Crater Lake, Oregon: A restricted basin with base-of-slope aprons of nonchannelized turbidites

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ABSTRACT

The basin floor of Crater Lake (10-km diameter, 600-m water depth) is covered by up to 75 m of sediment-gravity-flow deposits interbedded with mud. In the upper units (8 m thick), sand and gravel layers with numerous wedging, strong seismic reflectors characterize the base-of-slope aprons at the basin margin. These layers evolve to turbidites of mainly thin, fine-grained, basin-plain type, characterized by numerous flat and weak seismic reflectors in the central basin floor. Many individual debris-chute sources funnel sediment to base-of-slope aprons: there, coarse-grained parts of the sediment-gravity flows deposit nonchannelized beds attributed to the F, A, B turbidite facies. While traversing the base-of-slope aprons, flows evolve to sheet-flow turbidity currents that deposit D-facies beds over the central basin floor. These processes and patterns of deposition characterize small siliciclastic basins without channelized submarine fans and are common in carbonate basins of all sizes.

INTRODUCTION

The deep, nearly circular caldera basin of Crater Lake, Oregon, is a natural laboratory to study sediment-gravity-flow processes and base-of-slope apron development in a small basin (Fig. 1). Previous work, based on 50-cm gravity cores, has outlined the general limnology and sedimentology of the near-surface sediment (Nelson, 1967). The present studies utilize high-resolution Uniboom and a 1-in^3 air gun with a trackline spacing of 200–500 m combined with new side-scan sonar profiles, underwater television tapes, bottom-camera photos, and an additional 15 gravity cores penetrating as much as 2 m. These data provide information on a small, modern basin where turbidite sedimentary processes and siliciclastic deposits have not been altered by high Holocene sea level as is true for most present-day examples (Nelson and Nilsen, 1984).

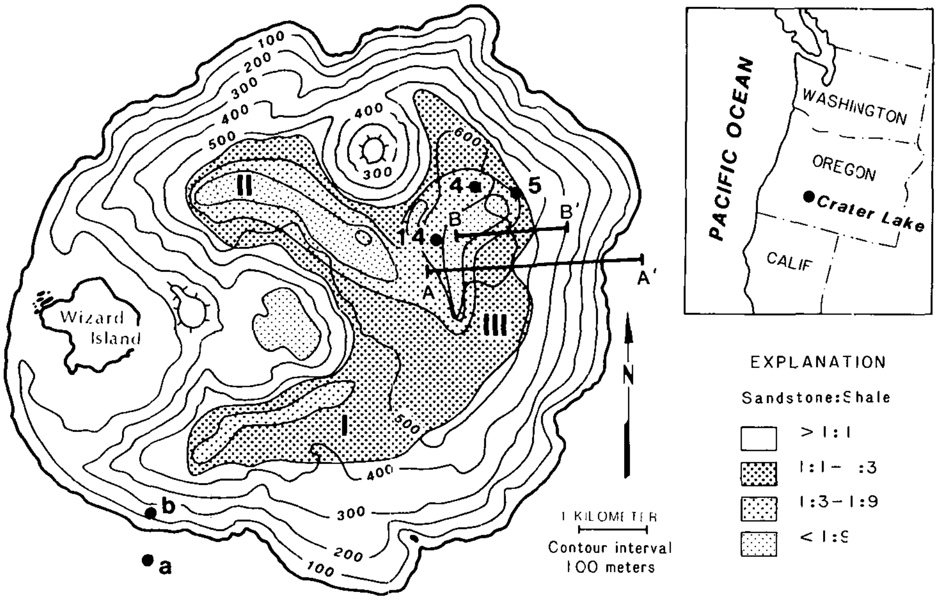

Figure 1. Bathymetry of Crater Lake basin (after Byrne, 1962) showing areal distribution of sand:shale ratios in Crater Lake from 0.5–2-m gravity core samples. Mud thickness is reduced to one-third to calculate equivalent shale thickness, according to Hamilton's (1959) method. Note location of core transect (A-A′) and seismic profile (B-B′) shown in Figure 4. Numbers 4, 5, and 14 are locations of cores with radiographs; a and b are locations for photos in Figure 3.

