MIDDLE AND UPPER ORDOVICIAN CONODONT AND GRAPTOLITE BIOSTRATIGRAPHY OF THE MARATHON, TEXAS GRAPTOLITE ZONE REFERENCE STANDARD

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ABSTRACT. Samples from the Marathon Ordovician succession, by many considered the reference standard for the Pacific Province graptolite zone succession in North America, have produced numerous conodonts, which provide new information on the correlation of the graptolite succession and the mutual relations between Pacific Province graptolite zones, North Atlantic Province conodont zones, and European Province graptolite zones. Most of the Marathon *Glyptograptus* cf. *G. teretiusculus* Zone is equivalent to the Baltoscandian *G. teretiusculus* Zone and the lower subzone of the *Pygodus anserinus* conodont Zone. The base of the Marathon and Baltoscandian *Nemagraptus gracilis* Zone occupies the same stratigraphic level, but no strata corresponding to the highest part of the Baltoscandian *N. gracilis* Zone have been found at Marathon, where a large hiatus separates the Woods Hollow Shale from the overlying Maravillas Formation. The basal part of the Maravillas, the reference interval of Berry's *Orthograptus trucatus* var. *intermedius* Zone, is of Maysvillian (late Ordovician) age and represents the *Amorphognathus ordovicicus* conodont Zone and is probably coeval with the *Pleurograptus linearis* Zone. Its stratigraphic incompleteness and other factors make the Marathon succession a less than ideal reference standard for the North American Middle and Upper Ordovician graptolite zone succession.

GRAPTOLITES have traditionally served as the principal fossils for long-distance correlations of shaly Ordovician rocks. However, like most other organisms in the Ordovician fossil record, graptolites exhibit a striking provincialism, and two main provinces, the European (Atlantic) and the Pacific Provinces, have been recognized by most workers. Provincial differences in the graptolite faunas are most conspicuous in rocks of Lower and early Middle Ordovician (Arenig through Llanvirn) age, but some provincial distinctions have been recognized also in younger parts of the system. Inter-provincial correlations between units in the graptolite zone successions established in each of these provinces have been difficult in several intervals and have remained controversial even after recent re-evaluations.

For a long time, the classical sections for the Ordovician graptolite zonal succession in North America have been those in the New York–Quebec area (Ruedemann 1904, 1908; Berry 1962; Riva 1969, 1972, 1974). Although some of the exposures in this area are magnificent, many are structurally complex, and the graptolites are rarely sufficiently well preserved to permit isolation by means of acids. Further, some parts of the Ordovician succession are not known to be represented by graptolitic strata. Recent comprehensive studies by Berry (1962, 1963, 1970, 1973) and Riva (1969, 1972, 1974, 1976) have added much new information on the zonal assemblages and their stratigraphic significance, but much remains to be learned about the vertical ranges of individual species and many forms are in need of taxonomic re-assessment.

Through the well-known work of Berry (1960), the Ordovician Pacific Province graptolite faunal succession in the Marathon area, south-western Texas, was shown to be one of the most remarkable in North America. In the Marathon Ordovician succession, Berry (1960) recognized 15 graptolite zones, which were correlated with zonal units elsewhere in North America, Australia, and Europe. The Marathon succession was considered to be without appreciable gaps and it has subsequently been widely regarded as the reference standard of the Ordovician graptolite zone succession of Pacific Province type in North America.

However, even a superficial inspection of the graptolite species lists of the various zones of the Middle and Upper Ordovician of New York-Quebec and Texas, respectively, reveals some rather striking differences, and the faunal basis for precise correlation of the various units in the post-*gracilis*—pre-*complanatus* part of the successions in the two areas has not been very strong. After a re-evaluation of the New York-Quebec succession, Riva (1969, 1972, 1974) concluded that several of the upper Middle and lower Upper Ordovician graptolite zones recognized there apparently are missing in the Marathon succession. It was not clear whether this is due to gaps in the succession, provincialism, or local environmental control, lack of collections from certain intervals, or other factors. Rickard and Fisher (1973) suggested that the differences between Berry's and Riva's zonal successions were basically a matter of differences in definition of individual graptolite zones rather than the relative stratigraphic completeness of the successions in the two areas. They attempted a correlation between Berry's and Riva's zonal schemes (Rickard and Fisher 1973, text-fig. 1) showing no gaps in the zonal successions in either New York-Quebec or Texas. Evidently, this implies that if Berry's zones are taken to have the same stratigraphic scope as in the Marathon succession, where they were originally recognized, the latter succession has to be interpreted to be without major gaps. A comparison between the interpretations by Riva (1972, 1974) and Rickard and Fisher (1973) is given in text-fig. 1.

The Marathon succession is undoubtedly one of the most widely known Ordovician sequences in North America and its graptolite zone succession has figured prominently in both the national and international biostratigraphic literature since 1960. In view of this, and of the fact that it appeared that the biostratigraphic problem outlined above had reached the stage where it was unlikely that graptolites alone could provide decisive data, it was thought appropriate to investigate if new and informative data on the problem could be gained from other biostratigraphically useful fossils such as conodonts. A study of conodonts looked particularly promising because large parts of the Marathon succession consist of limestones that can be readily digested in weak acids. Such a study was also of considerable interest because it could be expected to provide critical direct ties between graptolite zones in a key Pacific Province succession and the standard conodont zones of the North Atlantic Province. In view of the fact that recent studies (Bergström 1971, 1973a, 1977b) have made it possible to calibrate the North Atlantic Province conodont zone succession with the European Province graptolite zone succession, a study of the Marathon conodonts also had the potential of indirectly producing new data on the mutual relations between Pacific Province and European Province graptolite zones.

This paper is concerned with the biostratigraphy of only a portion of the Middle and Upper Ordovician in the Marathon area. Although informative data are available also on the older part of the succession (Bergström 1977a), they will be presented separately. It should be noted that the terms Middle and Upper (Late) Ordovician are used throughout this paper in their usual North American sense, that is, to denote Champlainian and Cincinnatian age strata, respectively. The interpretation of the mutual relations between these units follows that set out by Sweet and Bergström (1971).

N. Am. Series	RIVA (1972, 1974)		RICKARD & FISHER (1973)		British Series
	Eastern North America	Texas (Berry, 1960)	Berry	Riva	
CINCINNATIAN	Climacograptus prominens-elongatus	No fauna	Not dealt with		ASHGILL
	Dicellograptus complanatus	Dicellograptus complanatus			
	Climacograptus manitoulinensis	?	Orthograptus quadrimucronatus	Climacograptus manitoulinensis	
	Climacograptus pygmaeus	Orthograptus quadrimucronatus		Climacograptus pygmaeus	
	Climacograptus spiniferus	Orthograptus "intermedius"		Climacograptus spiniferus	- - ? - -
CHAMPLAINIAN	Orthograptus ruedemanni	No fauna	Orthograptus truncatus var. intermedius	Orthograptus ruedemanni	CARADOC
	Corynoides americanus			Corynoides americanus	
	Diplograptus multidens		Climacograptus bicornis	Diplograptus multidens	
	Nemagraptus gracilis	Climacograptus bicornis N. gracilis	Nemagraptus gracilis	Nemagraptus gracilis	

TEXT-FIG. 1. Comparison of different interpretations of relations between recently proposed late Middle and Upper Ordovician graptolite zonal schemes in North America. Left half of diagram shows relations between New York-Quebec and Texas graptolite zones according to Riva (1972, 1974). Right half illustrates relations between Berry's (1960) and Riva's (1969, 1972, 1974) zones as interpreted by Rickard and Fisher (1973).

GEOLOGICAL FRAMEWORK

The Marathon region is situated in south-western Texas (text-fig. 2) and represents one of the southernmost outcrop areas of the belt of deformed Palaeozoic rocks, commonly known as the Ouachita system (Flawn 1961), which can be traced along the whole southern margin of the North American craton. The exposed Ordovician rocks in the area are all allochthonous, having been thrust an unknown, but probably relatively short, distance toward the north-west (King 1938). They exhibit much folding and faulting but are not notably metamorphosed.

The Ordovician succession, with a total thickness of 700–800 m, is customarily subdivided into five formations, which are, in ascending order, the Marathon Limestone, Alsate Shale, Fort Peña Formation, Woods Hollow Shale, and the Maravillas Formation. Only the last two, together with the upper part of the Fort Peña Formation, are of post-Lower Ordovician age and will be dealt with in this paper.

The Fort Peña, which has a thickness of 40–200 m (McBride 1969a), consists of limestone, shale, chert, conglomerate, and boulder beds. Many beds in the formation show evidence of being turbidites and recent studies (McBride 1969a) suggest that these strata were deposited on the continental slope at water depths in excess of 10–20 m. Graptolites (Berry 1960) and conodonts (Bradshaw 1969) indicate that the formation is of Arenig and Llanvirn age, although it is possible that its uppermost part may be as young as Llandeilo. The contact between the Fort Peña and the overlying Woods Hollow Shale appears transitional in outcrop (King 1938) but it is rarely well exposed.

The Woods Hollow, which reaches an estimated maximum thickness of 150–200 m, includes a generally very poorly exposed and structurally complex succession of dominant shale and mudstone with scattered beds of sandstone, siltstone, conglomerate, and limestone. There are also boulder beds, especially in the upper part of the formation. Many of the beds show turbidite characteristics (McBride 1969b). Recent interpretations (Thompson and McBride 1964; McBride 1967, 1969b) favour a relatively deep water environment of deposition, probably on the continental slope, for the Woods Hollow. Graptolites (Berry 1960) indicate a Middle Ordovician age for the entire formation.

The Woods Hollow is overlain by the Maravillas Formation, which has a maximum thickness of 150–175 m. The contact between the shales of the Woods Hollow below and the interbedded limestones and dark cherts of the Maravillas above is quite distinct in most places and is also marked locally by a prominent conglomerate. The nature of this contact has been controversial; some workers (e.g. King 1938; Wilson 1954a) have considered it a disconformity, but others (Berry 1960; Thompson and McBride 1964) have interpreted it as conformable.

The Maravillas is a lithologically very distinctive unit of interbedded dark chert and limestone with beds of shale, conglomerate, and dolomite. Some beds are apparently turbidites deposited on the continental slope. In the past, this formation—like the others in the Marathon Ordovician—was thought to have been deposited in shallow water but recent investigations (Thompson and McBride 1964; McBride 1970) have brought forward evidence that has been taken to suggest a deep water environment of deposition. Graptolites occur throughout the unit and have been interpreted to indicate either a Middle and Upper Ordovician age (Berry 1960) or an Upper Ordovician age (Riva 1972, 1974) only.

