CORRELATION OF ORDOVICIAN GRAPTOLITE-BEARING SEQUENCES

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ABSTRACT

Complete or nearly complete sequences of Ordovician graptolite zones are known in England, Australia, United States, and Sweden. Partial successions are present in Argentina, Norway, Russia, and Bohemia. Study of the assemblages of species characterizing the zones in these areas and attempted correlation of the zones indicate that three faunal regions were in existence in the Tremadoc, Arenig, Llanvirn, and Llandeilo. The identity of the regions started to become less distinct in Early Caradoc, and by Late Caradoc, graptolite faunas were nearly cosmopolitan. The regions were an Australian-American, an English, and a Scandinavian. Proposed correlation of them is: Tremadoc and Arenig with Lancefieldian, Bendigonian, and most of Chewtonian in Australia, Lower Ordovician in U. S., *Dictyonema* shale and Lower *Didymograptus* shale in Sweden; Llanvirn with uppermost Chewtonian, Castlemanian, Yapeenian, and most of Middle Ordovician in Australia, lower part of Middle Ordovician in U. S., and Upper *Didymograptus* shale in Sweden; Llandeilo and lower part of Caradoc with uppermost Middle Ordovician and Gisbornian in Australia, upper part of Middle Ordovician in U. S., and Lower *Dicellograptus* shale in Sweden; upper part of Caradoc and Ashgill with Eastonian and Bolindian in Australia, Upper Ordovician in U. S., and Middle and Upper *Dicellograptus* shales in Sweden.

INTRODUCTION

Graptoloid graptolites are commonly conceded to have been planktonic organisms that were readily and rapidly dispersed by oceanic currents. This fact and their many morphologic changes have led to a popular belief that graptolites are ideal forms for close intercontinental correlation. However, Bulman (1955, p. V17) pointed out: "many species are quite local, and some genera are at least comparatively restricted." The fact that most species of Ordovician graptolites are not widely distributed geographically makes correlation of zones based on assemblages of species difficult. The purpose of the present paper is to present an attempt at world wide correlation of Ordovician graptolite-bearing strata using the assemblages of species which characterize zones in the several regions. Because correlation on the species level is so tenuous, Bulman (1958) discussed general correlation using broader faunal units than zones. Such an approach to the vexing problem of long-range correlation is much needed, but it does not set forth clearly the provincialism of the Ordovician graptolite faunas.

Ordovician graptolite-bearing rocks have long been studied and almost from the earliest work on them, changes in assemblages of species in successive strata have been recognized. Lapworth's (1879–80) *Geological Distribution of the Rhabdophora* firmly established the stratigraphic usefulness of graptolites. Shortly thereafter, Tullberg (1882–83) proposed a division of the Ordovician of Scania using graptolites primarily, and Hall (1893, 1895) recognized a sequence of graptolite zones in part of the Lower Ordovician exposures in Victoria, Australia. The now classic work by Elles and Wood (1901—1918) and Elles (1922, 1925) clearly delimited the graptolite zones in the British Isles. Subsequently, complete or nearly complete successions of Ordovician graptolite zones were worked out in many parts of the world. The Australian zonal succession is considered to be complete and is the most detailed of all the known sequences. Hall's original scheme there has been enlarged and revised by Harris (1916), Harris and Keble (1932), and Harris and Thomas (1938). Ruedemann's work in eastern North America enabled him to recognize and describe (1947) twenty zones in New York state but they do not represent the entire Ordovician. The writer (1956, 1960) has delimited a complete succession of Ordovician graptolite zones in the Marathon region, Texas. Swedish graptolites and their stratigraphic zonation have held the attention of several workers since the days of Tullberg. Work on the Ordovician graptolite-bearing rocks by Törnquist (1901–04), Olin (1906), Ekström (1937), Hede (1951), Jaanusson and Strachan (1954), and Tjernvik (1956) has made the zonal sequence in Sweden well-known. Russian graptolite faunas are not, as yet, fully understood. However, a nearly complete sequence of Ordovician graptolite-bearing rocks is known in the Chu-Illiiski Mountains in Kazakhstan. The Bohemian graptolite faunas and their zonal development have been described by Bouček (1938) and Přibyl (1949).

