AGE OF BOGO SHALE AND WESTERN IRELAND GRAPTOLITE FAUNAS AND THEIR BEARING ON DATING EARLY ORDOVICIAN DEFORMATION AND METAMORPHISM IN NORWAY AND BRITAIN

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The Bogo Shale graptolite fauna from the Trondheim Region, Norway, has been restudied. As it is closely similar to North American Ordovician graptolite faunas, its age is determined in terms of the North American Ordovician graptolite succession. The Bogo Shale graptolite fauna has an age in the span of the *Isograptus* and *Paraglossograptus etheridgei* zones.

Similar faunas from western Ireland have the same faunal affinities and age. Trilobites from the same stratigraphic position as the graptolites in both the Trondheim Region and western Ireland also have North American affinity and indicate the same age as the graptolites.

The Bogo Shale graptolites were collected from near the base of the Lower Hovin Series. That group of rocks unconformably overlies Cambro-Ordovician rocks that were deformed prior to its deposition. The western Ireland faunas of the same age are also from rocks that unconformably overlie rocks that were deformed prior to their deposition. The deformation that resulted in the unconformity beneath the Lower Hovin Series has been termed the Trondheim Disturbance (Holtedahl 1920). Skjeseth (1952) suggested that the *Orthoceras* Limestone, a limestone unit that intervenes between the Lower and Upper *Didymograptus* Shales in the Oslo Region, may have been deposited during the Trondheim Disturbance. The *Orthoceras* Limestone may be correlated with the North American *Didymograptus bifidus* zone (the zone just prior to the *Isograptus* zone) and with the latter part of the *Didymograptus hirundo* and at least the early part of the *D. bifidus* zone in Britain. The Trondheim Disturbance is suggested to have occurred in that interval.

If the deformation and metamorphism of the rocks beneath the *Isograptus—P. etheridgei* zone rocks in western Ireland took place at the same time as the Trondheim Disturbance in Norway, then that deformation and metamorphism was going on during the latter part of the *D. hirundo* zone and the early part of the *D. bifidus* zone in terms of the British Ordovician graptolite zones. If, as many authors have suggested, the Dalradian Schists in Scotland were deformed and metamorphosed at the same time as those beneath the *Isograptus—P. etheridgei* zone rocks in western Ireland, then that deformation and metamorphism is also dated as pre-late British *D. bifidus* zone age.

The age of the Bogo Shale graptolite fauna described by Blake (1962) was reinterpreted by Skevington (1963), and its significance for dating tectonism within the Ordovician commented upon by Sturt, Miller & Fitch (1967). The graptolites from the Bogo Shale (Trondheim Region, Norway) comprise an association unlike others found in western Europe, with the exception of those from western Ireland. The total aspect of the fauna is more similar to that of faunas from western Newfoundland, Levis in Quebec, eastern New York state, and other parts of North America than to the Oslo Region, Lake District, or Welsh graptolite faunas.

The Bogo Shale graptolite fauna has an important bearing on the age of tectonism within the Ordovician because it occurs in strata that unconformably overlie the Röros and Stören Series that are Cambrian—Early Ordovician in age. A graptolite fauna similar to that of the Bogo Shale occurs in strata in western Ireland that also unconformably overlie older rocks.

The similarity of the Bogo Shale graptolite fauna to North American Ordovician graptolite faunas led the author to re-examine the specimens studies by Blake (1962) and to study some later collections made from the Bogo Shale. The author is indebted to Professor Gunnar Henningsmoen (Paleontologisk Museum, Oslo) for permitting him to examine these collections of Bogo Shale graptolites.

THE FAUNA

Blake (1962) recorded 17 graptolite species in his collections from three localities along and near the river Bogo in an area approximately 70 km southwest from Trondheim. One locality (locality 1 of Blake 1962, Fig. 1) yielded most of the material. The later collections in the Paleontologisk Museum which were studied by the author came from that locality.

