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Depositional Environments of a Wolfcampian Section of the Pennsylvanian-Permian Oquirrh Formation, Spanish Fork Canyon, Wasatch Mountains, Utah

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ABSTRACT

Five roadcuts, including approximately 300 m of Wolfcampian rocks, in the lower 4–5 km of Spanish Fork Canyon, are interpreted to represent a cross section through a deep sea fan. The rocks record a deep marine shallowing upward sequence in which there is also an increase in available oxygen upward. Individual units become progressively thicker, particle size increases, bioturbation increases from ichnofabric facies 2 to 4 (Droser and Bottjer 1986), and a transition from pyrite-rich to pyrite-poor sediments occurs. Uppermost units include carbonate conglomerate channel fills, up to 2 m thick, containing displaced skeletal fossils. Most of the deposits are turbidites that show extreme cyclicity and grade upward from sandstone displaying convoluted laminae to a finer grained, more thinly laminated siltstone. These sequences in each cycle are interpreted as representative of units C and D of the Bouma sequence.

INTRODUCTION

The Oquirrh Formation consists of over 7900 m of sandstones and carbonates that accumulated in the Oquirrh Basin of western Utah and southern Idaho (fig. 1). This basin covered approximately 54,500 km^2, but its deepest troughs were in northern and southern lobes that occupied roughly the same area as Salt Lake Valley and Utah Valley.

This study concerns Wolfcampian age rocks of the Oquirrh Formation of the southern lobe, rocks now exposed in a series of roadcuts in Spanish Fork Canyon (fig. 2). Baker (1972) demonstrated that the entire studied section is of Wolfcampian age, based on fusulinid faunas.

These rocks, on the basis of trace fossils, sediment types, and sedimentary structures, are evidence that the upper part of the Oquirrh Formation was deposited in a deep water environment and that these beds accumulated as a series of turbidites.

PREVIOUS WORK

The Oquirrh beds were first defined as a formation by Gilluly (1932), based on outcrops in the Oquirrh Mountains (fig. 1). Bissell (1959, 1962, and 1967) and Welsh and Bissell (1979) dealt with depositional limits, generalized depositional environments, regional tectonics and paleogeography, and biostratigraphy of the Oquirrh Basin and surrounding areas. Wells (1963) described the petrology and petrography of some clastic sedimentary rocks, particularly orthoquartzites, of the Oquirrh Formation. Work by Thompson, Verville, and Bissell (1950) included detailed fusulinid biostratigraphy of the formation. More recently, work by Alexander (1978), Chamberlain and Clark (1973), Jordan (1979), Konopka and Dott (1982), and Larson (1979) emphasized detailed sedimentologic and paleoecologic descriptions of various parts of the Oquirrh Formation.

LOCATION

The five studied exposures are located near the mouth of Spanish Fork Canyon, Utah, along the northeast side of U.S. 89, a short distance north and west of Cold Springs, approximately 4.8–7.2 km west of Diamond Fork Canyon (fig. 3) in the Spanish Fork 7½-Minute Quadrangle. From west to east, these five sections are located: (1) 213 m east and 61 m south of NW corner of section 2; (2) 579 m west and 427 m north of SE corner of section 2; (3) 274 m west and 274 m north of SE corner of section 2; (4) 213 m east and 46 m south of NW corner of irregular section 12; and (5) 915 m east and 244 m south of NW corner of irregular section 12.

METHODS OF STUDY

The roadcuts along U.S. 89 were selected for study because these fresh exposures offered the most character-

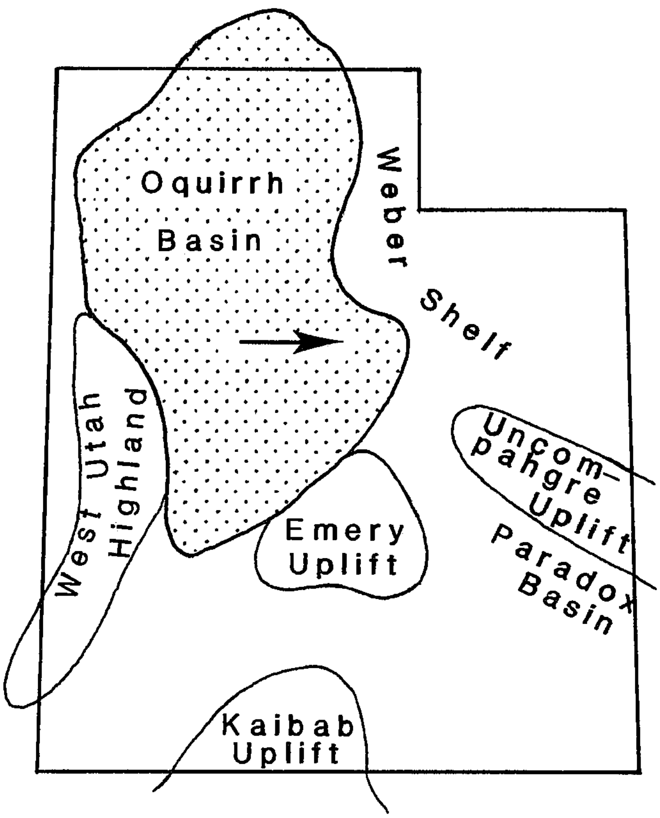


FIGURE 1.—*Index map showing location of the Oquirrh Basin and surrounding highlands during the Pennsylvanian and Early Permian on an outline map of Utah (modified from Bissell 1962a).*

istic and readily accessible outcrops of the formation in this area. A Jacob's staff, tape measure, and small ruler were used to determine unit thicknesses. Carbonate rock types were determined using the Dunham classification (1962). Color was established using the standard rock color chart of the Geological Society of America. Dilute hydrochloric acid was used to show the relative amount of calcium carbonate cement.

