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PALAEOCLIMATOLOGY

Clay-mineralogy of Jurassic Marine Black Shales in Spitsbergen: a Possible Evidence for Climate Cooling during Oxfordian

by

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Summary. Clay-mineral investigations were carried out on Jurassic marine black shale samples of the Janusfjellet Subgroup (Upper Bathonian-Hauterivian) collected from four field sections at Van Keulenfjorden and Isfjorden, Spitsbergen. Based on the presence or absence of kaolinite in the Jurassic parts of the stratigraphic columns studied, three subunits have been distinguished: (i) the kaolinite-bearing basal subunit; (ii) the kaolinite-free middle subunit; (iii) the kaolinite-bearing upper subunit. These subunits are unrelated to any observable change in the monotonous black shale lithology.

Taking into account stable palaeolatitudinal position of epicontinental seas, and lack of active terrestrial sources of clastics in and around Spitsbergen during the Upper Bathonian-Volgian times, it is suggested that the clay-mineralogical history of marine black shales in the Jurassic part of the Janusfjellet Subgroup reflects predominantly a global or regional climate change. We suppose that the climate, warm and favourable to kaolinite formation on borderlands of the Spitsbergen sea at the onset (lower subunit: Upper Bathonian-Callovian), subsequently considerably cooled as no kaolinite was supplied from the land to the sea (middle subunit: Oxfordian), then warmed again as the kaolinite supply was re-established (upper subunit: Kimmeridgian-Volgian).

1. Introduction. Samples for clay-mineralogical investigation were collected in 1985 in central Spitsbergen (Fig. 1) by K. Krajewski and J. Kutyba from four sections of marine shales of the Janusfjellet Subgroup (Upper Bathonian-Hauterivian). This was part of a geological project of the Polish Academy of Sciences led by K. Birkenmajer. Three sections: at Ingebrigtsenbukta, Foldaksla 1, and

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Tilasberget were sampled at Van Keulenfjorden, southern coast. A combined section at Wimanfjellet-Janusfjellet was sampled at Isfjorden, southern coast (Figs 1, 2).