The interpretation of the nature of the upper contact of the Maravillas is also controversial. Although it is generally distinct in the field, it has been variously interpreted as conformable or marking a major gap in the succession. The overlying Caballos Novaculite has yielded early Devonian conodonts (Graves 1952; Ziegler 1971, p. 239) but the conodont-bearing beds are at least 40 m above the base of the unit, and in the absence of finds of diagnostic fossils the age of the lower part of the Caballos remains uncertain. Most past workers have considered the Caballos to be of Devonian age in its entirety and hence separated from the Maravillas by a prominent unconformity; however, some recent workers (McBride and Thompson 1970) have suggested that the lower Caballos is of Silurian age, with the Maravillas-Caballos contact conformable and not representing a significant break in deposition. It should be noted that there is still another, apparently previously unpublished, possibility, namely that at least a portion of the lower Caballos is of latest Ordovician age. This possibility is discussed further below (p. 732).
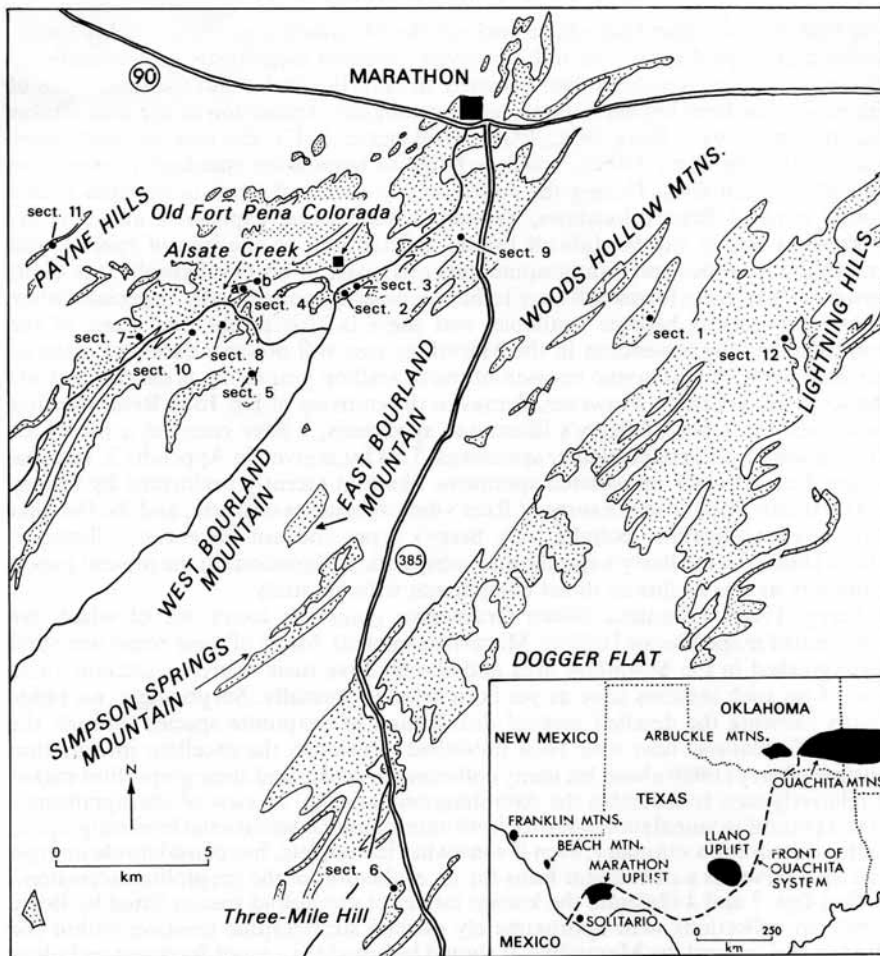
TEXT-FIG. 2. Sketch map of the major portion of the Marathon Ordovician area (dotted; after King 1938) showing location of collecting sites. For further information on localities see Appendix 1. The Marathon anticlinorium includes the area from the town of Marathon toward the south-west; the Dogger Flat anticlinorium includes the area from Lightning Hills to Three-Mile Hill. Inset map shows areas of Ordovician exposures mentioned in the text in Texas and adjacent states. Baylor Mountain is located immediately adjacent to Beach Mountain and is included in the latter outcrop area on the map.

GRAPTOLITE BIOSTRATIGRAPHY

The Middle and Upper Ordovician rocks of the Marathon area are not richly fossili-
ferous and graptolites are the only relatively common megafossils in practically all
of the succession. Although their presence in both the shales and the limestones of
the region has been known since the early geological exploration of the area (Baker
and Bowman 1917; King 1931, 1938; Ruedemann 1947), the first comprehensive
study is that by Berry (1960), which is likely to remain the standard reference on
Marathon graptolites. During the course of my own field work in the area I have
visited most of Berry's localities, as well as many other exposures, and it is my
impression that it will be difficult to add substantially to the lists of species, and
graptolitic localities and stratigraphic intervals given in his monograph. It is clear,
however, that many forms will have to be re-assessed taxonomically, especially when
isolated specimens become available, and there is little doubt that some of the
graptolite-bearing limestones in the Marathon area will produce excellent material
for such work. A taxonomic revision of the Marathon graptolites is entirely outside
the scope of this study. However, thanks to the courtesy of Dr. John Riva, who has
re-studied the types of Berry's illustrated specimens, I have received a list of *his*
identifications of these particular specimens. This list is given in Appendix 2. Because
future detailed work on isolated specimens like that recently performed by Finney
(1977) is also likely to make some of Riva's determinations obsolete, and the fact that
Riva's re-investigation includes only Berry's types and not his entire collections,
I have chosen to use Berry's specific and subspecific designations in the present paper,
especially as this facilitates direct comparison with his study.

Berry (1960) recognized fifteen Ordovician graptolite zones, six of which are
represented in the Woods Hollow-Maravillas interval. Many of these zones were first
distinguished in the Marathon area and should have their reference sections there
even if no such sections have as yet been selected formally. Surprisingly, no range
charts showing the detailed vertical distribution of graptolite species through the
various formations have ever been published. However, the excellent information
given by Berry (1960) about his many collecting localities and their graptolites makes
it relatively easy to assemble the data diagrammatically. In view of the significance
of this graptolite faunal succession for both national and international biostratigraphy,
such a distribution summary, even if somewhat incomplete, has considerable interest
and also serves as a convenient basis for an evaluation of the graptolite succession.

Text-figs. 3 and 4 illustrate the known ranges of graptoloid species listed by Berry
(1960) in collections with approximately defined stratigraphic position within the
Woods Hollow and the Maravillas. It should be noted that, apart from not including
imprecisely located collections, these diagrams are generalized and imperfect in that
factors such as structural complications, poor exposures, variable formation
thickness from locality to locality, etc. necessarily make determination of exact
collecting levels within the formations subject to errors, especially in a summary
diagram. In an attempt to eliminate at least some of the effects of the considerable
difference in total thickness of the Maravillas in the Marathon and Dogger Flat
anticlinoria, respectively, the faunal successions of the two areas are shown separately
in text-fig. 4. These diagrams invite some comments on the graptolite biostratigraphy,
and each formation will be discussed separately below.

The Woods Hollow Shale

Berry (1960) recognized three zones within the Woods Hollow, in ascending order, the *Glyptograptus* cf. *G. teretiusculus* Zone (Zone 10), the *Nemagraptus gracilis* Zone (Zone 11), and the *Climacograptus bicornis* Zone (Zone 12).

The Glyptograptus *cf.* G. teretiusculus *Zone.* Although Berry's collection 49 from 4 m above the base of the Woods Hollow was referred to the *N. gracilis* Zone, his text makes it plain (Berry 1960, pp. 23, 25) that the basal 7–13 m of the formation was included in the *G.* cf. *G. teretiusculus* Zone. On the basis of the stratigraphically well located samples, one can only conclude that the boundary between Zones 10 and 11 falls somewhere between the levels of Berry's collections 46A and 139 in an interval without control that is approximately 14 m thick. The graptolite fauna of Zone 10 is impoverished in the Marathon area and the species present are not very distinctive. Early forms of *Dicellograptus* and *Nemagraptus*, as well as other characteristic forms present in the *G. teretiusculus* Zone in Scandinavia, have not been found there and this might be one of the reasons why Marathon Zone 10 has also been correlated, in my view incorrectly (see below p. 745), with the *Didymograptus murchisoni* Zone (Skevington 1963, 1971, 1973, 1976). It should be noted that Erdtmann (1976, table 6) lists *N. gracilis* from Zone 10 in the Woods Hollow as well as from the same zone in the Athens Shale of Alabama. This is either an error or based on previously unpublished collections because there is no published information of such occurrences in the literature.

The Nemagraptus gracilis *Zone.* The graptolite fauna of this zone is varied and, by and large, very similar to that of the same zone elsewhere in North America (Riva 1974; Berry 1962; Finney 1977) and Europe (Nilsson 1977). Unfortunately, graptolite control is poor in the middle part of the Woods Hollow. This is apparently due to lack of exposures of that part of the formation, the only good section being the stratotype, which is not graptolitic in that particular interval (Berry 1960, p. 112).

The Climacograptus bicornis *Zone.* The upper 50 m of the Woods Hollow was distinguished as the *C. bicornis* Zone by Berry (1960, p. 26). The boundary between this unit and the *N. gracilis* Zone is between the levels of Berry's collections 103 and 122 in a 26 m thick interval without graptolite control. According to Riva (1972, 1974) the Marathon *C. bicornis* Zone contains 'the same fauna' as the *N. gracilis* Zone and should be included with the latter. However, the faunal differences noted by Berry (1960, p. 26) should not be neglected (*cf.* text-fig. 3), especially as some of them are recognizable also in the carefully studied sections in Sweden (Nilsson 1977) and the Southern Appalachians (Finney 1977). Although it is questionable that the *C. bicornis* graptolite assemblage, as distinguished by Berry (1960), is distinctive enough to merit its use for the definition of a separate zone, it might well prove useful in the classification at the subzonal level, if the *N. gracilis* Zone is subdivided. In this connection it should be pointed out that Berry (1960) recorded *Diplograptus multidens* (Elles and Wood) from the upper part of the Woods Hollow Shale in the Solitario area 75 km south-west of the Marathon area, and *D. multidens* var. *diminutus* Ruedemann from the upper part of the same formation in the latter area. This is likely to have been the prime reason for the recognition of the *D. multidens* Zone in the upper part of the Woods Hollow (Erdtmann 1976, table 7). The Woods Hollow succession at Solitario is structurally complex, poorly exposed, and little known. Further, a re-study of the poorly preserved rhabdosome fragment from Solitario identified as *D. multidens* suggests (Riva, pers. comm. 1975) that it is more properly referred to as *Amplexograptus* sp. Likewise, the record of *D. multidens diminutus* is of questionable biostratigraphic significance even if the specimens indeed are conspecific with Ruedemann's form. Clark and Strachan (1955, p. 696) considered this 'variety' as conspecific with *Diplograptus? molestus* Thorslund, which ranges from the lower part of the *N. gracilis* Zone to the top of the *Dicranograptus clingani* Zone in Baltoscandia (Nilsson 1977; Jaanusson and Skoglund 1963). In view of the fact that practically all the graptolite species listed by Berry (1960) from the upper Woods Hollow are known from the *N. gracilis* Zone elsewhere, and the forms typical of the *D. multidens* Zone are missing, there is no compelling graptolite evidence justifying reference of the upper part of the Woods Hollow to the *D. multidens* Zone.