The following species have been identified by the author in this review of the Bogo Shale graptolites:

Cryptograptus sp. (aff. *C. antennarius* (Hall)
Dichograptus sp.
Didymograptus cf. *D. cuspidatus* Ruedemann
Didymograptus cf. *D. dubitatus* Harris and Thomas
Didymograptus aff. *D. similis* (Hall)
Glossograptus hincksii (Hopkinson)
Glyptograptus austrodentatus var. *americanus* Bulman
Hallograptus cf. *H. inutilis* (Hall)
Isograptus caduceus var. *divergens* Harris
Isograptus caduceus cf. var. *velata* Harris
Pseudoclimacograptus? sp.
Tetragraptus bigsbyi (Hall)
Tetragraptus cf. *T. zhejiangenis* Geh.

As some of these forms have not previously been cited from the Bogo Shale, some comments on the specimens examined by the author are pertinent.

Several cryptograptid specimens were noted in the collection. Some of them are similar to *C. antennarius* in possessing moderately long lateral spines that diverge from the vicinity of the sicula.

The specimens considered to be similar to *D. cuspidatus* and *D. dubitatus* funicle length of 2.5 to 2.7 mm. These forms are similar to *D. separatus* Elles in thecal characteristics and stipe width. The funicle in them is not quite as long as it is in *D. separatus.*

The specimens considered to be similar to *D. cuspidatus* and *D. dubitatus* are poorly preserved, but the thecal spacing and thecal characteristics and the dimensions of the stipes appear to be relatively similar to these characteristics in those species.

The extensiform didymograptids resembling *D. similis* are similar to that species in stipe width, thecal spacing and inclination, and a ngle of stipe divergence. They are dissimilar in the rate at which the stipes widen and the length-width proportions of the thecae.

The specimens identified by Blake (1962, p. 233—234, Pl. 1, Figs. 14, 15; Pl. 2, Figs. 2, 6) as *Glyptograptus dentatus* are, as Bulman (1963, p. 684) noted, closely similar to *Glyptograptus austrodentatus* var. *americanus.* The Norwegian specimens studied widen from 1.1 mm at Th 1^1 to a maximum of 2.0 mm at 8 mm from Th 1^1, and they remain parallel-sided throughout the remainder of their extent. Seven thecae are present in the initial 5 mm of the rhabdosome and 5 are present in 5 mm in distal parts of the rhabdosome. Thecal form is closely similar to that in *G. austrodentatus* var. *americanus* and so, too, are the positions and spinosity of Th 1^1 and 1^2. The American specimens of this variety described by Bulman (1963, p 683—684) are slightly wider at Th 1^1 (1.3 mm) and sligtly narrower distally (1.6—1.9 mm) than the Norwegian. The Norwegian and American specimens appear to be closely similar in all other aspects.

The specimens compared with *Hallograptus inutilis* are narrower than the typical American forms of this species and they have more closely spaced thecae that are inclined to the rhabdosome axis at a lesser angle. They are similar to the American types in other characteristics.

Numbers of specimens of *Isograptus caduceus* var. *divergens* are present in the collections studied. This appears to be the most common form in the collections. The Norwegian specimens are closely similar to typical Australian specimens of this variety.

The specimens identified as *I. caduceus* var. *velata* appear similar to the figure (Harris 1933, Fig. 40) of this Australian form. As the Australian form has not been described and as the specimen figured by Harris has not been found in recent searches of the Australian collections, some doubt exists concerning its precise dimensions and characteristics.

The specimens considered to be *Tetragraptus bigsbyi* have four semielliptical stipes and curving thecae. These features are characteristics of this species. Maximum stipe width is 3.5 mm. The thecae number 11 to 13 in 10 mm.

