Trace element signatures in Dictyonema Shales and their geochemical and stratigraphic significance

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Neutron activation analysis of 12 black shale samples from the Cambro-Ordovician sequence in the Oslo Region, Norway corroborates the geochemical signature identified for *Dictyonema flabelliforme*-bearing rocks in the Baltoscandian region. This study not only confirms the relatively high values of molybdenum, uranium, and vanadium reported, but also extends the geochemical signature to include relatively high values of antimony, arsenic, and provisionally bromine and tantalum. The new work also indicates that relatively low values of cobalt, iron, and manganese may be part of the signature. To test if this geochemical signature may be linked closely with the occurrence of *Dictyonema flabelliforme,* or rocks of that age in the Atlantic Faunal Province outside of Scandinavia, an additional 19 graptolite-bearing shale samples were examined. These shales include Early Tremadoc *D. flabelliforme*-bearing or coeval rocks from the Llyn Peninsula, Wales; Levis, Quebec; Schaghticoke, New York; and the Cordillera in Bolivia. The geochemical signature of the Baltoscandian Dictyonema Shales was not found in coeval rocks outside Scandinavia. This characteristic geochemistry is suggested to have resulted from the interaction of submarine basaltic volcanic and hydrothermal activity with highly anoxic waters during black shale deposition. That combination of volcanic, oceanographic, and depositional conditions, thus far, has not been recognized in the Early Tremadoc record outside of the Baltoscandian region.

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The curiously high concentrations of the minor elements, vanadium, molybendum, and uranium in the Alum shale in Sweden (Mid-Cambrian to Early Ordovician) and the Tremadoc Dictyonema Shales in the Baltoscandian region in general, have been known since the pioneering spectrographic geochemical work on shales by Goldschmidt and his colleagues in the 1930's (see Tourtelot 1970 for complete references on early analytical studies of black shales; Andersson et al. 1983 for the Cambrian Alum shale; and Bjørlykke 1974 for a general discussion of the Lower Paleozoic shales in Scandinavia concentrating on the Oslo Region). Sundblad & Gee (1985) have compiled averages and ranges of uranium, vanadium, and molybdenum in these rocks from various locales in the Baltoscandian area. As noted by Vine & Tourtelot (1970, pp. 253–254), these shales 'cannot be distinguished from barren black shales except by chemical analyses'. This is corroborated by Bjørlykke (1974) for uranium and vanadium, and Gee (1980) who found that these shales 'retain their geochemical signature' of high values of molybdenum, uranium, and vanadium when traced into the Caledonian orogen, despite an increase in metamorphic grade from sub-greenschist to amphibolite facies. Subsequently, Gee (1981) found that the Tremadoc or latest Cambrian-earliest Ordovician *Dictyonema flabelliforme*-bearing phyllites in the Nordaunevoll area in eastern Trøndelag, Norway possess a trace element geochemistry that is 'strikingly similar to that of sediments of similar age and type on the Baltoscandian Platform in Skåne and Östergotland'. Samples of Dictyonema shales from Skåne and from Nordaunevoll (Gee 1981, Table 1) contain molybdenum between 68 and 144 ppm, uranium between 26 and 103 ppm, and vanadium between 729 and 3600 ppm compared with molybdenum between 80 and 230 ppm, uranium between 50 and 215 ppm, and vanadium between 800 and 2800 ppm from Dictyonema shales in Sweden and Estonia (Sundblad & Gee 1985, p. 270). Also, Gee (1981, p. 94) emphasized 'the importance of studies of trace element geochemistry in shales (particularly black shales)' for 'they may play an important role in the identification and correlation' of stratigraphic units and, therefore, play 'a decisive role' in tectonic interpretations. Gee (1981, p. 94) noted that Bulman (1971) showed that *Dictyonema flabelliforme* is characteristic of the Atlantic or European faunal province during the Tremadoc. Accordingly, Gee (1981, p. 94) concluded his discussion by stating that 'both trace element geochemistry and faunal provinciality favor deposition of the Nordaunevoll formation on the eastern side of the Iapetus Ocean in the latest Cambrian to earliest Ordovician, a line of evidence so important that it warrants further assessment'. Sundblad & Gee (1985) also used these arguments in the geochemical examination of graphitic phyllites in the Swedish Caledonides finding a signature with high values of uranium, vanadium, and molybdenum similar to that found in fossiliferous Dictyonema Shales.

