du Dr. P. Sartenaer, Chef de Section à l'Institut Royal des Sciences Naturelles à Bruxelles d'avoir pu emprunter et étudier certains spécimens de *Drepanophycus spinaeformis* qui y sont conservés.

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SPORES FROM THE DEVONIAN/MISSISSIPPIAN TRANSITION NEAR THE HORSESHOE CURVE SECTION, ALTOONA, PENNSYLVANIA, U.S.A.

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ABSTRACT

Streel, M. and Traverse, A., 1978. Spores from the Devonian/Mississippian transition near the Horseshoe Curve section, Altoona, Pennsylvania, U.S.A. Rev. Palaeobot. Palynol., 26: 21—39.

A section of sandstones and shales of the Catskill and Pocono Formations (Devonian and Mississippian) was described by Swartz (1965) at the Horseshoe Curve between Altoona and Gallitzin in Pennsylvania (U.S.A.). The most shaley beds contain two major assemblages of spores: the lower one, with *Cirratriradites hystricosus* Winslow or *Spelaeotriletes lepidophytus* (Kedo) Streel, corresponds to the uppermost part of the Devonian in Western Europe; the higher one, with *Hymenozonotriletes explanatus* Kedo and *Vallatisporites vallatus* Hacquebard, crosses the Devonian/Carboniferous (Mississippian) boundary and is well known in undoubtedly Carboniferous sections in Western Europe. The results obtained permit assignment of latest Devonian age (Fa2c-Fa2d-Tn1a-lower Tn1b) to the lower part of the Pocono Formation in the Horseshoe Curve section. The *Adiantites* megaflora occurring in the section is clearly more recent than the *Archaeopteris* megaflora from Bear Island, and is presumed to cross the Devonian/Carboniferous (Mississippian) boundary or to be entirely on the Mississippian side of this boundary.

RÉSUMÉ

Une coupe de grès et schiste appartenant aux Formations de Catskill et Pocono (Dévonien et Mississippien) a été décrite par Swartz (1965) à la Horseshoe Curve section entre Altoona et Gallitzin en Pennsylvanie (U.S.A.). Les couches les plus argileuses contiennent 2 assemblages majeurs de Spores: l'inférieur avec *Cirratriradites hystricosus* Winslow ou bien *Spelaeotriletes lepidophytus* (Kedo) Streel correspond à la partie la plus récente du Dévonien en Europe occidentale; la supérieure, avec *Hymenozonotriletes explanatus* Kedo et *Vallatisporites vallatus* Hacquebard, passe la limite Dévonien/Carbonifère (Mississippien) et est bien connue de sections carbonifères en Europe occidentale. Les résultats obtenus permettent d'attribuer un âge Dévonien le plus récent (Fa2c-Fa2d-Tn1a-Tn1b inf.) à la partie inférieure de la Formation de Pocono de la Horseshoe Curve Section. La mégaflore à *Adiantites* connue dans cette coupe est plus récente que la mégaflore à *Archaeopteris* décrite de l'île aux Ours; elle est supposée à cheval sur la limite Dévonien—Carbonifère ou entièrement du côté mississippien de celle-ci.

INTRODUCTION

Near Altoona, the Pennsylvania Railroad's famous Horseshoe Curve was one of the greatest engineering feats of its time, conquering the Alleghenies, the biggest obstacle in the westward march of the railroad. The cuts along the main line expose one of the finest displays of later Paleozoic strata to be found along the course of the Allegheny Front. The stratigraphic sequence in this area has been described by various investigators, especially by Butts (1905, 1918, 1945) and by Swartz (1946, 1965). This paper is concerned with the Pocono Formation, which consists mainly of gray sandstones and shales and lies between the Mississippian Loyalhanna Limestone and the Upper Devonian Catskill red beds, below. The contact between the Pocono Formation, and the Catskill red beds is particularly well exposed west of Milepost No.244 (Fig.1). The Pocono Formation is subdivided downwards (Fig.2) into 3 members:

the Burgoon Sandstone Member
the Middle Sandstone and Shale Member
the Lower Sandstone Member.

The megafossil content of the Pocono Formation near the Horseshoe Curve is given by Swartz (1965, tab.I) summarizing data from Butts (1905), Koppe (unpublished), Spackman (unpublished) and others (see Fig.2). Most of the related text below is quoted from Swartz (1965, pp.15—17).

The plants recorded from the Burgoon Member, as well as those from the highest part of the middle sandstone and shale member are representative of the widespread Mississippian *Triphyllopteris* flora of Read and Mamay (1964).

Read (1955) reported that *Adiantites spectabilis* Read, *Lagenospermum* sp., and *Girtya pennsylvanica* Read occur near the base of the Pocono, 16 km to

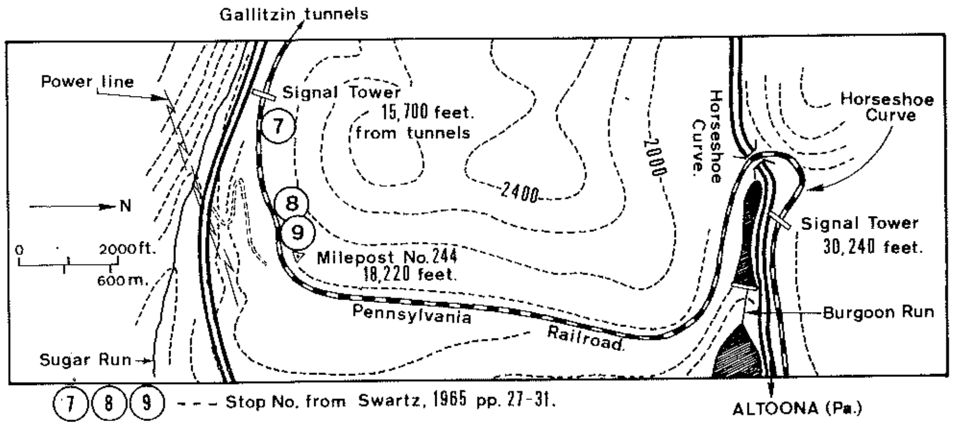


Fig.1. Map of the Horseshoe Curve section, showing locations of stops 7, 8 and 9. (Mainly redrawn from Swartz, 1965).

the northeast and added that at a "somewhat higher level" in the lower Pocono at the Curve itself there are found *Rhacopteris latifolia* (Arnold) Read, *Adiantites spectabilis* Read, *Rhodea* sp., *Alcicornopteris altoonensis* Read and *Lepidodendropsis* sp.

