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Graphic correlation of Argentine Precordillera and North American Lower/Middle Ordovician sections

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*Present work demonstrates that a level equivalent to the proposed Whiterockian basal GSSP can be located graphically in a composite section anchored by the Niquivil section of the Argentine Precordillera. The FAD of *Cooperignathus aranda* in the Niquivil composite section, a candidate for GSSP of the Lower/Middle Ordovician boundary, projects to a level very close to the FAD of *Tripodus laevis* in the Whiterockian reference section. The conodont-based framework reported here includes the potential for recognition of the proposed Whiterock Canyon-based GSSP, the *Cooperignathus aranda*-based GSSP, and, possibly, the *Baltoniodus triangularis*-based GSSP, recently proposed.*

Introduction

In a study completed more than four years ago, but published only recently, Sweet, Ethington and Harris (2005) report on the assembly by graphic means of a conodont-based composite reference section for the Whiterockian Series. The compiled reference section has six components, including the well-known section in Whiterock Canyon, Monitor Range, Nevada, in which Ross and Ethington (1991) sited the basal stratotype of the lower Middle Ordovician Whiterockian Series at the base of the *Orthidiella* brachiopod Zone. In their report, Sweet, Ethington and Harris compile the Whiterockian composite reference section graphically with the Ibexian/Whiterockian composite that was assembled by Sweet and Tolbert (1997) and with a major composite assembled in several steps by Sweet (1979, 1984, 1995a, 1995b) from range-data on Ordovician conodonts in sections at more than 80 localities in eastern and western United States. Thus, the resultant composite section spans the entire Ordovician and serves as a template for evaluation and high-resolution correlations in this important system. The pan-Ordovician composite section is shown by Sweet (2005), who also comments on its assembly.

Until recently, discussions of temporal correlations of Ordovician rocks have been conducted within a very traditional biostratigraphic framework composed of biozones of varying type and scope. Conodonts and graptolites have been important in establishing and recognizing these biozones. Conodonts have been especially useful because of their common occurrence in a variety of lithofacies, because of the ease of their extraction from samples of marine rock, and because of the widespread distribution in Paleozoic and Triassic seas of many species. Despite these factors, however, it has not yet been possible to extend worldwide any particular scheme of biostratigraphic zones. However, because the distribution of conodonts in many Ordovician sections has been reported in non-zonal context these range data are especially useful in a method of stratigraphic correlation commonly termed graphic correlation.

In the Whiterock Canyon section, the conodont *Tripodus laevis* (or *T. combsi*) also appears for the first time at (or very near) the base of the *Orthidiella* Zone; hence, in subsequent discussions of Ordovician conodont biostratigraphy the first occurrence of *T. laevis* has commonly been used to mark the base of the Whiterockian Series and thus, in North America at least, of the Middle Ordovician. Graphic correlation of lower Middle Ordovician rocks in central Nevada demonstrates, however, that *Tripodus laevis* occurs first at a level some 40 csu (= composite-standard units) below its first appearance in the Whiterock Canyon section. Thus *T. laevis* cannot serve as a reliable regional marker of the Whiterockian base. Indeed, Sweet, Ethington and Harris (2005) concluded that they were "...unable to identify a single conodont species, in a credible developmental sequence, to serve as biological marker of [the basal Whiterockian] boundary."

Although unable to cite the first occurrence of any conodont species as regional marker of the Whiterockian stadial base, Sweet, Ethington and Harris (2005) were able to integrate the Whiterock Canyon section graphically into their Whiterockian reference section. Thus they could demonstrate that the GSSP is 599 csu above the base of the pan-Ordovician composite section detailed in their report. Unfortunately, that level can be identified only in sections that can be compared graphically with the Whiterockian reference section established in Sweet, Ethington and Harris's report.

