A storm-related origin for the Jurassic Brentskardhaugen Bed of Spitsbergen, Norway

HARMON D. MAHER, JR.

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The laterally persistent but thin, Jurassic age (Bathonian-Callovian) Brentskardhaugen bed is poorly sorted (often with mud to cobble size), and is crudely normally and/or reversely graded without internal discontinuities. These traits may indicate a short-lived depositional event, and are inconsistent with an origin as a basal, transgressive gravel lag formed in a terrestrial or shoreline setting. Mega-storm events on a shallow marine shelf with an underlying condensed section may account for the poor sorting, grading, stratigraphic position and remanie character of the bed.

Harmon D. Maher, Jr., Dept. of Geography and Geology, University of Nebraska, Omaha, 68182, U.S.A.;
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A distinctive and thin conglomerate to pebbly mudstone horizon on Spitsbergen occurs between underlying deltaic and shallow marine Kapp Toscana Group strata and overlying, deeper water (below wave base) black shales of the Janusfjellet Formation. This conglomerate was initially described in detail by Frebold (1929, 1930) and informally referred to as the 'Lias conglomerate' (e.g. Parker 1967). The formal stratigraphic term of 'Brentskardhaugen Bed' was introduced by Parker (1967). A recent and thorough description and analysis of the bed can be found in Bäckström & Nagy (1985), and this discussion owes much to their work. The stratigraphic assignment of the bed is uncertain. Buchan et al. (1965), Birkenmajer (1975), and Bäckström & Nagy (1985) argue that it belongs to the Janusfjellet Formation (i.e. with the overlying black shales), while Parker (1967) and Mørk et al. (1982) include it with the underlying Triassic to Jurassic Kapp Toscana Group (Fig. 1).

Although the exact deposition mechanism is not specified, most authors interpret the Brentskardhaugen Bed (BB) as a remanie, a gravel lag associated with a quick transgression (Flood et al. 1971; Birkenmajer 1975; Bäckström & Nagy 1985) after a widespread depositional hiatus. Toarcian to Bathonian fossils that are within phosphatic clasts of the BB (Bäckström & Nagy 1985) represent the sediments reworked during the hiatus. In that black, ostensibly deep-water marine shales and siltstones overlie the BB, which is Bathonian to early Callovian in age, the transgression is thought to be a result of a rapid eustatic rise at this time (Bäckström & Nagy 1985; K. Maher 1987).

Bäckström & Nagy summarize the depositional history for the BB as follows: 'During this (Aalenian-Bathonian) regression the shelf became exposed to coastal erosion with energy high enough to break up parts of the Wilhelmøya Formation and concentrate its coarse and resistant constituents, among these the phosphorite pebbles. A new transgression started probably near the end of the Bathonian contemporary with a global elevation of the sea level at the transition between Bathonian and Callovian. This event led to renewed reworking and final deposition of the remanie sediments forming the Brentskardhaugen Bed' (p. 27). Mørk et al. (1982) provide a similar account: 'Subsequent [to Toarcian] regression and emergence was followed by renewed transgression where the abraded phosphatic material was deposited as a transgressive conglomerate underlying the dark shales of the Adventdalen Group' (p. 389).

	A	B	
ADVENTDALEN GROUP	JANUSFJELLET FM	JANUSFJELLET FM MARHØGDA BED BRENTSKARDHAUGEN BED	JURASSIC
KAPP TOSCANA GROUP	BRENTSKARDHAUGEN BED WILHELMØYA FM	WILHELMØYA FM	
	DE GEERDALEN FM	? ?	TRIASSIC
	AUSTJØKELEN FM	DE GEERDALEN FM	

Fig. 1. Lithostratigraphic nomenclature for the Brentskardhaugen Bed and adjacent units. A: Scheme of Mørk et al. (1982) for western outcrop belt from Sørkapp to Bellsund. B: Scheme of Bäckström & Nagy (1985) for central Spitsbergen.

The simplest, and perhaps implicit, interpretation is that the BB is a shoreline conglomerate formed during the transgression. If so, the conglomerate would be the cumulative result of many tidal cycles and shoreline processes over the duration (albeit possibly short) of the transgression. The following is a summary of difficulties with such an interpretation and a more specific suggestion for the depositional mechanism – that of a mega-storm deposit on a shallow shelf. Implications of this mega-storm interpretation are also discussed. Published literature, and observations from southern Nordenskiöld Land, Midterhuken, Wedel Jarlsberg Land, and Hornsund (Treskelodden, Fig. 2) made during Norsk Polarinstitutt's 1988 summer field expedition are the basis of the following discussion.