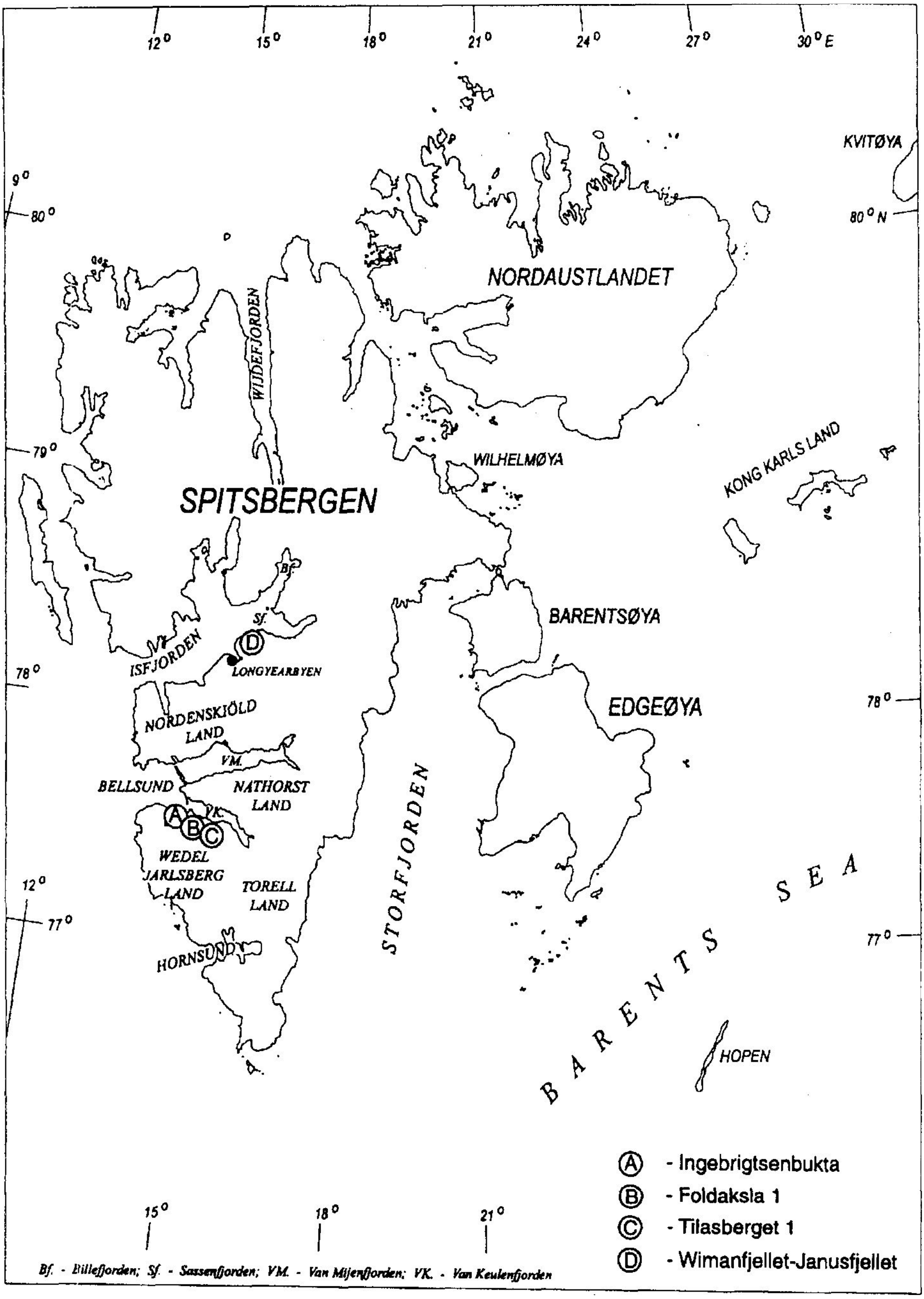


Fig. 1. Location of sampling sites (A-D) in the Janusfjellet Subgroup, Spitsbergen

W. M. Bausch and T. Grunenberg undertook clay-mineralogical investigation of the samples at the Mineralogical Institute, University of Erlangen-Nürnberg (Germany).

2. Geological setting. The investigated sections represent a type development of the lower part of the Janusfjellet Subgroup: predominantly black clayshales with sideritic (clay-ironstone) bands/layers and megaconcretions. The rocks were deposited in a deeper part of marine shelf basin under dysoxic/anoxic conditions.

