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Upper Jurassic Overlapping-Fans Slope-Apron System: Brae Oilfield, North Sea

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Abstract

The Brae oilfield reservoir in the North Sea comprises Upper Jurassic resedimented conglomerates and sandstones interbedded with organic-rich silstone and mudstone thin-bedded turbidites. The system represents a series of small overlapping fans that form a thick (300 m) slope-apron accumulation of sediments deposited in a narrow (<10 km wide) belt along an active fault zone. The complex lateral and vertical distribution of facies was due mainly to variable tectonic activity, and partly also to sediment supply and sea-level changes.

Introduction

The Brae oilfield in the North Sea was discovered by the Pan Ocean Group in 1975. Since the discovery well, 14 more wells have been drilled on License Block 16/7a and over 2500 m of core have been recovered. The field is structurally complex and can be divided into northern, central, and southern parts. Together these make up the Brae slope-apron system. The operator and her partners have released a significant amount of structural and sedimentological data in papers by Harms and others [1] and Stow and others [2]. These data, including core descriptions and analysis, electric logs, dipmeter logs, and seismic profiles, form the basis of this contribution. It should be noted that the former interpretation [1] as partly subaerial fan deltas differs significantly from the latter [2] suggesting overlapping submarine fans that formed a slope-apron system along a submarine fault scarp.

Geological Setting

The Brae slope-apron was developed on the western margin of the South Viking Graben adjacent to a major fault escarpment at the edge of the Fladen Ground Spur (Figure 1). The Graben is part of an elongate central rift system in the North Sea Basin that was initiated in the Late Triassic and has since been periodically reactivated as a major depocenter [3]. An intense phase of tectonic activity in the Late Jurassic caused uplift of the Fladen Ground Spur along a series of north to northeast-trending en-echelon faults that dip about 60° to 80° eastwards and became progressively younger to the west. Many of the fault blocks are antithetically rotated so that the deepest part of the downthrown fault block is adjacent to the Spur. Smaller antithetic faults downthrowing to the west within the Graben occur subparallel to the main fault-zone trend.

Rapid erosion of the newly uplifted terrain resulted in deposition of a thick sequence of coarse clastic sediments in a relatively narrow (~5 km) elongated zone extending for at least 15 to 20 km along the faulted margin. These Upper Jurassic (mainly Kimmeridgian to Volgian) sandstones and conglomerates, forming the Brae field reservoir, interdigitate basinwards along-strike and up-section with organic carbon-rich shales (the Kimmeridge Clay Formation) that provide the hydrocarbon source for the Brae field and associated plays.

The Brae slope-apron system overlies Middle Jurassic sandstones, shales, and limestones and is juxtaposed against impermeable Devonian sandstones and conglomerates to the