In addition to the regions given above where complete or nearly complete sequences of Ordovician graptolite zones are recognized, partially complete successions are present in many areas. Perhaps the best-known of these is that in the Oslo region, Norway where the lower part of the Ordovician bears graptolites which have been described in detail by Monsen (1925, 1937) and Bulman (1953 and 1954). Ordovician graptolites have been recorded from several places in South America and a sequence of zones for the lower part of the Ordovician was delimited by Turner (in Harrington and Leanza, 1957) in Argentina. Several occurrences of Ordovician graptolites in China have been noted and Hsu (1934) was able to recognize five zones in Early and Middle Ordovician black shales in the Yangtze Valley.

Using these zonal sequences, a correlation table of the principal graptolite bearing strata has been made (Table 1). The zones in the several areas are commonly characterized by different assemblages of species, therefore this table represents a correlation between faunal provinces and regions as well as correlation between time-stratigraphic or rock units.

TREMADOC

The Early Tremadoc graptolite faunas are markedly provincial. *Dictyonema flabelliforme flabelliforme* and its related varieties mark the base of the Ordovician in much of Europe and in South America. The *Dictyonema flabelliforme* group is associated with *Clonograptus* and *Adelograptus* in Britain and Sweden, with *Anisograptus* and *Triograptus* in Norway, and with *Anisograptus* in Argentina. The North American Early Canadian is characterized by *Anisograptus* and *Triograptus* with *Staurograptus* and local species of *Dictyonema*, whereas in Australia, the basal Lancefieldian is denoted by *Staurograptus* and local forms of *Dictyonema*. Thus, *Anisograptus* and *Triograptus* provide the best clues to correlation. Every area where Early Tremadoc graptolites are found has several species found exclusively in it, and there is, therefore, a distinctly local character about them. Correlation can only be made on the generic level.

Of particular interest is the occurrence at Famatina and Santa Victoria, Argentina of European varieties of *Dictyonema flabelliforme* with forms of *Anisograptus* that closely resemble North American species. Also, the presence of *Anisograptus* and *Triograptus* in Norway and in North America suggests an easier communication between them than between the British Isles and North America.

The local nature of the Early Tremadoc graptolite assemblages may be an indication that, at that time, graptolites were not truly planktonic. The Earliest Ordovician graptolites are dendroid in character, and although they lacked definite stems or basal connections such as are found in *Dendrograptus, Callograptus,* and other dendroid genera, perhaps they were, nevertheless, benthonic. Certainly, the Cambrian ancestors of *Dictyonema flabelliforme* and the anisograptids were sessile benthonic and these Early Tremadoc forms were much like them in numbers of branches and possession of three types of thecae. Structural changes had taken place in the direction of the graptoloids but most of the forms were still dendroids and probably had not attained the planktonic mode of life which was apparently characteristic of nearly all of the graptoloid graptolites.

In contrast to the many Early Tremadoc graptolite occurrences, Late Tremadoc graptolites are present in but a few areas. Monsen (1925) described a small fauna from the *Ceratopyge* shale near Oslo, which is surely Late Tremadoc. The *Clonograptus, Adelograptus, Bryograptus* asemblage recorded by Kindle and Whittington (1958, P. 331) from Western Newfoundland and like assemblages characterizing zone 2 of the succession in the Marathon region, Texas and Lancefieldian zone 2 in Victoria, Australia are also considered to be Late Tremadoc. No other sequence of Ordovician graptolites has a Late Tremadoc asemblage. A possible reason might be the influence of widespread tectonism in the major orthogeosynclines.

The Late Tremadoc graptolites are predominantly members of the Family Anisograptidae, however several graptoloid forms appear here and certainly the graptoloid development was established. Many of the species are provincial, but the Marathon and Victorian successions do include some species common to both.

ARENIG

Graptolite-bearing rocks of Arenig age are known in many parts of the world. The original zonation of the Arenig as worked out by Elles (1904, 1922, 1933) has been commonly accepted, however several authors have questioned the validity of parts of the sequence and recently, Bulman (1958, P. 164) has concluded that there is no evidence for zone 3, the *Dichograptus* zone and questions the evidence for the *Tetragraptus* subzones of zone 4, the *Didymograptus extensus* zone. The upper three subzones of the *D. extensus* zone and zone 5, the *Didymograptus hirundo* zone are readily recognizable. They are characterized by many species of the genera *Didymograptus* and *Tetragraptus* with *Isograptus* and biserial scandent genera also prominent.