Thin sections were made of the major lithologic types to aid in the investigation. These were studied under the petrographic microscope for analysis of composition and texture, and for classification.

GEOLOGIC SETTING

The Oquirrh Formation conformably overlies the Mississippian-Pennsylvanian Manning Canyon Shale and is overlain by the Lower Permian Kirkman Limestone in the southern Wasatch Mountains. In this area, most of the mountains are composed almost entirely of the Oquirrh Formation, including Mount Timpanogos, Cascade Peak, Loafer Mountain, and Mount Nebo, all high peaks of the southern Wasatch Mountains.

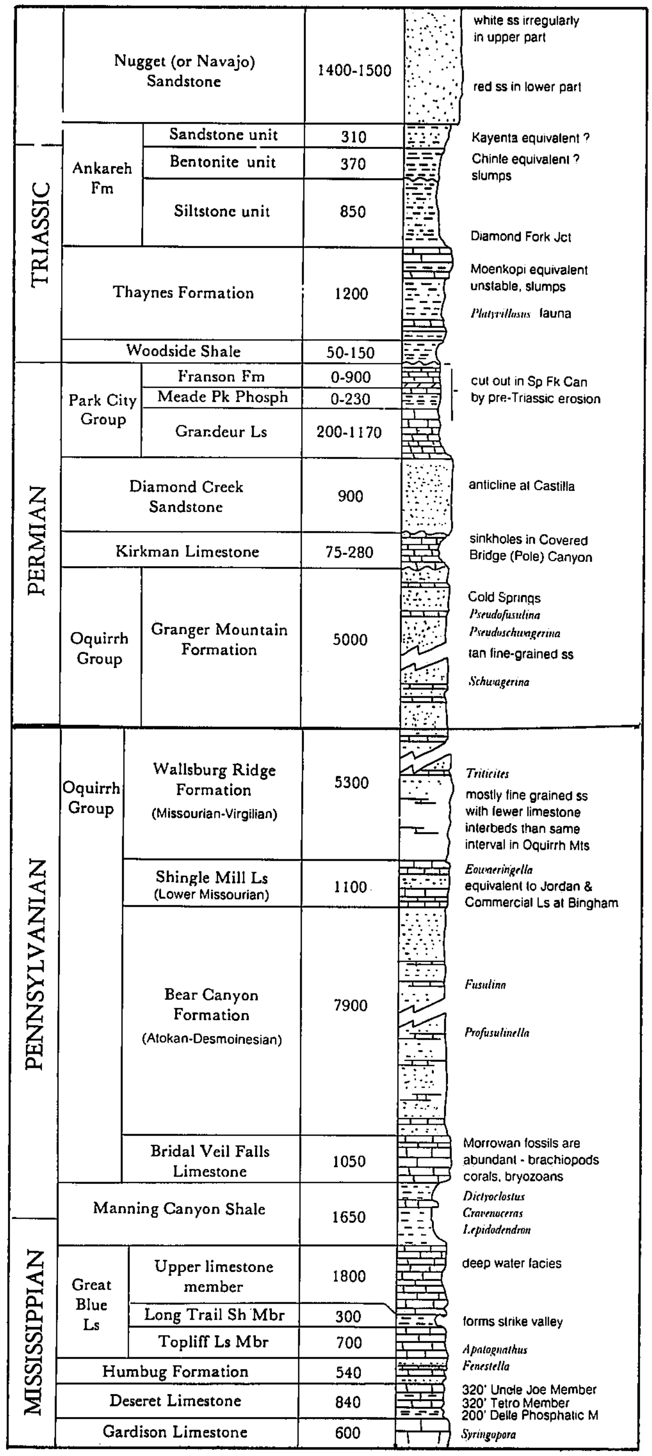


FIGURE 2.—*Generalized stratigraphic section of Spanish Fork Canyon area (modified from Hintze 1988).*