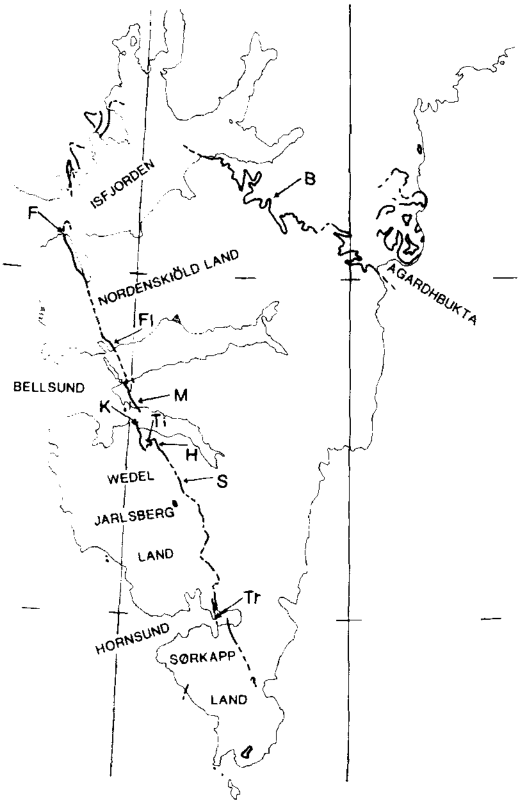

Fig. 2. Map trace of Brentskardhaugen Bed on Spitsbergen, modified from Winsnes (1988). Western outcrop belt is involved in Tertiary age folding and thrusting, while eastern outcrop (Isfjorden to Agardhbukta) lies within subhorizontal E limb of the central basin syncline. Localities referred to in text and map as follows: B = Brentskardhaugen area, F = Festningen, Fl = Flathaugen (S Nordenskiöld Land), H = Heimfjella (N Wedel Jarlsberg Land), K = Kapp Toscana, M = Midterhuken, S = Skiferkammen, Ti = Tilasberget, Tr = Treskelodden.

Sorting and grading of the BB

The BB is poorly sorted. Bäckström & Nagy (1985) demonstrate that, while the quartz and chert pebble show a much higher degree of sorting (probably inherited from a well sorted conglomeratic source bed), BB phosphatic clasts in the Isfjorden area can range in long-axis length from a cm or so up to extremes of 25 cm. Field observations also confirm this character for the BB exposed in the western outcrop belt from Bellsund to Hornsund. The large clasts vary from loosely packed grain support to a carbonate mud (siderite and/or ankerite) and/or sand matrix support. The total grain population is very likely polymodal, reflecting a variety of sources.

At many localities the BB is also graded (Fig. 4). Bäckström & Nagy's (1985) Fig. 6 shows a fining-upwards (normal) grading, and they state, 'in the Diabasodden and Brentskardet areas the Brentskardhaugen Bed passes gradually upwards into a 30–150 cm thick *microsparitic limestone* . . . Scattered pebbles of quartz, chert and phosphorite occurring in the lower part of the bed accord with the gradational contact between this unit and the underlying Brentskardhaugen conglomerate' (p. 9). The BB from southern Nordenskiöld Land (Flathaugen, Fig. 2) is also normally graded (Fig. 4). At Tilasberget and Skiferkammen the BB is reversely graded and at Treskelodden the BB shows reverse grading in the lower half and normal grading in the upper. Worsley (1986) also shows a photo of the BB near its type locality that shows a reverse grading from sand-sized or finer to large phosphatic clasts.

Internal stratification and discontinuities such as hardgrounds, bioturbation surfaces and/or paleosoil development were not observed within the conglomerate. The entire bed, usually less than half a meter thick, has the distinct appearance of representing one, short-lived depositional event. However, very similar conglomerates are found in the underlying Wilhelmøya Formation; hence, similar depositional events can be inferred.

As a single depositional event, the BB is hard to reconcile with a condensed transgressive lag origin, which could be expected to show many internal and lateral discontinuities. The mechanism producing a poorly sorted layer of widespread extent is not part of the normal 'everyday' litany of near-shoreline mechanisms (deposits of which should be well sorted and laterally discontinuous, reflecting the high-energy interface environment).

Phosphate clast shape

Many of the phosphatic clasts of the BB are smooth and well rounded (e.g. at Skiferkammen and Tilasberget), traits consistent with substantial reworking during a history of being concentrated as a lag and reworked by near-shore processes. However, several arguments suggest some clasts have retained an original concretionary/nodule shape and texture with minimal reworking. Bäckström & Nagy (1985) note that there is a strong correlation between clast shape and the type of fossil enclosed within. In particular, they indicate: 'Pebble containing pieces of wood or belemnites are oval, or even cigar shaped' (p. 19). Many wood-cored phosphatic clasts found in the Bellsund area show similar 'cigar' shapes. Such high aspect ratio shapes are not likely the result of rounding and abrasion processes, and might be especially prone to breakage. Other clasts approach a perfect sphere. Internal laminations, when present, are parallel to the clast's outer surface. Broken pisolitic carbonate-phosphatic clasts later overgrown by subsequent laminae were observed in samples from Midterhuken, but angular overgrown edges indicate excavation, reburial and pisolitic growth without significant abrasion.

In contrast, other phosphatic clasts within the BB have very irregular shapes with large reentrants (Fig. 4). Some indentations are clearly related to pressure solution effects at clast contacts, but much of the irregularity reflects original clast shape. The combination of perfect spherical and very irregular forms is consistent with an origin as relatively intact concretionary growths (near sediment surface growth, Bäckström & Nagy 1985), and significant abrasion is not necessary to explain the rounded forms.

