Graphic correlation of upper Middle and Upper Ordovician rocks, North American Midcontinent Province, U.S.A.

By WALTER C. SWEET

Ranges of conodont species are used to effect a graphic correlation of upper Middle and Upper Ordovician rocks in the North American Midcontinent Province. A Composite Standard Section (CSS) synthesized from the resulting network of correlated sections provides the total stratigraphic ranges of all species for which there is information in the system, stated in terms of the 477m sequence of upper Middle and Upper Ordovician rocks in the Cincinnati Region of Kentucky, Ohio and Indiana. The CSS is divisible into 80 vertically continuous 6m units, representing approximately equal time intervals, and also into a succession of chronozones with boundaries defined as the levels at which certain conodont species first appear in the CSS.

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Stratigraphic interpretation of Mohawkian and Cincinnatian rocks in the North American Midcontinent has been carried out within a chronostratigraphic framework divided into eight stages (cf. Ross *et al.* 1982), which are based on diachronous lithic units that vary in thickness from 14 to more than 80 m, can nowhere be shown to form a chronologic continuum, and formed in sedimentary environments with diverse but disparate organic assemblages. Distribution of most fossil groups has not been determined in stratotypes of Mohawkian and Cincinnatian stages, hence chronostratigraphic resolution below the stadial level is not possible.

In this report, the distritubion of conodonts in 61 stratigraphic sections in 18 sectors of the North American Midcontinent Province (Fig. 1) is used graphically to effect a high-resolution chronostratigraphic framework for the Mohawkian and Cincinnatian Series (Fig. 2) that is conceptually absolute. This framework includes data from stratotypes of seven of the eight stages in the traditional scale (Fig. 2), hence permits chronostratigraphic evaluation of those units and may enable their continued use.

Graphic correlation

The graphic-correlation method (Shaw 1964; Miller 1977; Sweet 1979 b) has not been much used because it requires data, in feet or meters above an arbitrary base, on the ranges of fossil species in all the stratigraphic sections to be compared. Data like those in Figs. 4, 5, and 7 are suitable. Range-data sets from pairs of section are compared graphically by plotting the range-bases and range-tops of species common to the two sets as points on graphs like those in Figs. 6 and 8–13. If the array of points is rectilinear, the equation of a straight line (LOC of Shaw 1964) fitted to it expresses the relationship between the sections that yielded the compared data sets. Commonly, the LOC is drawn through the lowest of the plotted range-bases and the highest of the plotted range-tops. Points at the common bases or tops of the sections compared may be ignored, for they may represent range-limits below or above the bases or tops of those sections. Points widely separated from the axis of the array represent range-limits that are not well established in one or both of the sections being compared and may also be ignored.

The LOC equation is used to translate range-data from the section plotted on the Y axis

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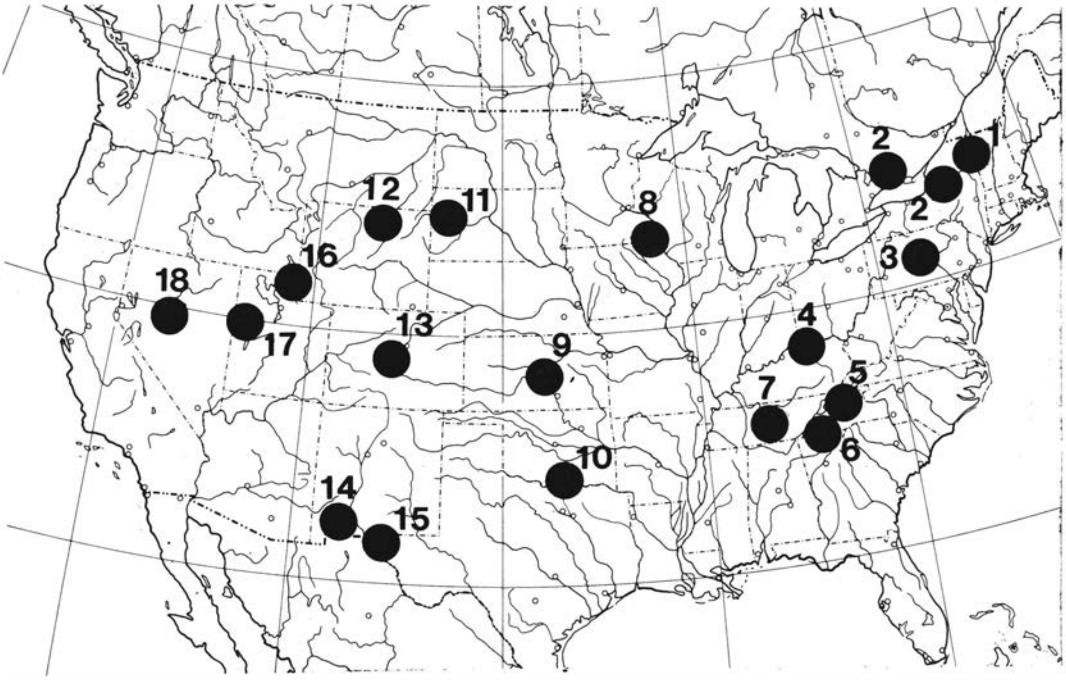


Fig. 1 – General location of sections or groups of sections that are now part of the graphic network described in this report. 1, Chazy and Crown Point, New York; 2, Black River and Trenton Group localities, southern Ontario and New York; 3, central Pennsylvania Salona-Coburn localities; 4, Cincinnati Region, Kentucky, Ohio, Indiana; 5, northeast Tennessee localities of Carnes (1975); 6, Friendsville, Tennessee sections; 7, Nashville Basin, Tennessee; 8, southeast Minnesota; 9, subsurface localities, Kansas; 10, Arbuckle and Hunton anticline localities, south-central Oklahoma; 11, northern Black Hills, South Dakota; 12, northern Wyoming localities of Sweet (1979 b); 13, central Colorado localities of Sweet (1979 b); 14, southwest New Mexico locality of Sweet (1979 b); 15, west Texas locality of Sweet (1979 b); 16, northeast Utah locality of Sweet (1979 b); 17, Ibex District, western Utah; 18, Antelope and Monitor Ranges, Nevada.

into terms of the one plotted on the X axis, which is initially a thick, well-controlled section chosen as a Standard Reference Section (SRS), but subsequently becomes a Composite Standard Section (CSS). From the two data sets, now stated in terms of the SRS, the lowest range-base value and the highest range-top value for each species is chosen and these are assembled into a CSS, which has the vertical dimension and extent of the SRS, but is synthetic in that it now includes range data from both initially compared sections.