The third zone of the Lancefieldian, all of the Bendigonian, and the lower two zones of the Chewtonian are considered herein as the Australian correlatives of the Arenig. In North America, graptolite zones 3 through 6, or the middle and upper parts of the Canadian series are the Arenig correlatives. The graptolite sequences in North America and Australia are nearly identical in species composition and are characterized by numerous species of *Didymograptus* and *Tetragraptus*. The same

TABLE 1. *Correlation of graptolite-bearing sequences.*

British Isles	Zone	*Australia* (Victoria)	Zone	*North America* (Marathon)	Zone	Sweden
Ashgill	15 14	Bolindian	25 24	Richmond	15	Upper *Dicellograptus* shale
Caradoc	13 12 11 10 9	Eastonian	23 22	Maysville Eden	14	Middle *Dicellograptus* shale
				Trenton	13	
		Gisbornian	21 20	Wilderness	12	Lower *Dicellograptus* shale
				Porterfield	11	
Llandeilo	8	Middle Ordovician	19 18 17 16	Ashby	10	
Llanvirn	7 6			Marmor	9	Upper *Didymograptus* shale
		Yapeenian	15 14	Whiterock	8 7	
		Castlemainian	13 12 11			
Arenig	5 4 3	Chewtonian	10 9 8	Canadian Series	6 5 4 3 2 1	Lower *Didymograptus* shale
		Bendigonian	7 6 5 4			
Tremadoc	2 1	Lancefieldian	3 2 1			*Dictyonema* shale

Norway	Zone	*Bohemia*	*Russia* (Kazakhstan)
Calcareous ss Gastropod ls	5b 5a	Zdice beds	Chokpar
Isotelus series	4d γ 4d β 4d α		
Tretaspis series	4c γ 4c β 4c α		
Chasmops series	4b δ 4b γ 4b β 4b α 4a β	Zahorany beds	Dulan-Kara Otar ? ? Anderken
Bronni beds *Ogygiocaris* sh	4a α_4 4a α_3	Drabov qtzites Svatá Dobrotivá sh	Karakan
Upper *Didymograptus* shale	4a α_2 4a α_1	Skalka qtzites Šárka beds	Kopalla
Endoceras ls *Asaphus* sh *Megalaspis* ls	3c γ 3c β 3c α	Komárov beds	Kogashik ? ?
Lower *Didymo-graptus* shale	3b ε 3b δ 3b γ 3b β 3b α		
Ceratopyge series	3a γ 3a β 3a α 2e δ 2e α	Krušná Hora beds	

theme — the appearance of *Tetragraptus approximatus* with a few clonograptids and adelograptids, then *Tetragraptus fruticosus* the 4-branched form followed by the 3-branched variety of the same species and finally the dependent didymograptid, *D. protobifidus* — is used for zonal determination in both successions. Few of the English species are found in either North America or Australia. Only two small isograptids and none of the biserial scandent forms are present in the zones that are considered correlatives of the Arenig in these regions.

The graptolite zonal assemblages in the Lower *Didymograptus* shale in both Norway and Sweden are virtually identical in species composition and although fewer than 50 per cent of the species are the same as are found in the correlative zones in either the British or Australian or American sequences, many representatives of the didymograptids and tetragraptids characterize the zones. Isograptids and biserial scandent forms are also present.

A few widely distributed, typically Arenig age species and some endemic forms are present in the Komarov beds in Bohemia. They are, therefore, correlated with the British Arenig.

The Kogashik beds in Kazakhstan bear some widely distributed Late Arenig species. In total aspect, the fauna has an essentially British affinity.

Late Arenig (zone of *Didymograptus hirundo*) graptolites that are prominently British types but include some endemic species have been found in the Ningkuo shale in the Lower Yangtze Valley. Recently Mu and Lee (1958) have reported some new species of *Cardiograptus* from the same horizon. Thus this heretofore typically Australian-American genus occurs in China in older rocks than it does elsewhere.