Fossil content and timing

The phosphorite clasts contain ammonites, belemnites, bivalves, and wood and bone fragments. Bäckström & Nagy (1985, Fig. 15) and Birkenmajer & Pugaczewska (1975) document a Toarcian to Aalenian age for the ammonites and a Toarcian to Bajocian (possibly Bathonian) age for the bivalves. Overlapping fossil ranges suggest that in the source area for the BB phosphatic clasts marine conditions prevailed throughout this time. Given a Bathonian to basal Callovian age for the BB itself (Birkenmajer 1972; Bäckström & Nagy 1985), the time span left for emergence of the source area, reworking of the phosphate-bearing strata and final deposition of the BB is limited to within the Bathonian (e.g. Bäckström & Nagy 1985, Fig. 23). Any widespread regression and associated hiatus is beneath the stage resolution provided by the fossil data. An alternate possibility, favored here, is that hiatuses are local and that marine environments occurred within the Svalbard area from Toarcian (or even earlier) to Barremian (the age of the terrestrial Festningen Member sandstones that overlie the marine Janusfjellet Formation).

South of Bellsund the strata underlying the BB have few fossils, and are commonly medium- to coarse-grained Wilhelmøya Formation sandstones. Birkenmajer (1972, 1975) infers a Hettangian or older age for these strata. Bäckström & Nagy (1985) indicate a Toarcian age for the underlying strata of the Isfjorden area. While not stated, a likely basis for this age is the range of ages of reworked marine fossils in the phosphorite clasts of the BB. However, if the BB was deposited in a marine setting by an offshore transport mechanism, then the underlying strata could locally be much younger than inferred on the basis of the reworked BB fossil content.

Furthermore, Mørk et al.'s (1982) description of this section as a condensed one with many internal hiatuses suggests that the sediments the BB was deposited on were variable in age and character. Such an irregular age distribution from shallow shelf sediments is common (Walker 1984). This would explain why 'Bathonian bivalves are found in the uppermost part of the Wilhelmøya Formation of Hellwaldfjellet' (p. 27, Bäckström & Nagy 1985), Toarcian palynomorphs in a shale interval 4.5 m below the BB (Bäckström & Nagy 1985, p. 15), and Norian to Rhaetian strata underlie the BB at Festningen (Bjærke & Dypvik 1977). The presence of phosphatic sediments within the Wilhelmøya Formation indicates deposition overlapped with phosphate nodule genesis and K. Maher (1987) describes a phosphate cement for a portion of the BB. Finally, at Wilhelmøya, shales overlying several phosphatic conglomeratic horizons may have a Bajocian/Bathonian age (Smith 1975).

The picture that emerges is of temporally continuous, spatially discontinuous, marine deposition, with phosphate nodule growth occurring before deposition of the BB over surface sediments with a range of ages. The BB itself may be diachronous. Local and variable stratigraphic gaps at the base of the BB, where present, could be due to shoaling sequences, tidal channel scour, longshore current scour, storm events or other shallow shelf processes.

Stratigraphic facies relationships

Bäckström & Nagy (1985) propose the name Marhøgda Bed for a 30 to 150 cm thick, microsparitic, partially dolomitized and sideritized limestone bed, overlying and gradational with the BB. The bed is oolitic and contains quartz, chert and glauconite grains. In southern Nordenskiöld Land the matrix of the BB is a sandy, micritic siderite, and underlying micritic siderite beds show cone-in-cone structures and stromatolitic laminations (Fig. 3). On Midterhuken oolitic and stromatolitic carbonate horizons occur several meters above and below the BB (Fig. 3). Oolitic, glauconitic carbonates above the BB (K. Maher 1987) may represent the Midterhuken equivalent of the Marhøgda bed of Bäckström & Nagy (1985). On Treskelodden (Hornsund), both at the peninsula tip (E side) and at the base of Hyrnefjellet, a massive 0.5 m thick micritic siderite horizon with an upper section with laminations and cone-in-cone structures is found 18 m below a conglomeratic horizon which may be the BB (Dallmann pers. comm.). The particular depositional environment that produced these Fe-rich carbonates existed locally, before, during and after deposition of the BB. Also, locally massive quartz sandstones very similar to those of the underlying Wilhelmøya Formation occur above the BB in Nordenskiöld Land and on Midterhuken.

Strongly bioturbated sandstones with discontinuous shale laminations directly overlie the BB in northern Wedel Jarlsberg Land and fine upward into dark marine shales within several meters (Fig. 3). Glauconite and chamosite grains occur in the BB and in underlying (Bjærke & Dypvik 1977) and overlying (K. Maher 1987) rocks. As environmental indicators (Porrenga 1967), these grains, along with the bioturbated and often gradational upper contact of the BB with overlying, extensively bioturbated siltstones-sandstones, suggest the conglomerate was deposited near or below fair-weather wave base.

Similar bioturbated sands occur immediately above the conglomeratic horizon on the southeastern tip of Treskelodden, Hornsund, but here they are part of a coarsening-upward sequence (Fig. 3) that ends with clean, cross-bedded sandstones with rootlets and thin gravel horizons with large wood fragments (Dallmann pers. comm.). The sequence immediately above this coarsening-upward section is poorly exposed here, and Erling Siggerud (pers. comm.) reports that a higher conglomeratic horizon, which I did not find, can be found during low tide further east, in which case this conglomerate bed is not the BB. Yet, the conglomerate has a significant Fe-rich carbonate component, typical of the BB but absent within many of the phosphatic conglomerate horizons within Wilhelmøya, which have a quartz sand matrix. Either a coarsening-upwards sequence exists above the BB, or multiple such beds occur, some of limited lateral persistence, and then stratigraphic assignment must be given to the highest such bed.