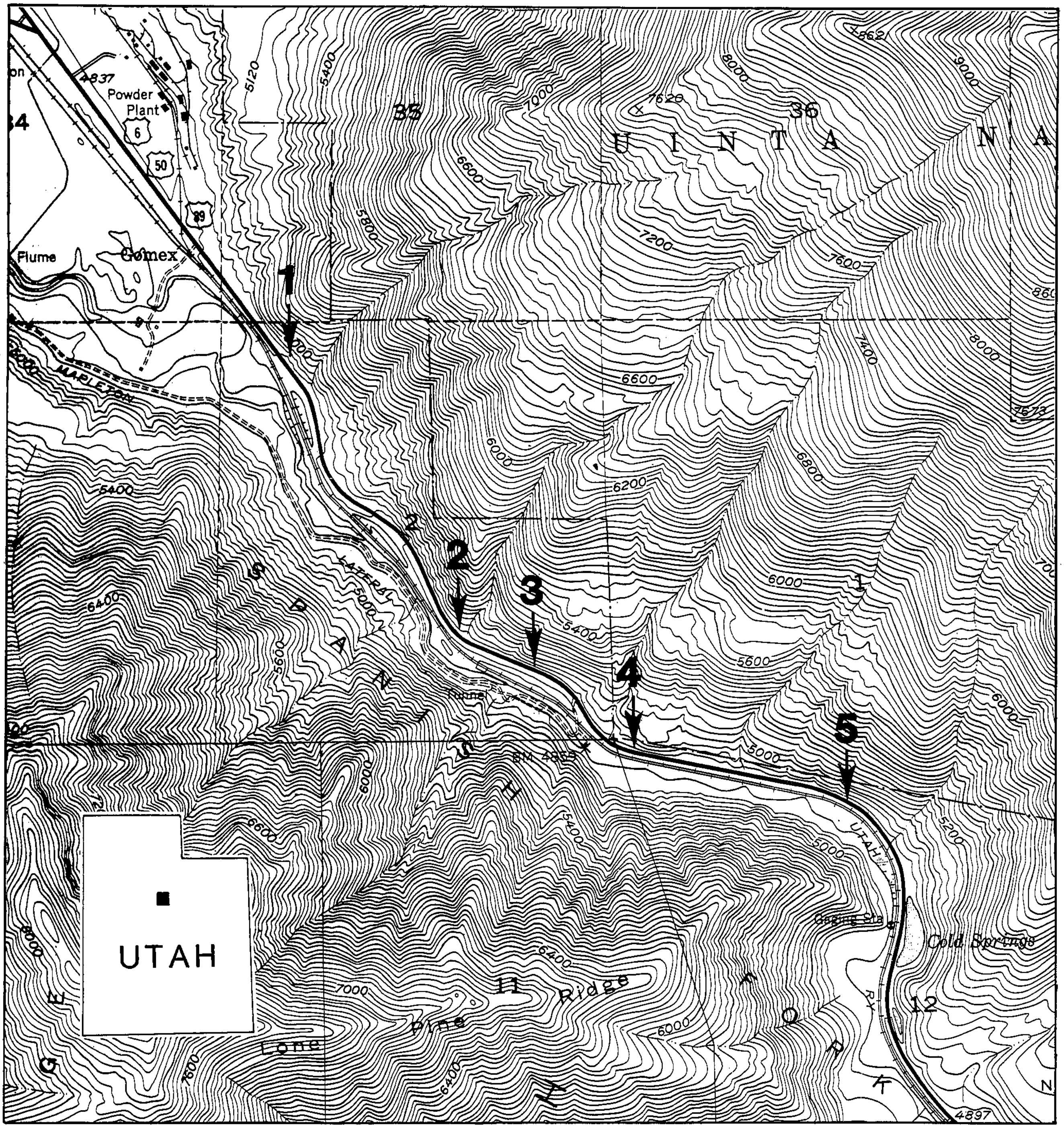


FIGURE 3.—*Locations of studied exposures in Spanish Fork Canyon on the Spanish Fork 71/2-Minute Quadrangle, Utah.*

During the Pennsylvanian, much of the region now encompassed by the state of Utah was covered by an epicontinental sea. The Cordilleran geosyncline included the basin now known as the Oquirrh Basin, in which marine strata more than 4.8 km thick were deposited (Konopka and Dott 1982). The sediment source for the eastern part of the Oquirrh Basin was the Weber shelf to the east (fig. 1).

Deposits 2700 m thick accumulated during the Permian and are included in the upper part of the Oquirrh

Formation. Subsidence, therefore, must have been rapid during this time in the northern part of the Oquirrh Basin (Hintze 1988). Chamberlain and Clark (1973) described trace fossils and sediment types in the Oquirrh Formation that provide evidence for significant subsidence and increasing water depth in the basin throughout the Pennsylvanian and into early Permian time.

Because of the extended period of deposition in the Oquirrh Basin, tectonic and depositional events probably changed gradually. Chamberlain and Clark (1973) documented the incremental variations in depositional environments by using trace fossils as depth indicators and showed that the environments changed in terms of bathymetry, subtly, over time.

During the late Mesozoic Sevier orogeny, Oquirrh strata were thrust several kilometers eastward on the Charleston-Nebo thrust (Hintze 1988). Oquirrh strata were then uplifted during the Early Tertiary Laramide orogeny, and erosion following Middle Tertiary to Recent basin-and-range faulting exposed much of the formation.

DESCRIPTIONS

The five roadcuts chosen for this study document a gradual upward change in lithology (fig. 3, correlation chart) and, therefore, a gradual change in depositional environment from outcrop 1 to 5. These transitions take place over a horizontal distance of approximately 3 km and through a stratigraphic sequence of 300 m.