This flora is well developed in at least the middle part of the middle sandstone and shale member. *Adiantites spectabilis* may also occur at the Curve at Horizon IV of Butts (see Fig.2) although it is less clear than would be desirable that the specimens so identified by Read came from this position.

Several leaf fragments from between horizon III and IV of Butts (see Fig.2) appear suggestive of the Upper Devonian genus *Archaeopteris* but Koppe states that better material will need to be found before identification of plants at this horizon can be considered to be satisfactory even on a generic basis.

In 1936, but not in 1939, Butts in addition cited "*Archaeopteris*", probably n. sp., as a member of the flora at the Curve, presumably in reference to a specimen at the United States National Museum that Arnold (1939) later placed in *Archaeopteris latifolia* Arnold with the comment that "The *Archaeopteris* horizon at the curve has been included in the lower part of the Pocono, but it is definitely Devonian, though post-Chemung". These specimens were collected by M.R. Campbell in 1903 and presumably were known to Butts in 1905, and since Arnold states that they are considered to be from the lower part of the Pocono it appears plausible that they were found in the lower of the two occurrences of ferns listed by Butts, at Horizon IV (see Fig.2).

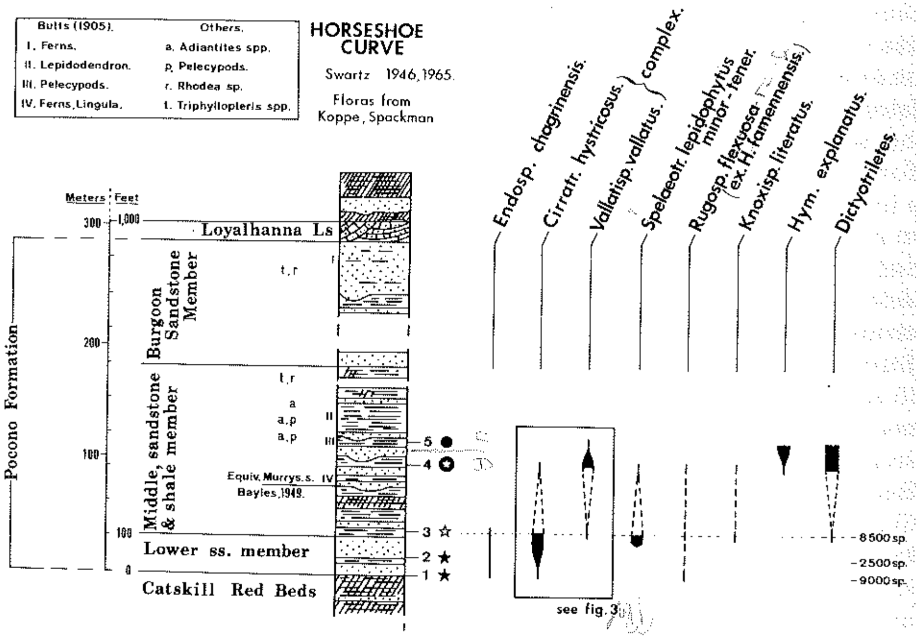


Fig.2. Stratigraphical ranges of the most important spore species compared to the bio-lithological data from the Pocono Formation at the Horseshoe Curve.

Among the invertebrate fossils at the Curve, the pelecypods do not appear to offer much more help in correlation.

Therefore, several authors have turned to lithostratigraphical correlation to date the section.

"Using information from many deep wells across the western part of Pennsylvania, Bayles (1949) published stratigraphic charts indicative of widespread persistence of the subsurface Murrysville Sand in near parallelism with the Pocono—Loyalhanna boundary at higher levels, as well as with the top of the lower-lying red beds of Catskill facies almost to the western limits of their occurrence. He concluded that by careful tracing, there is strong evidence for correlation of the Murrysville Sand northwards and westwards with Knapp—Cussewago beds in northwestern Pennsylvania and eastern Ohio, eastwards with Sandstones *in the middle part of the middle sandstone and shale member* of the Pocono at the Horseshoe Curve, and southwards into Laird's units E, G, H at the Youghiogheny Gorge in Laurel Hill . . ." (Swartz 1965, p.24). Because faunas of these last units are considered by Laird (1941) to be representative of Early Mississippian assemblages as opposed to Late Devonian assemblages found immediately below, the base of the Murrysville Sand is also considered by Bayles to correspond very nearly in position with the Devono-Mississippian boundary. The lateral equivalent of the base of the Murrysville Sand as projected by Bayles from the Youghiogheny Gorge to the Curve is plotted in Fig.2.

Quoting Swartz (1965), De Witt (1970, p.G8) assumed that "the Murrysville Sand of Bayles (1949) lies in the lower part of the sub-Burgoon Strata" containing the *Adiantites* flora. However his figs.2 and 3, in contradiction to Swartz (1965, fig.3), show the Murrysville Sand to lie *at or very near the base* of the Pocono, at the Horseshoe Curve. As the Cussewago (Murrysville) sandstone is overlapped in northeast Ohio by the Berea Sandstone and possibly by the Bedford Shale (De Witt, 1970, p.G7), De Witt determines Mississippian age for all these units, mainly arguing on the occurrence of the *Adiantites* flora in the Horseshoe Curve section.

On another hand as long as the base of the Mississippian is accepted at the base of the Carboniferous sensu Heerlen 1935 (base of the Hangenberg Limestone with *Gattendorfia subinvoluta* and *Siphonodella sulcata*, at Oberrödinghausen in Germany), a Devonian age (lowest Tn1b ?) for the Bedford Shale and the Berea Sandstone has been proposed (Streel, 1971, p.135 and fig.3) on the evidence of Winslow's (1962) material from Ohio, Eames (1974) has the same opinion for northeastern Ohio and, in Ontario, McGregor (1971, pp.21 and 22) reaches the same conclusion not only for the Bedford Formation (and the Berea Formation) but also for the Sunbury Formation, which overlies the Berea Formation, and carries not only *Spelaeotriletes lepidophytus* (Kedo) Streel but a typical assemblage of the "*pusillites—lepidophytus*" zone.