Subsequent steps in compiling range data from additional sections are like the initial ones, save that the CSS is plotted on the X axis and its range values are modified as each new section is added. After all available sections have been compiled, component sections are serially recorrelated with the ultimate CSS, from which values controlled by the recorrelated section have been removed. Recorrelation is continued through as many rounds as may be necessary to achieve a stable network. In the one described in this report, stability was reached at the end of the fifth recorrelation round.

Compilation of a Mohawkian-Cincinnatian CSS

A stable CSS for the Mohawkian and Cincinnatian Series of the North American Midcontinent has been compiled from range data on more than 100 conodont species in 61 stratigraphic sections in the 18 areas designated in Fig. 1. The well-controlled 477m section of Middle and Upper Ordovician rocks in the Cin-

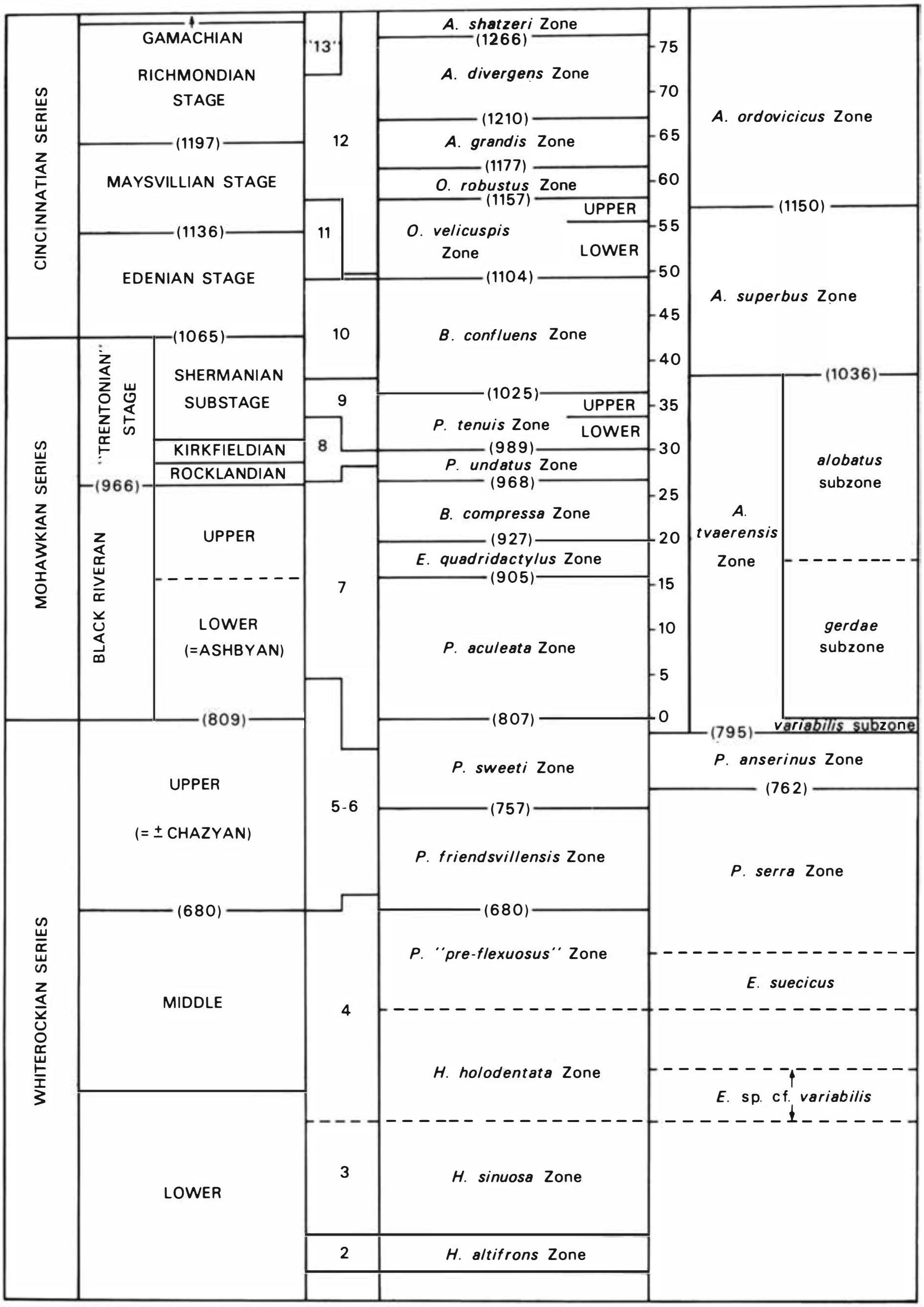


Fig. 2 – Middle and Upper Ordovician chronostratigraphic units (left two columns); conodont faunal units of Sweet, et al. (1971) (third column from left); conodont-based chronozones (fourth column); post-Whiterockian Standard Time Units (fifth column); and North Atlantic conodont zones of Bergström (1971) (right column). Vertical dimension and extent of all units determined from graphic correlation. Pre-Mohawkian conodont chronozones are defined in this report. CSS and SRS values of important stratigraphic boundaries given in parentheses.