Bäckström & Nagy (1985) document in the Isfjorden area an erosional, discontinuous contact of the BB with the underlying Wilhelmøya Formation sandstones, as does Birkenmajer (1975) for SW Torell Land. Locally in Wedel Jarlsberg Land and on Treskelodden bedding-parallel solution surfaces produce an abrupt lower BB contact, but elsewhere the lower contact is distinctly gradational, with phosphate and other clasts dispersed in the upper part of the sandstone. The sand was most likely a soft substrate during conglomerate deposition, and a reversely graded contact between the sandstone and BB (Fig. 3) suggests possible depositional continuity between the two.

Locally, similarities in rock types below and above the BB (K. Maher 1987; Fig. 3 this paper), coupled with a shallow marine character below (Mørk et al. 1982) and a variable, shallow (oolitic carbonates) to below-wave-base (bioturbated, glauconitic, laminated sands) marine character above, and locally gradational upper and lower contacts, suggest the BB could be contained within (not at the base of) a transgressive

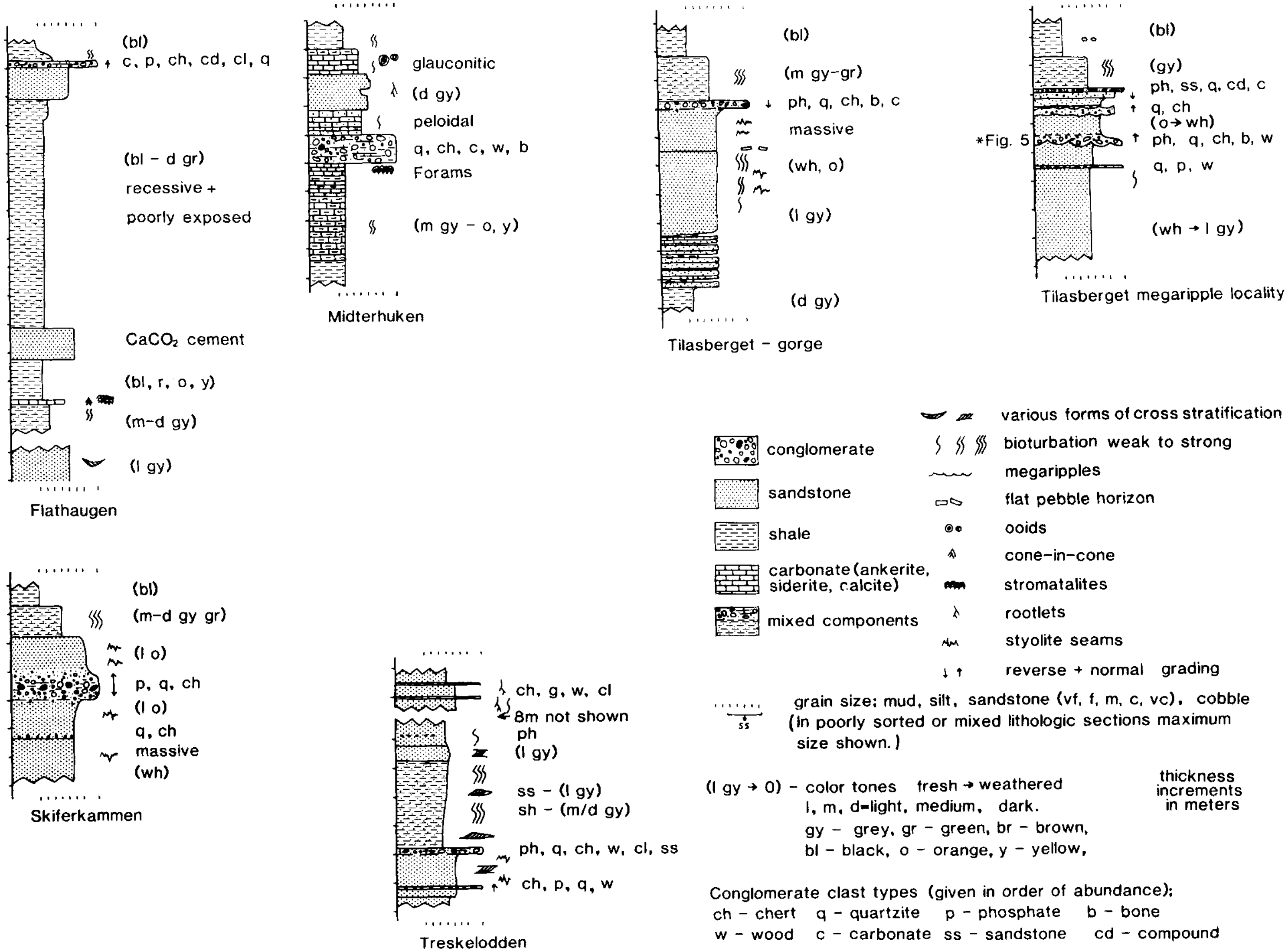

Fig. 3. Stratigraphic sections of lithologies immediately above and below the Brentskardhaugen Bed in the western fold-and-thrust belt of southern Spitsbergen. Midterhuken section modified from K. Maher's (1987) West Bravaisberget section. Treskelodden section modified from Dallmann, unpublished section; missing portion consists of a coarsening-upward sequence, and the conglomeratic horizon depicted may not be the BB (see text.)