Sandberg et al. (1972) have also expressed the same opinion: "Evidence for the Mississippian (Lower Carboniferous) age of the Sunbury Shale, Berea Sandstone, and most of the Bedford Shale in the Appalachian Basin of Ohio, Pennsylvania, and West Virginia, was summarized by De Witt (1970). On the basis of a conodont fauna reported by Hass (1947, p.136), we agree with De Witt (1970, p.G6) that the Sunbury, which does not contain *H. lepidophytus*, is unquestionably Mississippian in Ohio. However, the sole conodont species reported by De Witt (1970) from the Bedford Shale, which does contain *H. lepidophytus*, is *Spathognathodus anteposicornis*. This species characterizes the latest Devonian *Protognathodus* Fauna in the Upper Mississippi Valley. Conodonts or other fauna are unreported from the Berea Sandstone".

Thus, the Horseshoe Curve section might provide a good opportunity to compare plant macro- and microfossils for determining the Devonian/ Mississippian boundary in these regions.

STUDIED MATERIAL AND METHODS

Several samples have been tested ranging from Catskill red beds to Burgoon Sandstone Member. Five samples were selected for not being too much weathered and for carrying the largest amount of spores.

From the top to the base of the section (Fig.2):

Middle sandstone and shale member of Pocono Formation:

5: Siltstone included in the 15 to 0 feet bed at total footage 1,375 mentioned by Swartz (1965, p.29, stop No.7), collected by M. Streel (MS:21)

4: Siltstone included in the 30 feet bed at total footage 1,437 mentioned by Swartz (1965, p.29, stop No.7), collected by M. Streel (MS:22).

3: Shale from a 12.5 cm thick greenish-gray shale between sandstone beds, 5.40 m above the base of the Middle Member of the Pocono Formation, included in the 22 foot bed at total footage 1,635 mentioned by Swartz (1965, p.30, stop No.7), collected by Ch. Sandberg (USGS Paleobot. Loc. D4873) (CS:Penn 2).

Lower sandstone member of Pocono Formation:

2: Siltstone included in the 70 feet bed at total footage 1,705 mentioned by Swartz (1965, p.31, stop No.8) collected by A. Traverse (AT:72-14).

1: Shale from a 25 cm thick greenish-gray shale between two conglomerate beds just above the base of the Pocono, collected by Ch. Sandberg (USGS Paleobot. Loc.D4812) (CS:Penn 1). Swartz (1965, p.31, stop No.9) mentioned this bed as "At top are 2 feet of greenish clayey shale, possibly regolithic" and assigned it to the top of the Catskill. This sample is considered belonging to the Pocono because above the lowest conglomerate.

DESCRIPTION OF THE MIOSPORE ASSEMBLAGES AND COMPARISONS WITH OTHER AREAS

Species identified in the five samples are listed in generic alphabetical order on Table I.

TABLE I

List of species recorded from the Horseshoe Curve section

	Devonian				Mississippian
	Fa2c		Upper Tn1a —Lower Tn1b		Upper Tn1b —Tn2
	1	2	3	4	5
Ancyrospora spp.	×	×			
Aneurospora greggsii (McGregor) Streel	×	×	×	×	
Aneurospora incohata (Sullivan) Streel	×	×	×	×	×
Auroraspora hyalina (Naum.) Streel	×	×	×	×	
Auroraspora macra Sullivan	×	×	×	×	×
Auroraspora poljessica (Kedo) Streel	×	×	×		
Auroraspora torquata Higgs	×				
Auroraspora solisorta Hoff. St. et Malloy	×		×		
Auroraspora sp. cf. *P. perinatus* Hughes et Playford	×	×		×	
Camptotriletes prionotus Higgs				×	×
Cirratriradites hystricosus Winslow	×	×	×	×	
Convolutispora oppressa Higgs		×			
Convolutispora vermiformis Hughes et Playford					×
Corbulispora cancellata (Waltz) Bhar. et Venk.					×
Dictyotriletes spp.			×	×	×
Emphanisporites rotatus McGregor	×			×	
Endosporites chagrinensis Winslow	×	×	×		
Endosporites? crassaspinosus Winslow	×		×		
Grandispora cornuta Higgs	×	×	×		
Grandispora cf. *tenuispina* (Hacq.) Playford	×		×		
Grandispora uncata (Hacq.) Playford					×
Gulisporites torpidus Playford					×
Hymenozonotriletes cassiculus Higgs	×		×		
Hymenozonotriletes explanatus (Luber) Kedo				×	×
Knoxisporites literatus (Waltz) Playford			×	×	
Pustulatisporites sp.A in Higgs					×
Raistrickia spathulata (Winslow) Higgs			×		
Rugospora flexuosa (Jusch.) Streel	×	×	×	×	
Rugospora versabilis (Kedo) Streel	×	×	×		
Spelaeotriletes lepidophytus (Kedo) Streel			×	×	
Vallatisporites vallatus Hacq.			×	×	×
Vallatisporites verrucosus Hacq.				×	
Verruciretusispora pallida (McGregor) Owens					×

Comparison with the Ardennes—Rhine basins in Europe

Samples 1 to 4 carry an assemblage with *Rugospora flexuosa*, *R. versabilis*, *Grandispora cornuta*, *Auroraspora* div. sp. and *Aneurospora greggsii*, which is typical of the Fa2c—lower Tn1b timespan in the Ardennes—Rhine basins.

Sample 5 which (with sample 4) has less well preserved spores, carry nevertheless a different assemblage dominated by *Dictyotriletes* div. sp. and large numbers of *Hymenozonotriletes explanatus.* This assemblage is more typical of the lower Tn1b—Tn2a timespan in the Ardennes—Rhine basins.

Both assemblages contain species of the "*Hymenozonotriletes pusillites* Kedo *sensu lato*" complex of spores which will be discussed later.

The ranges of the most important species for stratigraphical correlation are shown on Fig.2. We have emphasized the first occurrence levels of each one and therefore have tried to quantify these levels: *S. lepidophytus*, *Knoxisporites literatus* and *Dictyotriletes* spp. occur, for the first time, at level 3, 11500 specimens (sp. on Fig.2) having been scanned below; *H. explanatus* first occurs at level 4, 20000 specimens having been scanned below.