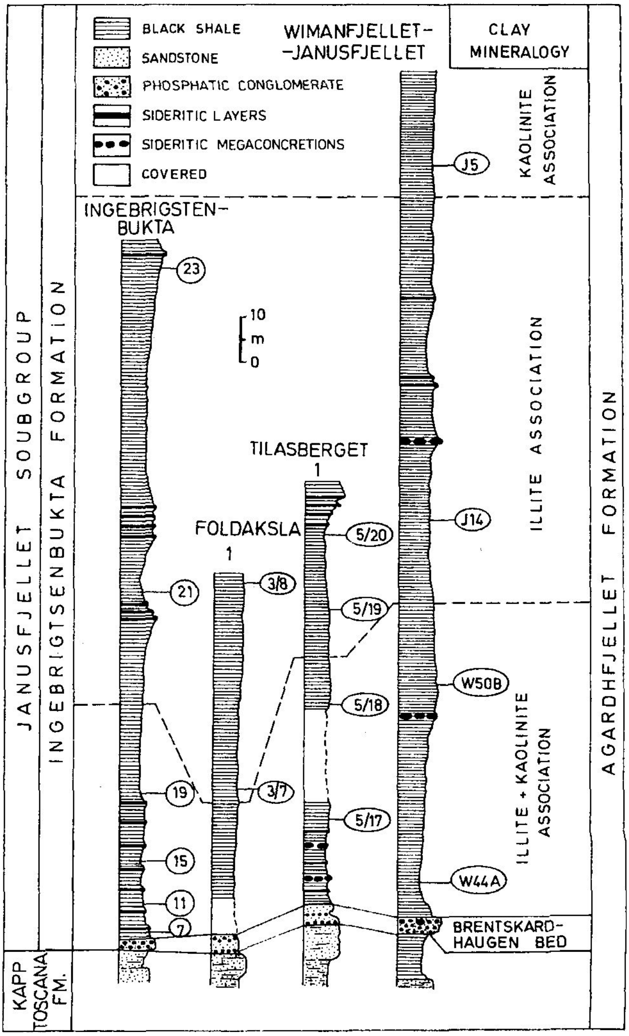


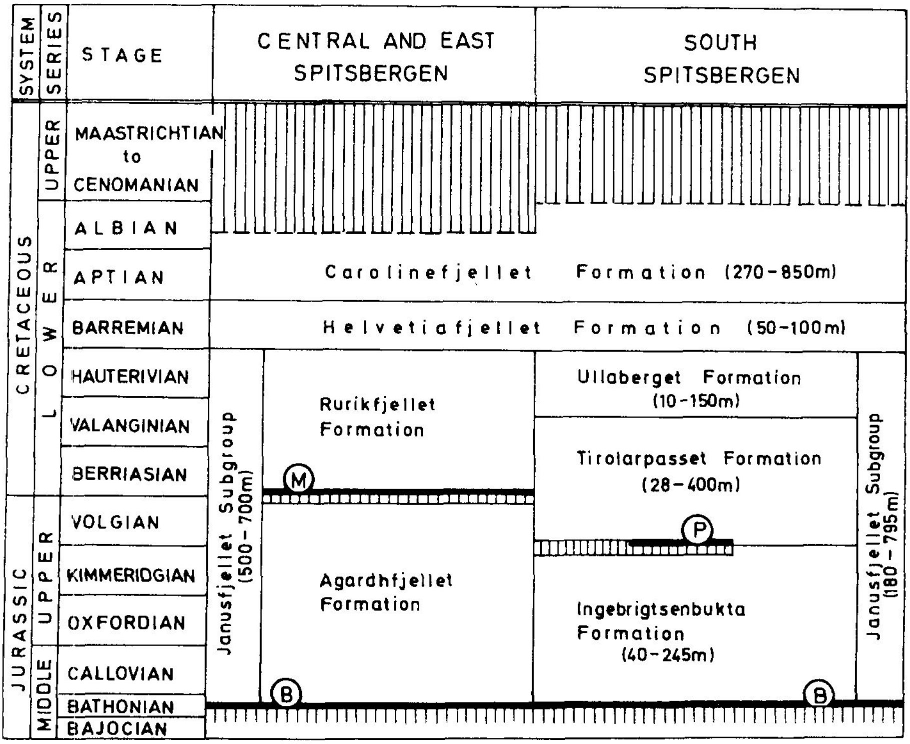
Fig. 2. Stratigraphic position of investigated samples and domains of clay-mineral associations in the Janusfjellet Subgroup, Spitsbergen (for location of sections — see Fig. 1)

Their fauna consists mainly of ammonites, belemnites and bivalves, with a characterstic bivalve of the genus *Buchia* (previously: *Aucella*, hence the older name *Aucella* shales) [3–5, 7–11, 13, 16–19].

Samples for clay-mineral investigations were collected from lower parts of the Janusfjellet Subgroup: the Ingebrigtsenbukta Formation at Van Keulenfjorden, and the Agardhfjellet Formation at Isfjorden (Fig. 2, Tab. 1).

TABLE 1

Jurassic-Cretaceous stratigraphy in central, east and south Spitsbergen (modified from [4])



B — Brentskardhaugen Bed; M — Myklegardfjellet Bed; P — Polakfjellet Bed. Vertical hatching denotes sedimentary hiatuses

The Ingebrigtsenbukta Formation represents the Upper Bathonian through Kimmeridgian time span (Tab. 1). The overlying Tirolarpasset Formation (Volgian — Valanginian) begins with a thin conglomerate (Polakkfjellet Bed) following a short sedimentary hiatus about the Kimmeridgian/Volgian boundary [3, 17].

The Agardhfjellet Formation in central and eastern Spitsbergen represents the Upper Bathonian-Callovian through Volgian stages [4, 8–11, 16, 19]. A combined section measured at Wimanfjellet and Janusfjellet, about 180 m thick

(Fig. 2), correlates well with thicknesses of the Agardhbukta Formation in central Spitsbergen: 200 m at Wimanfjellet-Knorringfjellet, and 220 m at Janusfjellet [10, 11]. A short sedimentary break at the Jurassic/Cretaceous boundary separates the Agardhfjellet Formation from the succeeding Rurikfjellet Formation (Berriasian-Hauterivian). The latter begins with the Myklegardfjellet Bed [4] (Tab. 1). In our combined Wimanfjellet-Janusfjellet section, the uppermost part of the column (Fig. 2, sample J5) still belongs to the Volgian.