Arenig age graptolites from South America give a somewhat perplexing picture. Endemic species are mixed with those having widespread distribution, and with some characteristic Scandinavian forms and some Australian-North American species. The total aspect of the fauna, however, suggests closest affinities with North America.

LLANVIRN

The Llanvirn in the British Isles is characterized by dependent didymograptids and many biserial scandent forms. The dependent Didymograpti, *D. bifidus,* the name-giving species to the lower zone of the Llanvirn, and *D. murchisoni,* the name-giver to the upper zone, are both geographically widespread. However, less than 30 per cent of the species in the Llanvirn of the British Isles are found in rocks of comparable age in any other succession.

Graptolite-bearing rocks placed in the Whiterock and Marmor stages in North America are correlated with the Llanvirn. Three zones are recognized in this interval in North America. The lowest of these is characterized by *D. bifidus* and *D. artus,* two other typically British forms, and several endemic species. The succeeding two zones are characterized by an Australian fauna. Isograptids, cardiograptids and a few biserial scandent forms denote the lower zone, whereas representatives of *Didymograptus, Glossograptus, Glyptograptus, Lasiograptus,* and *Trigonograptus* typify the upper.

The Australian units considered correlative with the Llanvirn are the highest zone of the Chewtonian, the Castlemainian, the Yapeenian, and the lower three zones of the Middle Ordovician. The Castlemainian has three zones based on varieties of *Isograptus caduceus;* and the Yapeenian has two zones, the lower characterized by *Oncograptus* and the upper by *Cardiograptus.* The three zones of the Middle Ordovician are determined by combinations of species of the same genera that are found in the highest zone of the Llanvirn correlative in North America. With the exception of the highest zone of the Chewtonian, which is correlated with the *D. bifidus* zone in North America on stratigraphic position, the Australian and North American successions are quite alike. The Australian sequence has been more closely divided, however identical species occur in similar assemblages in both.

The Upper *Didymograptus* shale in both Norway and Sweden bears nearly identical zonal assemblages. *D. bifidus* with many other species of dependent didymograptids and biserial scandent forms characterize the lower zone of the unit and *D. murchisoni,* its variety *geminus,* other dependent didymograptids, biserial scandent species, and representatives of the genera *Janograptus* and *Pterograptus* typify the upper part of it. Although the combination of genera is quite similar in both the Upper *Didymograptus* shale and the British Llanvirn, very few species are common to both.

The Sárka beds in Bohemia bear a graptolite fauna that has strong British Llanvirn affinities. It constitutes one firm tie point in an otherwise sparsely fossiliferous sequence of Ordovician graptolite-bearing strata. *D. bifidus* is common in the lower part of the unit and *D. murchisoni* and *D. murchisoni* var. *geminus* are prominent in the upper part. A few Scandinavian species and some endemic forms are also present.

The Kopala beds in the Chu-Illiiski Mountains of Kazakhstan have been correlated by Keller (1956) with the Llanvirn. They bear a fauna characterized by biserial scandent forms with some declined didymograptids and isograptids. The assemblage has an Australian aspect with many endemic species and some widely distributed forms admixed.

Hsu (1934) correlated the fauna from the upper part of the Ningkuo shale in the Lower Yangtze Valley with the *D. bifidus* zone. Widely distributed species found typically in that zone and many endemics are present.

The Gualcamayo shales in the Precordillera in Argentina bear an Australian-American assemblage of species and may be correlated with the Castlemainian, Yapeenian, and lower part of the Middle Ordovician in Australia. A few typically Scandinavian forms and some endemics are also present in the fauna. The Llanvirn correlative units in Peru and Bolivia include more Scandinavian species and some widely distributed forms including *D. bifidus* and *D. artus* at a lower horizon and *D. murchisoni* and its variety *geminus* in an upper.

LLANDEILO

The Llandeilo stage in the British Isles contains but one graptolite zone—that of *Glyptograptus teretiusculus.* It is characterized by the first appearance of the name-giving species, the presence of several kinds of biserial forms, and the absence of didymograptids.