Samples 1 and 2 do not contain *S. lepidophytus* but carry *C. hystricosus*. As this last species is clearly conspecific with *V. pusillites* (Kedo) Dolby et Neves 1970 that one of us (M.S.) has used so far, we have a conflicting situation as far as the correlation with the Ardennes—Rhine basins is concerned.

Indeed, *S. lepidophytus* and *V. pusillites* occur together at the same level in western Europe, the first species (S.l.) characterising the base of the Fa2d (Streel et al., 1976). Whether *C. hystricosus*' first occurrence is diachronous or belongs to a pre-*lepidophytus* zone which is lacking in Europe, is a matter to be discussed later. But whatever conclusion we reach, samples 1 and 2 should have a Fa2c connotation.

Sample 3 which contains *S. lepidophytus*, also carries *Cristatisporites echinatus* and *Knoxisporites literatus* which, in the Ardennes—Rhine basins are characteristics of the upper part (PLs) of the *V. pusillites—S. lepidophytus* zone of upper Tn1a—lower Tn1b age.

Some of the specimens belonging to *S. lepidophytus* in sample 3 have the morphologic trends of the var. *minor* and *tener* which characterise the biometric zone D to F in Belgium (Streel, 1966). The population of *S. lepidophytus* in sample 3 has, however, a diameter-size histogram in which the interquartile ranges from 56 to 81 μm, which in terms of the biometric zonation of this species, means a zone C of Fa2d age in Belgium.

Warg and Traverse (1973) have demonstrated that, in continental beds 80 km to the northeast, such size distributions are strongly influenced by the sediments which incorporate them. Larger *S. lepidophytus* being transport and deposited with the relatively coarser sediments. In marine sediments, spores from different sources are expected to be mixed and the size range picture given is supposed to integrate the effect of these different lithologies. As the biometric scale has been erected on a succession of marine assemblages in Belgium, and as only one sample from the Horseshoe Curve section made possible a study of diameter size on a sufficient number of specimens, a direct comparison is here precluded.

Sample 4 which also contains, but less abundantly, *S. lepidophytus*, is characterised[1] by murornated forms belonging to *Dictyotriletes* or *Corbulispo* With the first occurrence of *H. explanatus*, this sample corresponds to the

[1] In addition to a "*H. pusillites sensu lato*" complex of spores which will be discussed later.

lower part of the TE (*C. trivialis—H. explanatus*) zone recently demonstrated in the Hangenberg Sandstone, at Stockum in Western Germany (Alberti et al., 1974). That part of the Hangenberg Sandstone where the base of the TE zone occurs is still Devonian in age, containing a Lower *Protognathodus* conodont fauna. It is not clear however whether *S. lepidophytus* and *R. flexuosa*, which characterise the lower part of the TE zone, cross the Devonian/Carboniferous limit or not, because the spore material becomes very poor upwards and also because the limit is not identified in that section by the goniatites or conodonts used in the type section (Alberti et al., 1974).

Accepting the correlation by conodonts, the Hangenberg Sandstone must be a lateral equivalent of part of the Lower Hastière Limestone in the Dinant area and therefore of pre-Carboniferous lower Tn1b age.

An assemblage dominated by *H. explanatus* like in sample 5, is not known from Western Europe so far. A TE zone without *S. lepidophytus* and *R. flexuosus* has been originally defined (Paproth and Streel, 1971) and recently illustrated (Streel, 1977) in the upper Tn1b and Tn2a from the Tournai area in Belgium. But *H. explanatus* in these beds, as in the Hangenberg Sandstone in Germany, is rare.

In addition and due to unfavourable rocks for spore preservation, the base and the top of this zone cannot be delineated in the Ardennes—Rhine basins. We have thus to turn to other basins for correlation purposes.

Comparisons with the British Isles basins

Only the upper part of the PL zone of the Ardennes—Rhine basins succession has been recognized stratigraphically downwards in the British Isles. But the succeeding zones are more accurately defined here than elsewhere.

In southern Eire (Clayton et al., 1974; Higgs, 1975), *H. explanatus* has been noted in the uppermost part of the PL zone, occurring before the characteristic species of the following NV (*V. nitidus—V. vallatus*) zone which has been subsequently subdivided in two subzones. Sample 4, where *H. explanatus* and *V. verrucosus* occur together with *S. lepidophytus* and *R. flexuosa*, most probably belongs to the LN (*S. lepidophytus—V. nitidus*) subzone. Nearly absent in the Tournaisian beds of the Ardennes—Rhine basins, but sometimes dominant elsewhere, *V. nitidus* seems to be somewhat facies controlled (see also Playford, 1964, table 1).

In the British Isles, *H. explanatus* ranges into the PC (*S. pretiosus—R. clavata*) zone which succeeds the NV zone upwards. *Spelaeotriletes pretiosus* (Hacq.) Neves et Belt and other characteristic species of the PC zones being absent in the Horseshoe Curve, *H. explanatus*, which is there very abundant with many tetrads and immature ? specimens, is supposed to represent a special facies of the VI (*V. vallatus—R. incohatus*) subzone. In southern Eire, there is evidence from conodont studies to suggest that the PC zone is of Tn2 or Tn3 a-b age. An upper Tn1b—middle Tournaisian age for sample 5 (and the VI subzone) is thus most probable.

Comparisons with the North American basins

Winslow (1962) in Ohio, McGregor (1971) in Ontario and Nova Scotia, Richardson (1969) in New York State and Pennsylvania, Warg and Traverse (1973) in Pennsylvania and Eames (1974) in Ohio have published uppermost Devonian palynological data more or less close to the present area.

In Ohio, *C. hystricosus* and *S. lepidophytus* (= *E. lacunosus* Winslow) are shown by Winslow (1962) to occur together at the top of the Cleveland Member of the Ohio Shale, higher than the last occurrence of *E. chagrinensis* (see Winslow, 1962, fig.4). But samples from the Ohio shale were rather poor in plant microfossils compared with those of higher strata (Winslow, 1962, p.24). A correlation of samples 1 and 2 with the Ohio Shale (Cleveland member or below?) is possible on the basis of the common occurrences of *E. chagrinensis*. With a larger spore/body diameter ratio, *E. chagrinensis* is very comparable with, but different from, *R. versabilis*, an abundant species in pre-*lepidophytus* assemblages of the Upper Famennian in Belgium.