3. Clay mineralogy. The clay minerals were determined by X-ray diffraction on whole-rock samples. The shale samples were free of carbonates, with the exception of sample 3/7 which contained some dolomite. They consisted mainly of clay, with insignificant admixture of sand or silt. No additional preparation methods, such as removal of carbonates by acid treatment, or Attenberg-separation, were deemed necessary.

The X-ray diffraction diagrams were obtained with the use of standard methods. Oriented sediment preparations, first untreated, then with glycol saturation, were analysed. The main component of the samples is quartz, associated with illite and albite. Kaolinite is often, but not always, present, K-feldspar and chlorite occasionally occur (Tab. 2 and Figs 3–5).

4. Results. The most important result of the clay-mineralogical study is shown by vertical distribution of kaolinite within the Janusfjellet Subgroup (Figs 2, 3). In basal parts of three sections — Ingebrigtsenbukta, Tilasberget 1, and Wimanfjellet-Janusfjellet (Remark: no sampling was made in the basal part of the Foldaksla 1 section), kaolinite occurs right from the bottom up to a certain level of the sections. Higher up, kaolinite completely disappears, but reappears in the highest sampled strata at the Wimanfjellet-Janusfjellet combined section.

Based on the presence or the lack of kaolinite, it is possible to distinguish three sub-units in the otherwise very monotonous, lithologically undifferentiated black shale sequence of the Janusfjellet Subgroup: (i) the kaolinite-bearing basal subunit (illite-kaolinite association); (ii) the kaolinite-free middle subunit (illite association); (iii) the kaolinite-bearing upper subunit (kaolinite association) — Fig. 2. (Remark: It should be noted that in our sections illite is seldom associated with mixed-layer components, contrary to other clays or clay mineral-bearing strata where such associations are a rule.)

5. Discussion. According to their clay-mineral association, the Jurassic (Late Bathonian-Volgian) strata of the Janusfjellet Subgroup in Spitsbergen belong to the same illite-kaolinite province as established in France and South Germany by Bausch [1]. While illite is ubiquitous in marine sediments, the appearance of kaolinite in the Janusfjellet Subgroup needs a special explanation. Kaolinite does not form under normal marine conditions due to elevated pH values of seawater. It

TABLE 2

Results of mineralogical investigations of samples from four sections of the Janusfjellet Subgroup, Spitsbergen (for location of samples — see Fig. 2)

SECTION		SAMPLE No	J	K	Chl	Q	W	A	T	SUM	J(%)	K(%)	Chl(%)	Q(%)	W(%)	A(%)	Chl/Q	J/Q	K/Q	A/Q	T/Q	Chl/T	J/T	K/T	A/T
A	INGE-BRIGT-SEN-BUKTA	23	3.04			4.16		0.99	2.64	8.19	37.12	0.00	0.00	50.79	0.00	12.09	0.00	0.73	0.00	0.24	0.63	0.00	1.15	0.00	0.38
		21	1.08			8.64	0.96	0.90	1.40	11.58	9.33	0.00	0.00	74.61	8.29	7.77	0.00	0.13	0.00	0.10	0.16	0.00	0.77	0.00	0.64
		19	1.30	1.20	0.36	3.92		0.60	2.58	7.38	17.62	16.26	4.88	53.12	0.00	8.13	0.09	0.33	0.31	0.15	0.66	0.14	0.50	0.47	0.23
		15	1.90	0.96		4.44		0.80	2.76	8.10	23.46	11.85	0.00	54.81	0.00	9.88	0.00	0.43	0.22	0.18	0.62	0.00	0.69	0.35	0.29
		11	3.04	0.90		3.50		0.87	3.00	8.31	36.58	10.83	0.00	42.12	0.00	10.47	0.00	0.87	0.26	0.25	0.86	0.00	1.01	0.30	0.29
		7	1.36	1.50		2.88		0.44	3.12	6.18	22.01	24.27	0.00	46.60	0.00	7.12	0.00	0.47	0.52	0.15	1.08	0.00	0.44	0.48	0.14
B	FOLD-AKSLA 1	3/8	1.36			3.84		0.75	3.29	5.96	22.82	0.00	0.00	64.43	0.00	12.75	0.00	0.35	0.00	0.20	0.86	0.00	0.41	0.00	0.23
		3/7	0.80			1.20			0.84	2.00	40.00	0.00	0.00	50.00	0.00	0.00	0.00	0.67	0.00	0.00	0.70	0.00	0.95	0.00	0.00
C	TILAS-BERGET 1	5/20	1.40			4.20		0.80	2.25	6.40	21.88	0.00	0.00	65.63	0.00	12.50	0.00	0.33	0.00	0.19	0.54	0.00	0.62	0.00	0.36
		5/19	1.65			5.35		0.95	2.64	7.96	20.73	0.00	0.00	67.21	0.00	12.06	0.00	0.31	0.00	0.18	0.49	0.00	0.63	0.00	0.36
		5/18	1.20	0.84		3.88		0.88	2.88	6.80	17.65	12.35	0.00	57.06	0.00	12.94	0.00	0.31	0.22	0.23	0.74	0.00	0.42	0.29	0.31
		5/17	0.84	1.02	0.40	4.00		0.56	2.20	6.32	12.32	14.96	5.87	58.65	0.00	8.21	0.10	0.21	0.26	0.14	0.55	0.18	0.38	0.46	0.25
D	JANUS-FJELLET	J5	0.56	1.95	0.54	4.00	1.80	0.96	1.02	9.81	5.71	19.88	5.50	40.77	18.35	9.79	0.14	0.14	0.49	0.24	0.26	0.53	0.55	1.91	0.94
		J14	0.93			2.80		0.54	3.36	4.27	21.78	0.00	0.00	65.57	0.00	12.65	0.00	0.33	0.00	0.19	1.20	0.00	0.28	0.00	0.16
	WIMAN-FJELLET	W50B	0.56	1.02		5.04		0.60	1.60	7.22	7.76	14.13	0.00	69.81	0.00	8.31	0.00	0.11	0.20	0.12	0.32	0.00	0.35	0.64	0.38
		W44	0.60	1.00		4.08		0.80	2.04	6.48	9.26	15.43	0.00	62.96	0.00	12.35	0.00	0.15	0.25	0.20	0.50	0.00	0.29	0.49	0.39