The Maravillas Formation

The Maravillas Formation is far better exposed than the Woods Hollow and both its shales and limestones contain relatively abundant, and locally, well preserved
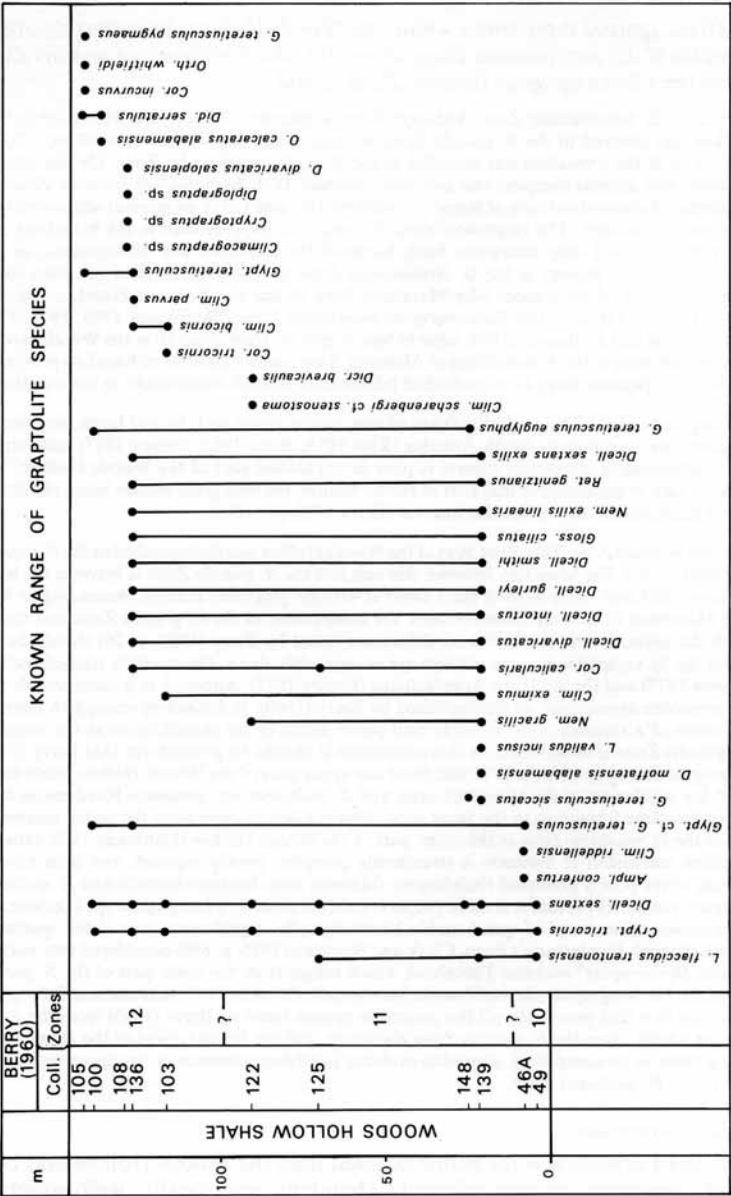
TEXT-FIG. 3. Known ranges of graptolites in the Woods Hollow Shale based on data in Berry (1960). Collections 38, 46, 94A, 94B, 94C, 104, 127, 137, and 150 are not included because their precise stratigraphic position within the formation is unknown. Also collection 124 is omitted because it lacks graptolites of zonal significance. For some updated identifications see Appendix 2.
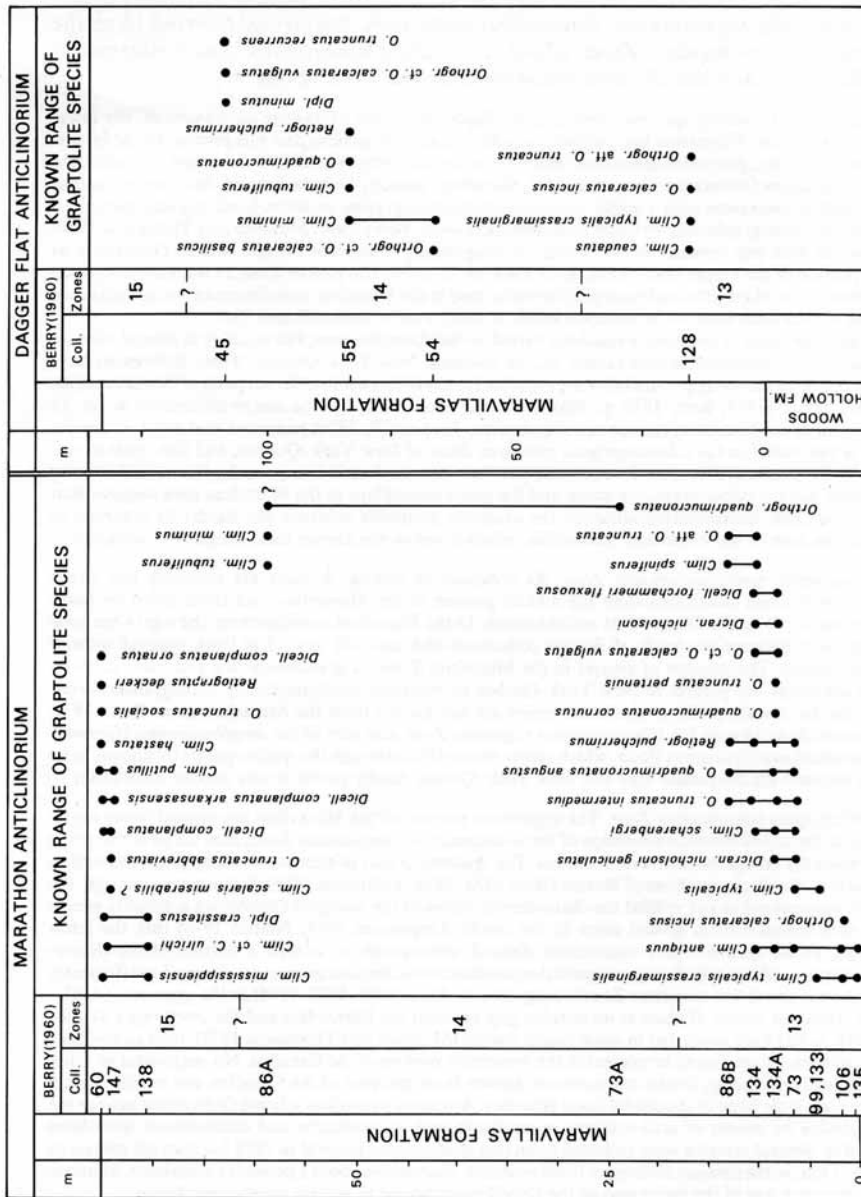
TEXT-FIG. 4. Known ranges of graptolites in the Maravillas Formation in the Marathon and Dogger Flat anticlinoria, respectively, based on data in Berry (1960). Collections 83A, 83B, 93, 131A, and 132 are not included because their precise stratigraphic position within the formation is unknown. Also collections 131 and 144 are omitted because they lack graptolites of zonal significance. For some updated indentifications see Appendix 2.

graptolites. Berry (1960) recognized three zones in the formation, in ascending order, the *Orthograptus truncatus* var. *intermedius* Zone (now frequently referred to as the *Orthograptus* '*intermedius*' Zone (Zone 13)), the *Orthograptus quadrimucronatus* Zone (Zone 14), and the *Dicellograptus complanatus* Zone (Zone 15).

The Orthograptus truncatus *var.* intermedius *Zone.* Especially in the Marathon anticlinorium, the lower part of the Maravillas Formation has yielded graptolites in several sections and this portion of the formation is one of the best graptolite-controlled intervals, as far as closely spaced collections are concerned, in the entire Marathon Ordovician succession. It is, therefore, amazing that the base of this zone, as well as the zone itself, is associated with a highly controversial biostratigraphic problem involving interpretations ranging from a stratigraphically virtually complete succession (Berry 1960; McBride and Thompson 1970) to a proposed wide gap beneath the Maravillas, corresponding to most of the late Middle Ordovician as well as a portion of the Upper Ordovician (Riva 1969, 1972, 1974). The base of Zone 13 is taken to coincide with the base of the Maravillas and the top of the same zone in the Marathon anticlinorium is at an unknown horizon in a 10 m thick interval between the levels of Berry's collections 86B and 73A.

The graptolite fauna of this zone is relatively varied in the Marathon area, but it differs in several respects from presumably contemporaneous faunas in, for instance, New York–Quebec. These differences have been interpreted as reflecting provinciality in graptolite faunas of this age in different parts of North America (Riva 1969, pp. 551–553; Berry 1970, p. 306), but could conceivably also be due to differences in age, or local environmental control of the species distribution. Riva (1972, 1974) proposed that most of Berry's Zone 13 is equivalent to the *Climacograptus spiniferus* Zone of New York–Quebec, and this opinion was adopted by Erdtmann (1976, table 9). A comparison between the faunal lists given by Riva (1974) for the various New York–Quebec graptolite zones and the zonal assemblage in the Marathon area suggests that this is a reasonable interpretation although the available graptolite evidence can hardly be regarded as decisive in the case of the lowermost Maravillas, which is below the known local range of *C. spiniferus*.

The Orthograptus quadrimucronatus *Zone.* As indicated in text-fig. 4, there are relatively few stratigraphically well-dated collections from the middle portion of the Maravillas, and those listed by Berry (1960) are mainly from the Dogger Flat anticlinorium. In the Marathon anticlinorium, the top of the zone apparently falls between the levels of Berry's collections 86A and 138 in a 15 m thick interval without graptolite control. The number of species in the Marathon Zone 14 is relatively low and most of those recorded are either not present in New York–Quebec or represent stratigraphically undiagnostic forms. Further, the key zonal species in the latter region are not known from the Marathon area. Riva (1972, 1974) equates Zone 14 with his *Climacograptus pygmaeus* Zone and part of his *Amplexograptus* (formerly *Climacograptus*) *manitoulinensis* Zone, which seems reasonable although the species presently known to be common between the Marathon area and New York–Quebec hardly permit a very precise correlation.

The Dicellograptus complanatus *Zone.* The uppermost portion of the Maravillas has yielded many representatives of the characteristic assemblage of the widespread *D. complanatus* Zone, here taken in the scope as it is commonly recognized in North America. The uppermost part of this zone is likely to correspond to at least part of the *D. anceps* Zone of Britain (Riva 1972, 1974; Erdtmann 1976). Interestingly enough, the Marathon succession has not yielded the characteristic forms of the youngest Ordovician graptolite zones; there is now evidence from several parts of the world (Lespérance 1974; Nikitin 1976) that the latest Ordovician, as the system is now customarily defined, corresponds to at least a portion of the *Glyptograptus persculptus* Zone, which may be a partial equivalent to the *Amplexograptus prominens* Zone (formerly *Climacograptus prominens-elongatus* Zone) recognized by Riva (1969, 1972, 1974) in the uppermost Ordovician of Anticosti Island. If there is no notable gap between the Maravillas and the overlying Caballos Novaculite, as has been suggested in some recent papers (McBride and Thompson 1970), then equivalents to the latest Ordovician should be present in the lowermost portion of the Caballos. No graptolites or other stratigraphically diagnostic fossils are, however, known from this part of the Caballos and its lithological character gives little hope of successful fossil recovery. Attempts to confirm a latest Ordovician age for the lower Caballos by means of acid-resistant microfossils such as acritarchs and chitinozoans have been unsuccessful. Several samples were collected from this stratigraphic interval in 1975 but they all proved to be barren. Thus, in the absence of decisive fossil evidence, discussions about a possible Ordovician, Silurian, or even Devonian age of the lower part of the Caballos are bound to remain purely speculative.

CONODONT BIOSTRATIGRAPHY

The first studies on Ordovician conodonts from the Marathon area were made by Graves and Ellison (1941), who briefly described collections from all the various formations. The fact that they gave the approximate stratigraphic position of each of their samples greatly enhances the biostratigraphic value of their pioneer paper. More recent conodont work in the area includes that on the Fort Peña by Bradshaw (1969); this study, as well as one on the Maravillas conodonts (Bradshaw in preparation), are mainly taxonomic in character. Bergström and Cooper (1974) studied some Lower Ordovician conodonts and their biostratigraphic significance, and further data on the conodont biostratigraphy of the area have been published by the writer in a few preliminary papers (Bergström 1974a, 1976, 1977a).

The conodont data of the present study are based on about 50 5-10 kg samples from twelve sections of the Woods Hollow and/or Maravillas (for particulars regarding sampled sections and sample levels, see Appendix I; the location of sections studied is given in text-fig. 2). Most exposures mentioned or described by Berry (1960), as well as several other sections, were studied, and samples were collected from carefully selected levels. Great efforts were made to secure representative samples from stratigraphically carefully located levels in critical intervals such as near formational boundaries and graptolitic beds.

With very few exceptions, the samples proved to be productive of conodonts although the frequency of these fossils varies greatly from less than ten to many hundred specimens per kilogram. The state of preservation varies from excellent to barely adequate for specific determination. The specimens show a colour alteration index (CAI) (Epstein *et al.* 1977) ranging from 1-1·5 to 3-4, indicating a heating of the host strata from less than 90 °C to 200-300 °C. Interestingly, and as one might expect, the degree of conodont metamorphism increases, in general, from west to east; in the western sections, such as those at Alsate Creek and Roberts Ranch Road, the elements show little, if any, metamorphism (CAI 1-1·5) suggesting a heating of less than 90 °C; near Fort Peña Colorada, 4·5 km east of the area just mentioned, the CAI is 1·5-2 indicating a heating up toward 140 °C; and in the Woods Hollow Mountains and Lightning Hills a further 10-17 km to the east, the CAI is 3-4 suggesting a heating of 200-300 °C. No conodonts are as yet available from the southeasternmost localities of Ordovician rocks in the region such as those near Old Jones (Slaughter) Ranch, but it is likely that the CAI there will prove to be 4-5, or even higher. A similar, gradually increasing conodont metamorphism, reflecting progressively higher heating of the host strata in a peripheral direction from the stable continental interior, was previously best known from the Southern and Central Appalachians (Epstein *et al.* 1977).