Somewhat older terrigenous clastic sedimentary rocks of the Oquirrh Formation in the Hobble Creek area of the Wasatch Mountains and in the Oquirrh and Stansbury Ranges have been termed orthoquartzites by Wells (1963). However, thin-section analyses of somewhat similar terriginous rocks in the Spanish Fork Canyon area show that calcium carbonate cement is dominant. For this reason we have termed such rocks as calcareous sandstones, particularly for the massive units. Orthoquartzites described by Wells apparently formed in shallow water, contain abundant fusulinids, and demonstrate intragranular fracturing. They contain at least 50% silica cement. Rocks of this type are not widespread within the study area, but calcareous sandstones described here may be similar to the calcareous orthoquartzites described by Wells.

OUTCROP 1

A section of bedded, calcareous sandstone, approximately 20 m thick (fig. 4), is exposed at the mouth of Spanish Fork Canyon. The beds range from a medium blue gray to a grayish and brownish black. Rocks range from slightly calcareous mudstones to very fine grained, calcareous sandstones. There is a slight upward coarsening, toward the other outcrops located upsection, and the colors of the rocks tend to become lighter upsection as well. There is an upward fining of grain sizes within each of the individual laminae, in characteristic cyclic fashion. Fine cyclicity of grain sizes within each individual lamina is superimposed upon the larger scale cyclicity of bedding thickness and grain size between units that is measured in terms of one or two meters. Some of the units are massive cliff formers, whereas other units are slope formers because of their thin lamination.

Thin sections of the darkest units allow very little light to pass through. Small crystals of pyrite are easily exposed by acid etching of hand samples from these darkest units. The presence of pyrite and the dark color indicate a euxinic depositional environment. It is possible that some of the dark color of this outcrop is due to fine carbon derived from diagenesis of organic carbon.

Much of the stratigraphic section is delicately laminated, indicating a low-energy environment (fig. 5). Bedding is dominantly parallel. Large scale hummocky ripples with erosional bases exist in several of the units. Many of the units grade upward with decreased bedding thickness and grain size. The gradation is cyclic. Identifiable grains are predominantly spherical, and much quartz sand is present. Ripple marks are present in some units.

Minor horizontal burrows are the only trace fossils preserved, and they are limited to a few, thin beds in the eastern or upper part of the outcrop. These beds are the only parts of the exposure that show any evidence of bioturbation. These layers are somewhat lighter than overlying and underlying beds, and the trace fossils are the lightest gray parts. These are parts of the rocks where coloring matter has been removed. It is not possible to determine the type of animal that caused these trace fossils. Skeletal fossils are absent.

OUTCROP 2

Rocks exposed in outcrop 2 are transitional in lithology between those of outcrop 1 and outcrops 3 through 5. Trace fossils are more abundant than in outcrop 1. There was enough oxygen to support deposit feeders that produced the trace fossil genus *Scalarituba*. Lamination is still thin, but thicker than in outcrop 1. Grains are fairly uniform in size, but overall lithology grades upward from a calcareous sandstone to a calcareous siltstone.

Pyrite is still present, though less abundantly in these bedded sandstones. Pyrite occurs in extremely thin layers, a fraction of a millimeter thick, separated by quartz sand. Because pyrite is less abundant, a more oxygenated environment was probably present there during deposition of beds exposed in section 1.