Approach

To test further the ideas of Gee (1981) and Sundblad & Gee (1985): (1) on the use of trace element geochemistry to correlate unfossiliferous or otherwise undatable stratigraphic units, and (2) on the possible link between global occurrences of *D. flabelliforme* and the characteristic trace element geochemistry of the Baltoscandian Dictyonema Shale; graptolite bearing samples of Early Tremadoc age were collected and identified by Berry (with the exception of the Bolivian samples which were collected by others). The samples from Norway are the Dictyonema Shale from Eik and Tøyen, the Ceratopyge Shale (3ß beds) at Tøyen (see Erdtmann 1965); and the Lower and Upper Didymograptus Shales near Slemmestad. The Early Tremadoc samples from outside of Norway are from: the Llyn Peninsula at Abersoch, Wales; Levis, Quebec (Osborne & Berry 1966); Schaghticoke, New York (Berry 1962); and from sequences at Erquis, Cieneguillas, and Tucumilla near Tarija, Bolivia.

Elemental abundances on these samples were determined at the Los Alamos National Laboratory with an automated neutron activation analysis system (Minor et al. 1982). In this system uranium is measured by delayed neutron counting and the other reported elemental concentrations are determined by conventional reduction of gamma-ray spectra of the radioactive isotopes. The automated system has been calibrated against a collection of U.S. Geological Survey, National Bureau of Standards, and Canadian Geological Survey rock standards. The stability of the system is checked periodically against such rock standards. This analytical procedure provides abundances for a greater number of elements than were investigated by earlier workers (Bjørlykke 1974). A summary of these analyses is given in Table 1 for the Oslo Region samples and in Table 2 for Early Tremadoc rocks both in and outside the Oslo Region. More conventional chemical analyses of organic carbon and sulfur were not included in this study to limit the discussion to the trace elements. Also, Berner (1984, pers. comm.) has found in his studies of carbon to sulfur ratios (Berner & Raiswell 1983) that older material and particularly fossil or museum specimens are too oxidized to give consistent values when compared to fresh samples. A major purpose of this study is to analyze samples with recognizable fossils to relate the chemistry to stratigraphically dated material. Thus we avoided at this time adding known uncertainties to the discussion. Eventually, a more complete examination of the signature in black shales must include not only major element and isotope geochemistry (Goodfellow & Jonasson 1984), but also mineralogy and the partition of the elements into the proper mineral phases as outlined by Vine & Tourtelot (1970) and Tardy (1975) for North American black shales.

Oslo Region stratigraphy

A summary of the geology, stratigraphy, and geochemistry of the Lower Paleozoic of the Oslo Region is found in Bjørlykke (1974). The Dictyonema Shale is considered Early Tremadoc and underlies the Middle Tremadoc Ceratopyge Shale (Henningsmoen & Spjeldnaes 1960, Erdtmann 1965). Graptolites occur in both units (Bulman 1954, Monsen 1925, Erdtmann 1965). Bulman (1954, p. 2) described the rich and diverse graptolite fauna of the Dictyonema Shale and declared that 'The Dictyonema Shales (2e) of the Oslo Region provide the best and most complete section of Tremadoc rocks yet described'.

Neutron activation analysis of the Oslo Region Dictyonema Shale samples show high values of molybdenum, uranium, and vanadium. These values are consistent with the analyses recorded by Gee (1981) from coeval shales from Nord-

Table 1. Cambro-Ordovician elemental analyses – Oslo Region.