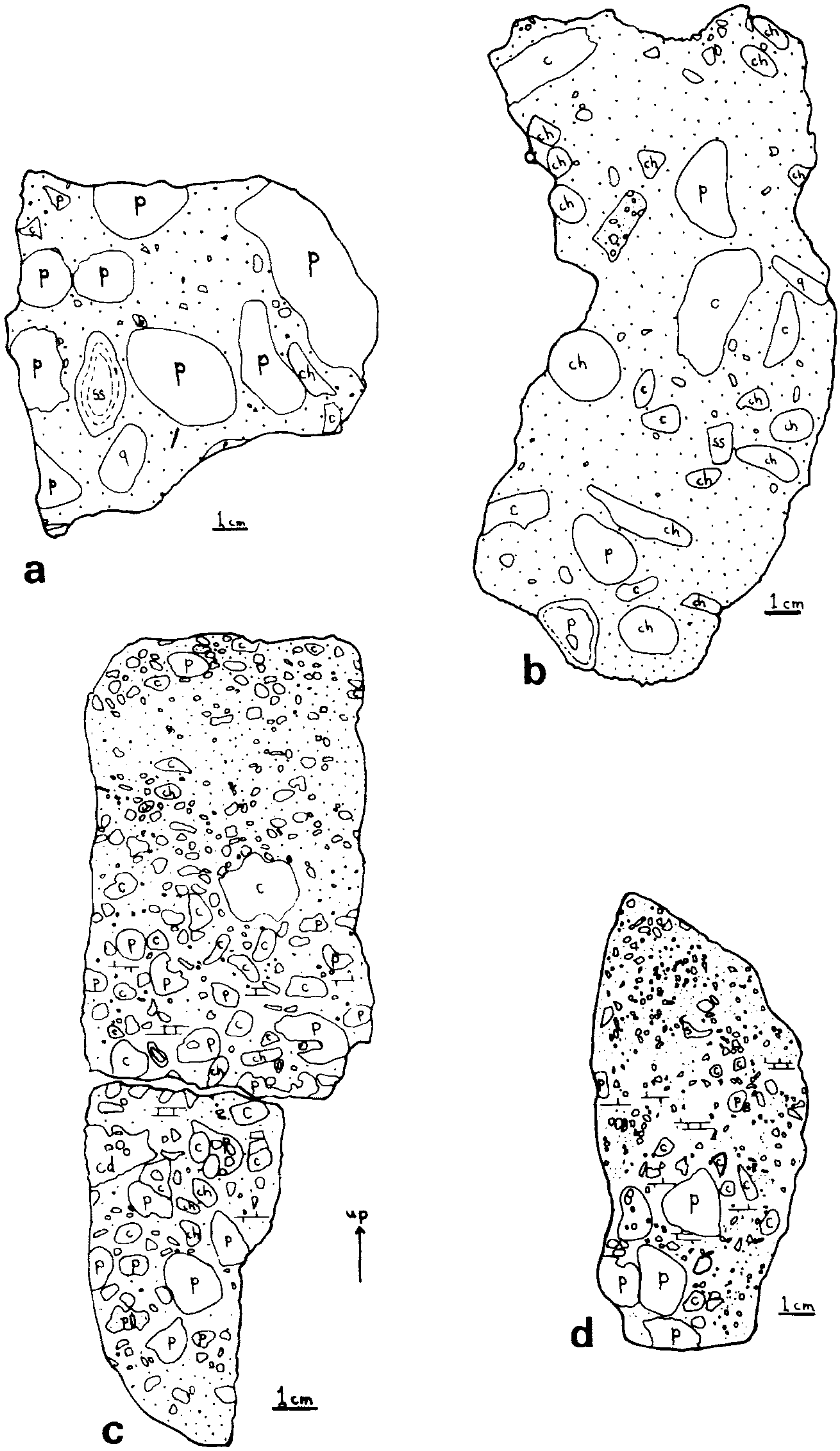

Fig. 4. Photosketches of slabs of the Brentskardhaugen Bed. a) from Kapp Toscana, b+c) from Flathaugen, d) from Tilasberget. c) represents the entire bed.

sequence. The conglomerate could occupy a slightly, locally variable position, separating a lower, condensed (and hence of variable age) marine section from a more complete section overhead. Why it might occupy such a position is discussed below. Such an interpretation would relieve the burden of requiring a transgression so sudden as to submerge the BB to beneath wave base without leaving any trace of shelf tide and current processes. Instead, shallow-shelf marine conditions gave way to below-wave-base conditions with the Bathonian eustatic rise of uncertain speed. Coarsening-upward cycles in the underlying Wilhelmøya could represent local offshore bar migration (Mørk et al. 1982; Worsley 1986) or delta-lobe progradation. Birkenmajer (1984) documents a regressive sequence ending in fluvial-deltaic, plant-bearing, cross bedded sandstones immediately underneath the BB at Agardhbukta (E Spitsbergen). Here, shallow shelf erosion or storm scour may have cut down to such an earlier lobe, removing overlying, possibly marine, strata.