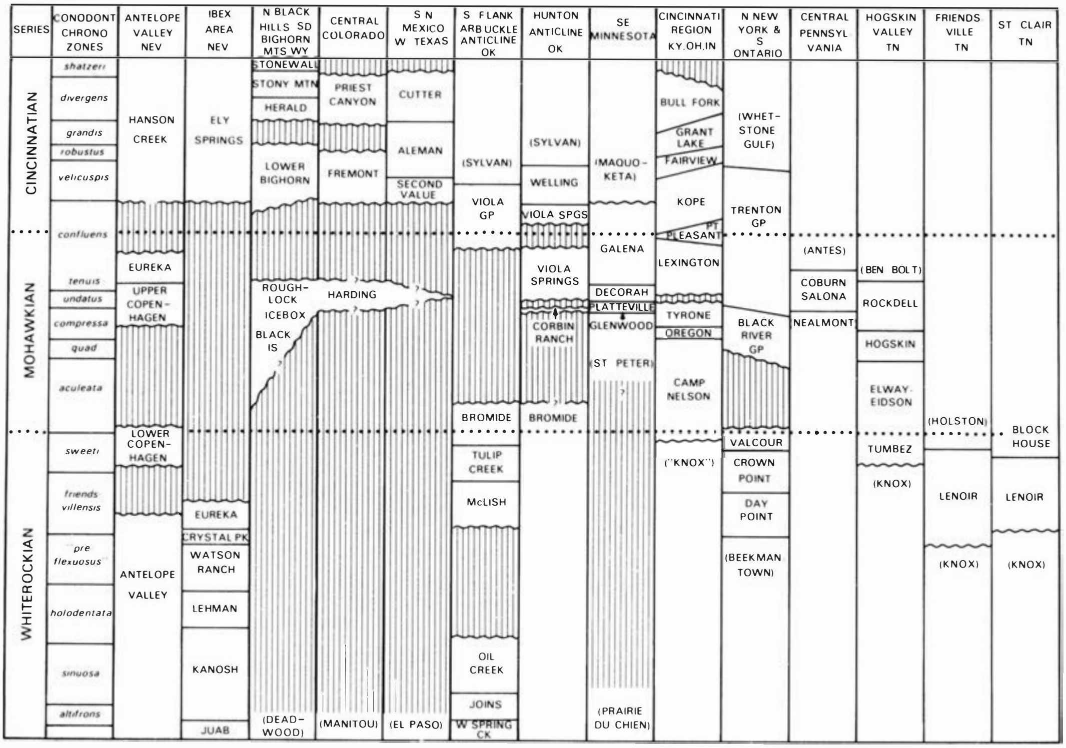


Fig. 3 – Correlation of lithostratigraphic units of selected localities in the United States, as determined by graphic correlation based on conodonts. Names in parentheses are those of under- or overlying units for which data usable in graphic correlation are not currently available.

cinnati Region of Kentucky, Ohio and Indiana was chosen as SRS. Pre-Mohawkian rocks have also been considered, primarily to ensure that the Mohawkian-Cincinnatian network could ultimately be extended to include older Ordovician strata, but also to be certain that there would not be overlap or gaps between the results of separate exercises. Results of graphic correlation at the end of the fifth recorrelation round are summarized in Figs. 6 and 8–13, and in the Appendix, which includes the names and fifth-round CSS ranges of all species used in correlation.

The upper, post-Whiterockian part of Fig. 2 summarizes the extent and relations of stratotypes of the chronostratigraphic units assembled by graphic correlation and indicates their relationship to pre-Mohawkian units. The vertical scale of Fig. 2 is that of the CSS; hence the extent of the units shown is proportional to their chronologic extent. Fig. 3 shows the lithic units recognized in the sections considered, at the vertical scale and the position indicated by graphic correlation.

Resolution. – Widths of the arrays (or W) used to establish the LOC's that relate sections of the graphic network to the SRS may be used empirically to set limits of maximum error. In the network described here, W has a maximum value of 6 m; hence a division of the SRS 6 m thick is the thinnest one that can be recognized with confidence in all component sections of the network. Thus the 477-m SRS (and the CSS based on it) may be divided into 79.5 6m units, the equivalents of which may be located in all sections of the network through use of the appropriate equations. Shaw (1964) argues persuasively that each of these SRS (and CSS) divisions, termed "Standard Time Units" (STU), represents the same length of time and

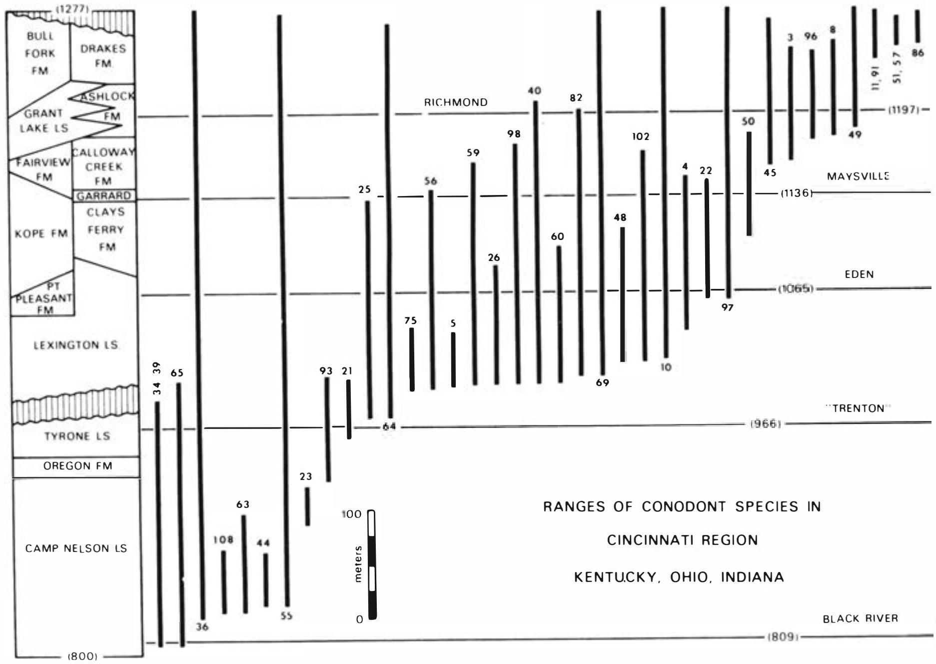


Fig. 4 – Ranges of conodont species in the Middle and Upper Ordovician of the Cincinnati Region, Kentucky, Ohio and Indiana. Data from Sweet (1979 a) and Votaw (1971). Names of species listed by number in Appendix.