Sample 3, with *S. lepidophytus*, is similar to the assemblages recorded in the Bedford Shale (? and the Berea Sandstone) in Ohio by Winslow (1962) and in Ontario by McGregor (1971, GSC loc. 7059), both containing *K. literatus* (*R. crassus* Winslow and *Archaeozonotriletes literatus* (Waltz) Naumova).

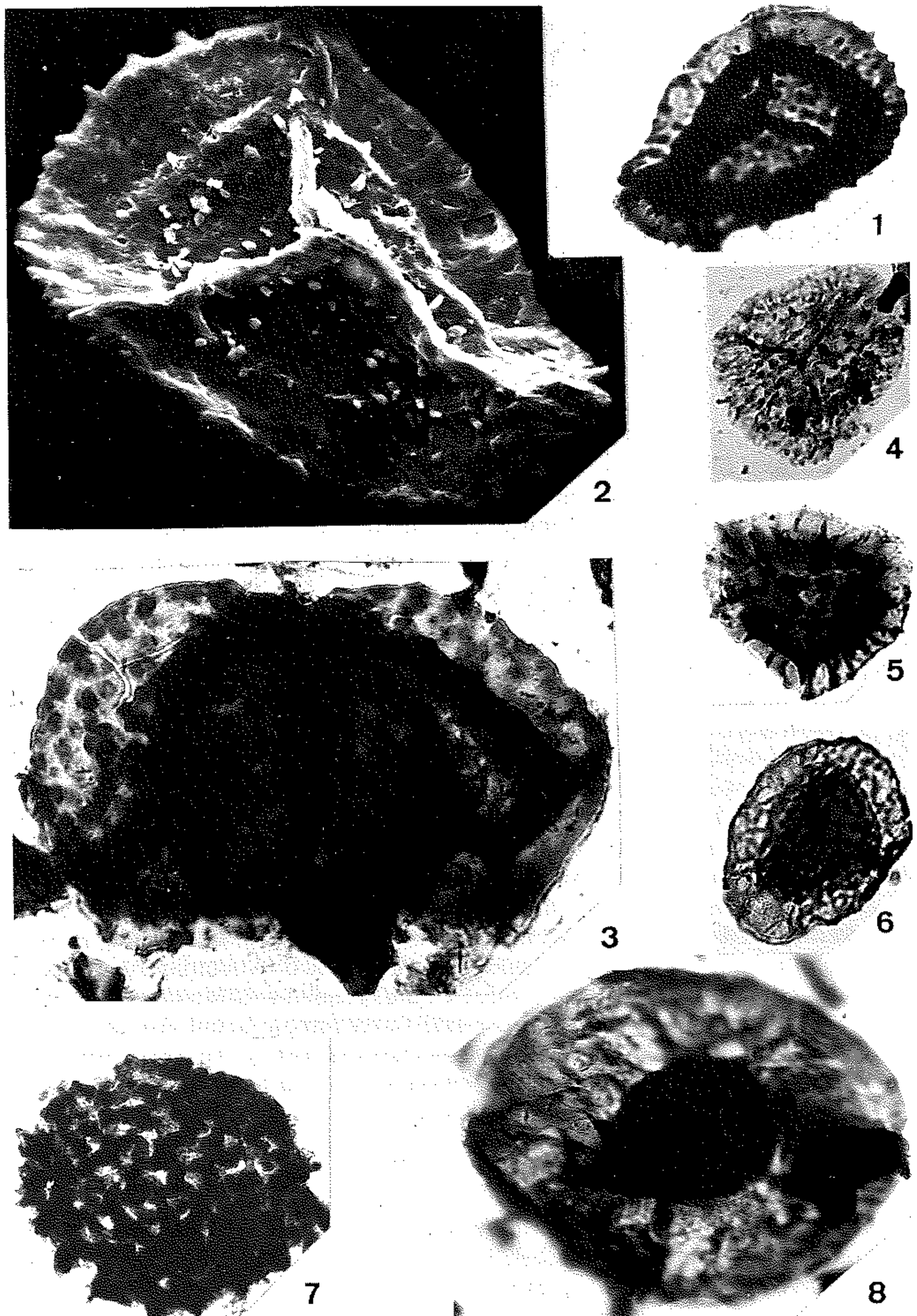
The Berea Sandstone in Ohio and Ontario and the Sunbury Shale in Ontario (McGregor, 1971, GSC loc. 7825) have assemblages (with *S. lepidophytus*) more or less comparable with sample 3 or 4 at the Horseshoe Curve section. They are insufficiently described to warrant a more accurate correlation. A palynological interpretation of the Devonian—Mississippian transitional layers of northeastern Ohio by Eames (1974) indicates a Late Devonian age for the Cleveland, Bedford and Berea and an Early Mississippian age for the overlying Cuyahoga Group (Including the Sunbury Shale at the base).

Warg and Traverse's (1973) study in central Pennsylvania, 80 km northeast of the Horseshoe Curve section provide the nearest palynological data available. However, they do not have any good independent litho- or biostratigraphic controls. Samples with *S. lepidophytus* and *C. hystricosus* (as *H. pusillites*, Plate I, 6) collected at cut-1 and a sample (S6) obtained approximately 30 m upwards are comparable with sample 3. A sample (P1) collected at cut-3, nearly 135 m above the cut-1 base, yielded a different assemblage lacking *S. lepidophytus*, as in Horseshoe Curve sample 5, but rich in *H. pusillites* (Plate I, 5) as in Horseshoe Curve sample 4. An intermediate stratigraphical position of P1 between samples 4 and 5 is therefore possible.

Richardson (1969, p.200 and plate 11-6) has also found a *lepidophytus* assemblage from Oswayo and Knapp Formations in New York State and northwestern Pennsylvania.