The Woods Hollow conodont succession

Apart from its calcareous basalmost portion, the Woods Hollow is very poorly exposed in the Marathon area and most exposures of the unit, except those of its top and bottom, consist of short sections of strongly folded and faulted beds with indeterminate precise stratigraphic position within the formation. The only relatively tectonically undisturbed section known is the type section in the Woods Hollow

Mountains (Berry's section XI). It provides good exposure of a major portion of the formation, but also in that section the upper 25–30 m are largely covered. Another factor that complicates conodont work is the fact that most of the Woods Hollow consists of hard shales and mudstones undigestible in weak acids and the few limestone beds that occur scattered through the formation may, at least in some cases, be turbidites with redeposited fossils. In view of this, it is probably more difficult to obtain good and representative collections covering the conodont faunal succession through the Woods Hollow than in the case of any other Ordovician formation in the Marathon region.

The Woods Hollow conodont collections at hand include 27 samples representing nine sections, which were collected by myself in 1974 and 1975. Thanks to the courtesy of Dr. Lael Bradshaw, I have also had access to four additional samples from a locality not visited by me. All these collections include a total of more than 10 200 conodont elements.

Most, but not all, of the samples from limestone ledges in the lower 25 m of the formation at the western localities (sections 4, 7, 8, 10) have proved to yield large numbers of excellently preserved specimens, among which forms of *Histiodella*, *Multioistodus*, and a characteristic undescribed platform species are particularly prominent (see Table 1, sample 75B20-2). Unfortunately, this *Histiodella–Multioistodus* species association, which evidently represents Fauna 3–4 of Sweet *et al.* (1971), is out of place stratigraphically here and it is interpreted as redeposited by turbidite flows (see below, p. 748). Other collections from the lower portion of the Woods Hollow at the localities mentioned are dominated by *Periodon* and several species of simple cones, representing types best known from the North Atlantic Province. No representatives of stratigraphically highly diagnostic species have as yet been found in the collections of this type, and their precise age in terms of conodont biostratigraphic units cannot be assessed. However, it seems reasonable to suggest that collections of this type may well be composed largely of the remains of conodonts that inhabited the environment in which the sampled limestone beds were formed.

In terms of conodont biostratigraphy, the currently best controlled section of the lower and middle part of the Woods Hollow is its type section (text-fig. 5) in the Woods Hollow Mountains (section 1). A set of samples from limestone beds in the lower 100 m of that section has yielded some 1900 conodont elements representing more than 20 multielement species, several of which are significant biostratigraphically (table 1, sample 75B26-10). Such species include *Pygodus anserinus* Lamont and Lindström (Pl. 79, figs. 1, 2) and a form of the *Polyplacognathus friendsvillensis–P. sweeti* lineage (Pl. 79, figs. 12, 13), both of which range through the entire sampled portion of the type Woods Hollow, and *Phragmodus flexuosus* Moskalenko (Pl. 79, fig. 16), which is present in most samples except the three topmost ones. The occurrence of the two first species mentioned is highly significant because it shows that, in terms of North Atlantic Province conodont units (Bergström 1973*b*; Bergström and Carnes 1976), the lower 100 m of the type Woods Hollow in its entirety belongs in the *Pygodus anserinus* Zone. Further, the type of *Polyplacognathus* present is the same as that referred to as *P. friendsvillensis–P. sweeti* transition by Bergström and Carnes (1976, fig. 2: 4), which is restricted to the lower subzone, and the lowermost part of the upper subzone, of the *Pygodus anserinus* Zone. The presence of *Phragmodus*

TABLE 1. Conodonts in three samples from the Woods Hollow Shale. For sample locations see Appendix I. Because of their very high abundance in sample 75B20-2, only a fraction of the total number of specimens of species marked with + were picked.

SPECIES	SAMPLES		
	75B23-2	75B26-10	75B20-2
'*Acontiodus*' *cooperi* Sweet and Bergström	4	6	0
Belodella sp. A	11	0	0
Belodella n. sp.	0	0	13
Belodina monitorensis Ethington and Schumacher	243	0	0
'*Cordylodus*' *horridus* Barnes and Poplawski	0	0	13
Cordylodus ramosus Hadding	0	9	0
Drepanoistodus sp. cf. *D. suberectus* (Branson and Mehl)	79	12	0
Eoneoprioniodus sp.	37	7	166+
'*Gothodus*' *marathonensis* Bradshaw	0	0	4
Histiodella sinuosa var. A McHargue	0	0	27+
Leptochirognathus sp.	0	37	0
Multioistodus sp.	0	0	35+
Oistodus multicorrugatus Harris	0	0	1
'*Oistodus*' sp.	0	0	5+
Panderodus sp. A	0	0	8
Panderodus sp. B	92	2	0
Periodon aculeatus Hadding	195	63	27
Phragmodus flexuosus Moskalenko	28	34	0
Plectodina sp.	48	44	0
Polyplacognathus friendsvillensis-sweeti transition	17	7	0
'*Protopanderodus*' *asymmetricus* Barnes and Poplawski	0	0	2
'*Protopanderodus*' *giganteus* (Sweet and Bergström)	0	28	0
'*Protopanderodus*' sp. cf. *P. strigatus* Barnes and Poplawski	0	0	14
Protopanderodus varicostatus Sweet and Bergström	28	19	0
Pygodus anserinus Lamont and Lindström	0	3	0
Staufferella sp. cf. *S. falcata* (Stauffer)	6	0	0
n. gen. n. sp. Raring	4	1	0
Platform conodont n. gen. n. sp.	0	0	18
Fibrous conodonts indet.	62	83	0
Indet. conodonts	27	4	20
Total	875	359	353+

flexuosus, as well as several species of unidentified fibrous forms, *Leptochirognathus* sp., and *Multioistodus* sp., suggests correlation also with Fauna 6 of Sweet *et al.* (1971; see also Bannigan Boger 1976). It should be noted that, by and large, the conodont fauna does not change appreciably through the sampled portion of the type Woods Hollow; this might be taken as further evidence that the formation has a relatively limited biostratigraphic range.

Due to the virtual absence of limestone beds in the few and poor outcrops of the topmost Woods Hollow, there seemed to be little hope of obtaining satisfactory conodont control of that interval. However, quite fortuitously, a thin and laterally impersistent bed of brownish, finely crystalline limestone was discovered in 1974

only about 8 m below the top of the Woods Hollow in the well-known section on the hillside 0·6 km north-east of the Picnic Grounds at Old Fort Peña Colorada (Berry's sect. XII). This section is particularly significant because it is the source of the youngest (in terms of stratigraphic distance beneath the local top of the formation) stratigraphically well-dated graptolite collections from the Woods Hollow in the Marathon area (collections 100 and 105 of Berry (1960); see text-fig. 3). These collections have been interpreted previously as representing the *C. bicornis* graptolite Zone (Berry 1960, p. 126).
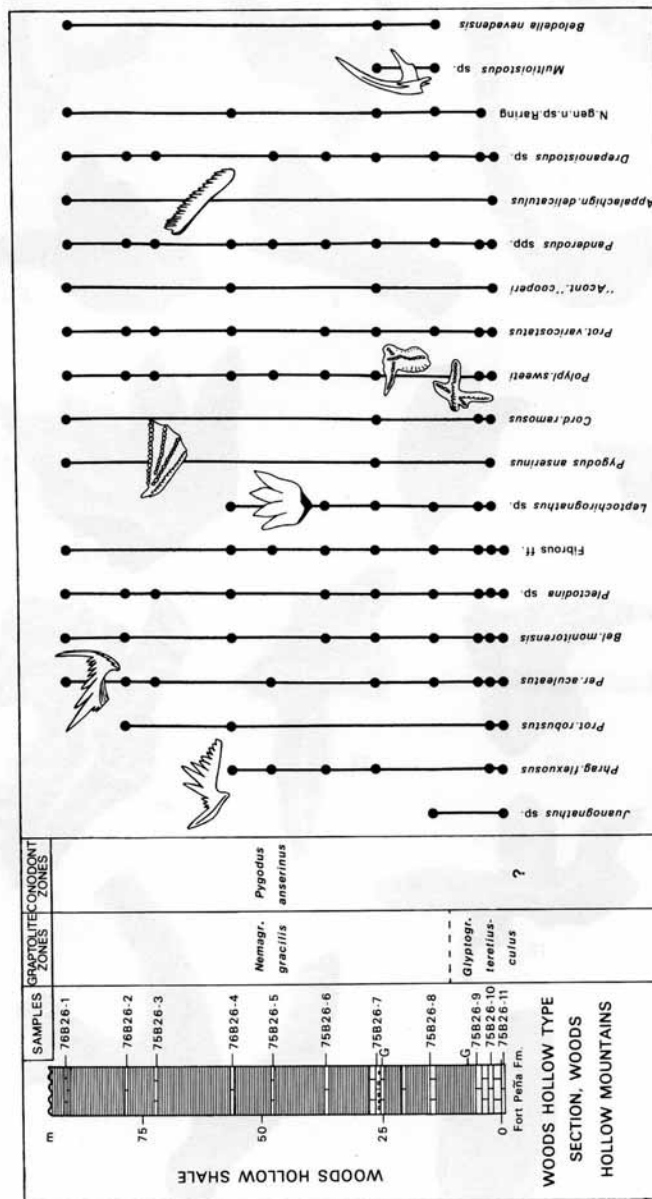
Samples of the Old Fort Peña Colorada limestone bed have produced some 875 conodont elements representing more than 20 multielement species (text-fig. 6; Table 1, sample 75B23-2). The conodont fauna of this bed is closely similar to that of the type Woods Hollow and includes representatives of *Phragmodus flexuosus* as well as the *Polyplacognathus friendsvillensis-P. sweeti* transition. The latter form suggests a biostratigraphic position no higher than the upper subzone of the *P. anserinus* Zone, which corresponds to a portion of the Baltoscandian *N. gracilis*

EXPLANATION OF PLATE 79

Figs. 1, 2. *Pygodus anserinus* Lamont and Lindström. 1, OSU 33401, lateral view of haddingodiform element, sample 75B26-10, ×95. 2, OSU 33402, upper view of pygodontiform element, sample 75B26-10, ×95.

Figs. 3-5. *Periodon aculeatus* Hadding. 3, OSU 33403, lateral view of periodontiform element, sample 74B32-2, ×95. 4, OSU 33404, lateral view of prioniodiniform element, sample 74B32-2, ×95. 5, OSU 33405, lateral view of falodontiform element, sample 74B32-2, ×95.

Figs. 6, 7. *Protoprioniodus varicostatus* (Sweet and Bergström). 6, OSU 33406, lateral view of acontiodontiform element, sample 74B32-2, ×95. 7, OSU 33407, lateral view of scandodiform element, sample 74B32-2, ×95.

Fig. 8. Gen. et sp. nov. Raring. OSU 33408, lateral view of almost complete element, sample 75B26-4, ×50.

Figs. 9, 10. *Belodella nevadensis* (Ethington and Schumacher). 9, OSU 33409, lateral view of belodelliform element, sample 74B32-2, ×150. 10, OSU 33410, lateral view of oistodontiform element, sample 74B32-2, ×130.

Fig. 11. *Leptochirognathus quadratus* Branson and Mehl. OSU 33411, posterior view, sample 75B26-7, ×95.

Figs. 12, 13. *Polyplacognathus friendsvillensis-sweeti* transition. 12, OSU 33412, bifid lateral process of polyplacognathiform element, sample 75B26-10, ×95. 13, OSU 33413, upper view of ambalodiform element, sample 75B26-10, ×95.

Figs. 14, 15. *Polyplacognathus sweeti* Bergström (typical form). 14, OSU 33414, upper view of fragmentary polyplacognathiform element (note simple antero-lateral process), sample LR-WH-11, ×95. 15, OSU 33415, upper view of mature ambalodiform element, sample LR-WH-11, ×95.

Fig. 16. *Phragmodus flexuosus* Moskalenko. OSU 33416, lateral view of phragmodontiform element, sample 75B26-4, ×95.

Fig. 17. Gen. et sp. nov. OSU 33417, upper view of dextral amorphognathiform element, sample 75B20-2, ×82.

Figs. 18, 19. *Belodina monitorensis* Ethington and Schumacher. 18, OSU 33418, lateral view of belodontiform element, sample 74B32-2, ×95. 19, OSU 33419, lateral view of eobelodontiform element, sample 74B32-2, ×95. Note 'wrinkle zone' on base of both elements.