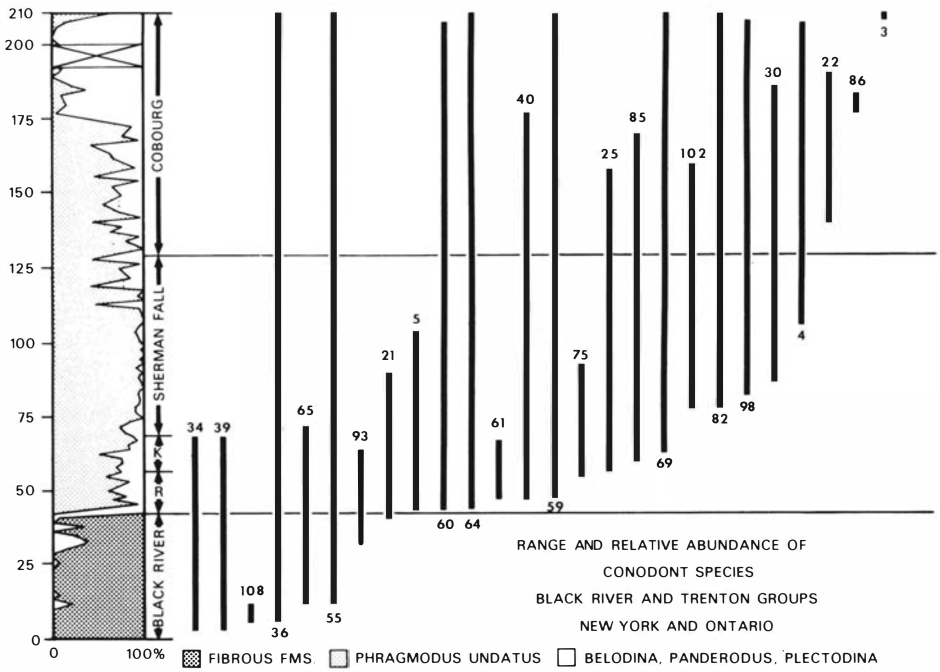


Fig. 5 – Ranges of Middle and Upper Ordovician conodont species in New York and southern Ontario. Relative-abundance log at left charts contribution of major faunal components. Data largely from Schopf (1966) and Votaw (1971); names of species listed by number in Appendix.

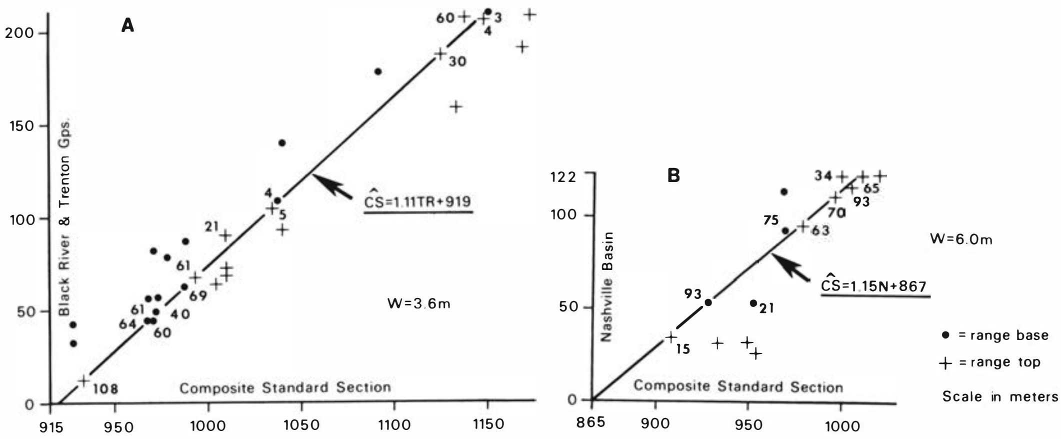


Fig. 6 – A, Graphic correlation of Black River and Trenton groups of New York and southern Ontario with Composite Standard Section. B, Graphic correlation of upper Murfreesboro, Pierce, Ridley, Lebanon and Carters formations of the Nashville Basin, Tennessee, with the Composite Standard Section. Data from Votaw (1971), sections 70VJ, VK, VL and VM. Names of species listed by number in Appendix.