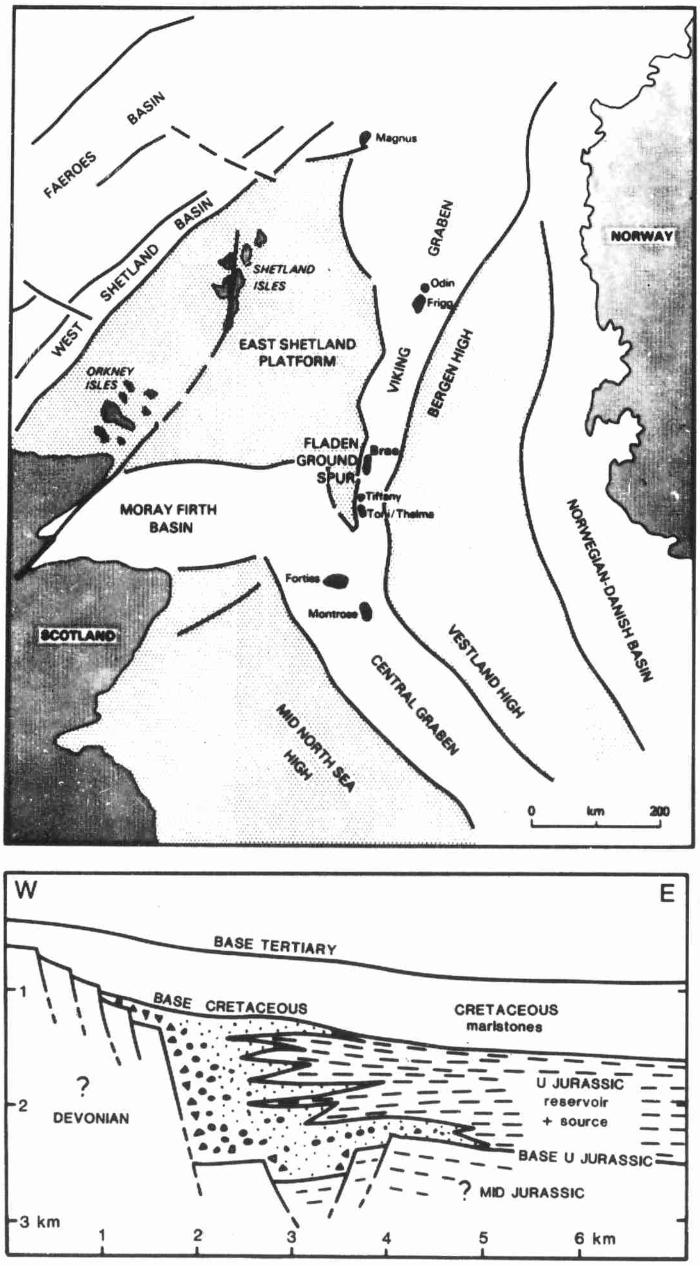

Figure 1. Location map (upper) Brae field, North Sea. Other oil and gas fields shown have also been interpreted as submarine-fan reservoirs. Cross-section runs across Brae field from Fladen Ground Spur to Viking Graben.

west. Latest Jurassic shales, followed unconformably by Lower Cretaceous marlstones and younger strata overlie the slope-apron sediments and onlap onto presumed Devonian basement to the west. Tectonic activity diminished through the Kimmeridgian, and subsequent minor tectonism has resulted in a series of gentle anticlines parallel to the Graben margin that now form the structural hydrocarbon trap.

Sediments

Four main facies groups are present in the Brae cores: mudstones, sandstones, conglomerates, and slumps (Figure 2), the first three of which can be further subdivided into separate facies. The *mudstone group* comprises interlaminated dark-grey micaceous mudstone and light-grey siltstones or fine-grained sandstones, and shows complete gradation from dominantly mudstone to dominantly sandstone facies. A range of microstructures, including basal scouring and mud injection, grading, fading ripples, and climbing low-amplitude ripples, indicate deposition from turbidity currents.

The *sandstone group* includes thin-bedded (1 to 10 cm) sandstones with internal grading, parallel and cross-lamination, and medium- to thick-bedded (>10 cm to over 40 cm) sandstones and pebbly sandstones that are commonly massive or with slight positive grading. They are interpreted as the deposits of higher-concentration turbidity currents and associated flows. They are quartz-rich with minor feldspar, mica, and other minerals, and variable amounts of carbonaceous debris, mudstone chips, and shell material. Porosity and permeability characteristics are commonly good, making these the main reservoir facies, but silica and calcite cementation are locally important. In addition, authigenic illite may also be present.

The *conglomerate group* is quite varied, including breccias, pebbly sandstones, pebbly mudstones, and possible tectonic breccia. Both graded-stratified beds 20 cm to 200 cm thick and massive matrix- or clast-supported conglomerates of indeterminate bed thickness are present. These probably result from rock-fall, debris flow, and other mass-flow processes. Clasts are very variable in size (1 cm to 150 cm), from angular to rounded in shape, and comprise presumed Devonian sandstones, quartz pebbles, dark-grey (? Jurassic) mudstones, dolomite, shell fragments, and carbonaceous debris. The sandstone matrix in some wells has good porosity and permeability, whereas others are very tightly cemented with carbonate.

Distinct *slump units* of variable thickness occur throughout, showing convoluted, contorted, and overturned laminae, small-scale faulting, steeply inclined lamination, and chaotic mudstone-sandstone mixes. They are indicative of deposition on a slope with periodic tectonic activity and/or rapid sediment build-up.

