* ex gr. *gracilis* forma *tenuicostata* Nikiforova; Rozman, p. 144, pl. 15, figs 9–14.

1976 *Alispira tenuicostata* Nikiforova; Lopushinskaya, p. 63, pl. 11, figs 3–4.

Type specimens. Nikiforova (*in* Nikiforova and Andreeva 1961) did not give a detailed type locality or type stratum for the species but remarked that *Alispira tenuicostata* was found in the same localities as *A. gracilis* in the Tunguska River area. The age of the illustrated specimens was cited as 'Llandovery'. According to Lopushinskaya (1976), *A. tenuicostata* ranges from the 'middle Llandovery' to 'lowermost Wenlock' in the Siberian Platform.

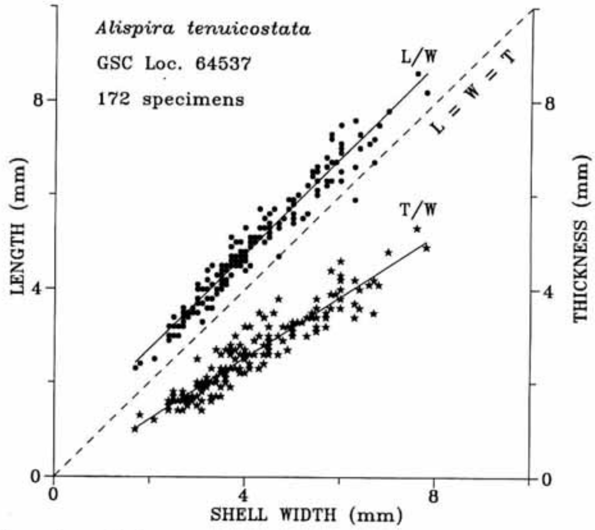
Description (based on collections from western Canada). Shell small, predominantly elongate, with average length 5·0 mm (maximum 8·6 mm), width 4·2 mm (maximum 7·8 mm), thickness 2·7 mm (maximum 5·3 mm), subcircular to elongate oval in outline, nearly equibiconvex in relatively large forms (Text-fig. 11). Hingeline nearly straight or slightly curved, attaining one-third to one-half of shell width. Anterior commissure finely denticulate, uniplicate.

Ventral umbo narrow, moderately carinated, with small, suberect beak extending about 1 mm beyond hingeline; deltidial plates thin, delicate, in some specimens coalesced medially to cover anterior portion of delthyrium (Pl. 2, figs 4, 14, 19); position of foramen submesothyridid; sulcus narrow, developed in anterior two-thirds of valve, occupied by one to three fine, subangular, bifurcating costae. Dorsal umbo flattened, marked by median furrow (prominent in some specimens); fold narrow, inconspicuous, carrying two to four bifurcating costae, developed only near anterior margin, in some specimens entirely absent. Each shell flank carrying seven to twelve fine, bifurcating or intercalating costae. Growth lines fine (3–4 per mm), commonly well-preserved near anterior margin.

Dental plates low, short, posteriorly fused to lateral shell wall, anteriorly becoming free (Pl. 2, fig. 22); teeth large, rounded; muscle field poorly impressed. Hinge plates relatively small, sessile on valve floor, connected by nearly flat, horizontal plate forming cardinal cavity between hinge plates (Pl. 3, figs 2–3); crura, jugum, and spiralia unknown.

Remarks. Nikiforova (*in* Nikiforova and Andreeva 1961, p. 247) distinguished *Alispira tenuicostata* from *A. gracilis* mainly on the basis of its more elongate shell (average length/width ratio about 1·25 compared to 1·08 for *A. gracilis*) with more numerous costae (16 to 30 on each valve). Specimens from the Nonda Formation are assigned to *Alispira tenuicostata* on the basis of their elongate shells (average length/width ratio 1·19, with a maximum of 1·38), fine, bifurcating, and intercalating costae, well-developed dental plates, and hinge plates connected by a horizontal plate. No crura, jugum, or spiralia were preserved in the disjunct, silicified valves, nor could these structures be revealed in cross-sections of solidly silicified specimens. Specimens from the Mount Kindle Formation (Text-fig. 12) are slightly larger than those from the Nonda and have more numerous costae (up to 27 on each valve).

Alispira tenuicostata was identified originally only from rocks of Llandovery age in the Siberian Platform (Nikiforova and Andreeva 1961). Subsequently, Lopushinskaya (1976, table 1) extended its range into the earliest Wenlock. Rozman's (1970, p. 114) record is from the Taskan beds (latest



TEXT-FIG. 11. Shell dimensions of *Alispira tenuicostata*. GSC Loc. 64537, Nonda Formation, Mount Mary Henry section, northern Rocky Mountains, British Columbia, Canada. Refer to text for statistical data.