The purpose of this brief report is to demonstrate that a level equivalent to the Whiterockian basal GSSP can also be located graphically, with some confidence, in a composite section anchored by the Niquivil section of the Argentine Precordillera. Furthermore, it can be shown graphically that the FAD of *Cooperignathus aranda* in the Niquivil composite section, a candidate for GSSP of the Lower/Middle Ordovician boundary, projects to a level very close to the FAD of *Tripodus laevis* in the Whiterockian reference section that was assembled graphically by Sweet, Ethington and Harris (2005). Finally, it is also shown that graphic-correlation procedures may also enable assembly of a high-resolution, non-biozonal, international chronostratigraphic framework within which to address and solve problems of Ordovician correlation.

Procedures

Using range data abstracted from the literature for the Niquivil, Peña Sombra, and Yanso sections (Albanesi et al., 1998, Albanesi et al., 2003, 2004) a Precordilleran composite section was compiled, with the Niquivil section serving as SRS (= standard reference section). This essentially straightforward procedure yielded the correlations shown in Figure 1. Range data used are given in Table 1.

Next, in Figure 2, the Niquivil-based Precordilleran composite section, given in Table 1, was plotted against the North American Midcontinent Composite section, also given in Table 1. Data for the

Figure 1 Relations between the three Precordilleran Ordovician sections compiled to form the Niquivil-based Composite Section. The Niquivil section is shown at its field-measured scale; the Yanso and Peña Sombria sections are shown at the vertical scale indicated by their graphic correlation with Niquivil. The Whiterockian base, which defines the L/M Ordovician boundary in North America, is projected at the level indicated in Figure 2.

Table 1 Numbers given in columns headed Niq-B and Niq-T, PY-B and PY-T, and PS-B and PS-T are FADs and LADs of the conodont species named in the column headed "Species". In the columns headed .82PYB+7.4 and .82PYT+7.4, and .83PSB+94.13 and .83PST+94.13, FADs and LADs of species represented in the Yanso and Peña Sombria sections are listed in terms of the relations indicated by their graphic correlation with the Niquivil section. The columns headed CS-B and CS-T include the lowest and highest ranges of species given in columns to the left. The columns at the right, headed MCB and MCT list the FADs and LADs in the N. American Midcontinent Composite Standard section of the species listed in the column headed "Species."

#	Species	Niq-B	Niq-T	PY-B	PY-T	PS-B	PS-T	82PYB+7.4	82PYT+7.4	83PSB+94.13	83PST+94.13	CS-B	CS-T	MCB	MCT
2	Acodus deltatus	21	22	0	2			7	9			7	22	340	550
3	Anodontos longus	13	14									13	14		
4	Ansellia jemtlandica	133	134	99	320	5	23.5	89	270	98	114	89	270	606	806
6	Baltoniodus navis			248	279			211	236			211	236		
7	B. norrlandicus			309	309			261	261			261	261		
8	B. triangularis			277	277			235	235			235	235		
8 A	Baltoniodus sp.					22	22.5			112	113	112	113		
9	Bergstr. extensus	46	104	0	120	1	5	7	106	95	98	7	106		
10	Cooperign. aranda	100	134	129	310	7	23.5	113	262	100	114	100	262	554	614
11	Cornuodus longibasis	46	104	8	310	1	13	14	262	95	105	14	262	260	658
11 A	Costiconus costatus					7	23.5			100	114	100	114		
12	Decorf. peselephantis	71	72	1	310	3	23.5	8	262	96	114	8	262	437	549
13	Diaphorodus russoi			1	147			8	128			8	128	365	646
14	Dipahorodus tovei			34	34			35	35			35	35		
15	Drepanodus arcuatus	14	139	0	320	2	23.5	7	270	96	114	7	270	315	654
15 A	D. reclinatus					1	1.5			95	96	95	96		
17	D. basiovalis			267	310			226	262			226	262	269	615
19	D. costatus	120	121									120	121		
20	D. forceps	14	127	120	320	3	23.5	106	270	96	114	14	270	293	688
21	D. pitjanti			244	310			208	262			208	262		
24	D. venustus			256	267			217	226			217	226	860	1245
25	Erraticodon balticus			303	320			256	270			256	270	704	858
26	Fahr. marathonsensis					2	23.5			96	114	96	114	413	735
28	Juanogn. jaanussoni	111	149	105	310			94	262			94	262	552	731
29	J. sserratus			310	310			262	262			262	262		
30	J. variabilis	64	107	64	127	1	3	60	112	95	96	60	112	438	637
31	Jumudontus brevis	46	47									46	47		
32	Jumudontus gananda	71	145	180	180			155	155			71	155	487	618
33	Kalidontus corbatoi	46	47			1	1.5			95	96	46	96		
35	Lundodus gladius	71	72	99	132	1	5	89	116	95	98	71	116	235	279
36	Microz. fiabellum			298	303	22	22.5	252	256	112	113	112	256	559	606
37	M. parva			294	303			244	256			244	256		
38	Oelandodus elongatus	14	21					14	79			14	21		
39	Oelandodus costatus			8	87							14	79	585	595
40	Oenikodus communis	87	121	46	110			45	98			45	121	438	618