The different well sections have very different proportions of these facies groups (Figure 3). Overall, the mudstone facies are slightly more common (about 45%) than the conglomerate facies (about 35%), with sandstones being less abundant (about 20%) and *recognizable* slump units relatively unimportant (<3%). Three scales of vertical sequences are recognized: thinning- and thickening-upwards sequences over 5 to 20 m, mainly thinning/fining-upwards megasequences over 50 to 150 m, and gradual basin-fill fining-up-

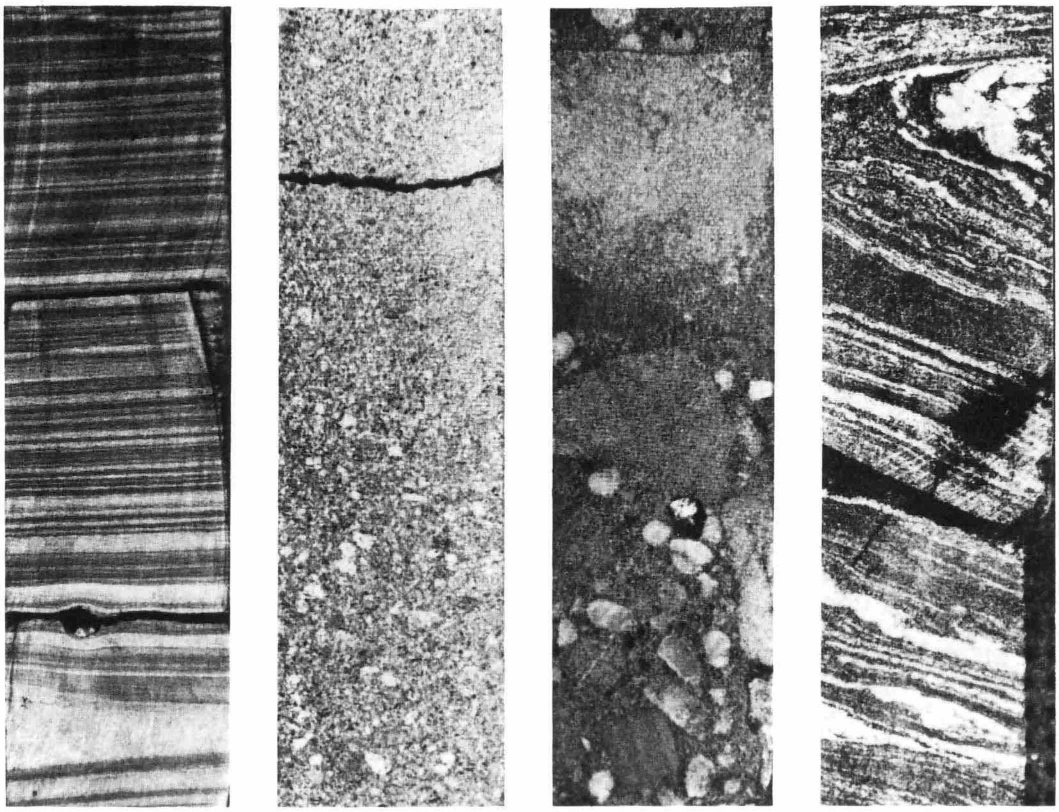

Figure 2. Photographs of typical resedimented facies from Brae field slope-apron system. From left to right, mudstone-group, sandstone-group, conglomerate-group, and slump facies. Core widths about 5 cm.

ward over the complete 300 to 600 m of section (Figures 3 and 4).

Horizontal variability is very marked. The basin-fill sequence is the only one that can be correlated with certainty between all wells. From three to six megasequences occur in a number of the wells, but the lateral variation over even short distances in both north-south and east-west directions makes correlation very tenuous. There is a general trend from more conglomeratic close to the main fault zone to more mudstone-rich in the east or basinwards. Compositional differences are also noted: shell debris and glauconite are most common in wells D, G, and H, but rare in the southern group of wells, J, K, L, M, and N. Well B appears to be mainly thick, clean sandstones and well J mainly mudstones, but neither were cored intensively so that their compositional characters are difficult to ascertain. Wells C, E, and F are on higher fault blocks or on the Fladen Ground Spur and comprise fractured and faulted conglomerates over Devonian basement.

The inferred paleogeography [3], the composition of clasts, and the overall fining of sediments to the east all imply a sediment source to the west. Dipmeter logs from the mudstone facies of several wells show low easterly dips after removal of a small structural component, commonly with slight vertical oscillations (2° to 4°) over 3 to 10 m of section. These have been interpreted tentatively as resulting from prograding mud lobes. The sandstone facies show less regular but mainly easterly dips, sometimes with irregular upward shallowing and steepening trends, whereas the conglomerates often have a random bag-o'-nails dipmeter pattern. These data certainly corroborate the derivation of sediment from the west but are not adequate to define radial or other paleocurrent trends.

