Exhumed rotational slides and scar infill features in a Cretaceous delta front, eastern Spitsbergen

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Coastal cliff exposures in the Helvetiafjellet Fm. deltaic succession near Kvalvågen on eastern Spitsbergen show spectacular evidence of syndepositional, gravity-driven deformation and resedimentation associated with delta-front instability, most probably triggered by earthquakes. This short article summarizes the results of a recent study of these features, with emphasis on the actual sequence of processes recorded in the outcrop. Detailed analysis of the structural style of the delta-front collapse and the associated sedimentation processes is presented elsewhere (Nemec et al. 1988).

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Spectacular synsedimentary collapse features, especially rotational slide blocks and a variety of associated scar-fill deposits, have been recognized in an early Cretaceous delta-front succession exposed near Kvalvågen, on the eastern coast of Spitsbergen, Svalbard. This well exposed example of an ancient delta-front instability illustrates in detail the two-dimensional (slope-parallel) geometry of large slides and the important role of various mass-transport processes in the subsequent rebuilding of the delta front. The latter supports the contention of Prior et al. (1979) that 'classical concepts of delta progradation by water suspended sediments need modification'. Furthermore, this example clearly demonstrates the important causative relationship between actual delta-front failure and the type and distribution of sediment facies which subsequently accumulate to repair the delta front.

The gravitational deformation features in the coastal cliff section near Kvalvågen were recognized during a Statoil expedition in 1982, when it became clear that the faults and rotated sandstone blocks in the lower part of the exposed Cretaceous succession (Fig. 1) were intraformational features (Fig. 2) and not simply parts of recent landslips.

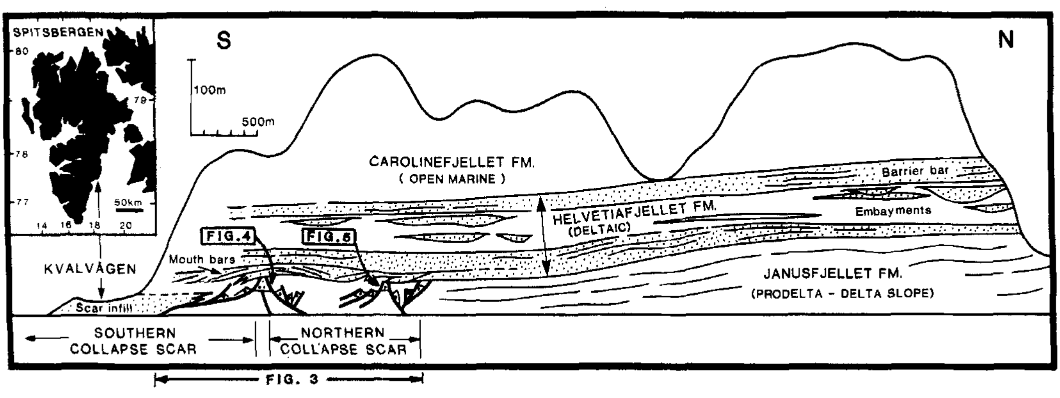

Fig. 1. Sketch of the cliff section north of Kvalvågen (inset), showing the Cretaceous deltaic succession with intraformational slide features at the Janusfjellet Fm./Helvetiafjellet Fm. boundary and with undisturbed strata farther north. Note the two buried collapse scars (for detailed view see Fig. 3) and the considerable vertical exaggeration in scale.

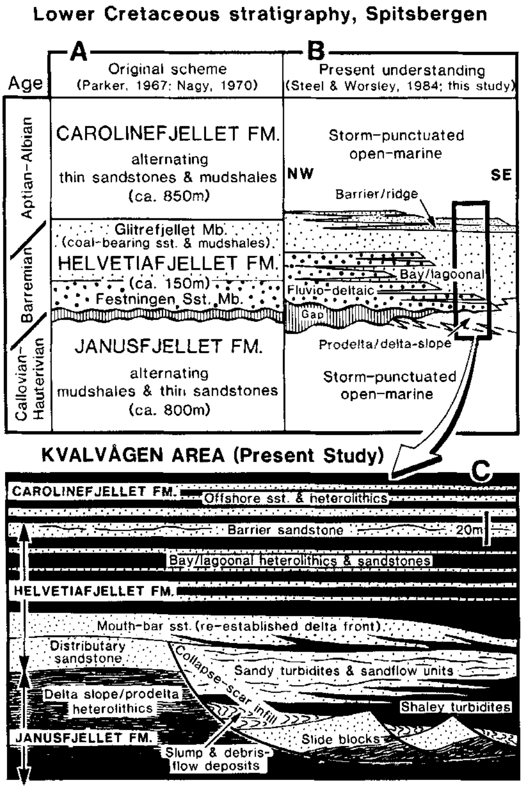

Fig. 2. Spitsbergen's Cretaceous lithostratigraphic scheme, in its original (A) and present revised version (B), with an interpretive cross-section perpendicular to the delta palaeoslope in the study area (C).