Values in parts per million

Element	29	22	23	154	30	27	28	31	32	33	10	11
Na 24	5300	5860	5500	5230	6850	5860	5020	4820	5810	405	8052	8385
Mg 27	8500	6010	6800	7870	6680	11300	13400	13000	13200	8350	12610	20720
Al 28	108000	79800	90300	89000	93900	99200	98300	103000	94600	65700	105000	105000
K 42	45700	47600	47700	46400	45000	44500	45200	44800	40800	25200	41800	35300
Ca 49	< 393	< 430	< 464	< 390	< 398	1900	7080	4920	5460	< 222	1130	< 549
Sc 46	16.8	13.5	15.5	15.5	15.6	15.9	21.0	20.4	20.4	12.2	29.7	30.1
Ti 51	7340	4920	6040	5040	5710	6000	5420	5640	5840	2790	5120	5510
V 52	259	1960	2890	2910	774	296	343	192	304	456	203	173
Cr 51	109	94	140	133	126	93	92	100	94.0	112	156	175
Mn 56	77.6	27.9	42.1	42.2	28.5	118	270	207	248	120	188	453
Fe 59	7970	5960	7580	7890	15700	31000	35700	39200	38700	17800	29000	61600
Co 60	1.27	0.98	0.99	0.91	2.5	24.4	18.2	24.0	31.7	6.59	5.98	29.1
Cu 66	< 150	< 200	< 230	< 240	< 160	< 120	< 150	< 130	< 160	150	< 140	< 160
Zn 65	< 8.74	< 6.01	< 5.95	< 7.4	240	139	< 10.2	893	< 7.80	< 8.42	< 8.91	< 10.1
Ga 72	22	18	16	20	16	16	19	22	18	11	19	18
As 76	6.3	16.9	27.8	29.6	18.4	11.0	10.2	14.2	21.3	6.6	10.1	13.1
Se 75	< 1.2	< 1.2	9.5	< 0.96	2.0	< 0.74	< 1.3	< 16	< 0.75	3.5	< 1.6	< 12
Rb 86	179	134	172	172	167	163	172	177	176	164	167	158
Zr 95	140	60	190	112	160	140	190	160	170	200	110	150
Mo 99	< 5.6	49.4	71.6	80.4	20.0	< 2.9	< 0.13	3.7	48.7	< 5.1	6.1	< 4.8
Sb 124	4.0	12	22	21	5.1	2.3	1.9	1.1	4.2	2.8	0.75	< 0.55
Cs 134	9.3	7.9	9.8	9.2	9.5	11.4	12.9	12.5	12.1	9.6	12.6	12.8
Ba 139	1310	11100	1330	1340	2730	1640	1620	1520	2760	1060	800	572
La 140	21.1	53.3	52.5	56.9	58.2	54.9	55.0	54.5	53.2	44.3	49.1	38.2
Ce 143	41.5	105	91.1		106	94.9	104	95.3	96.1	74.6	95.3	60.5
Nd 147	< 11	39	35	32	46	46	55	39	57	23	41	< 7.4
Sm 153	3.5	4.5	5.8	6.0	6.5	11	8.6	7.4	7.1	7.8	5.7	3.2
Eu 152	0.82	0.94	1.02	1.10	1.24	2.18	1.97	1.83	1.7	1.63	1.36	0.78
Tb 160	0.68	0.81	0.87	0.97	1.0	1.5	1.4	1.3	1.3	1.5	1.0	0.87
Dy 165	4.2	6.6	5.0	5.2	5.7	9.3	8.2	7.6	7.0	5.7	5.1	3.3
Yb 169	3.9	4.3	3.0	3.8	4.3	4.4	5.0	4.1	4.4	3.6	3.1	2.3
Lu 177	0.55	0.72	0.52	0.59	0.62	0.64	0.77	0.63	0.75	0.54	0.50	0.41
Hf 181	6.1	4.2	4.7	4.4	5.2	4.7	4.4	4.9	4.2	2.6	3.6	3.4
Ta 182	1.7	1.3	1.4	1.2	1.4	1.3	1.2	1.4	1.4	0.86	1.0	0.93
W 187	2.4	3.6	1.4	2.3	1.2	1.7	1.8	1.3	1.7	1.9	< 1.064	1.9
Th 233	11.3	12.8	12.5	13.9	15.5	17.0	16.5	17.4	15.2	13.3	11.4	10.7
U 235	6.83	87.1	30.1		15.0	18.6	18.5	6.83	25.3	6.4	8.0	3.0

Samples

29: Upper Middle Cambrian – Krekling RR Sta.
22: Dictyonema Shale – Eik
23: Anisopraptus Shale –Sars Gate
154: Anisograptus Shale – Sars Gate
30: Ceratopyge Shale – Sjøstrand, Asker
27: Lower ordovician – (3b) Tøyen.
28: Lower Ordovician – Slemmestad Eternite Valley
31: Lower Ordovician – Slemmestad Old Quarry
32: Lower Ordovician – (3b) Tøyen
33: Middle Ordovician – Eternite Factory
10: Middle Ordovician – Soccer Field. Oslo
11: Middle Ordovician – Eternite Factory