A few specimens of a *Tetragraptus* with a form similar to *T. quadribrachiatus* are present in the collections studied. The funicle in these forms is 2.6—2.7 mm long, and the stipes are a maximum of 0.5 mm wide. The thecae number 4 to 4½ in 5 mm and are inclined to the stipe at a low angle. Their ventral walls appear to be slightly sigmoidally curved. These forms are similar to *T. zhejiangensis* described by Geh (1964, pp. 393—394) in length of the funicle, stipe width, and in those characteristics of the thecae that may be examined. Poor preservation obscures most of the thecal features and precludes determination of the precise relationships of these forms.

AGE AND ZOOGEOGRAPHIC AFFINITIES

Although some of the species listed above have been recorded from European Ordovician deposits, the whole association of species that occur together in the Bogo Shale collections studied does not occur in other western European areas except in western Ireland. The overall aspect of the Bogo Shale graptolite fauna is more similar to that of faunas from North America and Australia than to that of faunas from western Europe.

Didymograptus cuspidatus, Glyptograptus austrodentatus var. *americanus,* and *Isograptus caduceus* var. *divergens* range through zone 8 *(Isograptus* zone) and 9 *(Paraglossograptus etheridgei* zone) in the North American Ordovician graptolite succession. They are joined in associations considered diagnostic of zone 9 by *Glossograptus hincksii, Hallograptus inutilis,* and the first pseudoclimacograptids and cryptograptids to appear in the North American Ordovician graptolite succession. A slender *Dichograptus* similar to *D. separatus* is present in zone 9 in the Marathon region, west Texas (Berry 1960. pp. 51—52). *Tetragraptus bigbyi* ranges from the *Tetragraptus approximatus* zone (zone 3) into the *Paraglossograptus etheridgei* zone in North America. Tetragraptids of the *T. quadribrachiatus* type have a similar range in North America.

Isograptus caduceus var. *velata* is known in Australia from strata that are the approximate correlatives of the North American *Isograptus* zone. *Didymograptus dubitatus* occurs in North America in the *P. etheridgei* zone. It is present in Australia in beds that are the approximate correlatives of the North American *P. etheridgei* zone. *Didymograptus similis* ranges from the *Didymograptus protobifidus* zone (zone 6) into the *P. etheridgei* zone in North America.

The graptolite fauna of the Bogo Shale, when all aspects of it are analysed, indicates an age in the span of the North American *Isograptus* and *P. etheridgei* zones. The presence of *Cryptograptus* and *Hallograptus* in the fauna suggests that it is more probably of North American *P. etheridgei* zone age than *Isograptus* zone age. Spjeldnæs (written commun., 1968) reported finding *P. etheridgei* with *Glyptograptus austrodentatus americanus in a collection* from a new locality in the Bogo Shale. The presence of *P. etheridgei* is indicative of a *P. etheridgei* zone age for the layers from which it came.

Correlation of the North American *Isograptus — P. etheridgei* zone interval with the North American shelly fossil stages is relatively well established. Berry (1966, 1967), Kindle & Whittington (1958), Ross & Berry (1963), Whittington (1963, 1966), and Whittington & Kindle (1963) have indicated that this graptolite zonal interval may be correlated with the Whiterock and possibly a part of the Marmor stages of Cooper (1956). These stages are based upon brachiopod evolutionary development. Correlation of this interval with the British shelly fossil series and graptolite zones is not well established. In the correlations suggested by Berry (1966, 1967), Kindle & Whittington (1958), Ross & Berry (1963), Whittington (1963, 1966), Whittington & Kindle (1963), and Whittington & Williams (1964), the *Isograptus — P. etheridgei* zone interval is considered correlative with the upper part of the *Didymograptus bifidus* zone and most if not all of the *Didymograptus murchisoni* zone in the British Ordovician graptolite succession. Using that correlation, the beds bearing the Bogo Shale graptolite fauna may be correlated with the interval that includes the upper part of the British *D. bifidus* zone and lower part of the *D. murchisoni* zone. The Bogo Shale graptolite fauna is thus concluded to be slightly younger than suggested by Skevington (1963) and notably younger than indicated by Blake (1962).