Flora and Fauna

Marine microplankton together with rare marine macrofossils, including ammonites, belemnites, and fragments of shallow-water bivalves are found throughout the Brae wells in the mudstone facies. These are mixed with terrestrial spores, pollen, and woody debris that are mostly well dispersed and rarely occur as thin carbonaceous horizons. The same mixed marine and terrestrial biogenic assemblage is restricted but still evident in many of the interbedded sandstones and, more rarely, the conglomerates. Clearly, the environment was marine but with a significant and probably local supply of terrestrial material.

Shelly debris is present mainly in the three wells in the central Brae area, and this may imply local development of

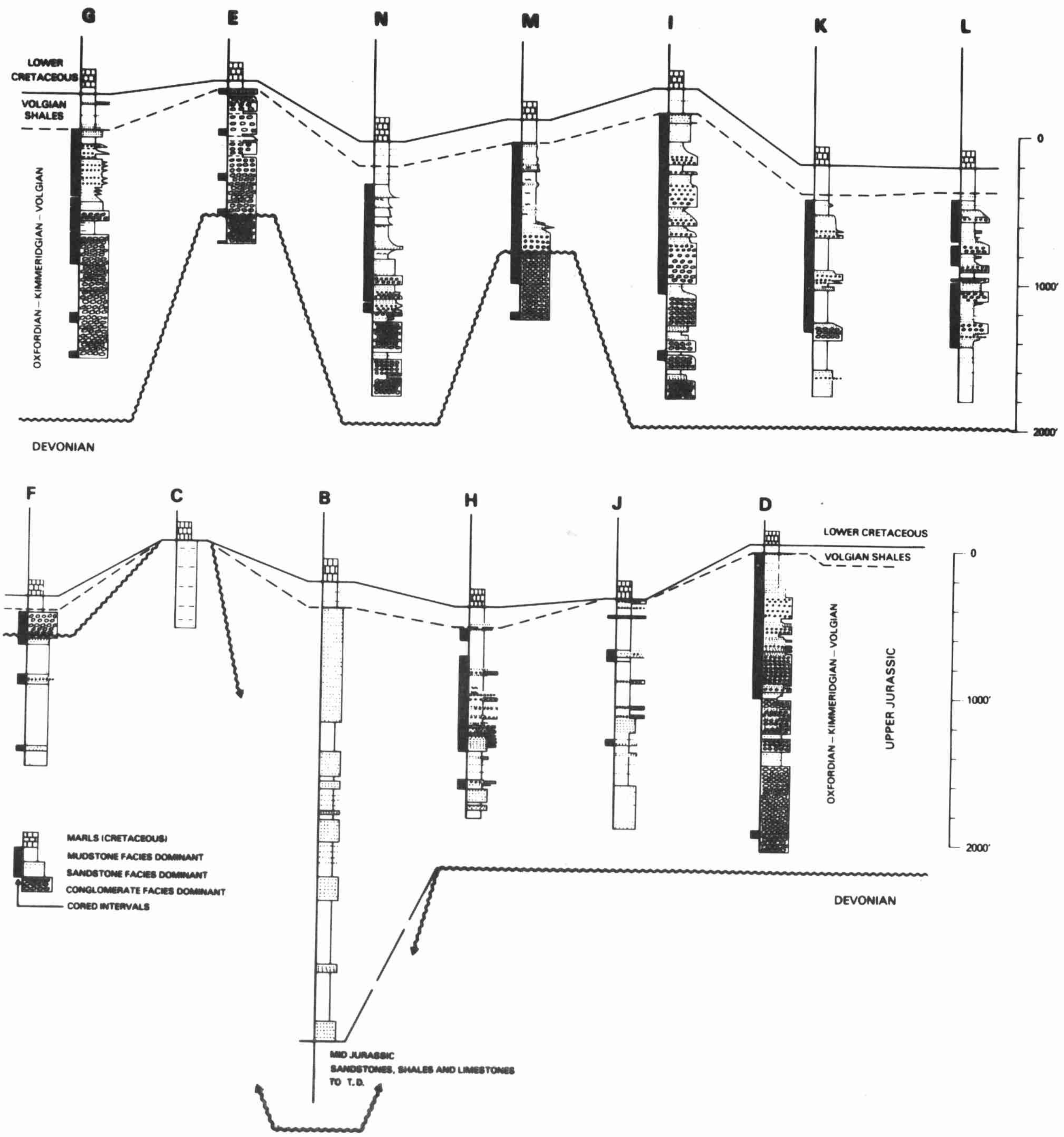

Figure 3. Summary well logs from Brae field slope-apron system, showing distribution of main facies groups and cored intervals. Well locations shown on Figure 4 (after [2]).