In the summer of 1985 the Kvalvågen section was revisited by a Norsk Hydro expedition, comprising sedimentologists from Norsk Hydro and Bergen University, which documented and reconstructed the structural and sedimentary development of the collapsed and re-established delta palaeofront. The purpose of this short note is to give a summary of the results. Detailed analytical account is presented elsewhere (Nemec et al. 1988).

The regional stratigraphical and depositional setting was one of a fluvial-dominated (braidplain) delta which prograded, mainly southeastwards and eastwards, across most of southern Spitsbergen in Barremian to early Aptian time, but was subsequently transgressed by the Aptian sea (Steel & Worsley 1984). Undisturbed sections through the delta-plain succession (Helvetiafjellet Fm.) are well exposed north of Kvalvågen (Fig. 1, see also Fig. 2), where these sandy deposits sharply overlie a thick sequence of earliest Cretaceous prodelta/delta-slope shaly heterolithic sediments (upper Janusfjellet Fm.). The Helvetiafjellet Formation is 100–140 m thick and consists of an extensive sandstone sequence (10–40 m thick) of braided distributary-channel origin, overlain by a sequence of thin, sheet-like to lensoidal sandstones and coal-bearing shales and siltstones, representing interdistributary bay to lagoonal environments. A distinct barrier-island sandstone unit separates the deltaic succession from the overlying, 800 m thick succession of open-marine sandstones and mudshales (Carolinefjellet Fm.).

Prominent collapse features in the Helvetiafjellet delta-front succession have, as yet, been documented only near Kvalvågen (Fig. 1). They consist of a series of rotational sandstone slide-blocks (mainly distributary-channel sands) resting on shallowly penetrating faults of inferred scoop-shaped geometry. These faults appear to merge into flat-lying or low-angle sole faults (Figs. 2–5). Although the palaeorelief between individual rotated blocks (fault-scarp height) is generally less than 35 m, the total (cumulative) relief created from the sole of the collapse scar to its head was at least 50 m. The overall picture gleaned from the pattern of faulting and associated block rotation is one of two large, complex collapse scars within the frontal part of the Helvetiafjellet palaeodelta (Figs. 1 and 3). The scars are at least 1 km and 1.5 km across. The timing of the creation of these scars and their infilling, prior to the development of overlying, extensive mouth-bar complexes, is evident in the outcrop (Figs. 2 and 3). These collapse features are conspicuously similar to the slope failures identified on some modern submarine slopes downdrift of large river mouths. The surface expression of such failures has been well documented from the curved, subparallel fault scarps seen on side-scan sonograph images of modern delta-front regions (Carlson & Molnia 1977; Prior & Coleman 1980; Prior et al. 1981). Specifically, the Helvetiafjellet delta slides resemble the 'shallow rotational slides' (Coleman et al. 1974) or 'periferal rotational slumps' (Prior & Coleman 1982) of the Mississippi Delta.

The large collapse-scar depressions created by the sliding were initially filled by minor mass-transport of material locally derived from the scar walls, and subsequently by sediments derived

