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Paleosalinity of Permian Nonmarine Deposits in Antarctica

Abstract. *Argillites of the Permian Mount Glossopteris Formation were analyzed for clay minerals, trace elements, and phosphate paleosalinity. Mainly degraded and stripped illites occur. The determined salinity range, 29 to 33 parts per mille is designated the "paleosalinity signature" of the formation. Analysis of trace elements supports phosphate paleosalinity determinations. Data from* Leaia*-bearing beds indicate a salinity range of 30 to 31 parts per mille that persisted some 137 years. Subsequent increase to 33 parts per mille corresponded to termination of leaiid occupancy of the area. These findings confirm and extend Nelson's study of phosphate paleosalinity.*

During the austral summer of 1966–67 one of us (P.T.) made a microstratigraphic study of a very thin Permian fossiliferous zone in the Ohio Range, Antarctica (*1*). This zone, containing ribbed valves of the extinct branchiopod conchostracan genus *Leaia*, is extremely restricted, being less than 1 m thick; because of faulting at both ends it is traceable laterally for about 30 m (*2*). Most samples analyzed by us came from this zone.

Contents of Al-PO_4, Fe-PO_4, and Ca-PO_4 were selectively extracted from shales (*3*) and determined spectrophotometrically. The trace-element analysis of raw samples was done with a Jarrel Ash 1.5-m Wadsworth spectrograph. Quantitative values were determined from photographic plates, measured with a densitometer. Oriented, nonoriented, and glycolated samples were used for x-ray diffraction analysis (*4*).

Studies of trace elements involved analysis of boron versus gallium and of boron versus vanadium (Fig. 1), as well as of boron alone (*5*). Regarding the analysis of boron alone, it has been shown that argillaceous rock containing 50 parts per million (ppm) of boron is probably of marine origin; less than 50 ppm suggests freshwater conditions at the time of deposition. Only sample 12 contained less than 50 ppm; the remaining samples were very close to the freshwater-marine boundary. In the boron-versus-gallium partition of samples, a freshwater trend is apparent (Fig. 1), while in the boron-versus-vanadium partition (Fig. 1), as with boron alone, a marine trend occurs. Thus, while the dominant condition was marine, one or more samples indicated freshwater conditions, and several samples were close to the partition boundaries in each of three geochemical analyses.

Some anomalous trace-element results merit comment; they are considered minor since independent checks are available to resolve such anomalies. In boron versus vanadium (Fig. 1), for example, the rock analysis of sample 12 plots on the marine side, while, as noted above, in the analysis of boron alone, it plots on the freshwater side. Moreover, the rock analysis of sample 11 partitions as freshwater (Fig. 1, top, and in the analysis of boron versus gallium) but plotted for boron alone the sample partitions as marine. Both samples 11 and 12 have a phosphate salinity of 31 parts per mille (ppt) (Table 1); thus this sea-water salinity is clearly lower than normal.

Generally the geochemical partition of samples into freshwater and marine on the basis of trace-element analysis was found to provide an independent check of determinations of phosphate salinity; apart from a few anomalies, the agreement is good. Of the four refinements in methodology discussed in this report, this is the first (that is, corroborative geochemical analyses).

Data on trace elements become important in the light of the salinity tolerance of conchostracans; these are chiefly freshwater (and, to a lesser degree, brackish-water) forms today and apparently so since Carboniferous time (*6*). No living forms inhabit marine basins.

The leaiid beds have been interpreted as representing a pond environment in a swamp area (*1*). *Glossopteris* flora at several horizons (Mount Glossopteris Formation), and thin coals observed far to the southwest of the leaiid zone and closer to the base of Mercer Ridge, as well as a carbonized leaiid zone and sooty plant bands above it, are some of the features suggestive of swamp conditions. Long (*7*) interpreted the formation to be a broad floodplain deposit; our data are in agreement. Freshwater ponds formed on a floodplain swamp at the margins of the sea coast. The water of such ponds was either a mixture of freshwater and marine water, or relict seawater that permitted conchostracan occupancy when it became less saline. We determined the clay mineralogy and phosphate paleosalinity of these beds also (*3*) (Table 1).

Illite is the chief mineral present, in a stripped or degraded form. (The variety of illite is determined by the characteristic shape and 2θ values of the x-ray diffractograms.) Table 1 shows that at station 0 [bed 021.13 (oldest) through bed 021.2 (youngest of the leaiid-bearing beds)] the dominant mineral is a mixed layer of illite and montmorillonite. The calcium phosphate fraction for the same sequence fluctuates in a narrow range (0.87 to 0.92) that corresponds to salinities of 30 and 31 ppt. The second refinement in methodology is in such precise identification of clay minerals comprising the shale being analyzed for phosphate paleosalinity (*8*).

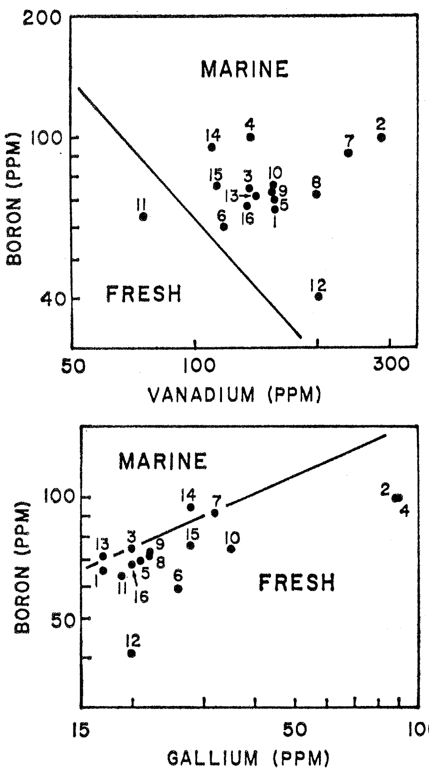

Fig. 1. Relations between boron and vanadium (top) and between boron and gallium (bottom) from Antarctic shales.