Chl — chlorite; J — illite; K — kaolinite; T — sum of clay minerals; Q — quartz; W — mixed layer minerals

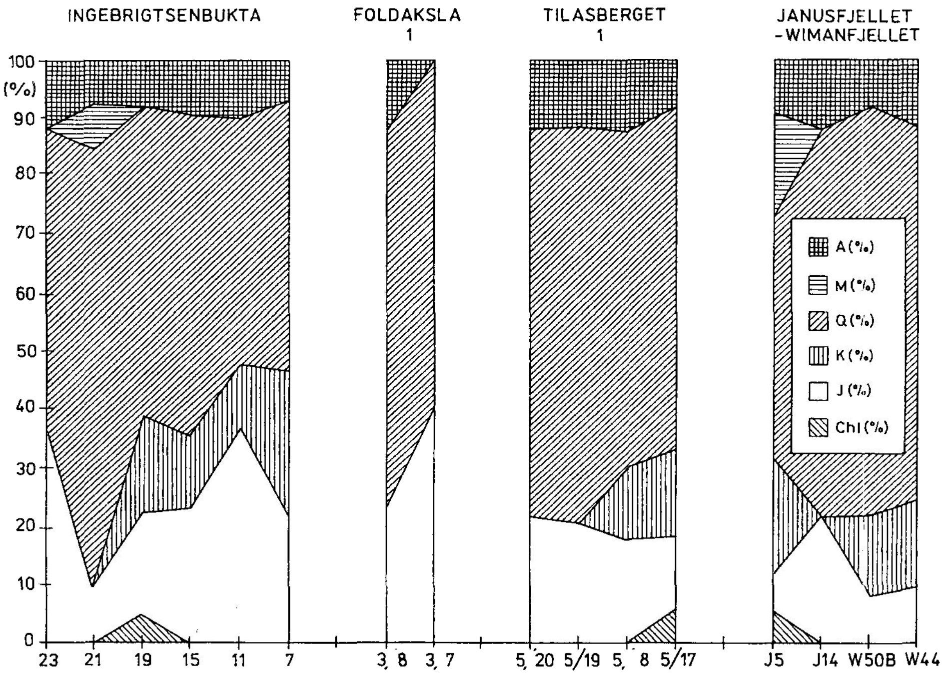


Fig. 3. Mineral composition of samples from four sections of the Janusfjellet Subgroup, Spitsbergen (for location of the sections see Figs 1, 2 and Tab. 2)
A — albite; Chl — Chlorite; J — illite; K — kaolinite; M — micas; Q — quartz