(Continued)

4 1	Oepikodus evae	64	102	75	120	1	5	69	106	95	98	64	106	558	612
4 2	Oepikodus intermedius	97	139	99	152			89	132			89	139		
4 2 A	Oepikodus n. sp.					22	22.5			112	113	112	113		
4 3	Oistodus lanceolatus	67	147	168	320	11	22	145	270	103	112	67	270	527	647
4 4	O. multirugatus	121	145									121	145	507	816
4 5	Oistodus striolatus			2	310			9	262			9	262		
4 6	Paltodus jemtländicus			256	310			217	262			217	262	599	658
4 7	Paltodus subaequalis	14	21	1	108			8	96			8	96	301	372
4 9	Paracordy. gracilis	21	22	0	75			7	64			7	64	293	444
5 0	Parapalt. simplicicimus	100	101	29	310			31	262			31	262		
5 1	Parapand. paracornu.			180	310			155	262			155	262	552	624
5 2	P. striatus	97	100									97	100	279	816
5 3	Paroist. cordylodi.	21	22									21	22		
5 5	P. originalis	71	140	99	320	1	23.5	89	270	95	114	71	270	561	685
5 6	P. paralellus	14	98	1	140			8	122			8	122	298	650
5 7	P. proteus	14	46	0	12			7	17			7	46		
5 8	P. n. sp.	93	94	129	132			113	116			93	116		
5 9	Periodon ac. zgierz.			259	320			220	270			220	270	Pa=563	Pa=914
6 0	P. flabellum	64	138	99	310	1	23.5	89	262	95	114	64	262	554	640
6 1	P. gladysi			309	310			261	262			261	262	599	676
6 2	P. primus	14	21			2	2.5			96	96	14	96		
6 3	P. selenopsis			1	132			8	116			8	116		
6 5	Polonodus galerus			309	310			261	262			261	262		
6 7	Prioniodus adami			87	92			79	83			79	83		
6 8	Prioniodus elegans	14	67	8	75			14	69			14	69		
6 9	Prioniodus oepiki			0	1			7	8			7	8		
7 0	Protopand. elongatus	80	145	2	152	1	1.5	9	132	95	95	9	145	508	676
7 1	P. gradatus	71	139	34	320	1	23.5	36	270	95	114	36	270	479	735
7 2	P. leonardii	14	108	0	120			7	106			7	108	428	666
7 3	P. nogamii	111	147			5	5.5			98	99	98	147		
7 4	P. rectus			64	320			60	270			60	270	559	724
7 6	Protoprion. papillosus	93	121	129	259			113	220			93	220	565	631
7 7	P. simplicissimus	22	108	256	256			217	217			22	217	356	539
7 8	Pteracont. cryptodens			244	320			208	270			208	270	566	750
8 0	Reutterodus andinus	22	108	0	120	1	3	7	106	95	96	7	108	489	588
8 1	Rossodus barnesi	22	121	1	310	7	23.5	8	262	100	114	8	262		
8 2	Scolopodus krummi	14	106	1	127			8	112			8	112		
8 3	S. oldstockensis	64	139	99	277			89	235			64	235		
8 3 A	Scolopodus striatus					5	23.5			98	114	98	114		
8 4	Scolopodus rex			147	279			128	236			128	236	260	598
8 5	Semiacont. portreril.	119	146	129	310	22	22.5	113	262	112	113	112	262		
8 6	Spinodus spinatus			236	310			201	262			201	262	466	466
8 7	Stiptognathus borealis			1	8			8	14			8	14	432	537
8 8	Stolodus stola	97	108	92	99	1	1.5	83	89	95	96	83	108	543	552
8 9	Texania heligma	100	133	127	152	22	22.5	112	132	112	113	100	133		
9 0	Triangulodus brevi.	144	145									144	145		
9 1	Tripodus laevis s.l.	128	150	147	277			128	235			128	235	554	730
9 1 A	Tripodus sp.									112	113	112	113		
9 2	Tripodus australis	80	107	99	129	22	22.5	89	113			80	113		
9 3	Tropodus comptus	14	73	2	46			9	45			9	73	347	571
9 4	Tripodus sweeti	14	106	0	103	1	1.5	7	92	95	96	7	106		
9 5	Ulrichodina quad.	0	21									0	21		
9 6	Walliserodus costatus			267	310			226	262			226	262		