aunevoll and elsewhere in Sweden and Estonia (Gee 1981, Sundblad & Gee 1985). In addition, our analyses show high values of antimony and arsenic with less obvious increase in bromine and tantalum in contrast to low values of manganese, iron, and cobalt. Samples from the superjacent Ceratopyge Shale and higher Middle Ordovician shales contain (1) lesser concentrations of uranium, vanadium, molybdenum, arsenic, antimony, bromine, and tantalum with (2) higher concentrations of manganese, iron, and cobalt (Table 2). As Gee (1981) suggested, trace element geochemical differences between the Dictyonema and Ceratopyge Shales are consistent with the faunal differences between the two units. This relationship suggests that the extended trace element signature may be used to trace and differentiate unfossiliferous time equivalents of Dictyonema and Ceratopyge Shales as indicated by Gee (1981) in Norway and by Sundblad & Gee (1985) in Sweden.

Table 2. Regional comparison of Dictyonema Shale trace element values.

Location	Stratigraphy	High value signature elements				Values in parts per milion				Low value signature elements		
		V	U	Mo	Ba	Sb	As	Br	Ta	Mn	Fe	Co
Scandinavia												
22	D. flabelliforme. Oslo	1960	87.1	49	11100	12	17	4.5	1.3	27.9	5960	0.98
23	Anisograptus, Oslo	2890	30.1	72	1330	20	28	2.8	1.4	42.1	7580	0.99
154	Anisograptus, Oslo	2910	37.9	80	1340	21	30	2.3	1.2	42.2	7890	0.91
Average of 3 samples		2587	51.7	67	4590	18	25	3.2	1.3	37.4	7143	0.96
Standard Deviation		443	25.2	13	4603	4	6	0.9	0.1	6.7	846	0.03
Wales												
12	Tremadoc, Abersoch	133	3.10	<4.9	1300	1.9	21	<0.9	0.76	711	99800	40.5
Canada												
19	Levis Sh., Quebec	195	5.87	4.7	1270	0.51	12	<0.71	0.79	125	29000	22.9
141	Levis Sh., Quebec	165	6.83	<7.2	647	0.60	8.0	<1.0	0.74	136	25700	17.0
116	Levis Sh., Quebec	258	3.28	<3.8	860	1.50	7.8	<0.83	0.66	150	31000	12.5
147	Levis Sh., Quebec	138	3.74	0.5	670	0.20	16.0	<0.90	0.57	159	25000	54.6
21	Levis Sh., Quebec	87	2.52	<5.6	713	0.48	4.3	<0.83	0.65	149	26800	11.4
20	Levis Sh., Quebec	179	3.20	<5.4	707	0.64	3.0	<1.00	0.62	149	25600	20.6
117	Levis Sh., Quebec	151	3.14	<7.5	580	2.20	9.9	<1.2	0.59	164	29400	20.0
115	Levis Sh., Quebec	127	3.06	<3.7	590	0.57	4.6	<0.68	0.31	205	25400	15.2
139	Levis Sh., Quebec	119	3.25	<5.0	720	1.70	9.7	<0.90	0.56	232	29000	18.0
137	Levis Sh., Quebec	61	1.47	<7.4	890	0.27	0.9	<1.2	0.30	310	17500	7.12
140	Levis Sh., Quebec	199	5.89	0.1	540	1.10	9.6	<1.2	0.54	432	24400	12.3
138	Levis Sh., Quebec	130	2.86	<4.8	440	0.87	4.6	<0.87	0.56	799	29000	18.0
Average of 12 samples		151	3.76	NA	719	0.89	7.5	NA	0.58	251	26483	19.1
Standard Deviation		51	1.52	NA	205	0.59	4.1	NA	0.14	186	3389	11.5
New York State												
112	Schaghticoke	180	4.90	1.4	770	0.76	18	<1.0	0.43	48.4	16100	6.25
156	Schaghticoke	154	4.48	<5.7	820	0.69	21	<1.0	0.53	60.0	13600	5.68
157	Schaghticoke	161	4.83	<8	710	<0.28	20	<1.3	0.50	56.9	17700	7.24
Average of 3 samples		165	4.74	NA	767	NA	20	NA	0.49	55.1	15800	6.39
Standard Deviation		11	0.18	NA	45	NA	1	NA	0.04	4.9	1687	0.64
Bolivia												
152	Cordilleran	319	6.45	<4.9	1460	2.0	6.4	<0.77	0.99	110	26180	4.17
153	Cordilleran	86	4.25	<4.9	524	0.8	7.6	<0.70	1.30	136	38200	2.32
148	Cordilleran	96	3.37	<4.3	750	0.8	3.8	<0.70	1.30	93	28300	2.97
149	Cordilleran	95	3.45	<5.9	685	0.6	5.3	<0.22	1.10	148	39700	2.06
150	Cordilleran	208	6.97	<4.4	1630	1.6	1.8	<0.31	1.48	120	21900	3.05
151	Cordilleran	102	3.64	<4.2	696	1.0	12	<0.64	1.11	544	50500	26.2
Average of 6 samples		151	4.69	NA	958	1.1	6	NA	1.21	192	34130	6.80
Standard Deviation		86	1.46	NA	424	0.5	3	NA	0.16	158	9681	8.70