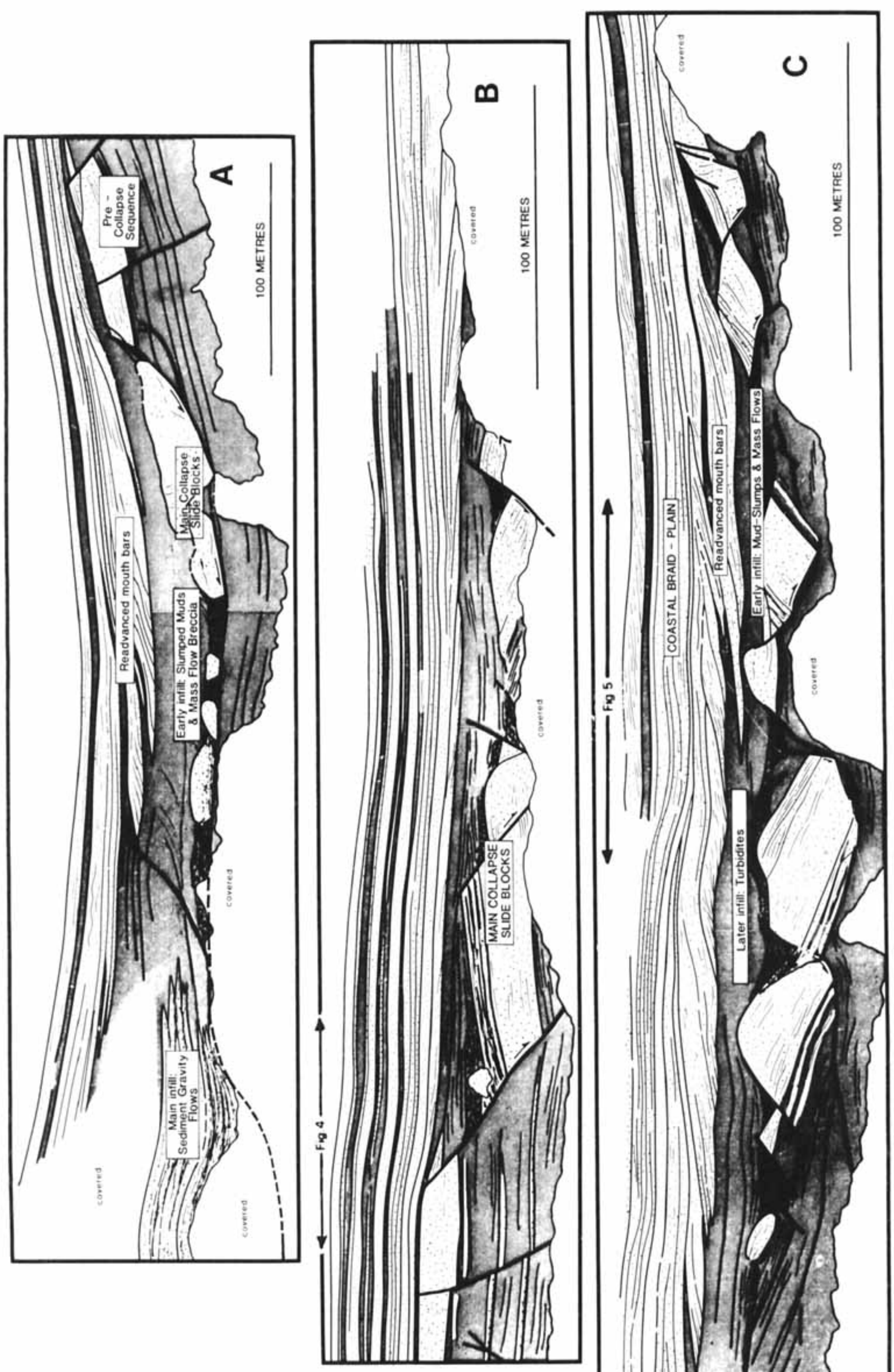

Fig. 3. Detailed sketch of the studied cliff section of the Helvetiafjellet Formation and uppermost Janusfjellet Formation, with intraformational slide features and buried collapse scars (drawn from a photomosaic). The section extends, with slight overlap, from the southern scar (A) through the northern scar (B and C), and corresponds to the left-hand (southern) part of Fig. 1. Some photographic details are shown in Figs. 4 and 5 (as indicated).