MORPHOLOGY

Crater Lake, the second deepest lake (622 m) in North America, lies in the collapse caldera (formed 6900 B.P.) of Mount Mazama in the Cascade Mountain Range of southwest Oregon (Bacon, 1983). The caldera walls rise 150 to 600 m above the water surface at up to 45°. They continue below the water at a 30° average slope and reach the nearly flat basin (0.5°) at a depth of about 550 m (Fig. 1). The general flatness of the floor is disrupted by two submerged volcanic cones and the partially emergent Wizard Island cone with its eastward submerged extension (Fig. 1). These volcanic cones divide the main lake floor into three flat subareas: (I) the southwest at 450-m depth, (II) the northwest at 500-m depth, and (III) the eastern at 600-m depth (Fig. 1).

STRATIGRAPHY

Little or no sediment cover exists on the caldera wall areas, the submerged volcanic cone regions, or the large platform east of Wizard Island (Fig. 2). This is shown by core and grab sampling (Nelson, 1967), Uniboom profiles, side-scan sonar, underwater television, and bottom-camera photos (Figs. 3, 4). Television scans and bottom photos over submerged caldera walls reveal large outcrops and overhangs dusted by diatomaceous ooze. Debris chutes occupy continuous narrow gaps between the outcrops on caldera walls and are covered with thin deposits of sand and gravel (Fig. 3).

Seismic profiles with numerous continuous, flat reflectors suggest that there is a thick sediment infilling of turbidites in the flat floor areas of the lake basin (Fig. 4, B-B′) (Nelson, 1967). The air-gun profiles indicate that the thickest sedimentary fill (75 m) is found in the eastern lake-floor area, whereas in the southwestern (I) and northwestern (II) lake-floor areas there is less than 50 m of sediment (Figs. 1, 2). Nowhere is there any evidence of surface or subsurface channels in seismic reflectors within the basin floor (Fig. 4, B-B′).

Cored sediment indicates that the flat reflectors of basin-floor areas I–III correlate with turbidites and other sediment-gravity-flow deposits. Strong reflectors occur where thick coarse-grained beds are found in near-surface cores; weak reflectors occur in areas of thin and fine-grained sand beds (Figs. 1, 3, 4). Strong reflectors that appear to represent thick beds per-

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sist across the smaller I and II basin-floor areas but not in the upper 8 m of sediment of the larger area III. In area III, strong reflectors occur at the margin, but in a short distance they become weak reflectors toward the lake center (Fig. 4, B-B′).

The typical depositional pattern for small clastic basins is represented by the upper 8 m of sediment deposited when sedimentary processes were not influenced by the intense seismicity of active lake-floor volcanism. Below the upper 8 m of sediment, strong reflectors across the entire eastern lake floor suggest a different, earlier sedimentary history (Fig. 4, B-B′). Most likely, high seismicity associated with the extensive development of caldera-floor volcanoes during the early lake history resulted in major landsliding, which produced thick, widespread, sediment–gravity-flow deposits and the strong subsurface reflectors that are observed below 8 m.