OUTCROP 3

Rocks in this exposure have significantly thicker lami-

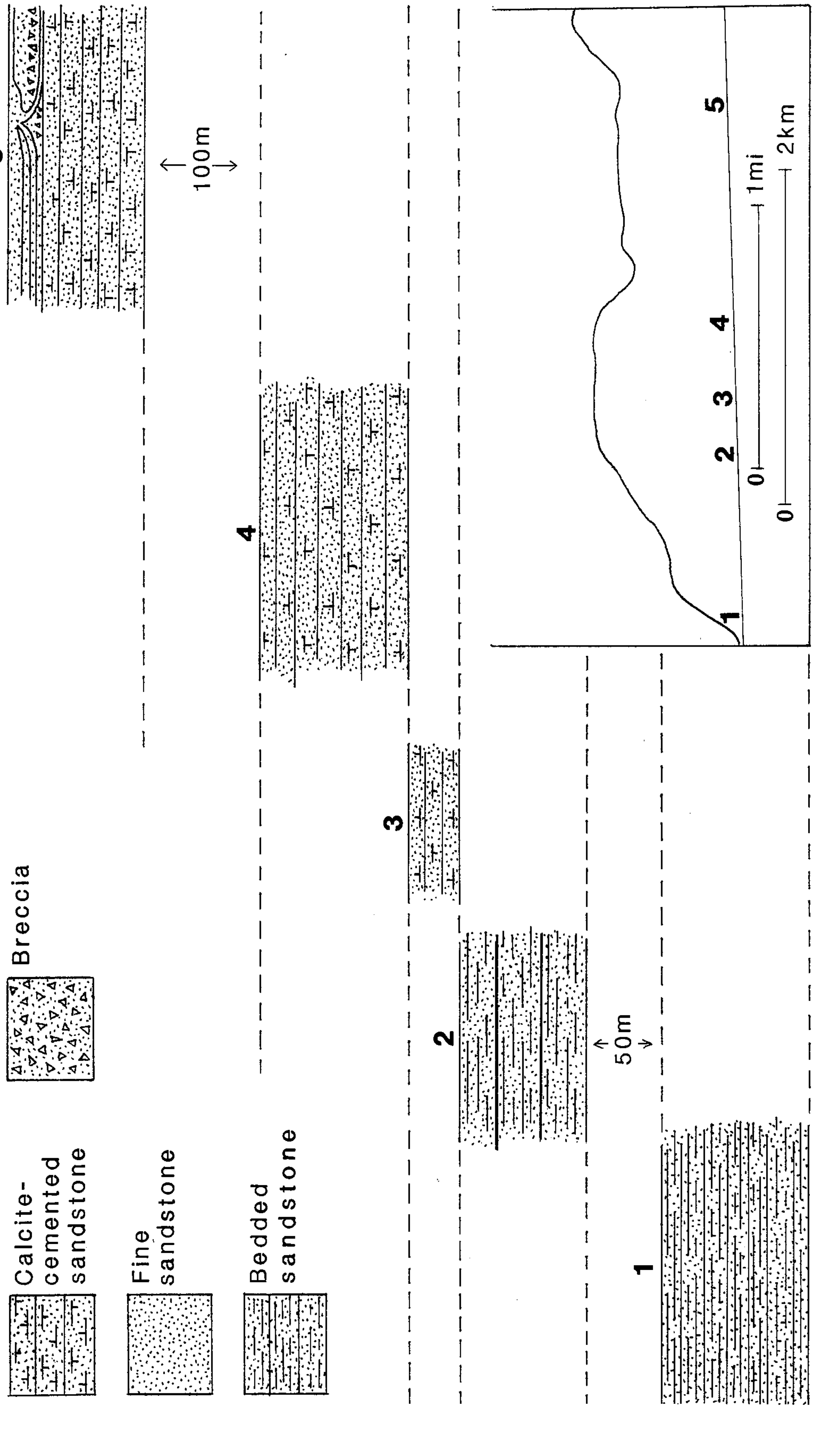


FIGURE 4.—*Correlation chart with general lithology and relative thicknesses of the studied exposures. Distribution of the five roadcuts in the canyon is also shown on the highway projection (straight line) below a generalized topographic profile above. Section 35, at the top, is one mile wide. Section 1 is approximately 20 m thick and is separated from section 2 by a 50 m covered gap. Section 2 is approximately 17 m thick, section 3 is 6 m thick, and section 4 is approximately 18 m thick. Section 5 is approximately 18 m thick and is separated from section 4 by a covered gap of approximately 100 m.*

FIGURE 5.—*Thin lamination, hummocky ripple, and bioturbation in outcrop 1. Thin lamination of outcrop 1 shows hummocky bedding and bioturbation.*

nae than in the previously described two outcrops, with individual laminate units on the order of 15 cm thick. Within these units each lamina grades upward in decreasing particle size, as in outcrops below, but here thicknesses of lower sandy parts are many times that of silty parts. Few structures are visible within the units, except for small ripple lamination in silty layers.

Trace fossils are abundant in this outcrop. *Scalarituba* is again the dominant genus, but one example of *Neonereites* was found. The fossils are concentrated in the upper finer-grained silty layers, indicating textural control and suggesting that nutrient supply was periodic. Only one thin layer contains skeletal fossils, and these are predominantly brachiopod fragments. Their fragmented nature indicates that they were transported rather than indigenous.

OUTCROP 4

Lithologies here are essentially identical to those in outcrop 3. However, individual units are somewhat thicker, up to 30 cm, and trace fossils are more plentiful.

OUTCROP 5

This sequence demonstrates a greater variation in lithology than the stratigraphically lower exposures. The units here are much thicker and have a greater range of thicknesses than the other outcrops studied. They range from a few centimeters to a meter or more thick, indicating large variations in magnitudes of depositional events. Generally, units in the outcrop thicken and sediments coarsen upsection, producing increasingly massive and resistant units.

Sedimentary structures, as in the previous outcrops, show a cyclic pattern, but here sandstone parts of each unit are thicker and much more resistant than in lower outcrops. Units in outcrop 5 contain, and occasionally are composed entirely of, laminae that are contorted or convoluted. Sandstones that contain these structures grade upward into siltstone units that are more thinly laminated, and in units generally less than 5 cm thick. The sandstones also contain "climbing" ripple-cross lamination. Such "climbing" ripples indicate rapid deposition during flow of a loaded current. The sedimentary structures are repeated, completing the cycles (fig. 6). Hummocky ripples are also present.

This exposure shows cyclicity in yet another manner. The trace fossils increase in both number and diversity upward from outcrop 1 and reach maximum diversity and density in outcrop 5. Four genera have been identified here, including *Neonereites Scalarituba* (fecal ribbon form), *Scalarituba* (large form), and *Spirophycus*. All these genera occur throughout the outcrop, but by far the greatest densities are found in the thin, cross laminated, upper silty part of each unit (fig. 7). All four ichnofossil genera represent deposit feeders that burrowed horizontally through the sediment, ingesting nutrients and expelling waste as they moved. Their densities increase substantially upsection, even within outcrop 5.

In uppermost units of outcrop 5, an abrupt change in sedimentary structures occurs, marking a distinct change in the depositional environment. Beds in the upper two meters of the outcrop are lenticular, less calcareous, cross-bedded on a much larger scale, and contain larger particles (fig. 8). The lower parts of some lenses are pebble and cobble breccias. Each lenticular unit grades upward from a coarse breccia to a fine sandstone. The lenticular units crosscut each other and can be relatively dated (fig. 9).