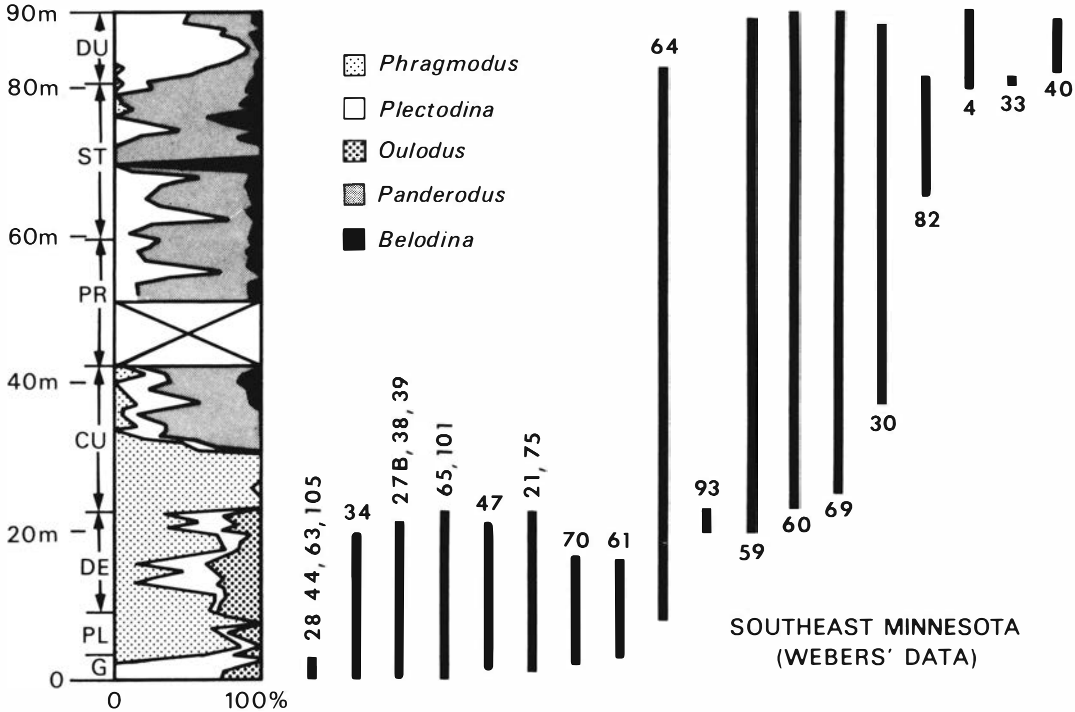


Fig. 7 – Ranges and relative abundances of conodont species in Glenwood (G), Platteville (PL) and Decorah (DE) formations and in Cummingville (CU), Prosser (PR), Stewartville (ST) and Dubuque (DU) members of Galena Formation in southeast Minnesota. Names of species listed by number in Appendix. Data from Webers (1966) and Votaw (1971, section 70VH). Species 33 is not known from southeast Minnesota, but occurs in uppermost Stewartville near Kendallville, Iowa.

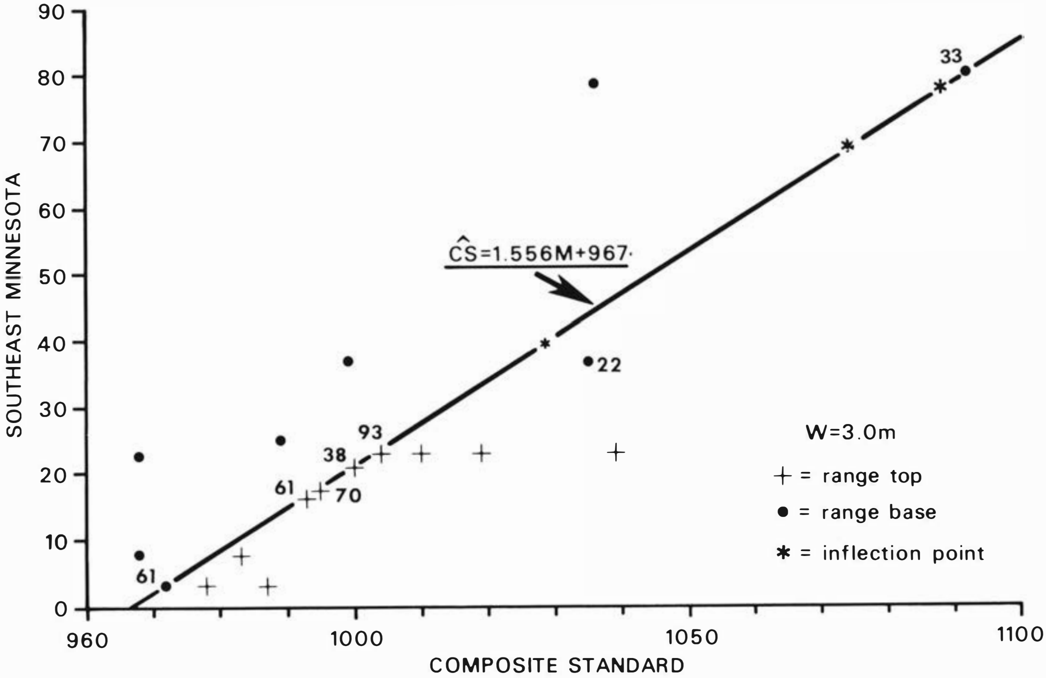


Fig. 8 – Graphic correlation of Glenwood, Platteville, Decorah and Galena formations of southeast Minnesota with Composite Standard Section. B33 plots on, but has not been used to determine LOC; its position, however, appears to confirm the fit made. Names of species listed by number in Appendix.

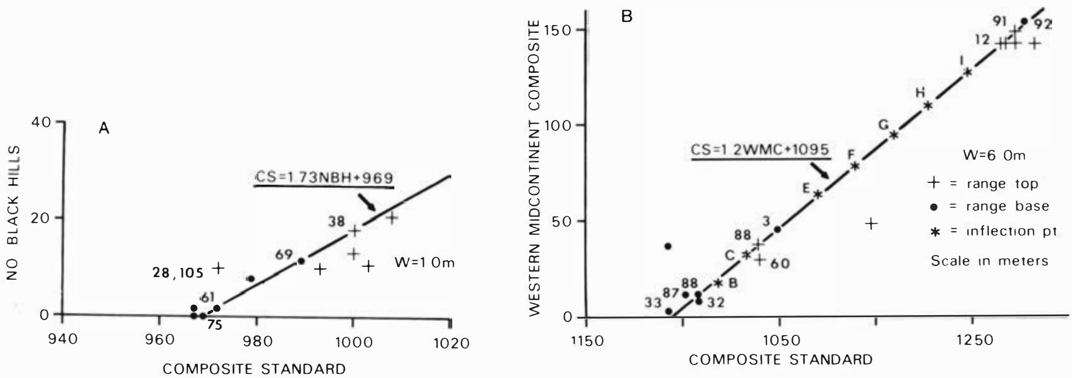


Fig. 9 – A, Graphic correlation of Icebox and Roughlock members of Winnipeg Formation of northern Black Hills, South Dakota, with the Composite Standard Section. Data from Sweet (1982). B, Graphic correlation of Western-Midcontinent CSS with Composite Standard Section; Western-Midcontinent CSS on Y axis summarizes range-data from 10 localities in South Dakota, Wyoming, Utah, Colorado, Kansas, New Mexico and Texas (Sweet, 1979 b). Names of species listed by number in Appendix.