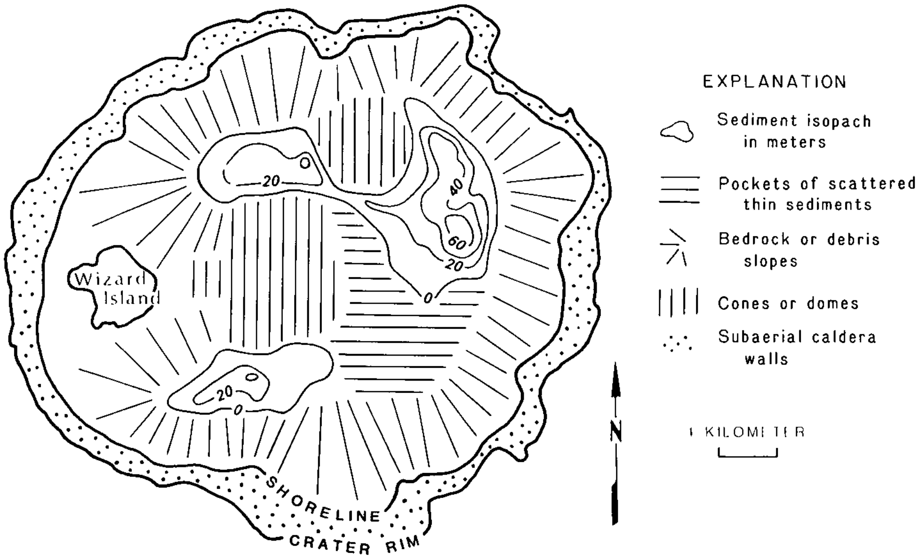

Figure 2. General sedimentary environments (after Nelson, 1967) and sediment isopachs based on 1-in^3 air gun seismic profiles.

Sediment in proximal base-of-slope accumulations (Figs. 3, 4) is lithologically similar to the unsorted sand and gravel deposits of the thin sediment patches on the caldera and volcanic cone slopes (Nelson, 1967). In the base-of-slope regions, however, the sediment aprons are several metres thick, individual sand and gravel beds are 10–50 cm thick but lack sedimentary structures, and mud interbeds are few (Figs. 3, 4, 5). Toward the center of the basin, the sand beds become fewer in number, interbedded with thicker mud layers, and vertically graded in grain size, and they develop good internal sedimentary structures. From the base-of-slope areas to the basin center, grain size grades laterally from gravel to very fine sand, and layer thickness is reduced to <10 cm (Figs. 3, 4).