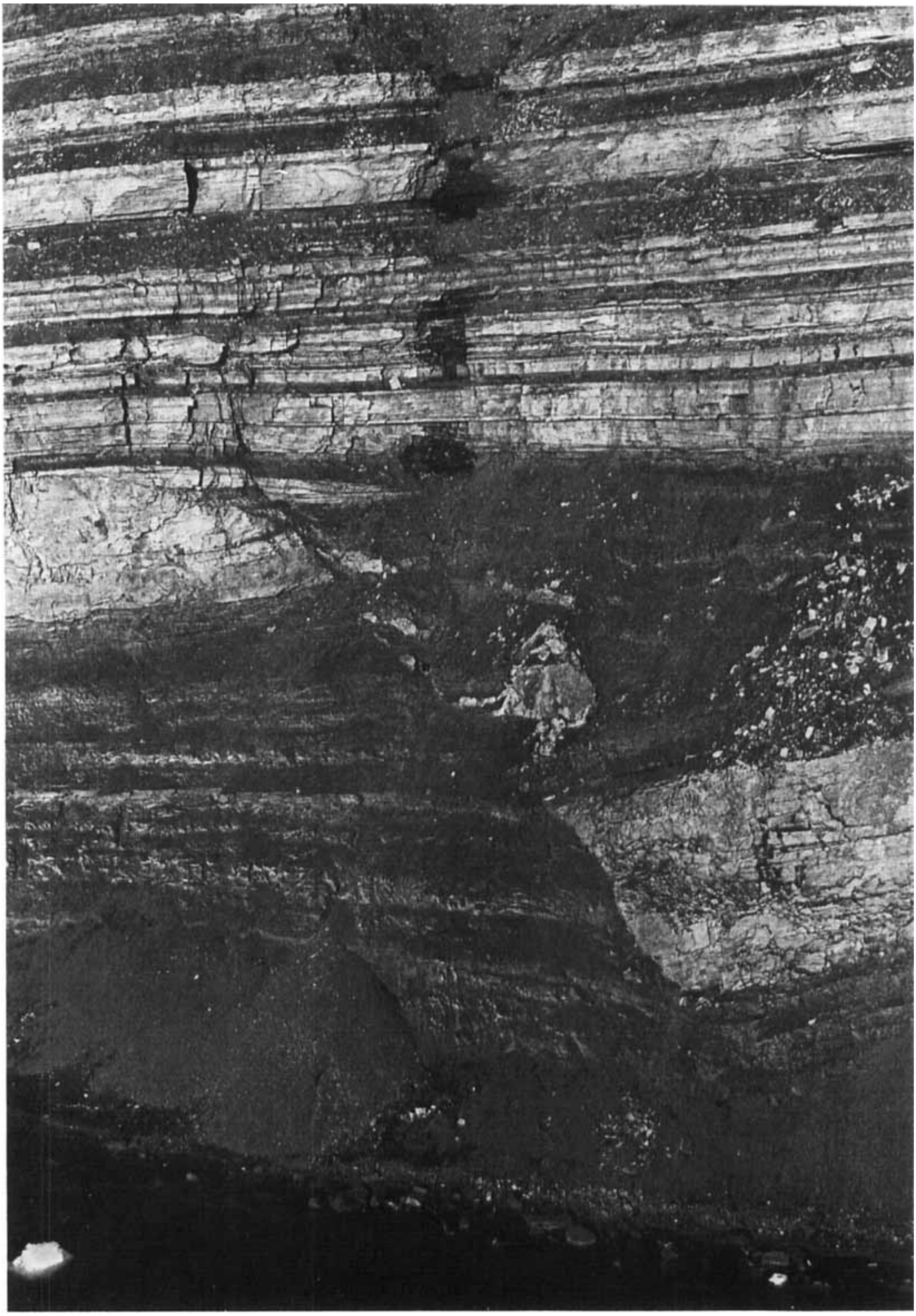

Fig. 4. Photograph of the in-situ buttress at the southern edge of the northern collapse scar (see Figs. 1 and 3B). The thickness of the downthrown sandstone slide-block (lower right) is c.20 m. The overlying mouth-bar sequence at the top of infilled scar is undisturbed.

Fig. 5. Photograph of rotational block faulting features near the northern edge of the northern collapse scar (Fig. 3C). Note the in-situ buttress in the centre and the tilted slide blocks on its flanks. The sandstone slide-blocks are c.20 m thick.

mainly from advancing mouth-bar systems which sought to re-establish the delta front. Slumps of contorted and isoclinally folded heterolithics, partially remoulded flowslides and debris-flow units with common slabs of delta-slope deposits line the bases of the scar depressions and appear to have largely filled local topography between the rotated slide-blocks (Figs. 3–5). The subsequent main infill, with a distinctly sandy facies assemblage particularly in the southern to central part of the southern scar (Figs. 1 and 3A), was provided by sediment gravity flows derived from the advancing, active front of the delta. The sediment was supplied by effluent-generated density currents and from the unstable slopes of large channel mouth-bars prograding to the scar edges. This *main infill* sequence can be divided into two parts: a lower unit (c. 8 m) consisting of thinly bedded, heterolithic turbidites, and an upper unit (c. 40 m) composed of interdigitating heterolithic turbidite packets (mainly effluent-derived), plane-stratified lensoidal sandstone packets (interpreted as gulley-mouth lobes of amalgamated turbidites) and thick lensoidal beds of massive sandstones (interpreted as lobate, gulley-derived, liquified sandflow deposits). The latter two sandstone facies tend to predominate upwards. This complex sequence of mass-flow deposits effectively infilled the scars, thus re-establishing the delta front and turning the collapse scars into interdistributary bays across which 'normal' (stable-slope) mouth-bar systems had then prograded (Figs. 2C, 3 and 5).