Fig. 20. *Cordylodus ramosus* Hadding. OSU 33420, lateral view, sample 75B26-10, ×90.

All specimens figured in Pls. 79 and 80 are in the type collection of the Orton Geological Museum at the Ohio State University (OSU).

PLATE 79

TEXT-FIG. 5. Position of conodont samples, known ranges of conodont taxa, and graptolite and conodont zones in the lower 90 m of the type Woods Hollow Shale. Note that the *Pygodus anserinus* Zone extends through the entire sampled portion of the formation, also including the upper part of the *Glyptograptus teretiusculus* (Berry's *G.* cf. *G. teretiusculus*) Zone. Thickness measurements were made by steel tape and are adjusted for dip, strike, and slope of the hillside section. Lithological symbols as in text-fig. 7. G marks level of graptolite collections (Berry 1960), the upper one representing the *Nemagraptus gracilis* Zone, the lower one the *Glyptograptus teretiusculus* Zone. Diagrammatic figures of conodont elements show only one or two elements of the assemblage of each multielement species [for *Polypl. sweeti*; read *P. friendsvillensis-sweeti*; transition].

Zone (Bergström 1971, 1973a, 1973b). Although the conodont-producing bed is 2-3 m below the lowest graptolite sample (Berry's collection 100), its stratigraphic position is apparently high in the interval referred to as the *C. bicornis* Zone by Berry (1960), which was said to include as much as the top 50 m (150-160 ft.) of the Woods Hollow.

Additional, but less precise, conodont control of the upper Woods Hollow is provided by a few samples collected from a section at Lightning Ranch and very kindly made available by Dr. Lael Bradshaw. That section is not suitable for detailed measuring and the precise stratigraphic position of the samples within the Woods Hollow is unknown. Nevertheless, one of her samples (LR-WH-11), which was collected within the top 25-30 m of the formation, is significant biostratigraphically in that it contains, among others, elements of the typical form of *Polyplacognathus sweeti* (Pl. 79, figs. 14, 15). The latter form belongs to the rapidly evolving *P. friendsvillensis-P. sweeti* lineage (Bergström and Carnes 1976, text-fig. 2) and suggests the presence of strata of the *Pygodus anserinus* Zone younger than those at the Fort Peña Colorada section. Although this shows that the Woods Hollow is likely to extend higher stratigraphically at Lightning Ranch than at Old Fort Peña Colorada, there is no evidence in the collections at hand of conodonts characteristic of strata younger than the *P. anserinus* Zone; indeed, even the topmost part of that zone may be missing in the area in view of the fact that it is characterized by another form of the *Polyplacognathus friendsvillensis-P. sweeti* lineage (*P. sweeti* (late form) of Bergström and Carnes (1976, text-fig. 2: 6)) and that form has not been found in the Marathon area.

As indicated in text-fig. 6, the upper subzone of the *Pygodus anserinus* Zone corresponds to a portion of the *N. gracilis* Zone below its topmost part (see also Bergström 1971, 1973a), at least as that zone is defined in Europe. Accordingly, it can be concluded that the *P. anserinus* Zone conodonts from the upper part of the *C. bicornis* Zone in the Woods Hollow support the idea that this zone, in its type area, does not extend above strata elsewhere included in the *N. gracilis* Zone.

The lower Maravillas conodont biostratigraphy

Although the actual contact between the Woods Hollow and the overlying Maravillas is exposed only at a few localities in the Marathon area, there are relatively numerous outcrops of portions of the lower part of the latter formation. Because the present study is concerned primarily with the nature of the controversial Woods Hollow-Maravillas contact and the age of the Woods Hollow and lowermost Maravillas rather than with the conodont faunal succession through the Maravillas, which is now being described by Dr. Lael Bradshaw, no effort was made to sample from strata higher than Berry's (1960) *Orthograptus truncatus* var. *intermedius* Zone. Samples from that zone were collected from the lowermost 8 m of the Maravillas at five localities (sections 2, 3, 5, 9, 11). Nine of the samples proved productive and yielded a total of more than 2100 conodont elements. Many of these are excellently preserved and even nearly complete specimens of delicate and easily broken elements of species such as *Amorphognathus ordovicicus* Branson and Mehl are not uncommon.

The best conodont control of the lower Maravillas, which extends down to within the lower 0·5 m of the unit, has been obtained from samples collected in the well-known sections (2, 3) along the ridge north-east of the Picnic Grounds (Berry's
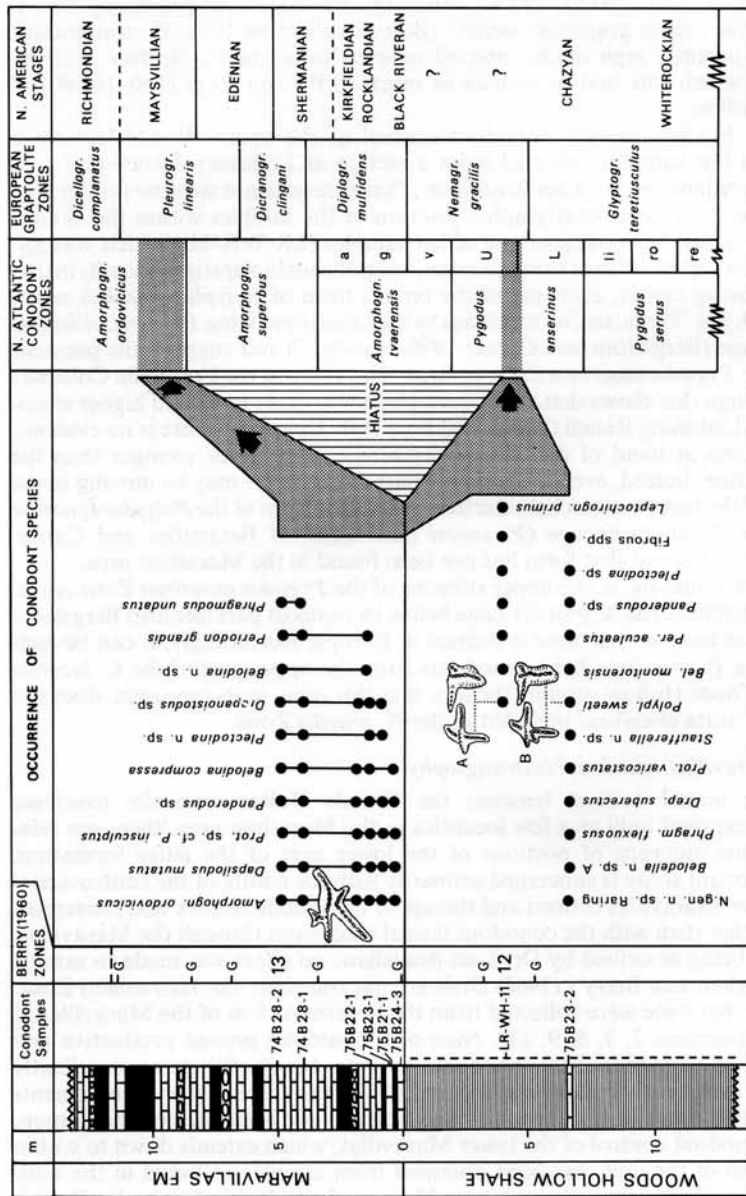
TEXT-FIG. 6. Known vertical ranges of conodonts in the Woods Hollow–Maravillas boundary interval near Old Fort Peña Colorada. The Maravillas lithic succession is a schematic composite based on sections on the ridge north-east of the Picnic Grounds. Woods Hollow column shows position of sample 75B23-2 in section 3, but also the interval (broken line) corresponding to that within which sample LR-WH-11 is likely to have been collected in the Lightning Hills. Right part of figure shows the extent of the Woods Hollow–Maravillas hiatus in terms of conodont and graptolite zones as well as North American stages. Lithological symbols as in text-fig. 7. Diagrammatic figures of conodont elements show only one or two elements of the assemblage of each multielement species. A, *Polyplacognathus sweeti* (typical form); B, *P. friendsvillensis*–*P. sweeti* transition.

sections XV and XII). A good exposure of the basal contact is on the hillside 3·5 km south of the Marathon railroad station (text-fig. 7), where the Maravillas overlies the Woods Hollow without a basal conglomerate. Productive samples from the lowermost Maravillas were also collected from sections north of Sunshine Springs (Berry's section XIII) and in the Payne Hills (section 11).

The composite section in text-fig. 6 is based on data from sections 2 and 3, and gives a somewhat schematic review of the lithological succession in the lowermost Maravillas at these localities. This figure also illustrates the stratigraphic position of conodont and graptolite (Berry 1960) samples as well as the vertical distribution of some of the multielement conodont species present in the samples; for additional data see Table 2. The conodont species associations in the samples from the lower Maravillas are all very similar and it is obvious that they all represent the same conodont zonal unit. Important species include *Amorphognathus ordovicicus* (Pl. 80, figs. 1–11), *Dapsilodus mutatus* (Branson and Mehl) (Pl. 80, figs. 21–23), a species of *Protopanderodus* close to, but not identical with, *P. insculptus* (Branson and Mehl), *Periodon grandis* (Ethington), *Phragmodus undatus* Branson and Mehl, some species of *Belodina* (Pl. 80, figs. 24–26) and *Plectodina* (Pl. 80, figs. 12–20), and several species of simple cones.

TABLE 2. Conodonts in three samples from the basal Maravillas Formation. For sample locations, see Appendix 1 and text-fig. 6.

SPECIES	SAMPLES		
	74B28-2	74B28-1	74B24-3
Amorphognathus ordovicicus Branson and Mehl	943	52	22
Belodina spp.	64	4	2
Dapsilodus mutatus (Branson and Mehl)	83	1	1
Drepanoistodus sp. cf. *D. suberectus* (Branson and Mehl)	86	3	1
Panderodus spp.	172	14	1
Peroidon grandis (Ethington)	21	1	0
Phragmodus undatus Branson and Mehl	40	2	0
Plectodina n. sp.	17	0	0
Plectodina sp.	20	42	1
Protopanderodus n. sp. cf. *P. insculptus* (Branson and Mehl)	12	3	1
Indet. conodonts	6	3	2
Total	1464	125	31

This conodont fauna is quite similar to that of 'the Maquoketa-Thebes' of Missouri (Branson and Mehl 1933) and it has much in common also with those of the Fremont of Colorado (Shatzer 1976), the Bighorn of the north-western Midcontinent, and the Montoya of western Texas and New Mexico (Sweet in preparation), as well as with those of the Allen Bay and Irene Bay in the Canadian Arctic (Weyant 1968; Barnes 1974). All these units contain conodonts indicative of Fauna 12 of Sweet *et al.* (1971; see also Sweet and Bergström 1976), which is characteristic of an interval from somewhere in the lower Maysvillian through the Richmondian. On the basis of conodonts, one can therefore conclude that the basalmost Maravillas is no older than Maysvillian in at least the sections studied, which in all likelihood are representative of the entire
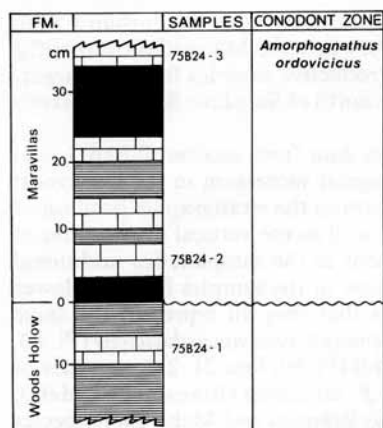
TEXT-FIG. 7. The Woods Hollow–Maravillas boundary interval at section 9, 3·5 km south of Marathon railroad station. Note absence of conglomerate in basalmost Maravillas at this locality. Samples 75B24-1 and 75B24-2 were barren but 75B24-3 yielded *Amorphognathus ordovicicus* and other conodonts of the *A. ordovicicus* Zone. Lithological symbols: black, chert; bricks, limestone; horizontal lines, mudstone and shale; ovals, conglomerate.

area. Particularly significant from the biostratigraphic point of view is the presence of abundant typical specimens of the zonal index *Amorphognathus ordovicicus*. This is the currently youngest known species in the *A. tvaerensis–A. ordovicicus* evolutionary lineage (Bergström 1971; Sweet and Bergström 1971, text-fig. 5) and its presence shows that the base of the Maravillas is no older than the *A. ordovicicus* Zone in terms of the North Atlantic conodont zone succession (text-fig. 6) and corresponds to

EXPLANATION OF PLATE 80

Figs. 1–11. *Amorphognathus ordovicicus* Branson and Mehl. 1, OSU 33421, upper view of asymmetrical dextral amorphognathiform element, ×70. 2, OSU 33422, lower view of same type of element, ×75. 3, OSU 33423, upper view of asymmetrical sinistral amorphognathiform element, ×75. 4, OSU 33424, antero-lower view of ambalodiform element, ×135. 5, OSU 33425, lower view of ambalodiform element, ×135. 6, OSU 33426, lateral view of dextral ambalodiform element, ×135. 7, OSU 33427, antero-lateral view of holodontiform element, ×130. 8, OSU 33428, lateral view of cordylodontiform (ligonodiniform) element, ×135. 9, OSU 33429, lateral view of hibbardelliform element, ×135. 10, OSU 33430, lateral view of keislognathiform element, ×135. 11, OSU 33431, lateral view of tetra-prioniodontiform element, ×135. All elements from sample 74B28-2.