Ashgill) in the Sette-Daban Range of Siberia; according to Rozman this form occurs in the basal Taskan beds just below the *Virgiana barrandei* Biozone. This basal unit was later considered by Lopushinskaya (1976) to be of earliest Llandovery age.

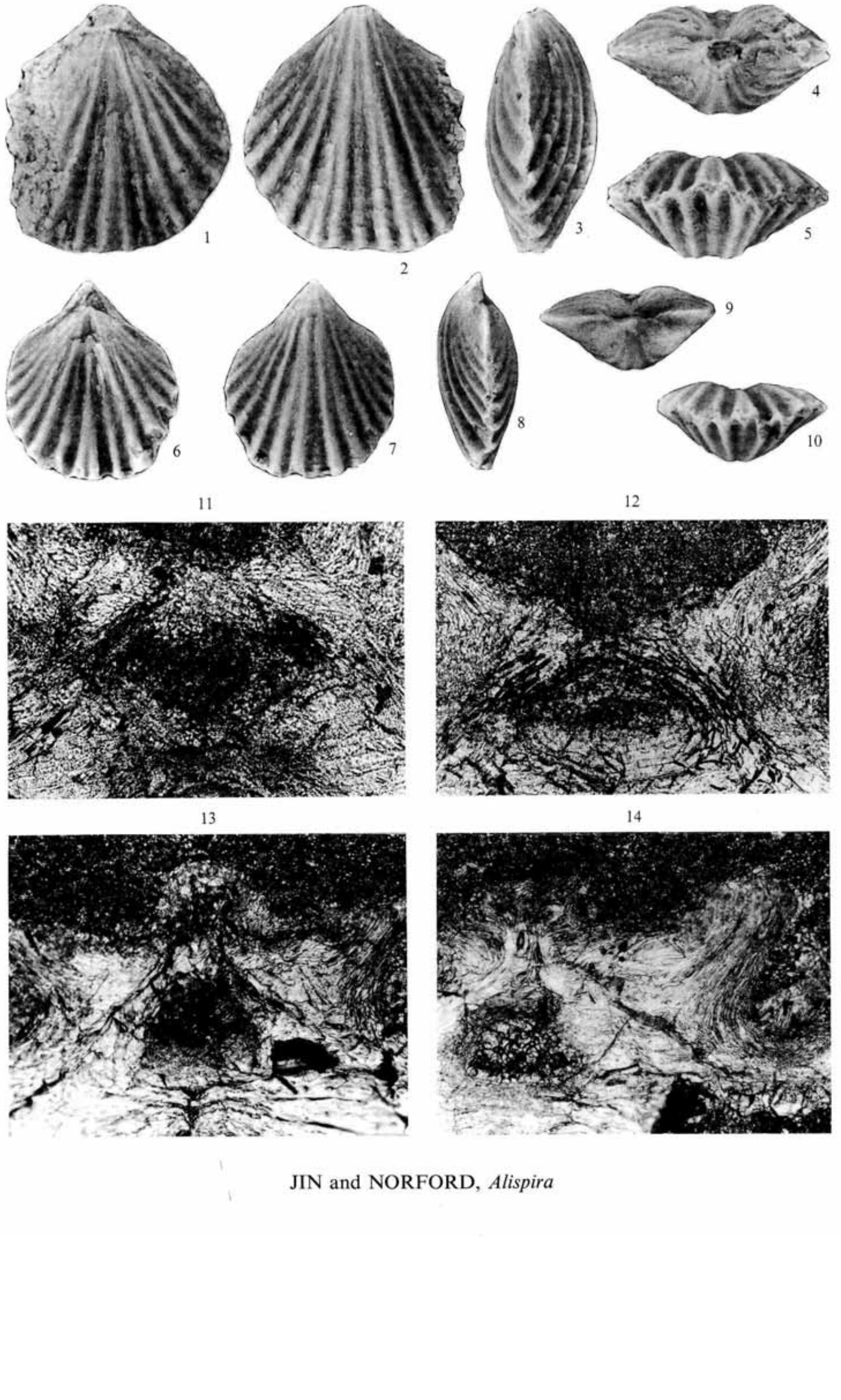
Occurrence. (Total 671 silicified specimens). Mount Kindle Formation. GSC Loc. 42027 (280 complete shells); GSC Loc. 69801 (about 30 specimens, mostly embedded in rock matrix). Nonda Formation, GSC Loc. 64537 (238 complete shells, 45 disjunct valves); GSC Loc. 64549 (27 complete shells); GSC Loc. 64550 (34 complete shells, 17 disjunct valves).