A similar spectrum of sediment-transport processes and other gravity-induced phenomena is known, or has been inferred, from shallow coring, side-scan sonar images and shallow seismic profiles across modern delta slopes. Elongate retrogressive slides/flowslides, mass-flow gulleys, coalescing mass-flow lobes and both slope-derived and effluent-generated turbidites have all been documented from the front of the Mississippi Delta (Prior & Coleman 1982, 1984; Coleman & Prior 1982). The ancient example reported here further emphasizes the important role of large submarine slides in both structural and sedi-

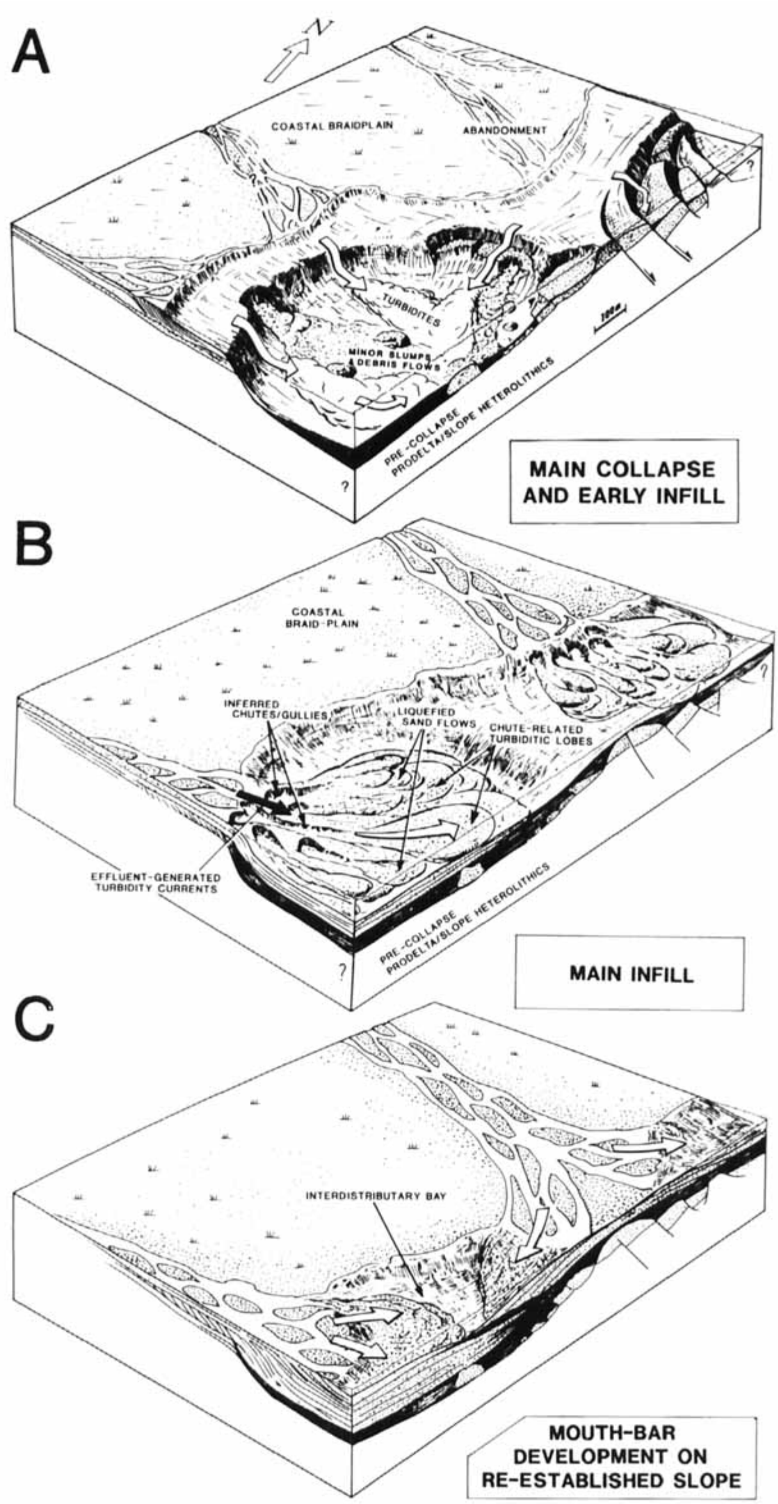

Fig. 6. Interpretive cartoon showing the inferred evolution of the Helvetiafjellet delta front near Kvalvågen: (A) collapse and initial infill of scars, (B) main infill stage and (C) mouth-bar development on the re-established delta front.

mentary reorganisation of large delta-front areas. The slope failures appear to have strongly controlled both the nature and distribution of the sedimentary facies which subsequently accumulated on the delta front.

The Kvalvågen example is also important in that it apparently reveals a sequential pattern of the delta-front collapse and rebuilding processes. We reconstruct this evolutionary sequence of main events as follows (Fig. 6):

(1) The delta front collapsed, by rotational block sliding, as a consequence of sedimentary loading and incipient instability, but the failure itself was probably triggered by earthquake shocking. This latter inference is based on the following evidence: (a) the collapsed delta-front segment had clearly been abandoned prior to its failure, as indicated by rooted coal-bearing cappings on the slide sandstone blocks; hence pure sedimentary loading is rather unlikely to have triggered the failure; (b) the study area is adjacent (distance of c.10 km) to the southern extension of the Billefjorden Fault Zone, which is known as a long-lived tectonic lineament that was active also during the Mesozoic (Harland et al. 1974; Steel & Worsley 1984); (c) probable 'seismite' horizons of soft-deformed or liquified sediment appear to occur within the scar-fill sequence and at its top, implying some events of seismic shocking (for details see Nemec et al. 1988).

(2) An initial infill of the collapse scars (Fig. 6A) was by slumps and cohesive debris-flows locally derived from the scar walls. This early infill was volumetrically insignificant and merely sufficient to partly smooth the local topography around the rotated slide-blocks. This indicates limited post-collapse derivation of material from the scar walls, as by major retrogressive flow-sliding or other large failures.