a narrow shelf on which a shallow-water benthic community existed and was periodically redeposited by turbidity currents and associated downslope flows. Bioturbation is almost completely absent even within the finely laminated mudstones, although the relatively high organic-carbon contents should have attracted a vigorous benthic infauna. It appears that conditions were unfavorable either because of anoxic/near-anoxic bottom waters and/or a very rapid sediment input.

Discussion

The Brae field wells were drilled through a series of small (<10-km radius) overlapping submarine fans that form a complex sediment apron along the faulted scarp margin of the Viking Graben (Figure 5). Distinctive fan geometry and morphology are not well established so that the system is better designated as a slope-apron, deposited for the most

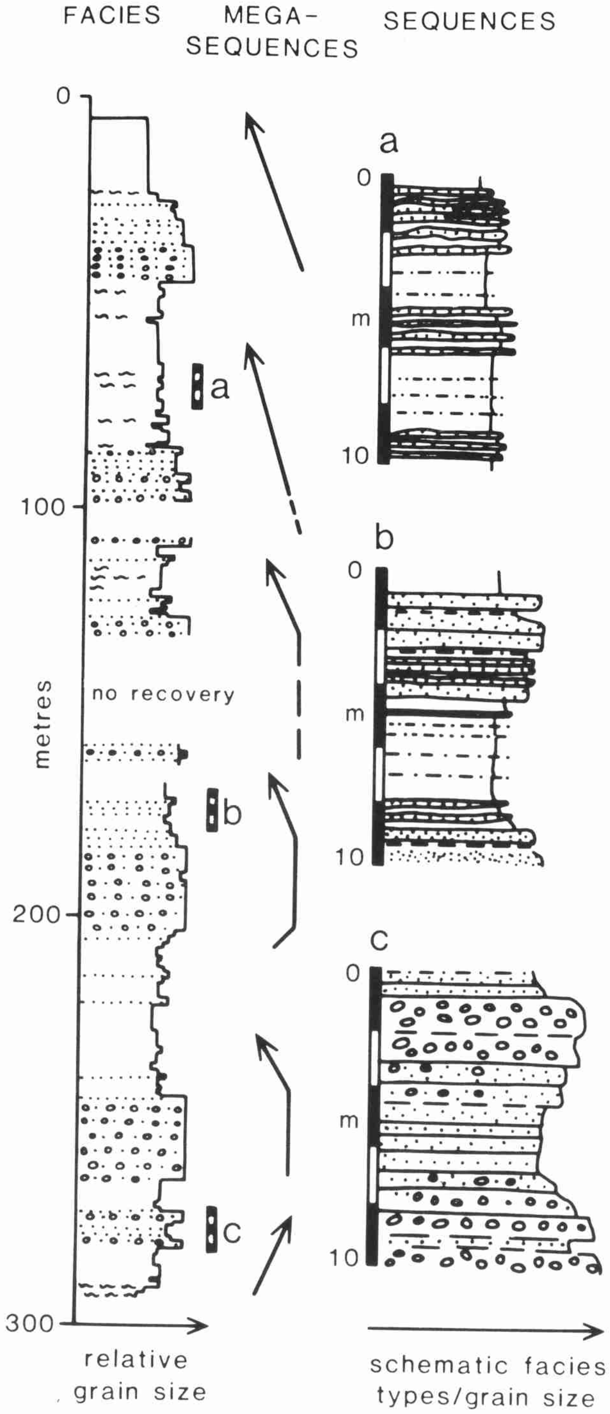

Figure 4. Detail of facies and vertical sequences through well L, southern Brae oilfield.