The shelly faunas of Whiterock age in the Trondheim Region have the same faunal provincial affinities that the Bogo Shale graptolites have. Strand (1960, p. 157) noted that the older Ordovician shelly faunas from the Trondheim Region had American affinities. Whittington (1963, p. 20) commented on the presence of trilobites indicative of North American faunal province affinities and the North American Whiterock stage in the Trondheim Region. He (Whittington 1963, pp. 19—20) included that trilobite fauna and the Trondheim Region in his Bathyurid faunal province. Whittington (1963, Fig. 2) indicated that his Bathyurid faunal province included North America, western Ireland, East Greenland, and the Trondheim Region during Whiterock time.

WESTERN IRELAND

Whittington (1963, p. 20) pointed out that trilobites of Whiterock age and North American faunal affinity had been identifed in collections from western Ireland. The trilobites occur there in limestone boulders included in the Tourmakeady Beds in the Tourmakeady and Glensaul districts by Gardiner & Reynolds (1909, 1910). These limestone boulders also bear brachiopods that are closely similar to Whiterock age faunas in North America (A. Williams, oral commun., 1967). The limestone boulders occur in a shale matrix. Graptolite collections were made from the shales in the Glensaul district by Gardiner & Reynolds (1910) who gave them to Dr. G. L. Elles for study. Dr. Elles suggested an Arenig age for the graptolite-bearing shales. One specimen from the Gardiner & Reynolds collections has been examined by the author who identified it as *Isograptus caduceus* var. *victoriae* Harris. Some new collections made by Dr. J. F. Dewey from localities close to those from which Gardiner & Reynolds made their collections have been examined by the author. The following species have been recognized in the collections made by Dr. Dewey:

Amplexograptus? sp.
Dichograptus sp. (aff. *D. separatus* Elles)
Didymograptus cf. *D. compressus* Harris and Thomas
Didymograptus cuspidatus Ruedemann
Glyptograptus austrodentatus var.?
Ramulograptus? sp.
Sigmagraptus? kirki (Ruedemann)
Tetragraptus cf. *T. erectus* Geh and Yin.

The graptolite associations in Dewey's collections are similar to that from the Bogo Shale. *Didymograptus cuspidatus* and glyptograptids of the *G. austrodentatus* group occur in both the *Isograptus* (zone 8) and *P. etheridgei* (zone 9) zones in North America. *Ramulograptus* occurs in the *Isograptus* zone in the western United States (Ross & Berry 1963). *Sigmagraptus? kirki* is present in strata correlative with the zone 8—9 interval in the western United States (Ross & Berry 1963). *Tetragraptus erectus* occurs in the Ninkuo Shale in Chekiang, China, in beds that are correlative with the North American zone 8—9 interval. The presence of *Isograptus caduceus* var. *victoriae* in one of Gardier & Reynold's collection is suggestive of an *Isograptus* zone age for the beds from which it came as that form is restricted to the *Isograptus* zone in North America and to correlative beds in Australia. This evidence suggets that at least some of the graptolite-bearing shales in the Glensaul area are probably of *Isograptus* zone age. The presence of a possible *Amplexograptus* with *Didymograptus* cf. *D. compressus* and *D. cuspidatus* in one collection is suggestive of a zone 9 age for the beds from which that collection came. *Amplexograptus* first appears in the North American succession in zone 9 and in correlative beds in Australia. *Didymograptus compressus* occurs in zone 9 in North America and in correlative beds in Australia.

The graptolites studied in collections from the Glensaul area are thus indicative of a zone 8—9 age for the shale matrix of the limestone boulders that bear Whiterock age trilobites and brachiopods. The shale matrix is thus closely similar in age to the boulders. Both the shelly faunas of the boulders and the graptolites in the matrix rocks are indicative of the same zoogeographic relationships as well as closely similar age.