Figs. 12–16. *Plectodina flexuosa* (Branson and Mehl). 12, OSU 33432, lateral view of ozarkodiniform element, ×105. 13, OSU 33433, lateral view of cyrtoniodontiform element, ×105. 14, OSU 33434, posterior view of zygognathiform element, ×140. 15, OSU 33435, lateral view of cordylodontiform element, ×140. 16, OSU 33436, posterior view of trichonodelliform element, ×140. All elements from sample 74B28-1.

Figs. 17–20. *Plectodina* sp. nov. 17, OSU 33437, lateral view of ozarkodiniform element, ×118. 18, OSU 33438, lateral view of cyrtoniodontiform element, ×111. 19, OSU 33439, lateral view of cordylodontiform element, ×110. 20, 33440, posterior view of zygognathiform element, ×107. All elements from sample 74B28-2.

Figs. 21–23. *Dapsilodus mutatus* (Branson and Mehl). 21, OSU 33441, lateral view of fragmentary element possibly belonging to this species, ×135. 22, OSU 33442, lateral view of fragmentary element, ×113. 23, OSU 33443, lateral view of more complete element, ×120. All elements from sample 74B28-2.

Fig. 24. *Belodina ornata* (Branson and Mehl). OSU 33444, lateral view, ×117. Sample 74B28-2.

Fig. 25. *Belodina inclinata* (Branson and Mehl). OSU 33445, lateral view, sample 74B28-2, ×241.

Fig. 26. *Belodina* sp. OSU 33446, lateral view, sample 74B23-1, ×136.

PLATE 80

BERGSTRÓM, Ordovician conodonts

a level in the European *Pleurograptus linearis* Zone. In the Marathon area, I have found no evidence at all of the presence of the *A. tvaerensis* and the *A. superbus* zones, which normally occupy the interval between the *Pygodus anserinus* and the *A. ordovicicus* zones (text-fig. 6) and which corresponds to a large portion of the upper Middle, as well as the lower Upper, Ordovician. Accordingly, it is reasonable to conclude that there is a considerable gap in this part of the Marathon succession, and interestingly, the conodont evidence is in this respect in close agreement with that of the graptolites as interpreted by Riva (1972, 1974). Obviously, it is quite conceivable that a portion of this hiatus is not due to non-deposition but to pre-Maravillas erosion of Middle and early Upper Ordovician strata. To test this possibility, a number of clasts from the basal Maravillas conglomerates were examined for possible presence of re-deposited post-*P. anserinus*, pre-*A. ordovicicus* Zone conodonts but no such forms were found. Thus, at present we have no faunal evidence of the former existence in the Marathon area of pre-Maravillas strata younger than the present top of the Woods Hollow.

As will be discussed below, the presence of this major unconformity clearly has an important bearing on the status of the Marathon succession as a suitable standard for the Middle and Upper Ordovician graptolite zone sequence in North America.

RELATIONS BETWEEN GRAPTOLITE AND CONODONT ZONAL UNITS
AND THEIR IMPLICATIONS

Although the graptolite faunal provinciality is not as marked during the time interval dealt with in the present study as during earlier parts of the Ordovician, it is, nevertheless, recognizable, especially at the sub-generic level. Such regional differences in the composition of the graptolite faunas have caused problems and controversy in the inter-provincial correlations of graptolite zonal units. The Marathon succession represents the Pacific Province and some of its graptolite assemblages differ substantially from those of the European Province. The conodont data assembled for this study add useful information to our previously poor knowledge of the relations between Pacific Province graptolite zones and North Atlantic Province conodont zones. Further, because the relations between these conodont zones and European Province graptolite zones are now relatively well known (Bergström 1971, 1973*a*, 1977*b*), the conodont data from the Marathon succession can be used also for interpretation of the mutual relations between some graptolite zones of the Pacific and European Province successions, respectively. These matters are discussed briefly below and the results are summarized schematically in text-fig. 8.

The Glyptograptus teretiusculus *Zone*

The new conodont data from the portion of the type Woods Hollow referred to the *Glyptograptus* cf. *G. teretiusculus* Zone by Berry (1960) show that at least the upper two-thirds of this zone is coeval with the upper portion of the *G. teretiusculus* Zone of Baltoscandia, both units having conodont faunas of the lower subzone of the *P. anserinus* Zone. The precise age of the uppermost Fort Peña, which Berry (1960) also referred to his *G.* cf. *G. teretiusculus* Zone, is still uncertain although the fact that the Fort Peña–Woods Hollow contact appears transitional (King 1938; Berry 1960)

may be taken as a suggestion that the uppermost Fort Peña does not differ greatly in age from the lowermost Woods Hollow. The suggestion (e.g. see Skevington 1963, 1971, 1973, 1976) that the *G.* cf. *G. teretiusculus* Zone of Texas is coeval with the *D. murchisoni* Zone of the European Province is not in agreement with the Marathon conodont data, at least with respect to the upper two-thirds of Berry's zone in its type area. It is also of interest to note that the same relations between conodont and graptolite zones as in the Marathon area prevail in the Athens Shale of Alabama; as shown by recent detailed studies (Finney 1977), the *N. gracilis* Zone there is underlain by graptolitic strata referable to the *G. teretiusculus* Zone. The *P. serrus–P. anserinus* zonal boundary is in the latter zone where it occupies such a stratigraphic position

N. Am. Series	MARATON FORMATIONS	GRAPTOLITE ZONES			CONODONT ZONES & SUBZONES	British Series
		Berry (1960)	Riva (1974)	Baltoscandia		
CINCINNATIAN	Maravillas	*O. truncatus v. intermedius*	*Climacograptus spiniferus*	*Pleurograptus linearis*	*Amorphognathus ordovicicus*	ASH-GILL
CHAMPLAINIAN			*Orthograptus ruedemanni*	*Dicranograptus clingani*	*Amorphognathus superbus*	CARADOC
			Corynoides americanus			
			Diplograptus multidens	*Diplograptus multidens*	*Amorphognathus tvaerensis*	
	Woods Hollow	*C. bicornis*	*Nemagraptus gracilis*	*Nemagraptus gracilis*	Upper	LLANDEILO
		Nemagraptus gracilis			*Pygodus anserinus*	
	Fort Peña	*Glyptogr.* cf. *G. teretiusculus*	Not dealt with	*Glyptograptus teretiusculus*	Lower	

TEXT-FIG. 8. Relations between Woods Hollow Shale and Maravillas Formation, graptolite and conodont zones, and North American and British series as suggested by the present study. Note the considerable vertical extent of the late Champlainian–early Cincinnatian unconformity in the Marathon area.

in relation to the top of the *G. teretiusculus* Zone that it is quite reasonable to suggest that in the Marathon area, this zonal boundary is likely to be in the uppermost Fort Peña. Unfortunately, only a single, specifically undeterminable *Pygodus* element is as yet known from that formation (Bergström and Cooper 1974), and further studies are needed to establish the precise position of this critical zonal boundary in the Marathon succession.

The conodont data now available support the conclusion that the base of the *N. gracilis* Zone, as currently defined in Baltoscandia (Hede 1951; Bergström and Nilsson 1974; Nilsson 1977), the Southern Appalachians (Finney 1977), and the Marathon area (Berry 1960) is at the same stratigraphical level, at least within the

resolution of the current conodont biostratigraphy which, in this particular interval, is more refined than that provided by the graptolites. Because the base of the *N. gracilis* Zone in the areas just mentioned has been placed at the level of the first appearance of *N. gracilis* itself, it seems that the appearance of this species was contemporaneous over a very large area and, indeed, represents a reference level of major biostratigraphic importance. This is contrary to the opinion expressed by Skevington (1971, p. 200) in a useful review paper on the *G. teretiusculus* Zone, who advocated that the base of the *N. gracilis* Zone be defined as the level of '. . . the entrance of *Dicellograptus* and *Nemagraptus*, and particularly the former, *irrespective of the (present known) species concerned*'. The fact that representatives of both these genera are known from well down in the *P. serrus* Zone in Baltoscandia, but are unknown below the *P. anserinus* Zone in North America, suggests that in order to avoid miscorrelations, the practice should be retained to define the base of the *N. gracilis* Zone at the first appearance of its zonal index.

The Nemagraptus gracilis *Zone*

Nemagraptus gracilis and several of its zonal associates are known from many localities in both the Pacific and European Provinces and the *N. gracilis* Zone is one of the most widely recognized Ordovician graptolite zones, traditionally providing one of the key reference levels for intercontinental correlations within the system. Conodonts are previously known from graptolitic strata of this zone in north-western Europe as well as the Southern Appalachians (Bergström 1971, 1973*b*; Bergström and Nilsson 1974), and the relations between North Atlantic conodont zones and the European *N. gracilis* Zone are now relatively well understood (text-fig. 6). Although many, if not most, of its conodont species are different from those of the corresponding strata in Baltoscandia, enough key conodonts are present in the Marathon *N. gracilis* Zone to show that the conodont-graptolite zone relations there are substantially the same as in Baltoscandia and the Appalachians. As noted above, the absence of the diagnostic forms of the *Amorphognathus tvaerensis* Zone, the lower part of which is coeval with the uppermost part of the *N. gracilis* Zone (text-fig. 6), may be taken as an indication that the uppermost part of the latter zone, as defined in Baltoscandia and the Appalachians, may not be present in the Marathon area. The suggestion by Erdtmann (1976, table 7) that the Woods Hollow includes equivalents to strata as young as the Baltoscandic Idavere lacks support in the conodont faunas.

The range of *Phragmodus flexuosus* through virtually the entire Marathon *N. gracilis* Zone is pertinent to the correlation between graptolite zones and the Midcontinent Faunas recognized by Sweet *et al.* (1971; see also Sweet and Bergström 1976); it shows that the upper portion of the interval of Fauna 6 of Sweet *et al.* (1971), which coincides with the upper part of the range of *P. flexuosus*, corresponds at least broadly to the *N. gracilis* Zone, which is in agreement with the conditions in the Southern Appalachians (Sweet and Bergström 1973). Unfortunately, the conodonts of the *N. gracilis* Zone in New York-Quebec remain unknown and no comparison can be made with that area at present.

The Orthograptus 'intermedius' (O. truncatus *var*. intermedius) *Zone*

This unit was first defined in the Marathon area and its original stratigraphic range is accordingly the interval in the lower part of the Maravillas that contains its typical graptolite assemblage. As noted above, this graptolite zone falls entirely within the *Amorphognathus ordovicicus* Zone in the North Atlantic Province conodont zone succession. The lower part of this zone apparently corresponds to the *Pleurograptus linearis* Zone in Baltoscandia. In New York State, the lower boundary of the *A. ordovicicus* Zone is in the Hillier Limestone (Bergström 1971), which according to Riva (1969) and Rickard (1973) corresponds to a portion of the *Climacograptus spiniferus* Zone. Riva (1969, 1972, 1974) interpreted the Marathon *Orthograptus 'intermedius'* Zone as corresponding to the upper two-thirds of the *C. spiniferus* Zone and the lowermost part of the overlying *C. pygmaeus* Zone (text-fig. 1), which is in close agreement with the new conodont data from the Marathon area. In this interpretation, the relations between conodont and graptolite zones are the same in the Marathon area and New York.