The Australian and North American correlatives of the Llandeilo—the highest zone of the Middle Ordovician in the Victorian succession and the graptolite-bearing correlatives of the Ashby stage in North America—both are also characterized by the first appearance of *G. teretiusculus,* the presence of many other kinds of biserial scandent forms, and the absence of didymograptids. The Australian and North American zones are nearly identical in species composition; however, only about 40 or 50 per cent of those species are also present in the British Llandeilo.

The *Ogygiocaris* shale in Norway and the lower part of the Lower *Dicellograptus* shale in Sweden are characterized by similar faunas. Jaanusson and Strachan (1954) used the name *Glyptograptus teretiusculus* for the lower zone of the Lower *Dicellograptus* shale and correlated it with the British zone of that name. The fauna of the Swedish and Norwegian zones includes many biserial scandent types, holdover species of *Didymograptus, Janograptus,* and *Azygograptus* and early representatives of *Dicellograptus* and *Dicranograptus.* In addition to the generic differences, few species are common to both Scandinavia and the British Isles.

Glyptograptus teretiusculus first appears in the Bohemian succession in the Svatá Dobrotivá shales and *Cryptograptus tricornis* is associated with it. Because these two species are common in Llandeilo rocks in many parts of the world, the Svatá Dobrotivá beds have been correlated with the Llandeilo on their faunal content and stratigraphic position.

The Karakan beds in Kazakhstan bear the first representatives of *G. teretiusculus* in that sequence. Hence, they, too, have been equated to the Llandeilo.

Definite evidence of the *G. teretiusculus* zone is lacking in China and most of South America, but some evidence is present that suggests that it may occur in the Precordillera in Argentina. *G. teretiusculus* occurs in the latter area with a few forms that are typically found in North America either in the zone of *G. teretiusculus* or in the zone below.

CARADOC

The base of the Caradoc in the British Isles is marked by the incursion of *Nemagraptus gracilis* with several species of *Dicellograptus, Dicranograptus,* and *Leptograptus.* The succeeding two zones are not easily recognizable. In Scotland both the *Climacograptus peltifer* and *Climacograptus wilsoni* zones have been determined, whereas in Wales, these two zones can not be recognized and in their place, a single zone, that of *Diplograptus multidens* occurs. Elles (1937) stated that the zones of *C. peltifer* and *C. wilsoni* could be regarded as passage zones between those of *N. gracilis* and *Dicranograptus clingani.* Whether one or two zones can be utilized must be determined by future work; however, the interval can be recognized by the association of the first orthograptids with dicellograptids, large dicranograptids, leptograptids, and climacograptids of which the spinose forms *C. bicornis* and *C. peltifer* are most common.

Overlying the *C. wilsoni* zone and extending to the top of the Caradoc are two readily recognized faunas—those of the zone of *Dicranograptus clingani* and the zone of *Pleurograptus linearis.* These are characterized by large orthograptids—primarily of the *calcaratus, quadrimucronatus,* and *truncatus* types—with large dicellograptids and leptograptids.

The correlative units of the Caradoc in Australia, the Gisbornian, Eastonian, and lower zone of the Bolindian, contain a fauna that has been divided to five zones. The assemblages of species that characterize each of these zones are nearly identical to those delimited in the Caradoc in Scotland.

A like situation is true in North America, where beginning with the zone of *N. gracilis,* the zonal assemblages are almost the same as those in Scotland. The *Nemagraptus gracilis* zone occurs in rocks correlative with the lower part of the Porterfield stage, the *C. bicornis* zone in rocks equivalent to the upper part of the Porterfield stage and the Wilderness stage, and the zone correlative with that of *C. wilsoni* in the Trenton stage. The zone of *Orthograptus quadrimucronatus,* which is present in rocks correlative with the Eden and Maysville stages, bears elements of the fauna of both the *D. clingani* and *P. linearis* zones. However, as yet, those two zones cannot be clearly delimited in North America.

The zone of *N. gracilis* is present in the Lower *Dicellograptus* shale in Sweden. It is characterized by a few small dicellograptids and dicranograptids and many biserial scandent forms. Although *N. gracilis* and its closely allied varieties are present, nearly 50 per cent of the species in the zone are endemics.

The zone of *Dicranograptus clingani* is readily recognized in the Middle *Dicellograptus* shale in Sweden. It is characterized by most of the same species of climacograptids, dicellograptids and orthograptids that typify the zone in Britain.