Skevington (Skevington & Sturt 1967) restudied the graptolites collected from slates and cherts in the Sruffaunduff, southwest of the summit of Bencraff, County Galway, western Ireland. Skevington & Sturt (1967) noted that the rocks bearing these graptolites had long been considered to be the oldest rocks in the Ordovician succession in that part of Ireland and that the graptolites 'have been used to give the younger age limit to the main metamorphism of the Dalradian Connemara Schists' which underlie the rocks bearing these graptolites. Skevington (Skevington & Sturt 1967) pointed out that these graptolites clearly had closest affinities with North America, Australia, and China. The fauna includes (Skevington & Sturt 1967) *Glossograptus acanthus* and *Hallograptus inutilis* with a glyptograptid of the *G. austrodentatus* group, a pseudoclimacograptid, a possible *Amlexograptus,* and *Didymograptus* cf. *D. dubitatus*. This association of species is clearly indicative of the North American *P. etheridgei* zone (zone 9). Inasmuch as the base of that zone is probably no older than the very youngest part of the British *D. bifidus* zone (Berry 1966, 1967), the beds bearing these graptolites are no older than that. This age interpretation is slightly younger than that suggested by Skevington (Skevington & Sturt 1967).

Cummins (1954) cited the occurrence of *Oncograptus, Isograptus caduceus* cf. var. *nanus, Tetragraptus, Glossograptus,* and *Didymograptus* cf. *D. deflexus* in a succession of interbedded cherty shales and tuffs exposed near Charlestown, County Mayo in western Ireland. These graptolites are clearly indicative of North American and Australian faunal affinites. *Oncograptus* and *Isograptus caduceus* var. *nanus* are particularly characteristic of the North American Early Ordovician faunal province. *Oncograptus* is restricted to the *Isograptus* zone in North America and to correlative beds in Australia, *Isograptus caduceus* var. *nanus* is present in both the *Isograptus* and *P. etheridgei* zones in North America. Didymograptids similar to the British *D. deflexus* range from the *Didymograptus protobifidus* zone (zone 6) into the *Glyptograptus* cf. *G. teretiusculus* zone (zone 10). *Glossograptus* makes its first appearance in zone 8 in North America and in beds probably correlative with zone 9 in Australia. The graptolites collected near Charlestown are thus indicative of an age in the span of zones 8 and 9 with, on the basis of the North American and Australian range of *Oncograptus,* a zone 8 age somewhat more probable. The beds bearing these graptolites are considered by the author to be correlative with the upper part of the British *D. bifidus* zone.

Graptolites with clearly North American affinites have been found in several localities in western Ireland. Inasmuch as they are most similar to North American Orodivician graptolite faunas, their age is best expressed in terms of the North American Ordovician graptolite succession. The geographic position of these faunas suggests that a pathway of faunal communication between North America and the Trondheim Region probably lay through western Ireland.

Both the western Ireland and Trondheim Region graptolite faunas under consideration are correlative with the North American Whiterock stage. These graptolite faunas indicate that the typically North American Whiterock age graptolite faunas had the same zoogeographic distribution that Whittington (1963, Fig. 2) indicated for the trilobites of the same age. Whiterock age brachiopod faunas also had a similar distribution (Williams 1965, p. H239—H241, and Fig. 152). The shelly and graptolite faunas of North American faunal affinity and Whiterock age thus had closely similar zoogeographic distribution although their modes of life and ecologic relationships were different.

The North American — western Ireland — Trondheim Region graptolite faunas correlative with the Whiterock stage are as dissimilar from graptolite faunas of comparable age in southeastern Ireland, Wales, and the Lake District in Britain and the Oslo Region, Norway, as Whittington (1963) indicated that the trilobite faunas of the same age in these areas were. These graptolites, as Whittington (1963) indicated is true for the trilobites, belong within the same faunal province.