Mississippian assemblages have been described by Hacquebard (1957) and extended by Playford (1964) in the Horton Group of Nova Scotia. Aside from poorly described (Winslow, 1962) or not yet published (Eames, 1974) data on the Cuyahoga group of Ohio, they are the nearest well-documented

PLATE I



available informations on post-*lepidophytus* assemblages. Several species like *Gulisporites torpidus*, *Spinozonotriletes uncatus*, *Vallatisporites vallatus* and *Verruciretusispora pallida* occur both in the undifferentiated Horton Group and Horseshoe Curve sample 5. It is also obvious that *V. nitidus* is not present, occurring only in the more recent Cheverie Formation.

A comprehensive discussion of the age of the Horton Group has been given by Bell (1960). He has concluded that the megafloral composition of the Horton Group "represents only a Tournaisian part of Jongmans' widespread Lower Carboniferous *Triphyllopteris—Rhacopteris—Lepidodendropsis* flora", and has close affinities with the Pocono flora of the United States.

"*HYMENOZONOTRILETES PUSILLITES SENSU LATO*" COMPLEX OF SPORES

Kedo (in Kedo and Golubcov, 1971, discussion and plate III) has clearly emphasized a rather wide concept of *H. pusillites* Kedo (1957) which obviously makes legitimate the assimilation by Dolby and Neves (1970) of spores similar to *C. hystricosus* in that species. However, work on material provided for comparison by Kedo has later (Chibrikova et al., in press) shown that this species was used by the Russian palynologists for quite different spores (see for instance Byvsheva, 1974, tab. XIV, figs.1 to 4). These divergences are particularly important because western palynologists are using the successive occurrence of *V. pusillites*, *V. verrucosus* and *V. vallatus* as stratigraphical markers where the Russian palynologists just do not distinguish these three species from *H. pusillites* Kedo.

In order not to compete with a CIMP working group revising the question, we prefer here not to propose a solution of the taxonomic problem involved. Nevertheless, we no longer agree to increase confusion by using *V. pusillites* (Kedo) Dolby et Neves. Therefore in this paper we will use the "*C. hystricosus* Winslow 1962" concept for specimens previously incorporated in *V. pusillites*, occurring with *S. lepidophytus* in the uppermost Devonian strata.

This statement does not mean, unfortunately, that the limits of the "*C. hystricosus*" concept *vis à vis* the "*V. vallatus*" concept are as yet fully understood. If material from samples 1, 2 and 3, with long, and rather scarce, spines obviously belong to "*C. hystricosus*", many specimens of sample 4 are, on the contrary, nearer *V. vallatus*. We have compared stereoscan pictures of

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PLATE I

1—3. *Hymenozonotriletes explanatus* Kedo. 1, 2. Same specimen shown in transmitted light (× 500) and with Stereoscan (× 1000). Sample MS 21. 3. Tetrad of immature ? specimens (× 1000). Slide 7680:1556. Sample MS 21.

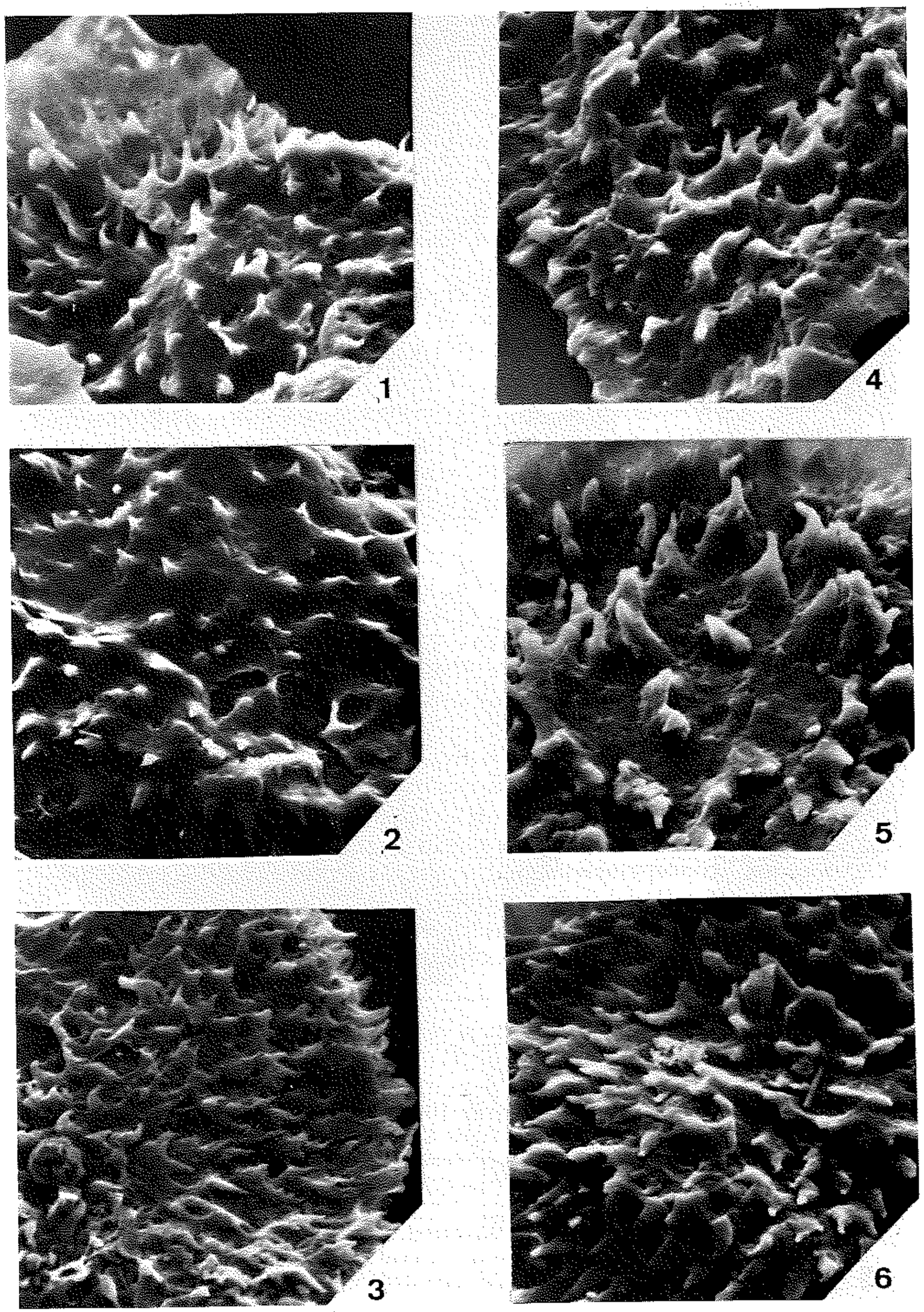
4—5. "*C. hystricosus—V. vallatus*" palynodemes. 4. Trend *V. vallatus* (× 500). Slide 7696:1326. Sample MS 22. 5. Trend *C. hystricosus* (× 500). Slide 15325:2847. Sample AT 72-14.