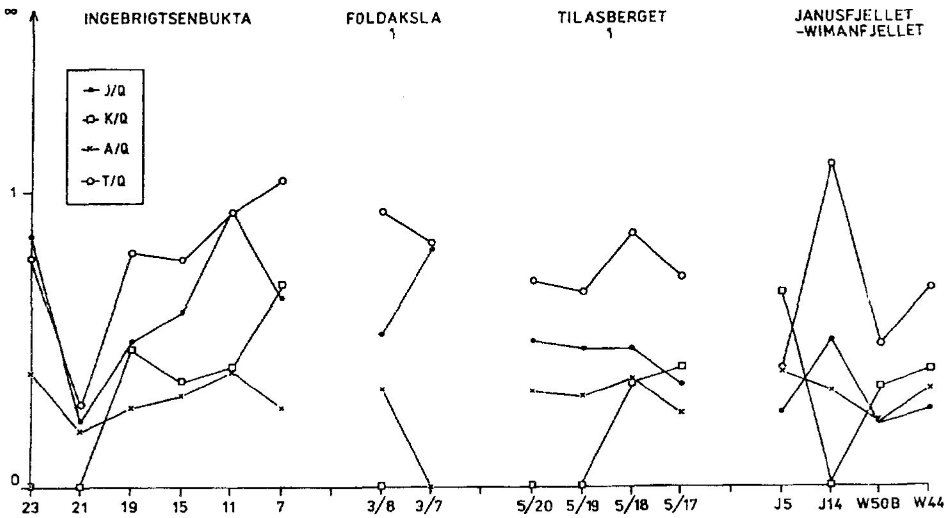


Fig. 4. Trends of mineralogical parametres in four sections of the Janusfjellet Subgroup, Spitsbergen (Sample numbers as in Fig. 2 and Tab. 2)
T — sum of clay minerals. Other symbols — as in Fig. 3

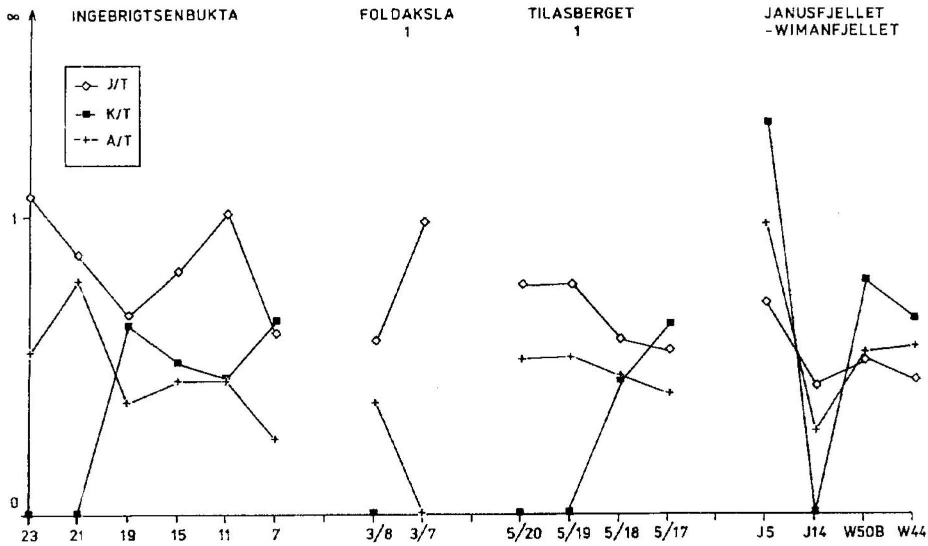


Fig. 5. Trends of mineralogical parametres in four sections of the Janusfjellet Subgroup, Spitsbergen (Sample numbers as in Fig. 2 and Tab. 2)
Symbols — as in Figs 3, 4.

forms only under acid conditions [15]. Thus, the occurrence of kaolinite in marine sediments is a result of: (i) weathering and reworking on land of older kaolinite-rich rocks, their detritus being subsequently transported and deposited in marine basin; or (ii) production of kaolinite on land under tropical/subtropical climatic conditions, subsequently transported and deposited in marine basin. The kaolinite may thus be an indicator for either a specific rock-composition of the source area, or for palaeoclimatic conditions prevailing during deposition of strata in a marine basin.