BARRIERS

The barriers that resulted in this faunal provincialism may include oceanic deeps and land masses. Lands appear to have been the more likely. Skjeseth (1952) presented evidence indicative that a land mass, which he termed Telemark Land, was present west of the Oslo Region during the early part of the Ordovician. He (Skjeseth 1952) suggested that Telemark Land could have been in existence during the time interval correlative with the British Llanvirn as well, in accordance with the views of Holtedahl (1909).

Dewey (1963) demonstrated that a land mass was present in central-western Ireland during the early part of the Ordovician. This land appears to have kept separate the western Ireland faunas from contemporaneous faunas in eastern Ireland and Wales. Whether Telemark Land and this Irish land were connected is not known. The fact that both the benthonic and planktonic faunas on the west side of each land are so markedly dissimilar from those on the east is suggestive that the two lands were connected.

DATING EARLY ORDOVICIAN METAMORPHISM AND DEFORMATION

The age interpretation of the faunas discussed here has a bearing on the age of Ordovician metamorphism and deformation that occurred not only in the Trondheim Region but also in western Ireland. It is possible, as Sturt, Miller & Fitch (1967) have suggested, that this period of metamorphism and deformation was also expressed in Scotland and throughout much of the Caledonide belt in Norway. Deformation began during this period in the northern part of the Appalachians.

The stratigraphic succession in the Trondheim Region include the Röros Series (which bears *Dictyonema flabelliforme)* conformably overlain by the Stören Series (Strand 1960). *Dictyonema flabelliforme* is indicative of a

Tremadoc age for the beds from which it came. Those beds are regarded as being near the top of the Röros Series. The Stören Series is unconformably overlain by the Lower Hovin Series which has prominent conglomerates at its base (Strand 1960, Vogt 1945). The Bogo graptolite-bearing shale lies near the base of the Lower Hovin Series. Blake (1962) pointed out that the precise position of the Bogo Shale in relation to the base of the Lower Hovin Series and to the basal conglomerates is uncertain. The base of the Lower Hovin Series is probably correlative with the upper part of the British *D. bifidus* zone, using the correlations discussed above and shown in Table 1. The deformation that produced the unconformity between the Lower Hovin Series and the underlying Stören Series occurred earlier than that and some time after the Tremadoc. Inasmuch as the Stören Series lies between the *Dictyonema flabelliforme*-bearing beds of the Röros Series and the unconformity, deformation probably occurred some time before the Latest Canadian—Earliest Whiterock (Latest Arenig—Earligst Llanvirn) time interval. The tectonism that resulted in deformation and metamorphism of the pre-Hovin Series rocks has been termed the Trondhjem (Trondheim) Disturbance by Holtedahl (1920). Vogt (1945) suggested that the Trondheim Disturbance may have had an effect in several areas in the Caledonide belt in western Norway although it is best documented in the Trondheim Region.

Skjeseth (1952) discussed the distribution of Oslo Region zone 3b age rock in Scandinavia and pointed out that the black shales typical of the Lower *Didymograptus* Shale in the Oslo Region were confined to a central basinal area which included the Oslo Region and extended eastward and southward

Table 1. Correlation of the Bogo Shale graptolite-bearing beds with those of comparable age from western Ireland and with the North American and British Early Ordovician Graptolite Zones and Shelly Fossil Series and Stages

NORTH AMERICAN PROVINCE		TRONDHEIM		BRITISH PROVINCE	
STAGES	GRAPTOLITE ZONES	REGION, NORWAY	WESTERN IRELAND	GRAPTOLITE ZONES	SERIES
Porterfield	11. *N. gracilis*	Lower Hovin Series		*N. gracilis*	Caradoc
Ashby	10. *Glyptograptus* cf. *G. teretiusculus*			*G. teretiusculus*	Llandeilo
Marmor					
	9. *P. etheridgei*	Bogo Shale	spilite, slate, chert, shale, etc.	*D. murchisoni*	Llanvirn
Whiterock	8. *Isograptus*				
	7. *D. bifidus*	DEFORMATION AND METAMORPHISM		*D. bifidus*	
Canadian Series	6. *D. protobifidus*	Stören Series	Connemara Schists	*D. hirundo*	Arenig
	5. *T. fruticosus* 3 & 4 br.				
	4. *T. fruticosus* 4 br.			*D. extensus*	
	3. *T. approximatus*			? ? ?	—?—
	2. *Clonograptus*				
	1. *Anisograptus*	Röros Series		*D. flabelliforme*	Tremadoc