6. *Spelaeotriletes lepidophytus* (Kedo) Streel. Slide D 4873(1):2287. Sample CS Penn.2.

7. *Corbulispora cancellata* (Waltz) Bhar. et Venk. Slide 7680:0976. Sample MS 21.

8. *Endosporites chagrinensis* Winslow Slide D4873(2). Sample CS Penn.2.

PLATE II



the distal surface (see plate II) of several specimens of sample 4 with specimens from the Horton Group where *V. vallatus* has been defined. They are indistinguishable.

In Fig.3, we have tried to measure the variability of the *Vallatisporites* occurring in samples 1 to 4 using two parameters: the size of the longest spines on a single specimen and the maximum number of spines between zones and two rays of the same specimens. These parameters are of course related, as decreasing of ornament size often corresponds to increase in ornament number.

Indeed, we can observe a progressive change from the lower samples 1 + 2 (full stars), through sample 3 (open stars) to sample 4 (stars in a circle). *C. hystricosus* holotype lies in the middle of the cloud of data. *V. vallatus* holotype would be somewhere in the area here marked *D* with spines of maximum size of 2 μm.

We may also break the major cloud of data into several purely artificial groups of classes: A, B and C. Then, we see (Fig.4) that all data of sample 1 and 2 fall in class A; a maximum of data of sample 3 in class B and a maximum of data of sample 4 in class C.

It is clear that *C. hystricosus* and *V. vallatus* cannot be easily separated using these parameters, unless some arbitrary limit is selected. Unfortunately we do not know of other parameters available and therefore we prefer to speak later about the *C. hystricosus—V. vallatus* palynodemes (sensu Visscher, 1971).

Such a concept may later prove very useful for a precise delineation of the Devonian—Carboniferous boundary where this complex of spores is abundant.

For instance, we have introduced in Figs.3 and 4 (black dots) some data recorded in the Hangenberg Shale at Oberrödinghausen in Western Germany, the type section for the Devonian/Carboniferous limit. This is an uppermost Devonian stratigraphical unit carrying a *lepidophytus* assemblage (Streel, 1969) which is locally separated from the Carboniferous Hangenberg Limestone upwards by the already mentioned Hangenberg Sandstone. Using the same parameters as for the Horseshoe Curve samples, we may assume that the Hangenberg Shale best fits between samples 3 and 4.

DISCUSSION AND CONCLUSIONS

(1) As a result of a study of assemblage comparisons and the "*C. hystricosus*—*V. vallatus*" palynodemes, we can summarize the following conclusions. At the Horseshoe Curve section, from the base to the top:

(a) The Lower Sandstone Member of the Pocono Formation is mainly of Fa2c age, yielding a pre-*lepidophytus* assemblage (samples 1 and 2). Its

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PLATE II

1—6. "*C. hystricosus—V. vallatus*" palynodemes. All stereoscan pictures (× 2000).
1—3. 3 different specimens from the Horton Bluff, Nova Scotia. 4—6. 3 different specimens from sample MS 22, Horseshoe Curve.

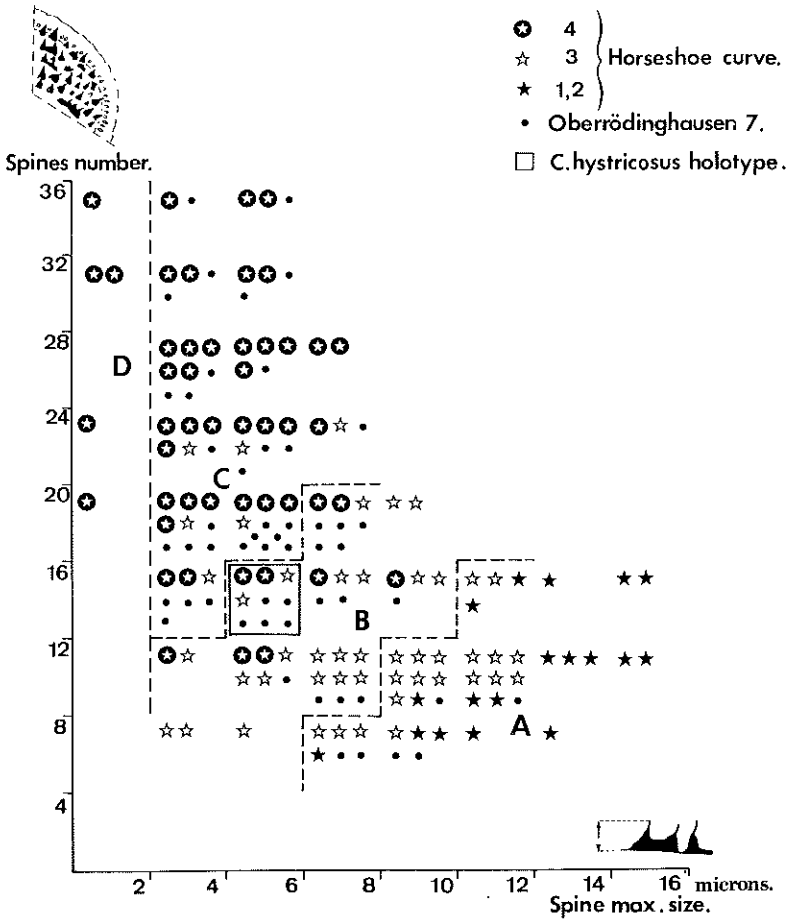

Fig.3. Variability of the *Vallatisporites* complex of spores occurring in samples 1 to 4 in the Horseshoe Curve section and in one sample of the Hangenberg Shales at Oberrödinghausen (W. Germany). Four groups of classes (A, B, C and D) were artificially selected.

nearer biostratigraphic equivalent probably is in Ohio in the upper part of the Ohio Shale (Cleveland Member or below ?).