The interval between the zones of *N. gracilis* and *D. clingani* cannot at present be correlated with the British zones. Nilsson (1953) described a fauna from this interval that contained elements of the zones above and below it. Perhaps this mixed assemblage can best be equated with the zone of *Diplograptus multidens* in Wales and not with the Scottish sequence.

The upper part of the Middle *Dicellograptus* shale bears a typical *Pleurograptus linearis* zone fauna. With but three exceptions, the same species are present in this zone in both the British Isles and Sweden.

The Norwegian succession above the 4a *α* horizon bears few graptolites and the correlation of it with the Swedish sequence is taken from Jaanusson and Strachan (1954). Some graptolites have been found in the Lower *Chasmops* shale which, according to Bulman (in Störmer, 1953, p.64), are slightly younger than the zone of *N. gracilis.*

The lower part of the Zahořany beds in Bohemia does not bear graptolites, but the upper part includes some biserial scandent forms. Many of these are endemics, but some are widespread. Přibyl (1949) recognized three zones which he correlated with the upper part of the Caradoc.

The Anderken and Otar beds in Kazakhstan bear but few graptolites. However, those that are present and the other fauna indicates a correlation of these beds with the lower and middle parts of the Caradoc. The Dulan-Kara beds in the same area include *Pleurograptus linearis* and other forms suggesting a correlation with the upper part of the Caradoc.

Hsu (1934) described graptolite assemblages similar to those of the British zones of *N. gracilis* and *C. peltifer* from the Hulo shale in the Lower Yangtze Valley. Many of the species are widely distributed forms but some endemics are admixed.

Typical British *N. gracilis* zone assemblages have been recorded from the Precordillera in Argentina by Harrington and Leanza (1957, P. 38). Bulman (1931) identified a fauna from Peru that is probably correlative with the upper part of the Caradoc. Other than these occurrences, Caradoc graptolites are not well-known in South America.

ASHGILL

As originally used, the Ashgill in the British Isles included two zones, that of *Dicellograptus complanatus* and that of *Dicellograptus anceps*. However, Elles (1937, P. 487) stated that the zone of *D. complanatus* had a pathologic fauna and left the zone out of her chart of the British zonal sequence. This opinion seems justified, and the zone of *D. anceps* is easily recognized in many parts of the world. Almost identical zonal assemblages are present in the upper zone of the Bolindian in Victoria, Australia, the highest zone of the Marathon region, Texas succession in beds equivalent to the Richmond stage in North America; the Upper *Dicellograptus* shale in Sweden; the Zdice beds in Bohemia; the Chokpar beds in Kazakhstan; and the Wufeng shale in the Yuyangkuan Wufeng District, China. Some endemic forms are present in each area, but most of the species have world-wide distribution.

CONCLUSIONS

A definite pattern of Ordovician graptolite distribution may be deduced from this discussion of correlation. Early Tremadoc was a time of provincialism with the faunas in Norway and the Americas surprisingly more similar than any others. Few Late Tremadoc graptolites are known, and of those that are, the faunas from Australia and North America are sufficiently distinct from the one in Norway that two faunal regions can be delimited. The Australian and North American faunas belonged to two distinct provinces within the region.

From the Arenig through the Llanvirn and Llandeilo, three distinct faunal regions were in existence. Australia and the Americas belong in one, Norway and Sweden in a second, and the British Isles in a third. South America is clearly a province within the Australian-American region and the occurrence of some Scandinavian and British species in it aid in correlation between regions. The successions in Bohemia, Kazakhstan, and China are not complete enough to definitely ascertain their affinities. The Kazakhstan units do contain some forms from both the Australian-American and British regions.

From the Earliest Caradoc and continuing throughout the rest of the Ordovician, The Australian-American and British regions lost their identity and their faunas became nearly identical. The Scandinavian region was a separate entity until the Late Caradoc when graptolite faunas became cosmopolitan.

Graptolites were dispersed by ocean currents and their distribution is a reflection of the direction of the currents. Land areas probably provided the most effective barriers. Certainly the Scandinavian and British regions were separated by land, and Skjeseth (1952) demonstrated that a land area, which he called "Telemark Land," existed west of the Oslo Region for most of the Paleozoic.

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