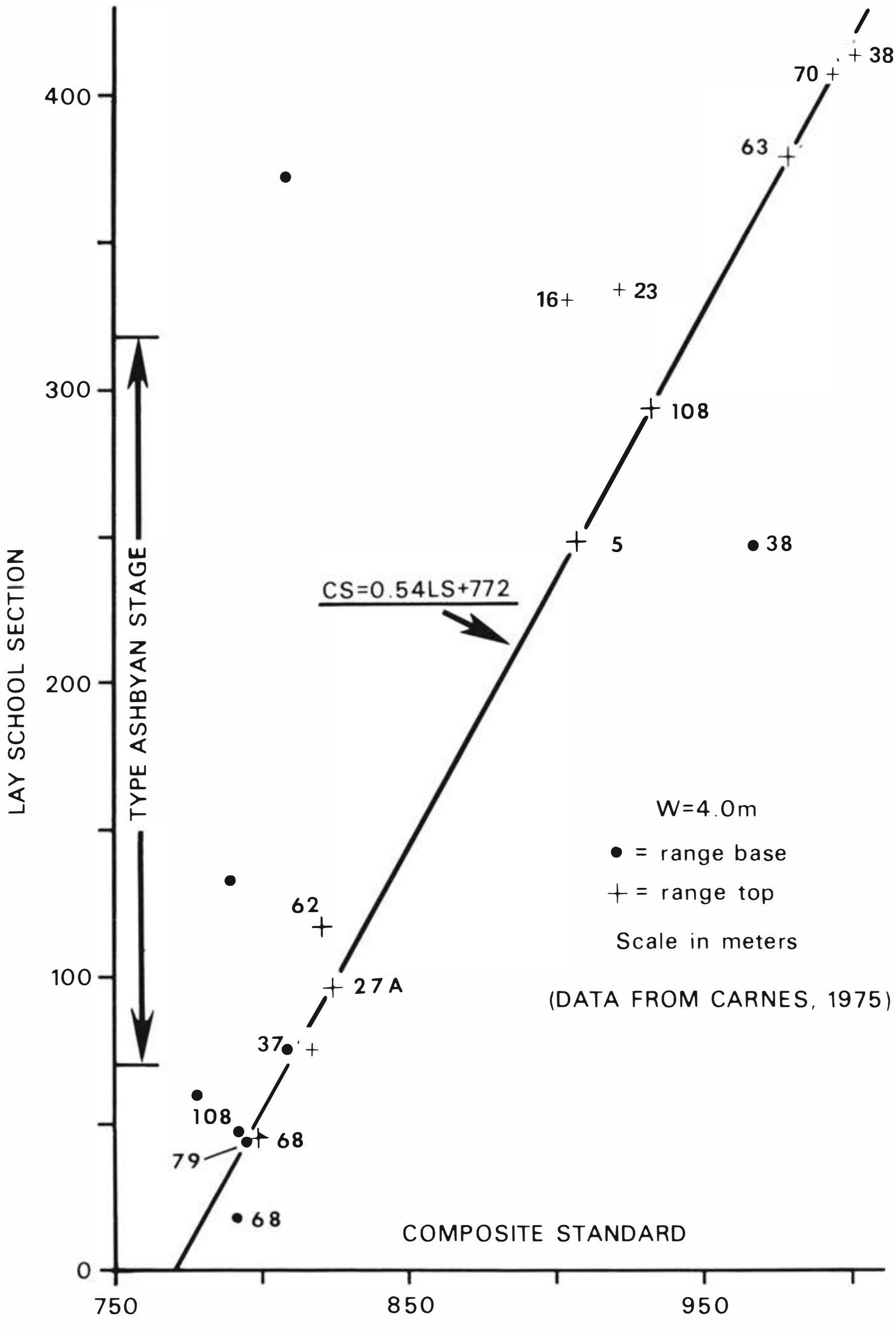


Fig. 10 – Graphic correlation of section at Lay School, northeastern Tennessee, with Composite Standard Section. Data from Carnes (1975). Elway-Eidson and Hogskin formations, 70–318 m above base of section, are stratotype of Ashbyan Stage of Cooper (1956). Bergström (in Ross et al. 1982) proposes that base of Elway-Eidson in this section be base of redefined Mohawkian Series. Names of species listed by number in Appendix.