Interpretation as a mega-storm deposit

Poorly sorted and graded layers of high lateral persistence are characteristic of turbidites. While most turbidity currents are associated with abyssal and not shelf settings, storm-generated 'turbidite' beds within a shelf setting have been increasingly recognized from the record (e.g. Brenchley et al. 1979; Fiqueirdo et al. 1982; Walker 1984 – the literature on storm deposits is extensive – Walker provides a list of references). Allen (1985) summarizes for storm-related deposits: 'Hence we may imagine that a turbidite-like bed of mainly shore-derived sand gradually spreads outwards over the shelf. Its base is likely to be erosional, and the lower part may include a lag of shell and other debris scoured up from the nearby shelf' (p. 265). However, storm 'turbidites' differ from abyssal turbidites (discussed later).

Such a storm interpretation could not only explain the sorting and grading (Fiqueirdo et al. 1982) within the BB, but it would also explain: 1) a lack of internal discontinuities and the implication that this was a short-lived depositional event; 2) the local existence of multiple such beds reflecting multiple storm events; 3) an erosional or gradational base (dependent on the specific storm-related mechanism (Fiqueirdo et al. 1982) and on a hard versus a soft substrate) and gradational top (Bäckstrom & Nagy 1985); 4) a bioturbated top and overlying bioturbated, laminated sandstones and mudstones (representing resumption of normal, below fair-weather wave base processes) at some locales, while at others overlying oolitic carbonates and clean sandstones indicate shallow shelf conditions (i.e. BB deposition occurred in variable water depths); 5) the relatively intact character of the phosphate nodules (transported by storm event(s), and hence not subject to repeated transport-deposition cycles of a terrestrial or shoreline character). Fair-weather bottom shelf currents may have winnowed the soft sediments from around phosphate concretions, prior to any storm transport. Both reverse and normal grading are consistent with a storm event, possibly representing the growing and diminishing phases of a storm. A complete record might be reversely graded in the lower portion and normally graded in the upper.

Staining and irregular cementation observed at the base of the BB and extending into the underlying sandstones may represent an 'underbed' (Aigner 1982). According to Aigner (1982), '"underbeds" may be regarded as a type of concretion controlled by the sudden porosity change at the base of the tempestite' (p. 191). Importantly, these underbeds can serve as 'reference horizons' – the base of storm scour, reworking and redeposition – due to their early cementation. Several previous storm episodes may be preserved in one final storm deposit as underbed and associated hardground clasts (Aigner 1982). This possibility should be investigated for the BB.

Aigner (1982) also describes steep-walled, linear storm scour features at the base of Middle Triassic storm deposits in SW Germany that he calls 'gutter casts'. K. Maher (pers. comm.) reports similar-appearing features from the base of the BB on Midterhuken, and Fig. 5 of Bäckström & Nagy (1985) may show some possible irregular gutter casts from the base of the BB along the S shore of Isfjorden.

Different conglomeratic facies (clast types and matrix composition) within the BB (e.g. Hornsund area, Birkenmajer 1975, p. 24) may be due to locally different substrates reworked during storm events, and due to different storm related processes (offshore currents and storm liquefaction), and are worthy of further attention in light of storm-depth determined facies distributions.

The occurrence of hummocky cross-stratification (HCS) in sandstones (one possible hallmark characteristic of a storm deposit; Walker 1984; Dott & Bourgeois 1982) in close stratigraphic association with the BB would be expected but was not looked for as I was unaware of its significance and appearance during the field season. Eikeland & Dypvik (pers. comm.) report hummocky cross-stratification within Wilhelmøya Formation sandstones. Above the BB it may be obliterated in many places by the intense bioturbation. Future workers might look for it, especially in the underlying Wilhelmøya sandstones, where similar size-graded conglomeratic horizons occur in association with mega-ripples (Birkenmajer 1972; Fig. 3), suggesting a storm origin (Fiqueirdo et al. 1982). However, the extent of HCS in Wilhelmøya sandstones may reflect more the preservation potential (related to the degree of fair weather reworking) of storm deposits in more shallow parts of the shelf than it does the frequency of storm events. Its existence and extent bears only indirectly on whether the BB is storm generated itself.

The exact transport mechanism of turbidite-like storm deposits is a matter of debate. Walker (1984) argues for storm-initiated, gravity-driven turbidity currents, in which case they should flow down-slope. Allen (1985) calls upon a wind-setup induced, offshore bottom current. Fiqueirdo et al. (1982) reject a gravity-driven turbidite model but describe three mechanisms for storm-related graded layers: 1) storm-induced offshore-longshore currents (as above); 2) bedform migration; 3) storm pumping and liquefaction. They emphasize that these are not mutually exclusive mechanisms, but that they likely operate together. Gradational contacts of the BB with underlying massive Wilhelmøya sandstones seen in Wedel Jarlsberg Land might represent the operation of the third mechanism. One important aspect of all models for storm deposits is that they represent either offshore and/or longshore transport.

Transport direction and paleogeography

Mørk et al. (1982) and Worsley (1986) describe a Late Triassic and Early Jurassic median shallow marine shelf with flanking eastern and western shorelines. The western shoreline in Late Triassic was a deltaic system with extensive offshore bar migration, and changed to an intermittently-emergent, starved shallow shelf in Early Jurassic (Wilhelmøya Formation times). The eastern shoreline was a delta front barrier located along Barentsøya and Edgeøya. Both shorelines are inferred to have a general north-northwest trend.