The fact that the base of the *A. ordovicicus* Zone is no older than Maysvillian in the North American Upper Ordovician standard sequence in the Cincinnati area (Sweet and Bergström 1971, p. 622) makes it plain that the base of the Marathon *O. 'intermedius'* Zone is also Maysvillian in age and not much older as suggested in several papers. However, it is important to note that the pre-Maysvillian age assigned to strata included in the *O. 'intermedius'* Zone at many localities especially in the Northern Appalachians is no doubt correct because of the frequent use of the zonal designation also for rocks lacking correlatives in the Marathon area. Berry (1970) discussed the status of his zone and emended it by subdividing it into two subzones, the lower one essentially corresponding to Riva's (1970, 1972) *Corynoides americanus* and *Orthograptus ruedemanni* zones, the upper one to Riva's *Climacograptus spiniferus* Zone. As shown above, both graptolite and conodont data indicate that equivalents to Riva's *Corynoides americanus* and *Orthograptus ruedemanni* Zones are lacking in the Marathon area and that the base of the *O. 'intermedius'* Zone there corresponds to a level well up in the *Climacograptus spiniferus* Zone of New York, that is, the upper subzone of the *O. 'intermedius'* Zone as defined by Berry (1970). Accordingly, it can be concluded that the re-definition of the latter zone has formally extended its stratigraphic range substantially downward to include a large portion of the upper Middle Ordovician not represented in the Marathon sections where the zone was originally recognized. Obviously, it is important to keep this revision of the stratigraphic scope of the zone in mind when its use in local and regional correlations is being evaluated.

REDEPOSITION OF FOSSILS

It has long been known that certain intervals in the Marathon succession contain 'exotic' boulders, which on fossil evidence can be shown to be out of place stratigraphically. Such boulder occurrences are reported from most, if not all, of the Marathon Ordovician formations. The best documented ones are probably those in the upper Woods Hollow (King 1938; Wilson 1954*a*; Berry 1960) and the Marathon Limestone (Young 1969). Many of these boulders represent rock types not known

otherwise in the Marathon area while others are not greatly different lithologically from the *in situ* rocks. The fact that most boulder bed occurrences are in the western portion of the area, along with the observation that many boulders represent shallow-water carbonates of shelf-type, suggest a shelf margin to the west or north-west as a probable source area. From this, detached boulders were transported oceanward as gravity flows down the upper slope into the somewhat deeper-water slope environment in which the *in situ* Marathon rocks were deposited. That this transport was not restricted to boulder-sized material is shown by the fact that many beds in the Ordovician succession exhibit graded bedding, sole marks, and other features suggesting that they are turbidites (Young 1969; McBride 1969*a*, 1969*b*). Interestingly, the source of the transported material might, at least in part, have been within the present Marathon area itself, namely the unexposed, presumably autochthonous, shelf deposits that from deep drillings (Flawn 1961, pp. 56, 57) are known to underlie the allochthonous slope rocks now exposed in the area. In a recent stimulating paper, Taylor and Cook (1976) developed a model of shelf-slope transition environment with debris-flows, which was based on studies of late Cambrian–early Ordovician strata in eastern Nevada. This model provides a meaningful explanation to many of the features observed in the Marathon Ordovician succession.

Clearly, the apparent common presence of redeposited material in the Marathon succession has an important bearing on its biostratigraphic interpretation because the age shown by redeposited fossils will be only the maximum, and not necessarily the true age of a particular bed. Although this was kept in mind during the field work and collecting was concentrated, as much as feasible, on beds showing no obvious evidence of containing redeposited material, subsequent analysis of the samples in the laboratory has revealed at least two instances of redeposited fossils.

The most striking of these is the collection of conodonts obtained from what looked like a 'normal' limestone bed in the upper portion of the Woods Hollow on the north-west slope of Three-Mile Hill (section 6). The conodont elements are well preserved but are of Lower, rather than Middle, Ordovician age, being representatives of Fauna C of Ethington and Clark (1971). Another instance of apparently redeposited conodonts is the presence, in the uppermost Fort Peña and lower Woods Hollow at some western sections, of very abundant and excellently preserved specimens of *Histiodella*, *Multioistodus* and several other Midcontinent province genera (Table 1, sample 75B20-2), evidently representing Faunas 3–4 of Sweet *et al.* (1971). Such faunas are well known from the Joins-Oil Creek formations in Oklahoma and equivalent Whiterockian strata in the Great Basin. Because faunas of this type are present in beds as old as the *Eoplacognathus suecicus* Subzone in the latter area, and the basalmost part of the type Woods Hollow represents the much younger *P. anserinus* Zone, it seems highly unlikely that they would range through this long stratigraphic interval without notable change, especially as they contain platform conodonts of complex types that otherwise exhibit very rapid evolution. Further, at some localities the basalmost Woods Hollow has yielded a different Midcontinent Province conodont association, which represents Fauna 6 of Sweet *et al.* (1971). Unless the basalmost portion of the Woods Hollow is of very different age in different sections, which seems unlikely, one is forced to conclude that the conodont elements of Fauna 3–4 are redeposited in this particular interval. This conclusion is supported by the fact that

at least some of the beds containing these conodont elements are conglomeratic with abundant clasts of a size down to a fraction of a centimetre.

The possible presence of reworked conodont elements does not greatly affect the dating of the basal Maravillas as Maysvillian because this is a maximum age based on the presence of abundant elements of the *A. ordovicicus* Zone. It is of interest to note that one sample (74B28-2) from a conglomeratic bed at section 2 has yielded a few fragmentary specimens of *Pygodus* sp. and some simple cones together with an excellent representation of species of the *A. ordovicicus* Zone. I think there is little doubt that the former elements are reworked and originate from the Woods Hollow.

The significance of debris-flow redeposition of conodont elements in the middle and upper parts of the Woods Hollow is somewhat more uncertain. Several of the thin limestone beds in the Woods Hollow type section are conglomeratic and/or contain worn megafossil debris. Such beds can be suspected to represent debris-flow deposits. Other beds in this particular interval lack evidence of this type, may contain graptolites oriented along bedding planes, and appear to be 'normal' *in situ* slope deposits. Samples from such beds form the bulk of my Woods Hollow conodont collection. The fact that the mutual relations between conodont and graptolite faunal successions in the Woods Hollow are in excellent agreement with those at localities elsewhere, which show no evidence of debris-flow deposits, suggests that even if redeposited specimens are present in some samples, it is unlikely that in this case they affect notably the establishment of the true age of the *in situ* deposits. Therefore, I find it justified to conclude that the stratigraphic range of the Woods Hollow shown by the new conodont data is likely to be reliable. Obviously, this conclusion could be confirmed if it were possible to separate the *in situ* specimens from the transported ones by, for instance, differences in mode of preservation, specific ecological requirements, etc. As far as mode of preservation is concerned, there seems to be no notable difference. This may be explained by the fact that the majority of the redeposited specimens were probably transported enclosed in limestone clasts. Specific environmental requirements or preferences of individual conodont taxa are still poorly known although considerable advances in this field of study have been made in the last few years (Barnes 1976). The data on individual conodont taxa represented in the Marathon succession, in the cases where they are available at all, are still both controversial and uncertain (e.g. see Bergström and Carnes 1976) and, therefore, currently of little use for safe separation of taxa in terms of their preferred living environment. Accordingly, neither of these methods provides critical assistance in solving the problem of elucidating the original living environment of individual Marathon conodont taxa.

SIGNIFICANCE OF THE WOODS HOLLOW-MARAVILLAS UNCONFORMITY

The presence of a considerable stratigraphic gap between the Woods Hollow and the Maravillas has obviously a bearing also on the interpretation of the environment of deposition of this part of the Marathon succession. King (1938) proposed that the prominent conglomerates present locally in the basal portion of the Maravillas were laid down in shallow water and provide evidence of an uplift associated with an

orogenic event of Taconic age. In a more recent study, Thompson and McBride (1964; see also McBride 1970) advocated a rather different view, namely that the conglomerates and associated graded calcarenites represent deep-water slide deposits. Interestingly, these ideas may not be in such an unresolvable conflict as they might appear at first sight.

First, it should be noted that a late Middle and early Upper Ordovician stratigraphic gap is by no means unique for the Marathon area but rather is a regional feature traceable over very large areas in the western and south-western United States, although the magnitude of this gap varies from area to area (Sweet and Bergström 1976, text-fig. 3). For instance, in the Middle–Upper Ordovician exposures closest geographically to Marathon, which are in the Franklin, Beach, and Baylor Mountains in westernmost Texas about 300 km to the north-west (text-fig. 2), the late Ordovician Montoya Group, a likely equivalent to the Maravillas, rests with a prominent unconformity on rocks of Lower to Middle Ordovician age (Suhm and Ethington 1975). In the Llano Uplift about 500 km east of Marathon, the late Ordovician Burnam Limestone directly overlies strata of the early Ordovician Ellenburger Group (Merrill 1965). Further, in the important Arbuckle Mountains succession in southern Oklahoma, about 750 km north-east of Marathon, conodonts and other fossils indicate that the upper Tulip Creek and lowermost Bromide (lower Mountain Lake Member) formations are the local equivalents of the Woods Hollow. Higher Bromide strata (upper Mountain Lake and Poolville Members) contain *A. tvaerensis* Zone conodonts (Sweet and Bergström 1973) and are clearly younger than the Woods Hollow. Yet, the Bromide is separated from the overlying Viola Limestone by what is generally interpreted as a prominent unconformity (e.g. see Ham 1961, p. 212); although the magnitude of this unconformity is controversial, it clearly falls within the time span represented by the Woods Hollow–Maravillas hiatus.

Although it can be argued that these sequences, as well as many others in the Southwest and West with similar unconformities, differ from the succession in the Marathon area by representing a shelf rather than continental slope environment of deposition, they nevertheless all preserve a record of a widespread regression during parts of middle and late Ordovician time. Accordingly, it is not unreasonable to suggest that, provided the Marathon slope environment of deposition was not in *very* deep water, it could well have been affected by the same regional regression. This idea is supported by some evidence from the Ouachita Mountains in Oklahoma–Arkansas (text-fig. 2), the easternmost outcrop area of the Ouachita system, where the Middle and Upper Ordovician are represented by a dark shale and chert succession that is likely to have been deposited at considerably greater water depth than the equivalent strata in the Arbuckle Mountains. In the Ouachita Mountains, the Middle Ordovician Womble Shale with *N. gracilis* Zone (and possibly slightly younger) graptolites (Decker 1952), as well as *P. anserinus* and *A. tvaerensis* Zones conodonts (Repetski and Ethington 1977) is overlain by the Bigfork Chert that has yielded fossils interpreted to be of late Ordovician age (Bradshaw 1974). The biostratigraphic control is as yet not sufficiently detailed to permit an estimate of the precise magnitude of the hiatus that apparently seperates the Womble and the Bigfork, but it is clearly smaller than that between the Woods Hollow and the
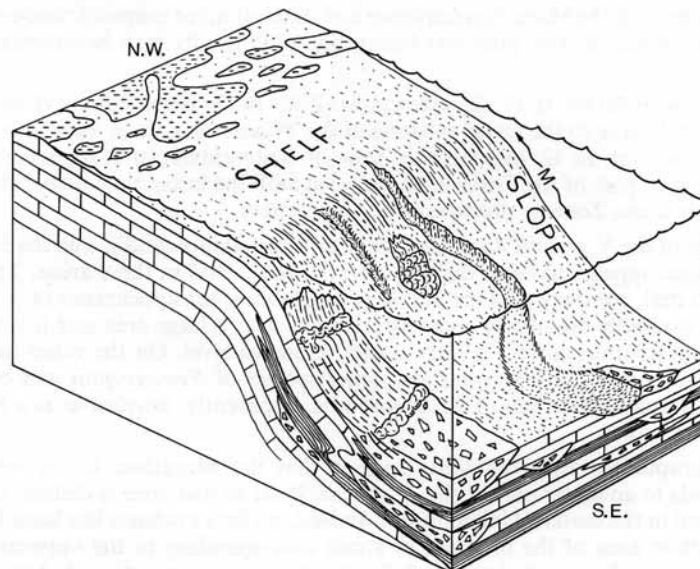
TEXT-FIG. 9. Diagrammatic interpretation of the depositional regime of the lower portion of the Maravillas Formation. The model is a modification of that of Taylor and Cook (1976). The Maravillas is considered to have been laid down on the upper portion of a south-east-facing continental slope (in area marked by arrows and the letter 'M') to which turbidity-flows brought shelf and shelf-slope material from the north-west. Inclination of continental slope is possibly much exaggerated.