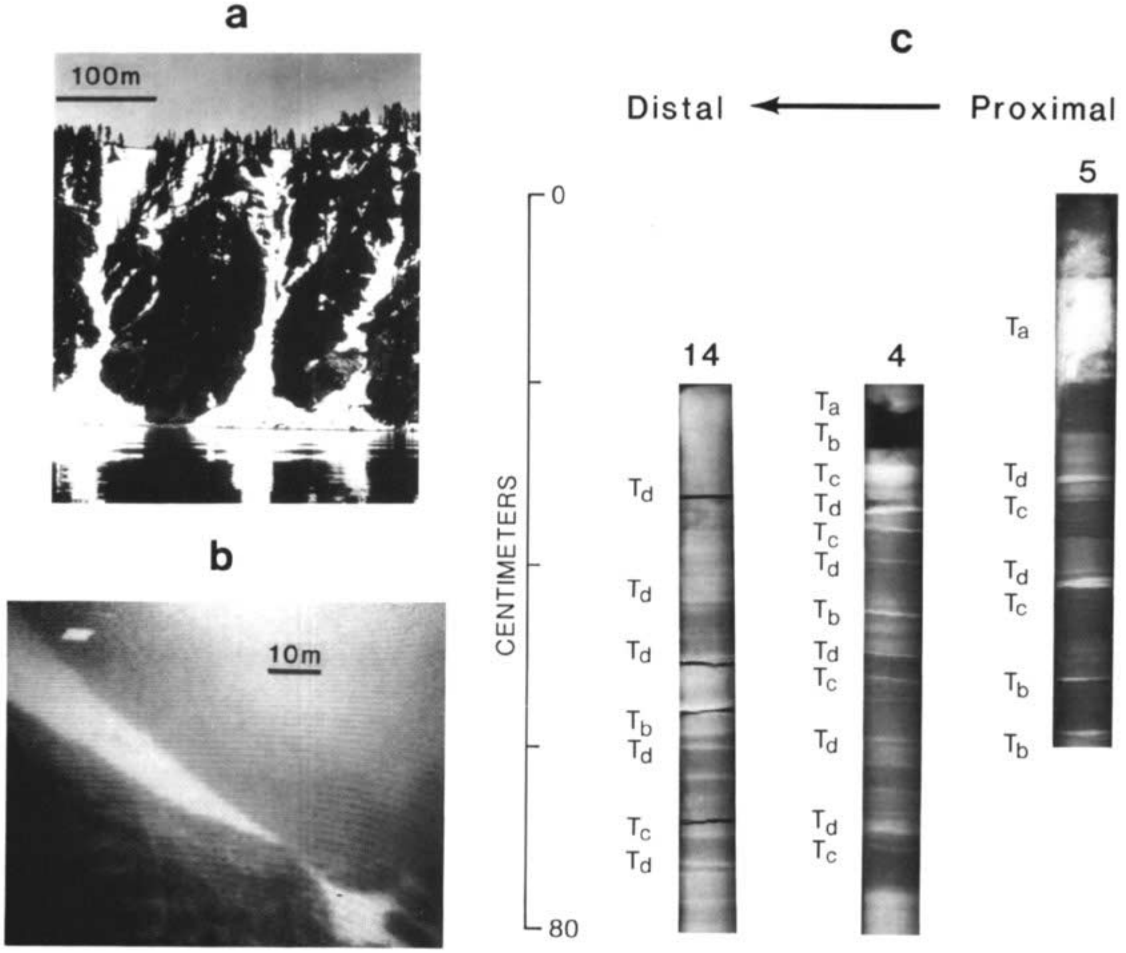

Figure 3. a: Photo of subaerial debris chutes with snow cover. b: Videotape photo of subaqueous debris chute with light-colored sediment cover. c: Radiographs of core transect across basin III depicting changes in core lithology and Bouma sequence of internal sedimentary structures (T_a, T_b, T_c, T_d) in sand and gravel layers (light color). Locations of photos and cores are shown in Figure 1.

The same sand-layer trends that are evident in traverses from basin margin to center can be summarized for the entire basin floor by compiling sand:shale ratios for each of the 65 cores. High sand:shale ratios occur at the edge of the slope, and they change to lower sand:shale ratios toward the center of the basin (Fig. 1). The smallest basin-floor region (I) shows the least change in sand:shale ratios toward the center, an observation expected in a region of less depth and where source slopes closely surround the center of this local basin-floor area (Fig. 1). The larger basin-floor areas (II, III) exhibit consistent trends of decreasing sand:shale ratios toward the basin centers. As expected, the sand:shale ratios from cores are more sensitive to sand-layer thickness in the northwest (I) and southwest (II) basins than are the seismic profiles that show strong reflectors throughout these areas (Fig. 1).