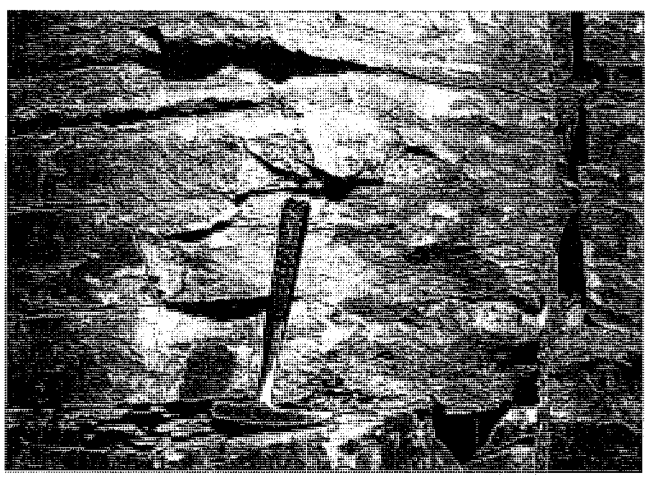


FIGURE 6.—*Exposure demonstrating cyclicity. Units grading upward from calcareous sandstone to calcareous siltstone in the lower part of outcrop 1.*

FIGURE 7.—*Trace fossils found in a typical upper silty part of a cycle in outcrop 5.*

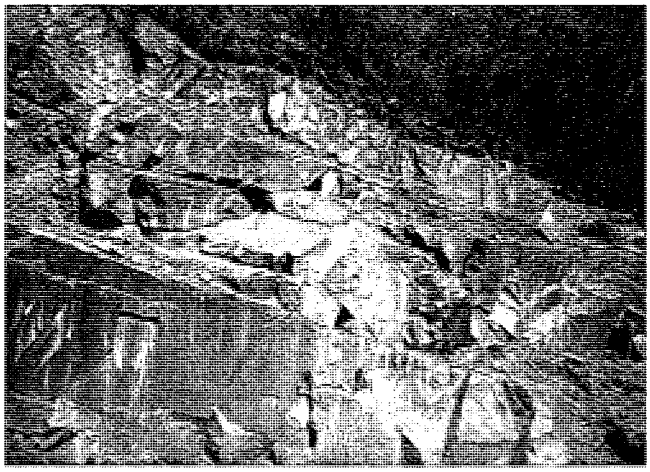


FIGURE 8.—*Lenticular beds of the uppermost part of outcrop 5. Prominent channel-fill lens in left center is approximately 1 m thick.*

These upper units appear to have been deposited in an environment too high in energy to allow growth of the deposit feeders. Broken pieces of some skeletal fossils occur in small numbers. These lenticular units are interpreted to be subaqueous channel fills.

The bed immediately beneath these channel fills also contains a lenticular deposit rich in fusulinid, brachiopod, echinoderm (particularly crinoid discs), and bryozoan debris. These fossils are all fragments, and the deposit as a whole is graded. These fossils were likely transported from the more oxygen-rich shelf areas to the east or northeast and deposited in the channel.

DISCUSSION

Several upward gradational trends in the lithology are evident in this part of the Oquirrh Formation. These are: particle size increases, units become less pyritic and more calcareous, trace fossils and displaced skeletal fossils become increasingly abundant and diverse, and individual units become thicker.

The upsection increase in grain size indicates increasingly higher-energy environments of deposition. Grain sizes in outcrop 1 are on the order of very fine sand, but grain size through outcrops 2, 3, and 4 slowly increases to a medium sand. Lower beds in outcrop 5 have a range from fine to coarse sandstone. Toward the top of this outcrop, however, grain size increases to a coarse sand and finally to a carbonate breccia in the channel fills, with angular clasts up to 5 cm in diameter. The amount and coarseness of displaced skeletal fossils also increases from outcrops 3 to 5.

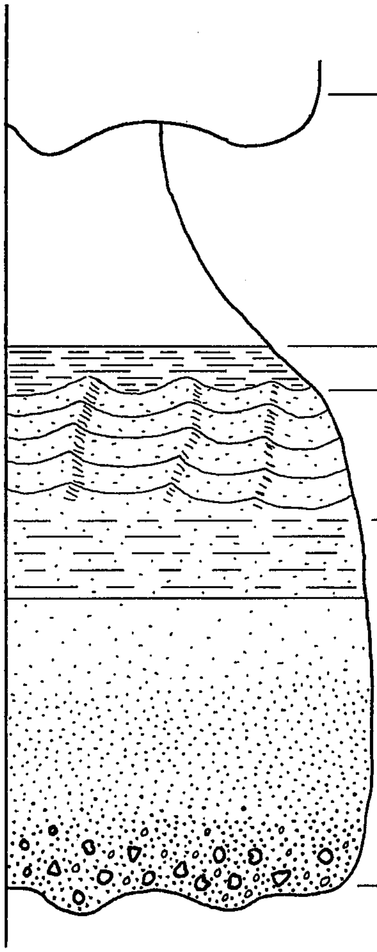
The upward progressively lighter color of the exposures is due to three factors: (1) an increasing amount of coarse pure quartz sand, (2) a decreasing amount of pyrite, and (3) increase of calcium carbonate. The outcrops, however, maintain a grayish color due to an increasing amount of dark organic matter, accompanying the corresponding decreasing amount of pyrite. The transition from pyrite-rich sediments to those lacking pyrite indicates a transition from disaerobic to aerobic conditions. The increasing abundance and diversity of trace fossils also demonstrates this. These organisms undoubtedly required oxygen to survive, and this is reflected in the rocks: where pyrite disappears in the sequence, trace fossils appear. Because trace fossil occurrence is cyclic, with densest populations in the upper silty layers, it would seem that the amount of available oxygen, and perhaps nutrient availability as well, was also cyclic.

