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COSTATION PATTERNS IN EARLY PENNSYLVANIAN SPIRIFERIDS

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Species discrimination of Early and Middle Pennsylvanian spiriferids in the United States has been based on morphologic characters that commonly are defined poorly and are difficult to assess on many specimens. The frequency distribution of number and pattern of lateral costae as discussed below is judged to afford another useful character for species discrimination. These spiriferids, long assigned to *Spirifer* Sowerby but recently described (Lane, 1963) as a separate genus, *Anthracospirifer* Lane, include *Anthracospirifer occiduus* (Sadlick), *A. opimus* (Hall), and *A. birdspringensis* Lane, which hereafter are referred to by their trivial names.

One sample each of these three species was obtained from three separate beds in the lower part of the Bird Spring Formation in Clark County, Nevada, and the samples were studied in detail as to the number and arrangement of lateral costations. Each sample had a frequency distribution of numbers of specimens with a specific number or pattern of lateral costae that allowed the samples to be discriminated statistically with respect to these variables.

The sample of 25 specimens from the stratigraphically lowest of the three beds (UCLA Loc. 4622) is identified as *Anthracospirifer occiduus* (Sadlick), based on the specimens' large size, extended hinge line, and large number of lateral costae, the inner ones of which commonly bifur-

cate (Sadlick, 1960; Easton, 1962). Forty-eight spiriferids from a thin bed of shale about 15 feet stratigraphically above the occurrence of *occiduus* (UCLA Loc. 4621), are identified as *opimus* (Hall). These spiriferids are somewhat smaller than *occiduus*, have a shorter hinge and more rounded lateral extremities, and fewer lateral costae that commonly do not split (bifurcate). The third and stratigraphically highest sample (UCLA Loc. 4414) consists of 45 topotypes of *birdspringensis*.

Because the arrangement of costae on the flank of a pedicle valve is a counterpart mirror image of the costation arrangement on the same brachial valve flank of the same specimen, all costation patterns are recorded as if they were developed on the right flank of a pedicle valve. Right and left as used here are the same for the specimen and observer, with the specimen oriented with the posterior toward the observer and the brachial valve up.

Each lateral flank on which the arrangement of costae could be tabulated accurately is recorded as a separate observation on Table 1 and in subsequent calculations based on that table. Lateral costae in this group of spiriferids consist of two types: those originating close to the beak or along the edge of the interarea and here called primary lateral costae; and those originating by splitting or bifurcation from primary lateral costae some distance from the beak, across the

TABLE 1—PATTERNS OF LATERAL COSTAE IN THREE SAMPLES OF *Anthracospirifer* LANE

Number of lateral costae	Pattern	Number of observed flanks		
		<i>occiduus</i>	<i>opimus</i>	<i>birdspringensis</i>
6	S-1-5	—	—	3
	S-1-a1-3	—	—	1
7	S-1-6	—	3	3
	S-1-a1-4	—	—	5
8	S-1-7	—	8	4
	S-1-a1-5	—	—	6
	S-1-a1-a1-3	—	—	6
	S-1-a1a-4	—	—	1
9	S-1-8	2	10	—
	S-1-a1-6	—	7	4
	S-1-a1-a1-4	—	1	2
	S-1-a1a-5	—	—	2
	S-1-a1a-a1-3	—	—	2
	S-1-1-1-a1-3	1	—	—
	S-1-1-a1-5	1	—	—
10	S-1-9	1	2	—
	S-1-a1-7	2	9	—
	S-1-a1-a1-5	—	3	3
	S-1-a1a-6	2	—	—
	S-1-a1-a1a-4	—	—	1
	S-1-a1a-a1-4	1	—	—
	S-a1-8	—	1	—
	S-a1-a1-a1a-3	—	—	1
	S-1-10	—	1	—
11	S-1-a1-8	4	1	—
	S-1-a1-a1-6	4	—	—
	S-1-a1-1-1-a1-4	1	—	—
12	S-1-a1-9	1	1	—
	S-1-a1a-8	1	—	—
	S-1-a1-a1-7	2	—	—
	S-1-a1-a1a-6	—	—	1
13	S-1-a1-10	—	1	—
14	S-1-a1-a1-9	1	—	—
16	S-a1-a1-a1-a1-a1-6	1	—	—
	Totals	25	48	45

visceral region of the flank. These latter costae are called secondary laterals; they are initially lower and narrower than the primary costa from which each originates, but they gradually increase in prominence anteriorly until each equals a primary costa in size. Among the total 118 flanks recorded, none had secondary costae arising by implantation or intercalation between primary costae nor bifurcating secondary costae.