Birkenmajer (1972) describes mega-ripples within the Wilhelmøya sandstones underlying the BB at Tilasberget, Van Keulenfjorden (Fig. 3). At least two horizons with mega-ripples exist. Phosphatic graded conglomerates occur in the troughs of the asymmetric mega-ripples (0.8–2.1 m wavelength) which have a trend indicating an N40E transport direction. The long axis of cigar-shaped clasts and bone and wood fragments within this conglomerate was measured and shows one population sub-parallel to the ripple axis and one at a distinct angle to it (Fig. 5). The second population suggests a more northerly current direction, and may represent a change in the current direction during diminishing flow. Fiqueirdo et al. (1982) in discussing storm deposits associated with the Holocene transgression on the Atlantic coast of the central United States note that 'the graded deposit will be confined to small areas such as troughs between mega-ripples and sand waves' (p. 183). These may represent the 'swell lags' of Brenner & Davies (1973), formed by the in situ reworking of bottom sediments, in this case possibly during the waning stages. Using many of the same lines of argument given above (bed grading and poor sorting), at least some of the conglomerates within Wilhelmøya also represent storm influenced deposits.

Measurements of long-axis orientation of cigar-shaped clasts within the BB were also made at Heimfjella, east of Tilasberget. The average direction of S80E suggests a N10E or S10W current direction. Given the information from Tilasberget, N10E is the simplest choice, and this is very similar to the second clast population (oblique to the mega-ripple axes) at Tilasberget. Observations of current directions in Wilhelmøya Formation sandstones of Treskelodden show a bimodal or polymodal pattern, but with a dominant northerly direction, suggesting this may be a long-term dominant, longshore transport direction.

Transport directions to the northeast and north are consistent with a storm origin and the above paleogeography of Mørk et al. (1982). Given that the west shore is the most proximal, they would represent some combination of offshore and

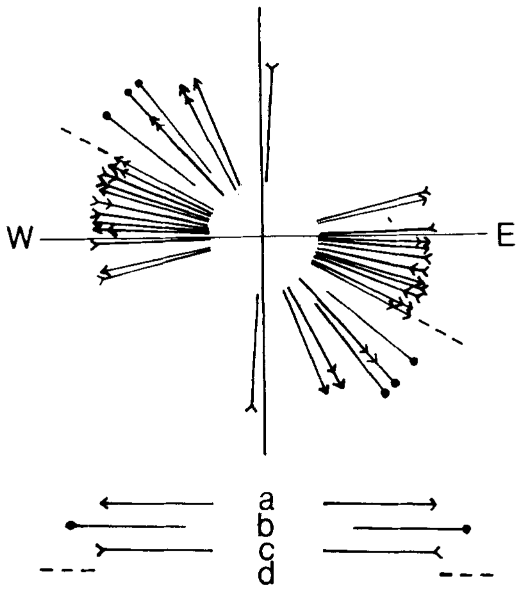

Fig. 5. Paleocurrent data for the Brentskardhaugen Bed and Wilhelmøya Formation from the Tilasberget and Heimfjellet areas. a) Long-axis clast orientation in conglomerate directly above the mega-ripple surface, Tilasberget (Fig. 3 for position), n = 14. b) Mega-ripple crest orientation, Tilasberget, n = 3, 2 surfaces. c) Long axis clast orientation in Brentskardhaugen Bed on Heimfjellet, n = 9. d) Mean orientation of long axis clast orientations from Brentskardet area as reported by Bäckström & Nagy (1985).

along-shore transport, both of which characterize storm deposits (Walker 1984).

Bäckström & Nagy (1985) document a strong, long-axis, preferred orientation within the BB of the Brentskardet area. They infer a N28E or S28W current direction, and note that small cross-beds from a sandstone within the BB have a southerly component. If the sandstone represents deposition between two storm events (two conglomeratic horizons), then the southerly direction could be unrelated to the clast orientation. In any case the BB has a fairly uniform clast orientation at Heimfjella and Brentskardet, two widely separated areas (Fig. 2). Also, the similarity in orientation between clasts in the BB and those in underlying conglomeratic layers at Tilasberget suggests similar conditions of formation. More paleocurrent analysis from the BB and underlying and overlying sandstones is likely to produce interesting results in the future.

Singularity of the BB?

A mega-storm interpretation for the BB raises the question of how many such events are preserved in the BB and adjacent strata. A one-time super storm for the BB is one possibility, but is philosophically unattractive (postulation of catastrophic events requires extraordinary evidence).

In many locales only one conglomeratic horizon separates the Wilhelmøya and Janusfjellet Formations, but Bäckström & Nagy (1985) describe two conglomeratic horizons separated by a sandstone interbed at Drønbreen, Brentskardet area. Both are shown with erosional bases on stratigraphic columns and, therefore, are likely separate events. Two closely spaced conglomeratic horizons of very similar character also occur locally on Midterhuken (separated by a carbonate bed, K. Maher 1987) and in Heimfjella (separated by a sandstone bed). The highest horizon in each case might be properly called the BB, but it seems apparent that they represent similar depositional events. These relations give rise to the possibility that the BB is actually not a single, continuous bed, but consists of several laterally-persistent beds within a limited stratigraphic interval that locally overlap each other.