Individual units thicken from only one or a few millimeters thick in lowest outcrops to as much as a meter thick in the upper ones. This apparently represents an increase in the amount of available sediment and dimensions of sediment pulses.

TURBIDITES

Sedimentary features such as cyclicity, graded bedding, and convolute lamination, together with the presence of hummocky ripples and displaced skeletal fossils in several beds of the Oquirrh section, indicate that these deposits are turbidites. Graded bedding and convolute and ripple-cross lamination is especially indicative of these types of deposits because they indicate rapid deposition and rapid to waning current in deep water. Such rocks are interpreted to represent units C and D of the Bouma sequence (fig. 7).

An individual typical turbidite deposit consists of five units, A through E, in the Bouma sequence. It consists, from bottom to top, of a basal massive graded layer com-



GRAIN SIZE		BOUMA (1962) DIVISIONS	INTERPRETATION
Mud	E	Pelite	Fine grained, low density turbidity current deposition
	D	parallel laminae	?
Sand-Silt	C	Ripples, wavy or convoluted laminae	Lower part of lower flow regime
	B	Plane parallel laminae	Upper flow regime
Sand to granule	A	Massive, graded	? Upper flow regime. rapid deposition

FIGURE 9.—*Ideal sequence of sedimentary structures, or Bouma sequence, in a turbidite bed. Thicknesses may range from less than a meter to several meters (modified from Boggs 1987).*

monly with an irregular or channeled base, a layer of parallel laminae, followed by wavy or convolute bedding, covered by upper semiparallel laminae, all capped by a pelite. Such a sequence is ideal, and few turbidite deposits contain all five units. High density turbidity currents produce well-developed A and B units, but C through E are often poorly developed or absent. Low-density turbidity currents produce well-developed C through E units, and poorly developed or absent A and B units.

In terms of the above model, the studied Oquirrh exposures accumulated as low-density turbidites throughout the sequence. They show a transition to high density in the upper part of outcrop 5 where the filled channels occur.

Such an interpretation is supported by the types and distribution of trace fossils in the Oquirrh beds. They were interpreted also to be bathymetric indicators (Chamberlain and Clark 1973). Trace fossil interpretation is based on the idea that organisms evolve behavioral patterns that are most efficient under particular environmental conditions. Factors of depth, and nutrient and oxygen availability, can be accurately imprinted in the sediment in this way. Chamberlain and Clark (1973) defined five main trace fossil facies in the Oquirrh Formation, each an indication of water depth. These facies are: (1) the *Cruziana* zone: shallow water; (2) the *Skolithos* zone: shallow water; (3) the *Glossifungites* zone: shallow water; (4) the *Zoophycos* zone: intermediate shelf; (5) the *Nereites* zone: bathyal-abyssal.

CONCLUSIONS

The trace fossil assemblage described in these deposits includes *Scalarituba, Neonereites,* and *Spirophycus,* which belong to the *Nereites* assemblage and indicate deep-water deposition of these units.

A deep marine environment of deposition is envisioned for the 300 m of Oquirrh beds included in our study. The sediments accumulated as deposits from turbidity currents that periodically flowed out over a broad deep sea fan (fig. 10). A typical fan is made of a coarse upper fan, a graded midfan with intermediate particle size, and a comparatively thin-bedded, finer-grained lower fan (fig. 8). As sediments accumulated, the sequence upsection is equivalent to the lateral facies toward the top of the fan (fig. 11). Each of these turbidity flows would introduce nutrients and oxygen to the area, and the deposit feeders would then take advantage of the more favorable situation. Bottom conditions became more aerobic upward and better capable of supporting life. Sediments also became coarser, eventually leading into channels, and individual turbidites would become thicker. All of this evidence—the shifts from disaerobic to increasingly aerobic conditions, the increase in density and diversity of trace fossils, the turbidite origin of the units, and the upward increase in energy of deposition—indicates that this entire sequence represents a prograding deep sea fan and records deposits from low or distal fan to midfan environments.