At the place where a secondary costa originates from a primary costa one can observe on which side of the primary costa the bifurcation occurs. Development of a secondary costa on the admedial side of a primary costa is more common in pedicle valves and is concurrent with a similar development on the abmedial side of a brachial valve primary costa. In order to describe the variation in patterns of primary and

secondary costae, after conversion of costation patterns of brachial valves and left flanks of pedicle valves to the standard recording scheme—as if only right flanks of pedicle valves were observed—the following shorthand notation is used on Table 1. The costa bounding the right edge of the sulcus is denoted "S." This costa originates at the beak, extends the full length of the shell, and is the most admedial lateral costa. From this costa two bifurcations generally occur; one results in an abmedial sulcal costa, and the other is the second lateral costa. The furrow bounding the edge of the fold in the brachial valve is the counterpart of the costa here called "S." This admedial lateral costa (S), and its bifurcations are not included in tabulation of number of splits or number of lateral costae on Table 1 because they are the same on all speci-

mens. Primary lateral costae are designated by the numeral "1," and secondary costae as lower case "a" placed to the right or left of "1," depending on whether the secondary lateral originates on the abmedial or admedial side respectively of the primary. The number of simple, nonbifurcating costae on the distal parts of the flank is indicated at the right of the notation. For example the pattern "S-1-al-ala-3" means that the first primary costa does not split; that the second primary costa has a secondary costa developed on its admedial side; that the third primary costa has secondary ones on both sides; and that the three outer primary laterals are simple, resulting in a total of nine lateral costae.

The three samples were tested for significance of difference in frequency distribution of total number of lateral costae per flank (Table 2) and of total number of bifurcations (splits) per flank (Table 3) using a Chi-square test (Text-fig. 1). In comparison of any two samples the frequency distribution of both variables was significantly different at the 5 percent level of confidence, except for the number of splits in *occiduus* and *birdspringensis*. In addition, the mean number of lateral costae and of splits per flank in each sample was compared using the parametric *t* test (Dixon & Massey, 1957), and each sample had a significantly different mean number of lateral costae and of splits per flank at the 5 percent level of confidence, except for the mean number of splits in *occiduus* and *birdspringensis*. Therefore, statistical analysis of number and arrangement of lateral costae in samples of *Anthracospirifer* is a useful means of discriminating different populations and is a usable criterion for distinguishing between species in conjunction with other morphologic criteria. Consideration of both the pattern and

TABLE 2—NUMBER OF COSTAE PER FLANK IN THREE SAMPLES OF *Anthracospirifer* LANE

No. of costae per flank	<i>occiduus</i>	<i>opimus</i>	<i>birdspringensis</i>
6	0	0	4
7	0	3	8
8	0	8	17
9	4	18	10
10	6	15	5
11	9	2	0
12	4	1	1
13	0	1	0
14	1	0	0
16	1	0	0
Total	25	48	45
Mean	10.9	9.2	8.2

TABLE 3—NUMBER OF SPLITS (BIFURCATIONS) PER FLANK IN THREE SAMPLES OF *Anthracospirifer* LANE

No. of splits per flank	<i>occiduus</i>	<i>opimus</i>	<i>birdspringensis</i>
0	3	24	10
1	9	20	16
2	11	4	16
3	1	0	2
4	0	0	1
5	1	0	0
Total	25	48	45
Mean	1.56	0.58	1.29

number of lateral costae in these three samples shows that 55 percent of the observed flanks of *occiduus* and *opimus* are distinct with respect to specific pattern and number of costae; that 60 percent of the flanks of *opimus* and *birdspringensis* are distinct; and that no flanks of *occiduus* and *birdspringensis* have both the same pattern and number of lateral costae.

Although detailed studies of lateral costae in other Late Paleozoic genera of spiriferids have not been reported, analyses of patterns of costae as described above most probably would serve to distinguish *Anthracospirifer* from *Neospirifer* Fredericks or other genera of Late Paleozoic spiriferids. In summary, this study of lateral costation indicates that *Anthracospirifer birdspringensis* has a significantly small total number of lateral costae and a large number of bifurcations per flank; that *opimus* has a small number and few bifurcations of lateral costae; and that *occiduus* has a larger mean number of lateral costae and common bifurcations of the costae.

Localities.—UCLA Loc. 4621. 750 feet due west of the southeast corner of sec. 18, T. 19 S., R. 59 E., Corn Creek Springs quadrangle, Clark County, Nevada. Five-foot shale exposed in south side of southern branch of main wash, containing *A. opimus*, *Orthotetes* Fischer, productid brachiopods, *Reticulariina* Fredericks sp., *Millerella* Thompson, *Endothyra* Phillips, *Tetrataxis* Ehrenberg, solitary rugose corals, bryozoans, and trilobites.