EXPLANATION OF PLATE 4

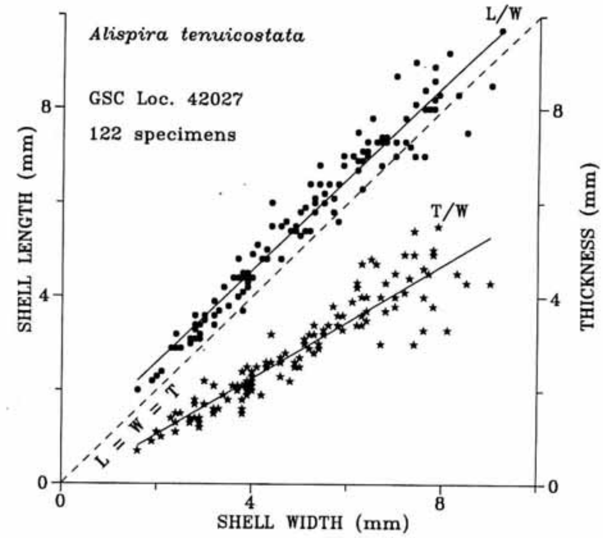
Figs 1–10, 13–14. *Alispira lowi* (Whiteaves, 1906). 1–5, reference specimen GSC 102532, calcareous specimen photographed before being serially sectioned, Severn River Formation, Kaskattama No. 1 Well (GSC Loc. C-783). 6–10, reference specimen GSC 102534, small shell from the same locality. 13–14, same specimen as Figs 1–5 (also refer to Text-fig. 10A); 13, section at 0·6 mm from apex showing horizontal plate with median ridge (cardinal process); 14, section at 0·8 mm from apex showing hinge plate and mushroom-like cardinal process.

Figs 11–12. *Alispira gracilis* Nikiforova, 1960. Acetate peels of serial sections across posterior portion of brachial valve, GSC 98109 (refer to Text-fig. 8), Beaverfoot Formation, Pedley Pass section (GSC Loc. C-164517); 11, section at 1·7 mm from apex showing cardinal cavity capped by a horizontal plate; 12, section at 1·5 mm from apex.

Magnifications: 1–5, ×7; 6–10, ×8; 11–12, ×70; 13–14, ×110.



JIN and NORFORD, *Alispira*



TEXT-FIG. 12. Shell dimensions of *Alispira tenuicostata*. GSC Loc. 42027, Mount Kindle Formation, near 'Red Rock Pass' section, District of Mackenzie, Northwest Territories, Canada. Note that variations in length/width and thickness/width ratios are greater in relatively large shells than in small ones. Refer to text for statistical data.