Faunal provinciality

As Gee (1981) pointed out, an abundance of subspecies of *D. flabelliforme* is considered indicative of an Atlantic or European faunal province in the Tremadoc. Bulman (1971), Jackson (1974), Landing et al. (1978), Cooper (1979), and Erdtmann (1982) discussed Tremadoc graptolite faunal provinces and their correlation. Neutron activation analysis of *D. flabelliforme*-bearing strata from the Schaghticoke Shale in New York and from Bolivia, as well as of *Anisograptus*-bearing shales from Levis, Quebec and unfossiliferous mudstones from the Tremadoc of the Llyn Peninsula of Wales, have shown that these rocks have significantly different geochemical compositions from coeval samples from Scandinavia. None of the samples from localities outside the Baltoscandian region have the relatively high concentrations of molybdenum, uranium, vanadium, antimony, and arsenic found in the Dictyonema Shale. The Norwegian Dictyonema Shale samples have lower concentrations of iron, manganese, and cobalt than was found in other *D. flabelliforme*-bearing samples. Accordingly, these values are interpreted as suggesting that the Norwegian Dictyonema Shale may have accumulated under an oceanic anoxic zone (Hunt et al. 1984, Wilde et al. 1984) different from that under which the New York, Bolivian, Canadian, and Welsh coeval shales formed.

Potential water mass control on graptolite faunas

Bulman's (1954) graptolite descriptions from the Oslo Region Dictyonema Shales include subspecies of *D. flabelliforme* and *Anisograptus* as well as forms of *'Bryograptus', ?Clonograptus, ?Didymograptus,* and *Triograptus,* in associations unrecorded elsewhere. Potentially, the Oslo Region, or perhaps more broadly, the Scandinavian Dictyonema Shales were deposited in oceanic environments under a water mass (Sverdrup et al. 1942, pp. 141–146) with distinct chemical characteristics as suggested by Størmer (1938). The Scandinavian *Dictyonema* fauna may have lived where upwelling waters contained nutrients and trace metals indicative of the unique composition of the anoxic water mass beneath the aerated surface layer (Berry & Wilde 1978, fig. 1, p. 265). Then the uniqueness of the graptolite faunas from the Baltoscanian Dictyonema Shale may reflect adaptation to a chemistry particular to a specific water mass. Accordingly, this planktonic fauna may have lived over the outer shelf where the depth exceeded about 100 meters to permit upwelling from anoxic waters and preservation after death in black shales. In any case, the water mass in which the graptolites lived may have been limited in its areal extent as a function of underlying anoxic conditions in the ocean. The geochemical signature of the Dictyonema Shale in the Baltoscandian region, which is typified by high values of arsenic, antimony, molybdenum, uranium, and vanadium, appears to be of stratigraphic significance there, but it is not found in coeval strata elsewhere (Table 2). Thus, the signature described by Gee (1981) and Sundblad & Gee (1985) and extended in this paper does not correlate with the distribution of *D. flabelliforme* in rocks analyzed from outside of Scandinavia. Additional work on other Dictyonema Shales or Tremadoc equivalents elsewhere, particularly those in Europe to the south and in Great Britain to the west, is required to refine the geographic extent of the signature.