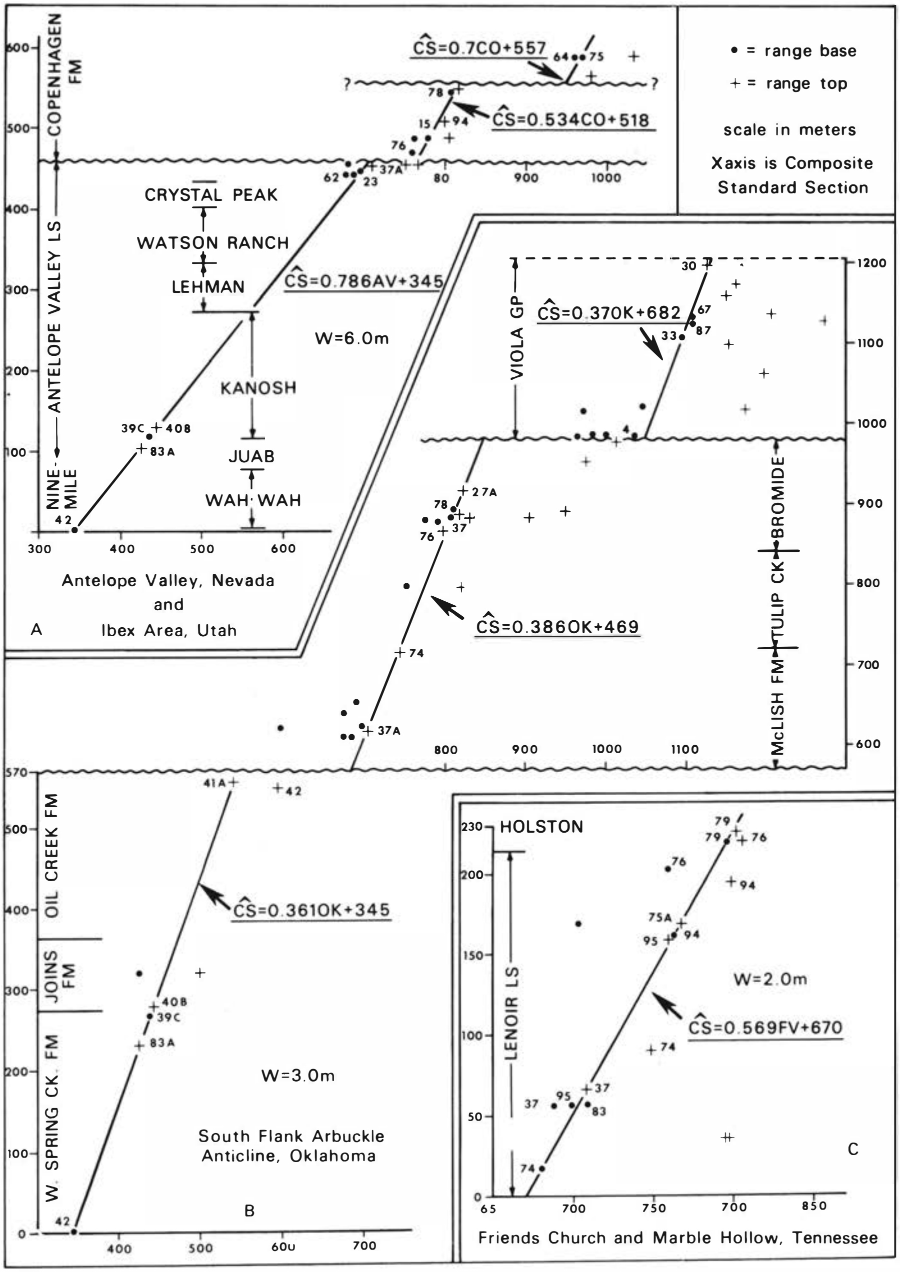
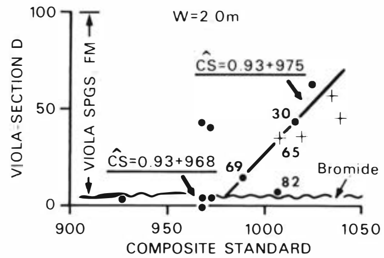
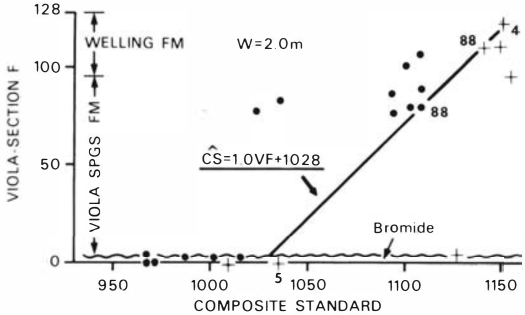


Fig. 11 – A, Graphic correlation with Composite Standard Section of Antelope Valley, Nevada – Ibex, Utah, composite section. Data largely from Harris et al. (1979) and Ethington & Clark (1982). Regional SRS is Antelope Valley-Copenhagen Limestone section described by Ross (1970) and Harris et al. (1979). B, Graphic correlation with Composite Standard Section of the upper West Spring Greek-Viola Group sequence along Interstate Highway 35, Arbuckle Mountains, Carter County, south-central Oklahoma. Data largely from undescribed Ohio State University collections, parts of which are now under study by Mr. Russell Dresbach. C, Graphic correlation with Composite Standard Section of the Friends Church-Marble Hollow section of Friendsville, Tennessee. Data from Bergström (1973) and Bergström & Carnes (1976). Lenoir strata in lower 90 m of this section are the stratotype of Cooper's (1956) Marmorian Stage. Names of species listed by number in Appendix.





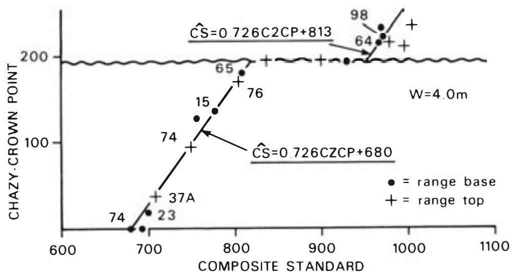


Fig. 12 – Graphic correlation of Viola Group at Alberstadt's (1973) localities D (above) and F (below) in the Arbuckle Mountains, south-central Oklahoma. Data from Oberg (1966) and Amsden & Sweet (1983). Names of species listed by number in Appendix.

Fig. 13 – Graphic correlation of Chazy Group (below unconformity) and Black River Group (above unconformity) of Lake Champlain Valley, New York. Data for Chazy from Raring (1972) and Roscoe (1973); Black River data from Roscoe (1973). Raring's qualitative statements of range assembled on Oxley & Kay's (1959) measured section of Chazy Group and compared graphically after network based on other sections had reached stability. Names of species listed by number in Appendix.

that the scale built from them is absolute.

Of the 79.5 STU's in the SRS, 78 represent post-Whiterockian time. Ordovician rocks at the top of the Bighorn succession in northern Wyoming (Fig. 3) are younger than any in the Cincinnati Region, however, and extend the SRS upward by 11 m, or nearly two STU's. Thus, a major result of the graphic-correlation exercise summarized here is division of a CSS for the post-Whiterockian Ordovician of the North American Midcontinent into 80 STU's, each closely similar or identical to all the others in temporal extent and each recognizable with confidence in all component sections of the graphic network. If the post-Whiterock Ordovician was about 37 million years long (Ross *et al.* 1982), then each STU represents 462,500 years.

The post-Whiterockian Ordovician of North America is divided into eight stages (Ross *et al.* 1982) and is embraced by just three of Bergström's (1971) North Atlantic conodont zones, the *A. tvaerensis, A. superbus* and *A. ordovicicus* zones. Thus the capacity to resolve 80 divisions within this same stratigraphic interval increases resolution by 10 to as much as 27 times.