ACKNOWLEDGMENTS

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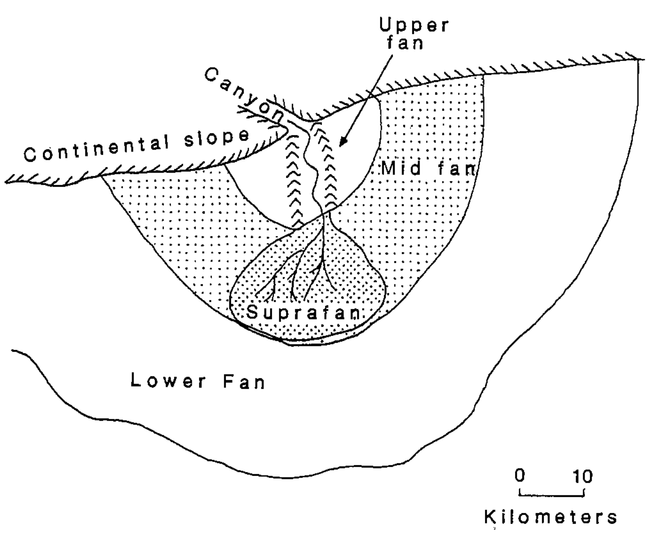

FIGURE 10.—*Schematic representation of facies and proportions of a submarine fan (modified from Boggs 1987).*

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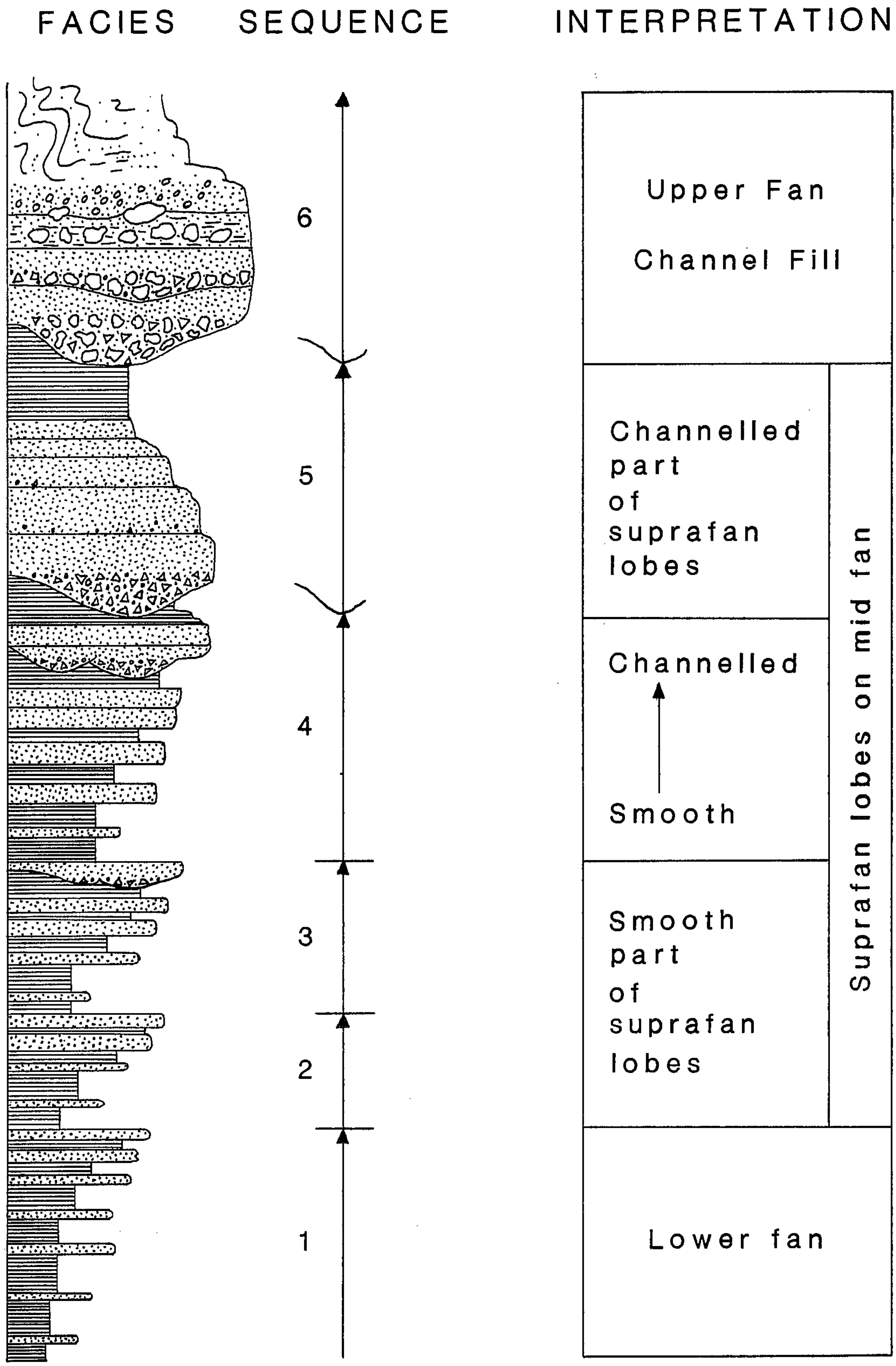

FIGURE 11.—*Generalized turbidite sequence of a prograding submarine fan. Sequences 1 and 2 are thickening upward classical turbidites. Sequence 3 and 4 are classical turbidites capped by massive, lenticular, pebbly sands. Sequences may range from a few meters to tens of meters thick (modified from Boggs 1987).*