(3) This initial stage of infilling was followed by the deposition of thin muddy turbidites, probably shed mainly from the scar walls by small, localized failures. There is a distinct boundary, due to a marked textural and colour contrast, between this thin series (c.8 m) of heterolithics and the overlying, effluent-derived turbidites.

(4) Renewed progradation of channel mouth-bar systems brought them to the scar edges and led to the main infill of the scar depressions: by effluent-generated, thin turbidites and, increasingly, by sandier (amalgamated) turbidites and liquified sandflows derived from the over-steepened, unstable mouth-bar slopes (Fig. 6B). The post-collapse depressions were thus entirely infilled, and eventually became shallow interdistributary bays.

(5) The cancellation of scar-margin relief made the advancing mouth-bar slopes stable. The sandy mouth-bar systems then prograded out across the re-established delta front, and laterally into the bays (Fig. 6C), as demonstrated by their extensive progradational wedges above the buried collapse-scars (Figs. 3 and 5).

(6) From the pattern of mouth-bar development it is inferred (Nemec et al. 1988) that the thick scar-fill deposits were subject to repetitive gravitational sagging at the latest infill stages and during mouth-bar advancement. The evidence indicates growth-faulting related to partial reactivation of the buried slide-scar surfaces, most probably related to seismic tremors (for detailed discussion see Nemec et al. 1988).

This study demonstrates how delta-front instability can be responsible for various deformational features, rapid facies changes, bed thickness variations and textural or facies anomalies in muddy delta-slope settings. Depending on local circumstances, the collapse-scar depressions that result from mass movement may be slowly infilled with mud (as reported from many other delta slopes), or may become sites of vigorous sandy sedimentation (as in the present case). Large scars, some kilometres wide, apparently may tap and trap great volumes of sand derived directly from the upper slope and thus give rise to new 'anomalous' facies assemblages. Accordingly, we share the contention of Prior & Coleman (1984) that the significance of episodic submarine mass movements in deltaic sedimentation models has commonly been underestimated. We further emphasize, through this case study, the important role of delta-front failure in controlling the actual pattern of subsequent sedimentation.

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