to include Scania. This basin and its accumulation of black shales is rimmed successively by limestones that commonly bear trilobites and then by littoral zone deposits (Skjeseth 1952). Skjeseth (1952) suggested that the littoral zone deposits to the west of the basin lay along the shores of Telemark Land. He noted that the lithofacies patterns for not only Oslo Region zone 3b time but also for most of the early part of the Paleozoic indicated that this land was emergent during most of the Ordovician and Silurian. Skjeseth (1952, p. 155) pointed out that the *Orthoceras* limestone, the rock unit that intervenes between the black shales of the Lower and Upper *Didymograptus* Shales in the Oslo Region, was a transgressive deposit and that deposition of it probably coincided with the Trondheim Disturbance.

The lower part of the Upper *Didymograptus* Shale has been included in the *Didymograptus murchisoni* zone in the Oslo Region (Berry 1964). Whether the Oslo Region *D. murchisoni* zone is precisely correlative with the British zone of that name is not certain. Comparison of the Oslo Region and British graptolite faunas suggests that the lower part of the Oslo Region *D. murchisoni* zone may be correlated with the upper part of the British *D. bifidus* zone. Otherwise, the Oslo Region and British *D. murchisoni* zones may be considered approximate correlatives. The upper layers of the Lower *Didymograptus* Shale in the Oslo Region bear biserial scandent graptolites described by Spjeldnæs (1963) that indicate correlation of those layers with at least the lower part of the British *Didymograptus hirundo* zone. The *Orthoceras* Limestone is thus probably correlative with at least the lower part of the British *D. bifidus* zone and possibly with the upper part of the *D. hirundo* zone.

If the *Orthoceras* Limestone was deposited at the time of the Trondheim Disturbance, then these correlations indicate that the Trondheim Disturbance took place during the time span of the older part of the British *D. bifidus* zone and possibly the latter part of the British *D. hirundo* zone. This would be at the end of the Canadian and the earliest Whiterock in terms of the North American stages and series.

Surely, the *Orthoceras* Limestone does indicate that a change in depositional regimen did take place in the Oslo Region to cause an interruption of those conditions under which the black shales of the Lower and Upper *Didymograptus* Shales accumulated. The limestone types and the faunas in the *Orthoceras* Limestone suggest that bottoms were habitable and that waters, even at the sea bottom, in the Oslo Region were open to broad-scale current circulation rather than being limited to local currents within a restricted basin during the time of deposition of the *Orthoceras* Limestone. Circulation patterns that were relatively free could have permitted some organisms that developed in the Oslo Region (and possibly also in Britain east of the land in Ireland) before the time of deposition of the *Orthoceras* Limestone to intermingle with those that had developed in the North American faunal province. Berry (1966, 1967) noted that some graptolite species and some species in lineages that had apparently originated in the European faunal area did begin to appear in the North American Ordovician graptolite succession as invaders during the time of the *Isograptus* zone. These invading stocks became well developed in the North American succession slightly later. This incursion of European elements into the North American succession took place at about the time when it is suggested that the Trondheim Disturbance was ending. The invasion of European stocks into the North American faunas suggests that the Trondheim Disturbance included movements that diminished the effect of the barrier between the North American and European faunal provinces for a time and permitted some communication between the two province faunas. Following that communication, some stocks from the European faunal province invaded and became well established in the North American.