Chronozones

In the central column of Fig. 2, the post-Whiterockian Ordovician is divided into 11 named zones. Six others are indicated provisionally for the Whiterockian primarily to set the younger ones in chronostratigraphic context. All these zones are subdivisions of the CSS derived from graphic compilation of conodont range data at the localities shown in Fig. 1. They are vertically contiguous groups of STU's, the boundaries of which are the actual or projected levels in the SRS at which the name-giving conodont species first appear. These zones are thus chronozones rather than biostratigraphic zones. Their chronologic equivalents may be recognized with confidence only in sections that are parts of the graphically correlated network, or in sections that can be added to the network by the same procedures used to establish it. Informally, however, these units may be used with perhaps greater precision of meaning than the numbered conodont faunal intervals of Sweet *et al.* (1971), which were never intended to be biostratigraphic or chronostratigraphic units but have been treated as such by numerous authors.

The post-Whiterockian conodont chronozones named in Fig. 2 have boundaries in the CSS and SRS indicated in that figure. Lists of conodont species characteristic of those chronozones may be compiled from the CSS in the Appendix.

Conclusions

The procedures and results summarized in this severely abbreviated report are sufficient to indicate that a chronostratigraphic network that resolves at a level 10 to 27 times higher than any previously proposed, can be constructed from existing data on the stratigraphic ranges of conodonts. The stable framework may be divided into units of various sorts, to suit different stratigraphic purposes and, because it is conceptually absolute, the framework may also be useful for constructing detailed paleogeographic maps or for considering biologic or sedimentologic problems in which rate is an important consideration. However, it should also be noted that each new section compiled will necessitate reconsideration of the entire network, and that chronostratigraphic divisions of the framework are recognizable only in sections that are components of the network or can be added to it by use of the same procedures employed in assembling it.

Appendix

The Composite Standard Section

Species No.	*Species Name*	*Range in CSS*
3	*Amorphognathus ordovicicus*	1150–1269
4	*A. superbus*	1036–1151
5	*A. tvaerensis*	968–1035
6	*Aphelognathus divergens*	1210–1264
7	*A. floweri*	1153–1255
8	*A. grandis*	1177–1248
11	*A. pyramidalis*	1234–1270
12	*A. shatzeri*	1266–1288
15	*Appalachignathus delicatulus*	778– 907
16	*Belodella nevadensis*	603– 949
21	*Belodina compressa*	927–1019
22	*B. confluens*	1025–1169
23	*B. monitorensis*	698– 953
25	*Bryantodina abrupta*	973–1133
26	*B. staufferi*	997–1085
27A	*B.* n. sp. cf. *B. typicalis*	795– 824
27B	*B. typicalis*	967–1000
28	*Chirognathus duodactylus*	967– 987

30	*Coelocerodontus trigonius*	1015–1126
32	*Culumbodina occidentalis*	1104–1154
33	*C. penna*	1092–1167
34	*Curtognathus expansus*	807–1008
36	*Drepanoistodus suberectus*	680–1288
37	*Eoplacognathus elongatus*	811– 822
37A	*E. foliaceus-reclinatus* transition	687– 708
37C	*E. suecicus*	613–651
38	*Erismodus quadridactylus*	905–1000
39	*E. radicans*	807–1008
39C	*Histiodella altifrons*	437– 500
39D	*H. holodentata*	537– 690
39E	*H. sinuosa*	461– 699
40	*Icriodella superba*	972–1205
40B	*Jumudontus gananda*	264–445
41	*Leptochirognathus* sp.	532– 797
41A	*"Microzarkodina" marathonensis*	193– 546
42	*Oistodus multicorrugatus*	345– 598
44	*Oneotodus ovatus*	797–972
45	*Oulodus robustus*	1157–1283
46	*O. rohneri*	1217–1285
47	*O. serratus*	969–1000
48	*O. oregonia*	1014–1111
49	*O. ulrichi*	1102–1288
50	*O. velicuspis*	1104–1184
51	*Panderodus angularis*	1243–1274
55	*P. gracilis*	680–1286
56	*P. panderi*	793–1286
57	*P. staufferi*	1236–1282
59	*Dapsilodus mutatus*	795–1278
60	*Periodon grandis*	968–1149
61	*Phragmodus cognitus*	972– 993
61A	*P.* n.sp. *("pre-flexuosus")*	614–692
62	*P. flexuosus*	680– 835
63	*P. inflexus*	789– 978
64	*P. undatus*	968–1282
65	*Plectodina aculeata*	807–1008
67	*P. florida*	1102–1271
68	*P. joachimensis*	781– 798
69	*P. tenuis*	989–1272
70	*P.* n.sp.	680– 995
74	*Polyplacognathus friendsvillensis*	680–749
75	*P. ramosus*	969–1039
75A	*P. rutriformis*	703– 766
76	*P. sweeti*	757– 805
78	*Prioniodus gerdae*	809– 814
79	*P. variabilis*	795– 799
82	*Protopanderodus liripipus*	980–1198
83	*P. varicostatus*	702–822
83A	*Protoprioniodus aranda*	354– 427
85	*Pseudobelodina dispansa*	986–1280
86	*P. inclinata*	1092–1268
87	*P. kirki*	1101–1257
88	*P. ? obtusa*	1108–1141
91	*P. vulgaris vulgaris*	1108–1273
92	*P. vulgaris ultima*	1278–1286
93	*P.* n. sp.	927–1004
94	*Pygodus anserinus*	762– 799
95	*P. serra*	702– 761
96	*Rhipidognathus rowlandensis*	1176–1240
97	*R. symmetricus*	1058–1278
98	*Rhodesognathus elegans*	971–1174
101	*Scyphiodus primus*	967–1003
102	*Staufferella falcata*	890–1167
105	*Stereoconus gracilis*	967–986
108	*Triangulodus* n.sp.	793– 932

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