latter were extracted from the right-hand column of Appendix B in the report by Sweet, Ethington and Harris (2005). In Figure 2, note that a line of correlation (LOC), with the equation $0.33Y+521$, defines the boundary between an area of the graph that includes nearly all the FADs (plotted as circles) from an area that includes nearly all the LADs (plotted as crosses). Note, also, that a vertical line at MC-599 would intersect the LOC 235 csu above the base of the Niquivil-based composite section. That level, although well above the top of the Niquivil section itself, is the approximate equivalent in the Niquivil-based composite section of the basal Whiterockian GSSP. The Niquivil FAD of *Cooperignathus aranda* (species 10), proposed as marker of the Lower/Middle Ordovician boundary, projects to the 554 csu level in the North American Mid-continent composite section, some 45 csu below the projected base of the Whiterockian Stage. In short, formal sitting of the Lower/Middle Ordovician boundary GSSP at the FAD of *Cooperignathus aranda* in the Niquivil section of the Argentine Precordillera would substantially lower the position of that boundary in North American Ordovician sections — however, in the graphically-derived frame-

work indicated in this report, one might easily recognize both the Whiterock Canyon-based GSSP and the *Cooperignathus aranda*-based GSSP proposed in another part of this report.

Baltoniodus triangularis, whose FAD in the Huanghuachang section of China has been proposed as GSSP of the Lower/Middle Ordovician boundary (Stouge et al., 2005), is not known in the Ibexian-Whiterockian sections of western North America compiled by Sweet and Tolbert (1992) or Sweet, Ethington and Harris (2005), and it has been identified at only one level in the three components of the Precordilleran composite section compiled in this report. Thus, in at least the Argentine Precordillera and western North America, *Baltoniodus triangularis* would not be useful as a guide to the Lower/Middle Ordovician boundary. It is of interest to note, however, that the single level of occurrence of *B. triangularis* in Precordilleran sections, projects to the 599 csu-level in the Ibexian-Whiterockian composite section assembled graphically by Sweet, Ethington and Harris (2005). Thus, the conodont-based framework reported here includes the potential for recognition of the Whiterock Canyon-based GSSP proposed many years ago by Ross and Ething-

ton (1991), the *Cooperignathus aranda* -based GSSP proposed by Albanesi et al. (2003, 2004), and, possibly, the *Baltoniodus triangularis* -based GSSP proposed recently by Stouge et al. (2005).

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The Neuquén Basin, Argentina

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