A third refinement provides a paleobiologic control for the geochemical data; there is a distinct change in the transition from the uppermost leaiid bed (Table 1, sample 9) to the next overlying bed with no fossils (Table 1, sample 8). This change is reflected in the clay-mineral suite of illite (stripped form), which is dominant, and in a small amount of kaolinite, as well as in increase in calcium phosphate. This last characteristic causes a jump in the phosphate fraction to 0.94 and in salinity from 31 to 33 ppt (*9*). Since at no time in the leaiid-bearing beds had salinity exceeded 31 ppt, this was a marked change. There is now a plausible explanation for the disappearance and subsequent nonrecurrence of leaiids in the formation: salinity increased (*10*).

A time factor (duration) is added to paleosalinity determinations as a fourth refinement in methodology. It was estimated (*2*) that intermittent leaiid occupancy of freshened pond waters on the floodplain swamp transpired over some 137 years; during this period of on-off occupancy of the area, salinities fluctuated very little from 30 to 31 ppt.

One can extrapolate evaluation of paleosalinity to other parts of the formation—beds 018, 019, and 020 (Table 1). Bed 018 is approximately 30 m above the base of Mercer Ridge, on the slope south of the leaiid zone. Bed 019 is some 3 m above 018; bed 020 is situated physically above bed 019 but is of unknown stratigraphic position relative to the latter because of faulting. Furthermore, bed 020 is geologically older than the leaiid zone and occurs a considerable but undetermined distance below it. All these beds are similar in lithology to the leaiid-bearing argillites but lack leaiid fossils while containing carbonized plant debris; they denote recurrent equivalences of paleosalinities during separate intervals of Mount Glossopteris time.

Coupled with Long's qualitative evaluation of the entire formation as nonmarine (*7*), these quantitative determinations may be taken as the "paleosalinity signature" of the Mount Glossopteris Formation (*11*). The total range of paleosalinities recorded at Mercer Ridge had 29 ppt as its lower limit and 33 ppt as its upper limit.

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Table 1. Phosphate data and paleosalinity from Antarctic shales. Results for sedimentary phosphates are expressed as micromoles of phosphate per gram of raw sample. The illite was the stripped form. Station (Sta.) 0 includes samples 7 (youngest) through 16 (oldest). Sample 5 is from 20′N and sample 6 is from 65′N of station 0; both are time equivalents of sample 13. Sample 1 (morainal debris from southwest of the leaiid zone) is of the same lithology as samples 2, 3, and 4 (see text).

Sample		Percentages in fraction finer than 2 μ				Micromoles per gram		Ca*	Salinity (ppt)
No.	Bed	Illite	Mixed layer	Kaolinite	Chlorite	Fe-PO_4 (*3*)	Ca-PO_4 (*3*)	Fe + Ca (*3*)	
7	021.1A, Sta. 0 (*2*)	> 90		> 5		5.9	107.7	0.95	33
8	021.1B, Sta. 0	> 90		> 5		6.7	103.4	.94	33
9	021.2, Sta. 0		> 90			6.7	46.3	.87	31
10	021.3, Sta. 0	†	‡			5.0	46.3	.90	31
11	021.4, Sta. 0		> 90			5.0	48.1	.90	31
12	021.8 (upper), Sta. 0		> 90			6.7	56.8	.89	31
13	021.8 (lower), Sta. 0	> 90				6.7	52.4	.89	31
14	021.10, Sta. 0		> 90		< 5	6.7	55.1	.89	31
15	021.12, Sta. 0		> 90			5.0	55.1	.92	31
16	021.13, Sta. 0		> 90		< 5	5.0	56.8	.92	31
6	021, Sta. 2	> 90				5.9	46.3	.89	30
5	021, Sta. 1		> 90			5.0	56.8	.92	31
4	020		> 90			6.7	41.9	.86	30
3	019		> 90			9.4	41.9	.82	29
2	018		> 90			11.2	103.4	.90	31
1	017	> 90				8.5	41.9	.83	29

* Calcium phosphate fraction. † Found in fraction finer than 1 μ. ‡ Found in fraction sized between 1 and 10 μ.

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9. The salinity of normal seawater (35 ppt) in Nelson's graph (*3*, fig. 1) would bear (as would all determinations by his method) a correction factor of ± 4.0 ppt. For comparative purposes one can ignore this constant; a higher figure will always indicate increasing salinity. For our study, the likelihood is that there should be a negative correction factor—parts-per-mille determinations (Table 1) should be lower.
10. This was one of the questions raised at the inception of the project.
11. The Mount Glossopteris Formation is a sequence of sandstones and siltstones, with argillite interbeds, coals, and some pebble conglomerates.
12. Supported by NSF grant GA 519 through the U.S. Office of Antarctic Programs. Logistic air support was provided by the U.S. Navy.

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