After the close of the Trondheim Disturbance, Telemark Land, or some descendent from it, apparently formed a new barrier to faunal communication between the North American and European faunal provinces. Water mass circulation became restricted once again because the depositional conditions existing in the Oslo Region prior to deposition of the *Orthoceras* Limestone developed there again. Black shales (the Upper *Didymograptus* Shale) conformably succeed the *Orthoceras* Limestone. The grapolite fauna from the Upper *Didymograptus* Shale may be correlated with the British *Didymograptus murchisoni* zone. That fauna has the same zoogeographic affinities as had the graptolite fauna from the Lower *Didymograptus* Shale. Those zoogeographic affinities are with the remainder of western Europe exclusive of western Ireland. Not only the graptolitic but also the shelly faunas of the same age from this area are different zoogeographically from faunas of comparable age in North America, western Ireland, and the Trondheim Region.

The deformation and tectonism of the Trondheim Distrubance may have occurred at approximately the same time as deformation and metamorphism in western Ireland and probably in Scotland as well. The Ordovician succession in the County Galway—County Mayo area in western Ireland includes the Connemara Schists unconformably overlain by a succession of spilites, cherts, tuffs, shales, slates, and some interbedded limestone breccias (Gardiner & Reynolds 1909, 1910, 1912, 1914; Dewey 1961). Dewey (1961) summarized the evidence for a pre-Arenig age of the metamorphism of the Connemara Schists and suggested that the Dalradian Schists in Scotland were metamorphosed at the same time. Dewey (1961) considered the age of the deformation and metamorphism to have been pre-Arenig because the age of the oldest graptolite faunas from the slates and shales at the base of the succession that unconformably overlies the Connemara Schists was thought at that time to be Arenig. Faunas from that stratigraphic position collected by Dewey have been discussed in a previous section where it was suggested that the oldest of those faunas is indicative of the North American *Isograptus* zone. That zone is considered the approximate correlative of the upper part of the British *D. bifidus* zone (see Table 1).

The fauna from Bencraff restudied by Skevington (Skevington & Sturt 1967) from a similar stratigraphic position has also been suggested to be slightly younger than originally interpreted. That fauna is indicative of the North American *P. etheridgei* zone which has been suggested to be correlative with the British *D. murchisoni* zone primarily. These suggested correlations indicate that the deformation and metamorphism in western Ireland occurred before the time of the latter part of the British *D. bifidus* zone. If the metamorphism and deformation of the Connemara Schists were essentially contemporaneous with that of the Dalradian Schists in Scotland as some authors have sugested (Dewewy 1961; Giletti et al. 1961), then the metamorphism and deformation of the Dalradian Schist were pre-late British *D. bifidus* zone in age.

The rocks that were deposited after deformation and metamorphism of the Connemara Schists in western Ireland are the same age as those rocks that were deposited after the Trondheim Disturbance in the Trondheim Region. These rocks are Whiterock in age. If the deformation and metamorphism were approximately the same age in western Ireland, Scotland, and Trondheim Region, Norway, and if the Trondheim Disturbance did take place during the time of deposition of the *Orthoceras* Limestone in the Oslo Region, then the metamorphism and deformation in western Ireland and Scotland would have occurred during the early part of the British *D. bifidus* zone and perhaps during the latter part of the British *D. hirundo* zone — in the Latest Arenig and Earliest Llanvirn — or in the Latest Canadian and Earliest Whiterock in terms of the North American succession.

Berry (in press) has summarized the evidence indicating that tectonism took place in the northern part of the Appalachians during the time interval of North American zones 8 through 11 primarily, but it began during zone 7 time. The major effects of tectonism in the northern part of the Appalachians were thus slightly later than the metamorphism and deformation in western Ireland, Scotland, and the Trondheim Region. Tectonism in the northern part of the Appalachians began just as, or slightly before, deformation and metamorphism were ceasing in western Ireland, Scotland, and the Trondheim Region.

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