(b) The lowest part of the Middle Sandstone Shale Member of the Pocono Formation (sample 3) has an upper Tn1a age or perhaps a pre-Carboniferous lower Tn1b age, but older than the Hangenberg Shale in the Oberrödinghausen type section in Germany. Its nearer biostratigraphic equivalent is in the Bedford Shales of Ohio and Ontario.

(c) The upper half part of the Middle Sandstone and Shale Member of the Pocono Formation, from the first accurately located *Adiantites* flora (level III, sample 5) upwards, has at least an upper Tn1b or middle Tournaisian as oldest age.

(d) The limit Devonian/Carboniferous (Mississippian) obviously lies in the lower half part of the Middle Sandstone and Shale Member of the Pocono

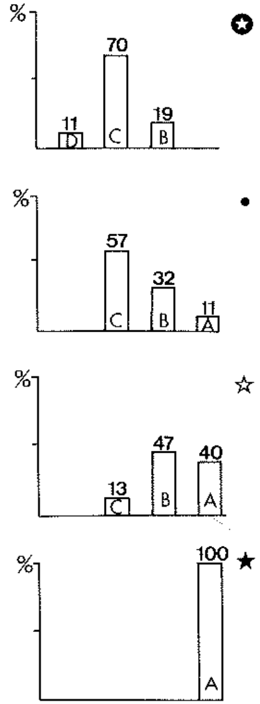

Fig.4. Percentage of each artificial group of classes selected in the *Vallatisporites* complex of spores in samples from the Horseshoe Curve and Oberrödinghausen sections.

Formation. Sample 4 does not permit tracing of this boundary unambiguous Sample 4 corresponds to a level more recent than the Hangenberg Shale in the Oberrödinghausen type section in Germany. It belongs to the LN subzo which in Western Europe is often accepted as uppermost Devonian. Howeve the exact position of the upper limit of this subzone regarding the Devonian Carboniferous boundary is not known. A lower Tn1b age is evident, but we cannot emphasize on which side of the Devonian/Carboniferous boundary this sample has been taken.

(2) The megafloral evidence unfortunately cannot help in this matter. An *Adiantites* flora is now, in the present paper, dated as of upper Tn1b—Tn2 age, but nothing is known about the age of its first occurrence.

The most recent, independently dated, pre-*Adiantites* flora is the Bear Island *Cyclostigma—Archaeopteris* flora described by Nathorst (1902) and extended by Schweitzer (1967, 1969). Kaiser (1971a, 1971b) has claimed this flora to be associated with an upper PL spore assemblage. However, the distinction between a PL and a subsequent LN subzone with *S. lepidoph* is more recent and, in addition, nothing is known of the upper limit of the megaflora. Consequently, it is quite possible that the so-called "Devonian" *Cyclostigma—Archaeopteris* might also cross the Devonian/Carboniferous boundary.

The reverse is also true, that the first *Adiantites* could occur in the uppermost Devonian. Thus, the occurrence of *Archaeopteris* versus *Adiantites* fronds at level IV or between levels III and IV, in the Horseshoe Curve, if confirmed, will not allow a more accurated dating than is known at present.

(3) The most interesting result of this study, as far as microfloral assemblages is concerned, is certainly the new potentiality of delineating the Devonian/Carboniferous boundary using biometry on the "*C. hystricosus—V. vallatus*" palynodemes. This is of course a challenge which is still waiting for appropriate material: we mean a well-dated section crossing that boundary, with on each side, abundant related material.

Unfortunately, the local abundance of *Vallatisporites* div. sp. is a well-known character of the Devonian/Carboniferous transitional layers (Streel, 1971, p.129; Warg and Traverse, 1973). If *Vallatisporites* is to be a genus with its geographical distribution climatically controlled, as suggested by Sullivan (1965, 1967), its stratigraphic distribution and particularly its abundance must have more local causal phenomena.

We suggest that at least the spores from the "*C. hystricosus—V. vallatus*" palynodemes that are locally abundant in the Tn1—Tn2 interval, probably occur with slightly different morphological characters at close but different stratigraphical levels, and that, therefore, their abundance cannot be used as a stratigraphic marker without previously studying these morphological characters.

Consequently also, if the "*C. hystricosus—V. vallatus*" palynodemes have such an irregular stratigraphical distribution, then we are not very much inclined to attribute much importance to their first occurrence in the stratigraphic column. Thus it is possible that *C. hystricosus*, which was not recorded in the Fa2c of Belgium, is present in time-equivalent sediments elsewhere.

In contrast, we consider as more secure the first occurrence of *S. lepidophytus*, which is an abundant spore in nearly all uppermost Devonian assemblages so far recognized around the world.

(4) Concerning the local stratigraphy, we may conclude that our results match rather well the bio-lithostratigraphical correlations proposed by Bayles (1949).

The lateral correlation suggested by De Witt (1970) between the Bedford Shales and perhaps the Berea Sandstone in Ohio and the lower part of the Subburgoon strata in the Horseshoe Curve, should be restricted to the lower part of the Middle Sandstone and Shale Member in that section. Occurring higher, the *Adiantites* flora cannot be used to date these strata.

ACKNOWLEDGMENTS

We would like to thank C.A. Sandberg of the U.S. Geological Survey (USGS), who collected samples 1 and 3 for us in May 1972. He was guided to the Horseshoe Curve section and assisted in collecting by W. de Witt and the late J.W. Huddle, also of the USGS. Sandberg, accompanied by these

same two coworkers, also made conodont collection OH-1 from the Bedford Shale at the Granger roadcut in Cleveland Ohio. This collection, which consists only of fragmentary specimens, nevertheless confirms a very late Devonian age for the Bedford Shale. According to Sandberg (written commun., Feb.9, 1978), the collection includes "*Spathognathodus*" *fissilis*, "*S.*" *culminidirectus*, *Bispathodus aculeatus anteposicornis*, and possibly a badly broken fragment of *Siphonodella praesulcata*. The collection is assignable to the Middle *Bispathodus costatus* Zone or, if the presence of *S. praesulcata* could be verified, to the overlying *S. praesulcata* Zone. We also thank R.A. Scott (USGS), who prepared samples 1 and 3.

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