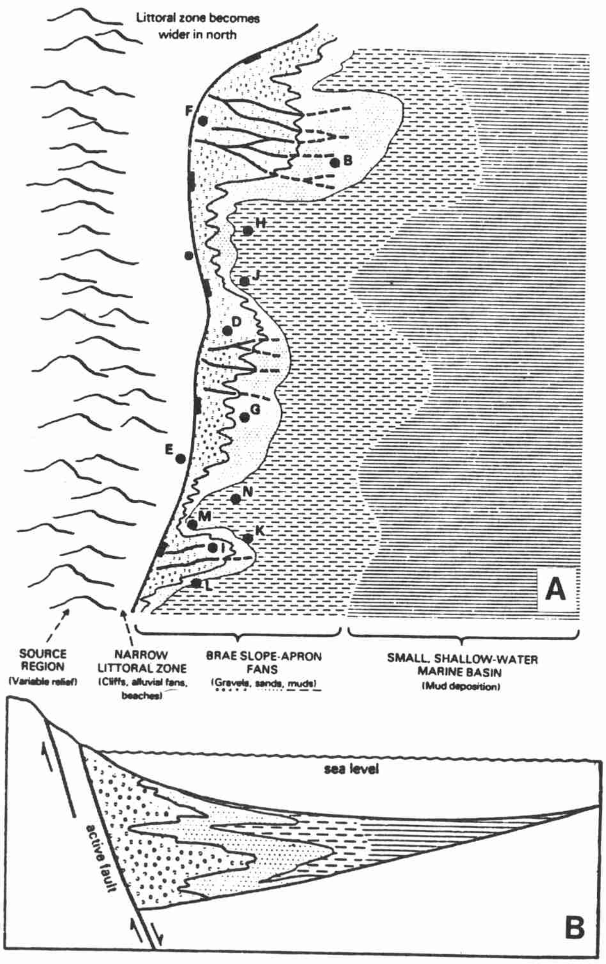

Figure 5. Schematic facies distribution for Brae field slope-apron system, North Sea, Upper Jurassic. A. Plan view showing boundary fault and well locations; facies indicated in solid ornament; solid and dashed lines represent probable submarine braided-channel system; B. Cross section showing schematic slope-apron sequence (after [2]).

part below wave base in a shallow marine basin. The three main facies groups occur in an irregular slope-parallel arrangement: a base of fault-scarp breccia-conglomerate association passing basinwards through pebbly sandstones and sandstones to a progressively more mudstone-dominated association. However, there is a complex interdigitation of these facies, with marked lateral and vertical facies changes which indicate that some channeling of the coarser facies occurred during deposition.

The main control on the development of this system appears to have been tectonic, but with important secondary controls being sediment supply and sea-level changes. Major fault movements and basin subsidence in the Oxfordian produced the first influx of coarse clastic sediments to the basin margin. Several subsequent episodes of active tectonism followed by relative dormancy probably resulted in up to six fining-upward megasequences through the Oxfordian-Kimmeridgian. Subsidence was most pronounced adjacent in the main fault zone so that a relatively thick but narrow wedge of sediment was developed. Faulting was not uniform along the margin either in time or place, so that the resulting separate redeposited systems are not readily correlated. "Piano-key" tectonics, causing differential uplift and subsidence, and transcurrent (east-west) faults, both acted to complicate the pattern of sedimentation. There is some evidence to suggest that these en-eschelon offset faults may have served as structurally controlled conduits to funnel sandy sediments beyond the slope-apron system into the Central Graben.

At times and along some parts of the margin, subaerial alluvial fans probably fed directly into the sea. In other parts, there was a narrow littoral zone in which pebbles were rounded, sands sorted, and both were mixed with broken shell fragments. This coastal zone was wider to the north, such that more mature dominantly sandy sediments were reworked downslope. Sediment supply may have been greater to the north because the platform was larger. A general decrease in fault activity, sediment supply and/or a relative rise in sea level through the Late Jurassic led to an overall fining-upward basin-fill sequence culminating in the Volgian black-shale transgression.

Similar slope-apron accumulations of turbidites and associated facies have been described in detail from both the Jurassic of east Greenland [4] and the Devonian-Carboniferous of the Polish Carpathians [5]. Recent work has shown that the South Arabian margin provides a modern example of this type of sedimentation (J. C. Faugeres, personal communication, 1983). Although not yet widely recognized, slope-apron systems are probably at least as common in the ancient record as the more classical submarine fan sequences.

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