Origin of the geochemical signature

The contemporaneous association of basaltic volcanics in the Caledonide Belt with organic rich, black shales of the Dictyonema Shales has been noted, for example, at Nordaunevoll (Gee 1981) and in the Köli napppes (Sundblad & Gee 1985). We suggest that the association of volcanism during deposition in anoxic waters may contribute to the geochemical signature even where there is no local evidence of simultaneous activity. Vine & Toutelot (1970, p. 254) assumed that 'the metals in the shales (Alum & Dictyonema Shales) are syngenetic'. Holland (1979) discussed the general problem of metal enrichment in black shales and presented models showing 'that the removal of trace metals from sea water in anoxic basins can account for the observed enrichment of many of these metals in black shales'. This suggests that the anoxic waters in the Baltoscandian Sea had a different metallic composition during *Dictyonema* time than elsewhere. Low values of manganese, iron, and cobalt without the concomitant high values of uranium, vanadium, molybdenum, antimony, and arsenic are found in other Lower Paleozoic black shales (Berry et al. 1984, Hunt et al. 1984, Wilde et al. 1984). Thus, this part of signature is not distinct; although the combination of high and low values apparently is limited to the Baltoscandian region. The high metallic values of the geochemical signature found in the Baltoscandian Dictyonema Shales may be due to contributions from contemporaneous volcanism or diagenetic reaction with interbedded or nearby volcanics. The three most notable elements: molybdenum, uranium, and vanadium may have been derived from the reaction of basaltic volcanism with anoxic waters. These elements were precipitated or sequestered in the shale facies, in the manner suggested by Holland (1979). The low values of manganese, iron, and cobalt may be caused by their mobility during deposition and diagenesis in highly anoxic bottom waters regardless of the initial contribution from the volcanics or hydrothermal vents. The mobility of these metals may be due to the sparsity of sulfide and carbonate anions, limiting precipitation of metals. The low carbonate and sulfide content of Dictyonema Shales noted by Bjørlykke (1974, p. 65) supports this idea. Armands (1972) found that uranium correlated with the authigenic feldspars in the Alum Shale, and vanadium with organic content in the Dictyonema Shale. Tardy (1975) also found correlation with the organic fraction for vanadium and molybdenum for composite North American black shales. There is a possibility that high values of some trace metals may be due to concentration by graptolites themselves. Vinogradov (1953) and Goldberg (1957) have reported high concentration of vanadium in hemichordates considered the closest relative of the graptolites (Kozlowski 1948). The occurrence of volatiles such as antimony, arsenic, and bromine in the signature suggests contributions from hydrothermal vents on a ridge-rise (basaltic) system. The linear nature of ridge-rise systems and their limited geographical extent may explain (1) the restriction of the geochemical signature ot the Baltoscandian Caledonides and (2) the lack of a record of such contemporaneous volcanism and shale deposition everywhere. The difference in the chemistry in the Dictyonema Shales (for example, low iron and manganese) from that found at modern vents on ridge-rise systems (Edmond et al. 1979) may reflect hydrothermal circulation using the anoxic bottom waters of the Paleozoic rather than the ventilated waters of the modern ocean. Addition of the signature metals during subsequent metamorphism seems unlikely because both overlying and underlying shales affected by the metamorphism do not bear the geochemical signature as noted by Vine & Tourtelot (1970), Bjørlykke (1974), and Gee (1981).

The chemical composition of the overlying Ceratopyge Shale suggests that those strata were formed in waters transitional from extreme anoxia of the Dictyonema Shale to the more ventilated waters of the Lower Didymograptus Shale, which overlies the Ceratopyge Beds. Bjørlykke (1974, p. 23) interpreted the dark and light grey laminae in the Ceratopyge Shales as indications of 'oscillations between reducing and oxidizing conditions'. Chemical conditions that led to the high concentrations of molybdenum, uranium, and vanadium in the Dictyonema Shale changed before the time of deposition of the Ceratopyge Beds. This change may have been linked to shifts in the source of regional volcanism, the geographic position of the ridge-rise system, the degree of anoxicity, and/or the depth of water.

Summary

The characteristic trace metal signature of the Baltoscandian Dictyonema Shale has been extended to include elements not analyzed by earlier workers. Our studies corroborate the suggestion that the unit may be identified by its geochemistry as well as its graptolite content. For this shale, the geochemical composition is an aid in correlation and identification, as Gee (1981) indicated.

However, this geochemical signature has not been found in *D. flabelliforme* or *Anisograptus*-bearing shales from Wales, eastern North America, or South America. Thus, the graptolite faunas and geochemistry of the Baltoscandian Dictyonema Shale show a local-to-regional character and not a world-wide character. These characteristics suggest accumulation under a water mass with distinct chemical properties. The elemental composition preserved in the shales may reflect nearby contemporaneous volcanic and hydrothermal activity in a highly anoxic zone in the Lower Paleozoic ocean.

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