UCLA Loc. 4622. 100 feet northeast of Loc. 4621, 2-inch thick blue-gray shaly limestone exposed on upper bedding surface of the 3-foot thick limestone with abundant *Orthotetes*, on south side of wash; shaly limestone contains large *Linoproductus* Chao, *Antiquatonia* Miloradovich, *A. occiduus* and bryozoans.

UCLA Loc. 4414. See Lane (1963).

CHI-SQUARE TESTS

NO. OF COSTAE	OC	OP	
	11 OR MORE	15	
10 OR FEWER	10	44	54
	25	48	73

$\chi^2 = 20.1$; $df = 1$;
 $\alpha = 0.05$

NO. OF COSTAE	OC	BI	
	10 OR MORE	21	
9 OR FEWER	4	39	43
	25	45	70

$\chi^2 = 39.7$; $df = 1$;
 $\alpha = 0.05$

NO. OF COSTAE	OP	BI	
	9 OR MORE	37	
8 OR FEWER	11	29	40
	48	45	93

$\chi^2 = 14.6$; $df = 1$;
 $\alpha = 0.05$

NO. OF COSTAE	OC	BI	
	10 OR MORE	19	
9	18	10	28
8	8	17	25
7 OR FEWER	3	12	15
	48	45	93

$\chi^2 = 17.4$; $df = 3$;
 $\alpha = 0.05$

NO. OF COSTAE	OP	BI	
	10 OR MORE	19	
9 OR FEWER	29	39	68
	48	45	93

$\chi^2 = 6.8$; $df = 1$;
 $\alpha = 0.05$

NO. OF SPLITS	OP	BI	
	2 OR MORE	4	
0 OR 1	44	26	70
	48	45	93

$\chi^2 = 12.4$; $df = 1$;
 $\alpha = 0.05$

NO. OF SPLITS	OC	OP	
	2 OR MORE	13	
0 OR 1	12	44	56
	25	48	73

$\chi^2 = 13.0$; $df = 1$;
 $\alpha = 0.05$

NO. OF SPLITS	OC	BI	
	2 OR MORE	13	
0 OR 1	12	19	31
	25	45	70

$\chi^2 = 0.28$; $df = 1$;
 $\alpha = 0.05$

NO. OF SPLITS	OP	BI	
	1 OR MORE	24	
0	24	10	34
	48	45	93

$\chi^2 = 6.5$; $df = 1$;
 $\alpha = 0.05$

t TESTS

OC - OP
COSTAE

$N_{OC} = 25$	$N_{OP} = 48$
$\bar{X}_{OC} = 10.9$	$\bar{X}_{OP} = 9.2$
$S_{OC}^2 = 0.83$	$S_{OP}^2 = 1.38$
$S_P^2 = 1.197$	
$t = 5.74$	
$t_{0.05} (df = 71) \cong 2.00$	

OP - BI
COSTAE

$N_{OP} = 48$	$N_{BI} = 45$
$\bar{X}_{OP} = 9.2$	$\bar{X}_{BI} = 8.2$
$S_{OP}^2 = 1.38$	$S_{BI}^2 = 1.57$
$S_P^2 = 1.80$	
$t = 2.96$	
$t_{0.05} (df = 91) \cong 1.66$	

OC - BI
SPLITS

$N_{OC} = 25$	$N_{BI} = 45$
$\bar{X}_{OC} = 1.56$	$\bar{X}_{BI} = 1.29$
$S_{OC}^2 = 1.08$	$S_{BI}^2 = 0.89$
$S_P^2 = 0.96$	
$t = 1.13$	
$t_{0.05} (df = 68) \cong 1.67$	

OP - BI
SPLITS

$N_{OP} = 48$	$N_{BI} = 45$
$\bar{X}_{OP} = 0.58$	$\bar{X}_{BI} = 1.29$
$S_{OP}^2 = 0.42$	$S_{BI}^2 = 0.89$
$S_P^2 = 0.65$	
$t = 5.26$	
$t_{0.05} (df = 91) \cong 1.66$	

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TEXT-FIG. 1—Chi-square and *t* tests of three samples of *Anthracospirifer*. OC, OP, and BI stand for *A. occiduus*, *opimus*, and *birdsringensis* respectively. Statistical procedure for the chi-square test is in accord with Siegel, 1956, p. 204-210; procedure and symbols for the *t* test are the same as in Dixon & Massey, 1957, p. 121.