Maravillas. This regressional phase might conceivably have been followed by a relatively rapid transgression, which in the Marathon area was initially associated during Maysvillian time with the deposition of coarse conglomerates locally and limestone beds with much redeposited material over larger areas. Even if this deposition was largely, if not entirely, below wave base, the water depth was not necessarily very great during early Maravillas time. Transport of boulders and carbonate debris by slumping can apparently take place down a continental slope with an inclination of no more than a few degrees (Taylor and Cook 1976). Particularly if the environment of deposition of the lower Maravillas was not far from the continental shelf-slope break, it is, therefore, not too difficult to visualize how relatively abundant allochthonous material could have been transported into this environment from the adjacent shelf even in relatively shallow water (text-fig. 9).

SUMMARY AND CONCLUSIONS

The present investigation of conodonts from the same localities, and in many cases the same narrow stratigraphic intervals, as those that yielded the graptolites that form the basis of the Middle–Upper Ordovician North American graptolite zone succession introduced by Berry (1960) have yielded important new data on the

biostratigraphy of the Marathon sequence and its relations to graptolite and conodont sequences elsewhere. The principal biostratigraphic results may be summarized as follows:

1. Conodonts from the *G*. cf. *G. teretiusculus* Zone in the basal Woods Hollow at its type section belong to the lower subzone of the *P. anserinus* Zone. Because this sub-zone is present in the *G. teretiusculus* Zone of Baltoscandia, it is suggested that at least the major part of the Texas zone is coeval with the latter zone rather than with the *D. murchisoni* Zone as proposed by some writers.

2. The base of the *N. gracilis* Zone, as defined in Texas, Baltoscandia, and the Southern Appalacians, appears to be at the same stratigraphic level in these areas. Thus, it is concluded that, contrary to some previous suggestions, the appearance of *N. gracilis* itself was evidently essentially contemporaneous over a large area and it is believed to represent a stratigraphically very useful reference level. On the other hand, the first appearance of *Dicellograptus* and other species of *Nemagraptus* was evidently earlier in Baltoscandia than in Texas and it is, apparently, unreliable as a basis for precise correlation.

3. Both graptolites and conodonts suggest that the Marathon *C. bicornis* Zone corresponds to an upper part of the *N. gracilis* Zone as that zone is defined in Balto-scandia and in the eastern United States. Indeed, no firm evidence has been found in the Marathon area of the presence of strata corresponding to the uppermost part of the *N. gracilis* Zone as that zone is defined in the areas just mentioned. Accordingly, there seems to be no particular reason to recognize a *C. bicornis* Zone, or even a *D. multidens* Zone, in the Marathon succession.

4. The Woods Hollow and Maravillas formations are shown to be separated by a hiatus corresponding to the late Middle and early Upper Ordovician. In terms of Baltoscandian graptolite zones, this gap includes the *D. multidens* and the *D. clingani* zones along with at least part of the *N. gracilis* Zone and possibly also a part of the *P. linearis* Zone. This stratigraphic gap occupies the same position as a prominent regional unconformity that can be traced over a very large area in the south-western and western part of the North American craton.

5. In the Marathon area, where it was first recognized, the *O. 'intermedius'* Zone (the *O. truncatus* var. *intermedius* Zone of Berry (1960)) is shown to correspond to strata no older than the *A. ordovicicus* conodont Zone, which is in agreement with Riva's (1972, 1974) suggestion that it is coeval with part of the New York–Quebec *C. spini-ferus* Zone. It is also noted that in the latter area, the original scope of the *O. 'intermedius'* Zone has been extended considerably downward to include a sizeable portion of the late Middle and early Upper Ordovician which is not known to be represented in the Marathon succession.

6. The existence of a prominent unconformity in the Marathon Middle–Upper Ordovician succession clearly has implications for the use of this succession as a graptolite zone standard. It is suggested that its stratigraphic incompleteness, along with the lack of graptolites at some significant intervals and its relative inaccessi-bility, make the Marathon succession less than ideal as a standard for the Pacific Province zonal succession in North America. It appears that in the case of this

particular stratigraphic interval, the New York–Quebec zone succession, regardless of how it is defined in terms of graptolite zones, is superior in most respects to those successions currently known from other areas in North America.

7. The environment of deposition of the Marathon Fort Peña–Maravillas succession is interpreted to have been on the upper continental slope and at least partly near the shelf-slope break. Although lithological evidence for this is unclear and somewhat controversial, the area might well have been emergent during late Middle and early Upper Ordovician time. There seems to be good reason to accept the idea that many of the coarse-grained limestone beds are turbidites. Although some of these beds yield abundant conodonts which are out of place stratigraphically and hence interpreted as redeposited, it is concluded that conodont collections from other beds are likely to provide a reliable age for their host strata. It is also concluded that the existence of redeposited fossils in some intervals at some localities in all probability has little bearing on the interpretation of the existence and stratigraphic scope of the Middle–Upper Ordovician unconformity in the area.

The Ordovician succession in the Marathon area is unique not only in North America but probably in the entire world in that it provides an unparalleled opportunity to tie together directly graptolite and conodont zones through virtually the entire system. Preliminary studies show that it also offers great promise of yielding significant representations of acritarch and chitinozoan faunal successions. Clearly, in order to make it possible to extract the maximum amount of useful biostratigraphic information from the fossil faunas, it is necessary to intergrate, as much as possible, detailed data from *all* fossil groups, including the microfossils, and relate these data to appropriate models of depositional environments as reconstructed on lithological and other types of evidence. Such integrated studies have been carried out in the Ordovician of Baltoscandia (e.g. Jaanusson 1976) but are just beginning to be attempted in North America. The present project may be viewed as a modest beginning of such a study in the Marathon Ordovician rocks, but clearly much more data are needed before the faunal dynamics (Jaanusson 1976) of this succession can be properly evaluated and understood.

APPENDIX 1

Collecting localities

Section 1. Type section of Woods Hollow Shale 9 km south-east of Marathon on south-eastern slope of anticlinal valley in which Old Louis Granger Place is located. Measured section is the same as section XI of Berry (1960. pp. 112, 113) and the Granger Place section of King (1938, pl. 2). For sample levels see text-fig. 5.

Section 2. Maravillas Formation in section on cliff along creek just north-east of Picnic Grounds about 1·2 km south of Old Fort Peña Colorada. This is section XV of Berry (1960, p. 113). For sample levels see text-fig. 6.

Section 3. Woods Hollow Shale and Maravillas Formation in exposure on hillside about 0·4 km north-east of section 2. Section XII of Berry (1960, p. 113). For sample levels see text-fig. 6. Two additional samples (77B2-1 and 77B2-2) were collected 15 and 30 m respectively below top of the Woods Hollow Shale. The level of 74B32-2 is the same as that of 75B23-2.

Section 4. Woods Hollow Shale as exposed in the bed of Alsate Creek (4a) and on nearby field (4b) 3·5 km west-south-west of Old Fort Peña Colorada. These outcrops are about 0·3 km north-east of section XVIII of Berry (1960, pp. 116, 117). Sample 75B18-1 was collected at section 4b from a limestone ledge about 25 m above base of Woods Hollow Shale at a spot half-way between Alsate Creek and the Fort Peña ridge to the north. Samples 75B19-1, 75B19-2, and 75B19-3 were collected 0·5, 3, and 8 m, respectively above base of about 10 m thick continuous section of the Woods Hollow. Provided there are no undetected structural complications, this exposure is estimated to represent an interval about 50 m above the base of the formation. This is section 4a.

Section 5. Basal Maravillas Formation and upper Woods Hollow Shale in hillside exposures on ridge north of Sunshine Springs, 10·6 km south-west of Marathon. Section XIII of Berry (1960, pp. 113, 114). Sample 75B21-1 was collected 0·5 m above base of Maravillas Formation; 75B21-2 was taken from a limestone bed at an undeterminable level in the upper third of Woods Hollow Formation.

Section 6. Woods Hollow Shale in section on north side of Three-Mile Hill about 25 km south of Marathon. Section XVII of Berry (1960, p. 116). Samples 75B25-1 and 75B25-2 were collected from the top 25 m of the Woods Hollow Shale but structural complications make the section unsuitable for detailed measuring.

Section 7. Basalmost Woods Hollow Shale in section near Roberts Ranch Road at loc. 81 of Berry (1960, p. 124), which is 12·8 km S 55° W of Marathon. Sample 75B16-1 was collected from within 1 m of the gradational basal contact of the Woods Hollow Shale.

Section 8. Basal Woods Hollow Shale in hillside exposure on south-east side of ridge east of Roberts Ranch road 10·4 km S 51° W of Marathon. Section X of Berry (1960, p. 112). Sample 75B20-2 was collected 3 m above base of formation.

Section 9. Basal Maravillas Formation and uppermost Woods Hollow Shale on hillside at north end of ridge 3·5 km south of Marathon station. For sample levels, see text-fig. 7.

Section 10. Lowermost Woods Hollow Shale in outcrops on south-east side of ridge 0·6 km south-east of Roberts Ranch road 11·5 km S 55° W of Marathon. Near section IX of Berry (1960, p. 111) and about 0·25 km south-east of end of southern portion of section 4 of King (1938, pl. 16). Sample 74B20-1 was collected about 10 m above base of the Woods Hollow Shale; sample 74B20-2 about 3 m lower stratigraphically.

Section 11. Maravillas Formation in hillside exposure on ridge in western part of Payne Hills south-east of Dugout Creek road, 15 km west-south-west of Marathon. Sample 75B27-3 was collected from topmost part of the Maravillas Formation.

Section 12. Woods Hollow Shale in field exposure in Lightning Hills. For details of this section see Bradshaw (1969, p. 1138), who collected sample LR-WH-11 and several other samples from the upper half of the formation at this locality.

APPENDIX 2

Notes from re-study of some Marathon graptolites

According to Riva (pers. comm. 1977), a re-study of Berry's type specimens of Marathon graptolites kept at Yale University suggests the following up-dated taxonomic designations. It should be stressed that because only the types have been examined, it is not now appropriate to use these designations in text-fig. 3 and 4 where the ranges are based on *all* stratigraphically well-located collections in Berry (1960). Berry's designations are mentioned first below.

Species listed in text-fig. 3: *Glyptograptus teretiusculus siccatus = Climacograptus brevis; Climacograptus eximius = Pseudoclimacograptus modestus; Glyptograptus teretiusculus euglyphus = G. euglyphus; Climacograptus scharenbergi* cf. *stenostoma = Pseudoclimacograptus stenostoma; Dicranograptus brevicaulis = D. parvangulus; Climacograptus parvus = Pseudoclimacograptus scharenbergi; Orthograptus whitfieldi = Hallograptus mucronatus.*

Species listed in text-fig. 4: *Climacograptus mississippiensis = C. tubuliferus; Climacograptus* cf. *C. ulrichi = C. putillus; Orthograptus truncatus abbreviatus = O. amplexicaulis; Climacograptus hastatus = C. trifidus; Climacograptus minimus = C. putillus; Orthograptus truncatus intermedius = O. amplexicaulis; O. quadrimucronatus angustus = O. quadrimucronatus; Retiograptus pulcherrimus = O. quadrimucronatus; O. truncatus pertenuis = O. amplexicaulis; O.* aff. *truncatus = O. amplexicaulis; O. truncatus recurrens = O. amplexicaulis.*

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Note added in proof. In a recent review of the pre-Permian geology of the Marathon area, which became available while the present paper was in press, King (1977) proposes a shelf-slope model for the Ordovician sedimentary environment that is closely similar to that suggested above.

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