Conglomeratic horizons that are sometimes poorly sorted and graded (Fig. 3) occur throughout the Wilhelmøya Formation (Mørk et al. 1982). As forementioned, some of these (e.g. at Tilasberget, Fig. 3) may also be storm deposits. The lower Tilasberget conglomeratic horizons are notably discontinuous, being absent some several hundred meters to the north in a series of excellent exposures of the Wilhelmøya Formation and BB (Fig. 3). Considering these in combination with the BB, at any one locale one to five or so mega-storm events are preserved in the conglomeratic horizons.

Storm deposits during the time spanned by the Wilhelmøya Formation, being deposited above fair-weather wave base, would more likely be destroyed by subsequent reworking. Some storm sediment may be preserved in local channels filled in by the storm or in other such spotty settings above fair-weather base. The Tilasberget mega-ripples and trough conglomerates may represent such an occurrence. A much reduced lateral persistence of Wilhelmøya Formation storm deposits in comparison to that of the BB is thus explicable.

The BB is distinct from the underlying phosphatic conglomerates of the Wilhelmøya Formation in being more laterally persistent and usually thicker, and in having more of a fine-grained carbonate matrix. The BB matrix is similar to that of the massive carbonate beds that occur above and below it. A more persistent character is in accord with being deposited below fair-weather base, as is the presence of heavily bioturbated sandstones and mudstone directly overhead. More storm deposits might be expected in the overlying Janusfjellet strata, but a Bathonian eustatic rise (Vail et al. 1977) may have submerged a shallow, flat shelf below even mega-storm wave base at such a rate that only few such events were preserved.

During a eustatic rise the sedimentologic potential of a storm will increase in a shallow epicontinental sea by increasing water surface area (and thereby fetch and wave size), and also by submerging shallow sandbars that would act as wave barriers (which would reduce the 'effective' fetch). This may explain why the BB is the thickest storm horizon associated with the most extensive reworking. Several previous storm events may be recorded as carbonate underbed and/or hard-ground clasts (laminated carbonate tabular clasts occur in the Nordenskiöld Land and Treskelodden conglomeratic horizons), but this remains to be investigated. With increasing 'power' during transgression, the last major storm event before submergence below even mega-storm wave base would likely rework previous events. Seilacher (1982) discusses the formation of a shelf equilibrium surface near extreme-storm wave base, developed during a sea-level standstill by the winnowing and offshore transport effect of the storms. This may represent an alternate model for the BB, with a formation before, as a storm generated 'submarine peneplanation' basal deposit, and not during, a rapid eustatic rise.

The term mega-storm is used for the BB in a relative sense – if these conglomeratic horizons are storm related, then the BB is the thickest and has the largest clasts, and hence represents the largest storm preserved in the record. Also, the storm-related currents necessary to entrain 15 to 25 cm sized phosphate clasts are notable. While channel currents could be large enough, the BB is a 'sheet' deposit and not a channel deposit.

Conclusions

1) The poorly sorted and locally graded character of the Brentskardhaugen Bed, along with the lack of internal discontinuities, is inconsistent with a 'stratigraphic' origin (Fiqueirdo et al. 1982) of a terrestrial or shoreline deposit formed during a quick transgression. Instead, locally the BB is likely the result of a short-lived depositional event, specifically a mega-storm turbidite on a shallow shelf. Throughout Spitsbergen, probably more than one storm event is represented by the BB.

2) Extensive reworking and abrasion is not necessary to explain the smooth, rounded phosphate clasts within the BB. Although they clearly were excavated from older marine strata (Birkenmajer 1972; Bäckström & Nagy 1985), winnowing by a variety of shallow shelf currents during condensed sedimentation and entrainment and transport of excavated fossiliferous concretions by storm events may have produced the BB's remanie character.

3) Marine fossils, of Toarcian to Bathonian age, found within the phosphate clasts limit a period of widespread exposure and erosional hiatus prior to BB deposition to within the Bathonian (<3 Ma). An alternate interpretation, of local, variable stratigraphic gaps due to shoaling and shallow shelf submarine erosion within the condensed section, is preferred.

4) The stratigraphic position of the BB is that which would be expected from (a) storm deposit(s) between underlying, mostly shallow marine, shelf sediments and overlying, above overall, deeper water sediments. Locally, similar facies exist below and above the BB (K. Maher 1987), consistent with a storm deposit punctuating 'normal', fair-weather processes, with deposition in variable water depths.

5) Sparse paleocurrent data are equivocal, but are presently consistent with an offshore/longshore transport component typical of a storm deposit. The Tilasberget locality (Birkenmajer 1972) is especially informative in this regard.

6) Locally, more than one size-graded, poorly sorted layer occurs at the BB interval; hence, more than one storm event is represented. Similar 'lag' gravels within the Wilhelmøya Formation strata beneath may represent other storm deposits.

7) As a transgressive lag deposited after a widespread hiatus, the BB would correctly be included with the overlying Janusfjellet Formation (Birkenmajer 1975; Bäckström & Nagy 1985). As a storm deposit on a shallow shelf submerged below

wave base during a Bathonian eustatic rise, the stratigraphic assignment would be less certain. However, inclusion within the Kapp Toscana Groups (Mørk et al. 1982) would be consistent with the existence of similar horizons in the Wilhelmøya Formation, and would also more or less separate shallow shelf, above wave-base sediments from below wave-base deposits. The base of the bioturbated shale to siltstone sequence of the lower Janusfjellet Formation would be more precise in making such a separation.

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