Monotonous deposition of marine black shales of the Janusfjellet Subgroup in central and east Spitsbergen was continuous from Late Bathonian through Volgian. In the Hornsund area, south Spitsbergen, it was continuous from Late Bathonian through Valanginian. South of Van Keulenfjorden, the black shale deposition was interrupted at the Kimmeridgian/Volgian boundary, and in inner Isfjorden (central Spitsbergen), and at Agardhbukta (east Spitsbergen) — at the Volgian/Berriasian boundary (Fig. 2), by slight positive movements of sea-bottom associated with Neocimmerian uplift [5]. Local folding and faulting associated with minor basic intrusive activity (dolerite sills) between the deposition of the Agardhfjellet and Rurikfjellet formations, recognized locally in east-central Spitsbergen [16], occurred along southern prolongation of the pre-Mesozoic Balliolbreen fault.

(1) No sedimentary breaks have been recorded from lower parts of the Ingebrigtsenbukta and the Agardhfjellet formations (Fig. 2). In both cases, the sam-

pled strata were older than the Kimmeridgian/Volgian boundary hiatus (Tab. 1). The boundary between the first and the second clay-mineral subunits, corresponding to an abrupt change from illite-kaolinite association (first subunit) to illite association (middle subunit), is unrelated to any observable change in the black shale lithology.

(2) The boundary between the second (illite association) and the third (kaolinite association) clay-mineral subunits, is also unrelated to any observable change in monotonous black shale lithology at the Wimanfjellet-Janusfjellet section. At the Ingebrigtsenbukta section, the middle/upper subunits boundary supposedly lies above the highest shale bands sampled (Fig. 2).

(3) Taking the above (1, 2) into account, we suggest that the primary cause of clay-mineral composition changes in the Jurassic marine sedimentary column of the Janusfjellet Subgroup in Spitsbergen is a climatic one. The lower and upper kaolinite-bearing subunits, roughly correlating with the Late Bathonian-Callovian, and the Kimmeridgian-Volgian epochs, respectively, would thus reflect warm climate epochs, while the middle, kaolinite-free subunit — a cooling of climate during the Oxfordian.

(4) During the Jurassic, Spitsbergen was situated off north-east corner of Greenland (see [2] fig. 289), or even off north corner of Ellesmere Island (see [13] fig. 19.16). Its palaeolatitudinal position from Early Jurassic through Early Cretaceous was stable. Deposition of black shales of the Janusfjellet Subgroup at Isfjorden (central Spitsbergen) and at Van Keulenfjorden (central-south Spitsbergen), occurred in a stable deep shelf environment, which was rimmed on the north and west by a belt of distal shallow shelf (see [18] fig. 26).

(5) There are no indications that the Spitsbergen marine basin migrated, as a result of lithospheric plate motions during the Late Bathonian to Volgian times, from low-latitude to high-latitute, and again to low-latitude positions.

(6) Expansion of Jurassic marine basins and related transgression caused by eustatic world ocean-level rise could also be considered. This transgression reached its apogee during Oxfordian times (159–154 Ma [12]). It was expressed as coastal onlap worldwide (see [14] fig. 4), and as maximum deepening of oceanic Tethyan troughs (e.g. [6]). Therefore, the absence of kaolinite in the middle parts of the Jurassic sections investigated might, alternatively, be explained by flooding of coasts of the Spitsbergen marine basin during its maximum Oxfordian extension that caused a dramatic reduction of kaolinite supply. Reappearance of kaolinite at the end of the Jurassic could, alternatively, correlate with increasing tectonic instability on the Spitsbergen shelf related to Neocimmerian uplift, that caused shrinking of the basin.

6. Conclusion. Taking into account stable palaeolatitudinal position of epicontinantal seas, and lack of active sources of terrestrial clastics in and around Spitsbergen during the Upper Bathonian-Volgian times, it is suggested that the clay-mineralogical history of marine black shales in the Jurassic part of the Janusfjellet Subgroup predominantly reflected a global or regional climate change. We suppose that the climate, warm and favourable to kaolinite formation on borderlands of the Spitsbergen sea at the onset (lower subunit: Upper Bathonian-Callovian), subsequently considerably cooled as no kaolinite was supplied from the land to the sea (middle subunit: Oxfordian), then warmed up again as the kaolinite supply was re-established (upper subunit: Kimmeridgian-Volgian).

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