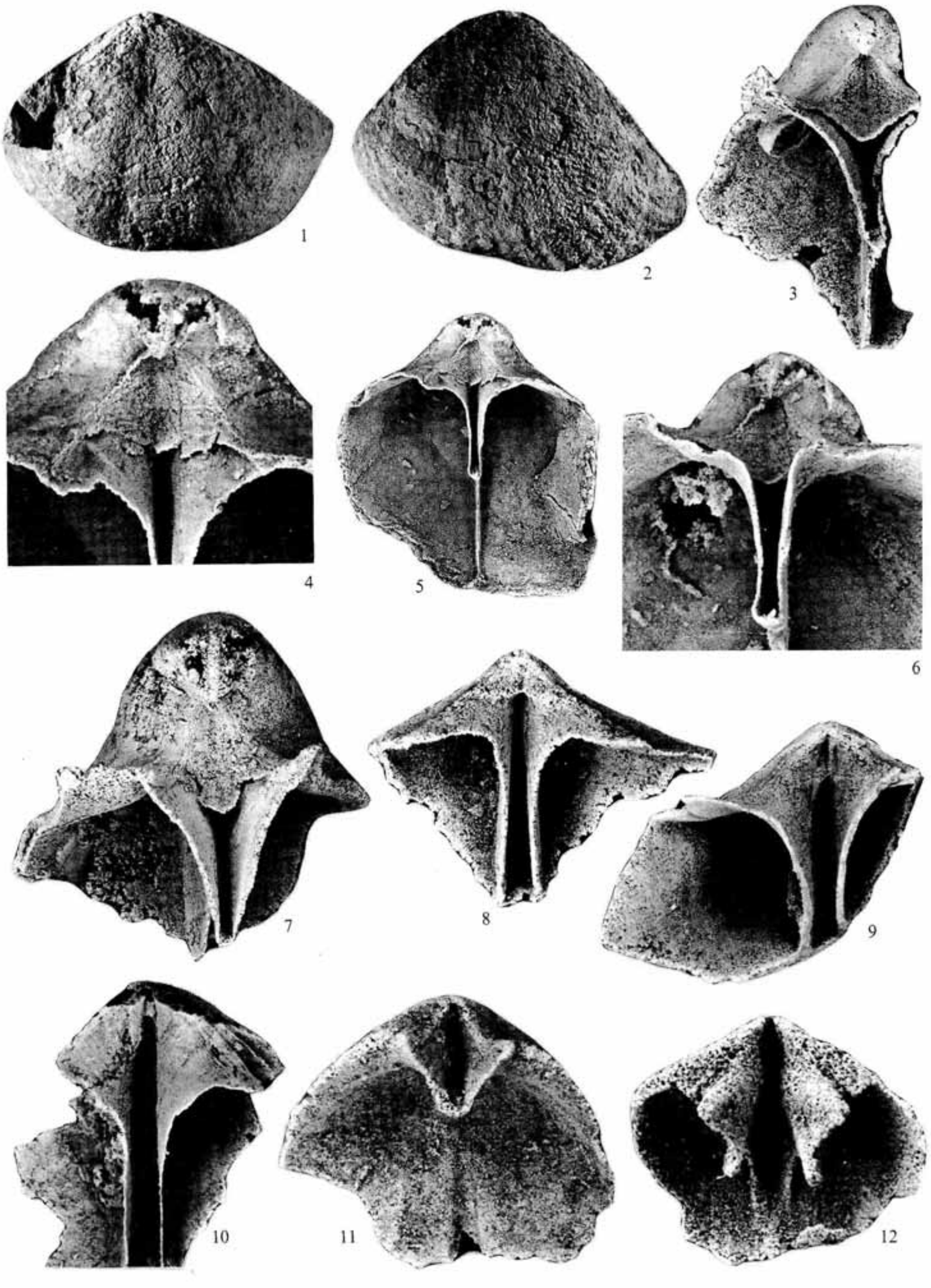
EXPLANATION OF PLATE 5

Figs 1–2. *Virgiana norfordi* Boucot and Chiang, 1974. GSC 98119, posterior portion of pedicle valve with median furrow on umbo (Fig. 1) and faint costae developed anterior of umbo (Fig. 2, oblique view), Mount Kindle Formation, Mount Kindle section (GSC Loc. 69803).

Figs 3–10. *Pentamerus oblongus* J. de C. Sowerby, 1839. Silicified specimens from the Nonda Formation, Guilbault Creek section (GSC Loc. 64473). 3, GSC 98120, broken pedicle valve with well-preserved pseudodeltidium covering posterior portion of spondylium. 4–6, GSC 98121, pedicle valve with narrow spondylium supported by high median septum and capped posteriorly by pseudodeltidium. 7, GSC 98122, broken pedicle valve. 8, GSC 98123, brachial valve with subparallel outer plates. 9, GSC 98124, brachial valve with 'cardinal process' arching between posterior part of brachial plates. 10, GSC 98125, brachial valve with large, triangular inner plates and subparallel outer plates.

Figs 11–12. *Stricklandia lens lens* (J. de C. Sowerby, 1839). 11, GSC 102535, posterior portion of pedicle valve with short, broad, anteriorly free spondylium, Nonda Formation, Toad River Bridge section (GSC Loc. 64555). 12, GSC 102536, posterior portion of brachial valve showing triangular inner plates, brachial processes, and long outer plates, same locality as Fig. 11.

Magnifications: 1–3, 6–7, 10, ×2; 4, 8, ×2·5; 5, ×1; 9, ×3·5; 11, ×3·2; 12, ×5·2.



JIN and NORFORD, *Virgiana*, *Pentamerus*, *Stricklandia*

STATISTICAL DATA OF SHELL DIMENSIONS

L, shell length; W, shell width; T, shell thickness; L/W, length/width ratio; T/W, thickness/width ratio (shell convexity); AVG, average; STD, standard deviation; MAX, mximum; MIN, minimum.

Alispira gracilis Nikiforova, 1961. GSC Loc. C-164517.

	L	W	T	L/W	T/W
AVG	5·87	5·06	2·97	1·17	0·58
STD	1·05	1·06	0·72	0·09	0·06
MAX	7·50	7·40	4·50	1·34	0·73
MIN	3·70	3·00	1·50	1·00	0·49

Alispira tenuicostata Nikiforova, 1961. GSC Loc. 64537.

	L	W	T	L/W	T/W
ACG	4·98	4·22	2·67	1·19	0·63
STD	1·28	1·23	0·68	0·08	0·07
MAX	8·60	7·80	5·30	1·38	0·83
MIN	2·30	1·70	1·00	0·94	0·45

Alispira tenuicostata Nikiforova, 1961. GSC Loc. 42027.

	L	W	T	L/W	T/W
AVG	5·64	5·10	2·87	1·12	0·57
STD	1·83	1·82	1·15	0·09	0·08
MAX	9·70	9·20	5·50	1·36	0·75
MIN	2·00	1·60	0·70	0·88	0·39

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