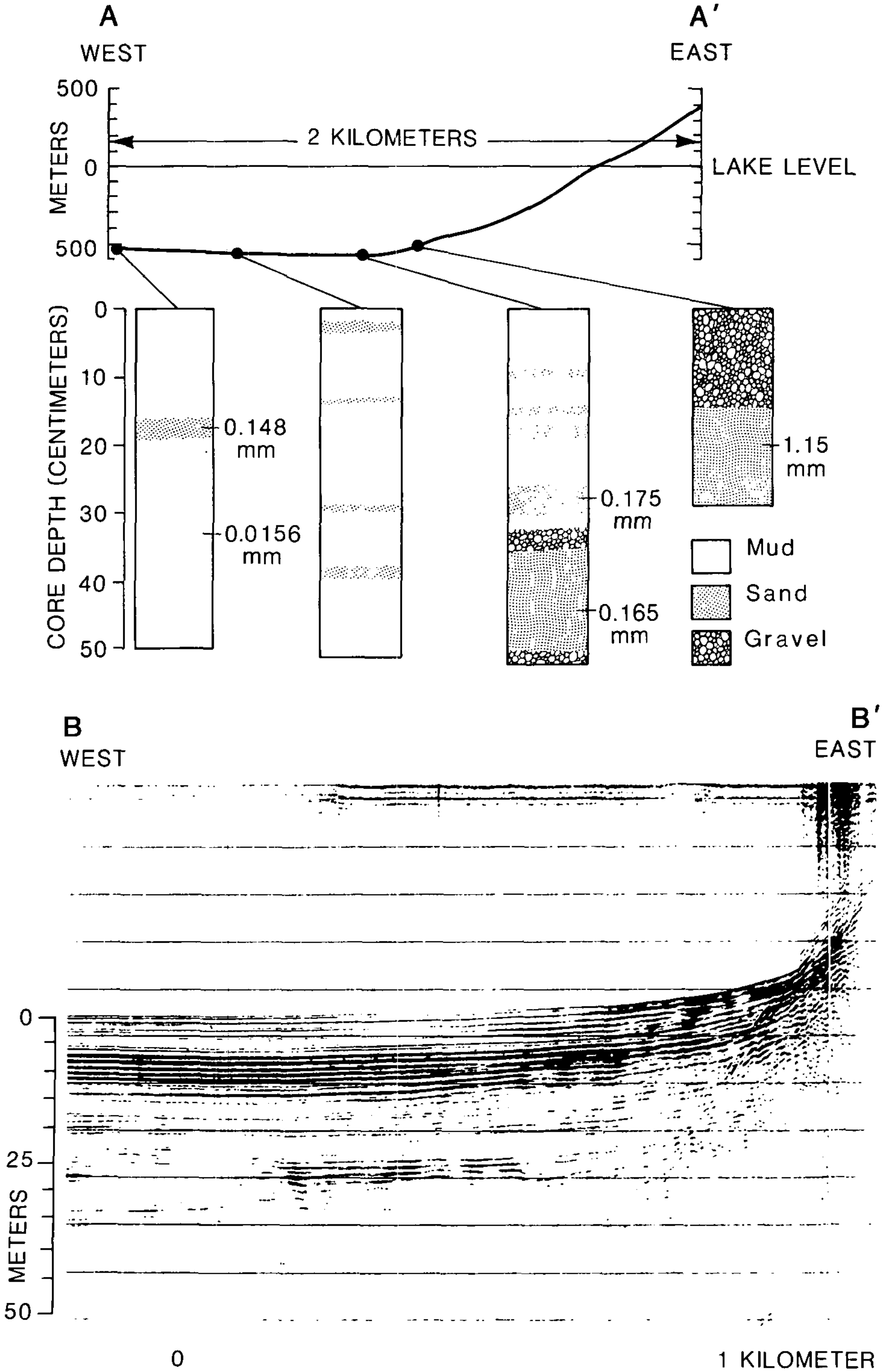

Figure 4. A-A′: Simplified lithologic sections of core transect from basin edge to center (after Nelson, 1967). All grain sizes are median diameter (M_d). B-B′: Example of seismic reflection profile from Uniboom. Locations of A-A′ and B-B′ are shown in Figure 1.

Although resolution of profiles is less than that for cores, and shallow cores cannot verify reflectors in the seismic section, the general patterns of core and seismic stratigraphy agree. We interpret the thick sand and gravel beds and slightly wedging strong reflectors at the base of slope to represent base-of-slope aprons; the thinner sand beds and weaker reflectors toward the basin center represent basin-plain turbidites.

DEPOSITIONAL PROCESSES AND PATTERNS

Numerous debris chutes traverse the caldera walls above the water (Fig. 3). They are a few metres to tens of metres wide and are covered with unsorted rockfall and debris-flow material. Underwater television and bottom-camera photos show that subaerial chutes continue below water as pathways for sediment–gravity flows. The widely varying petrography of the caldera walls and the individual mineralogy of sand layers at each location on the caldera floor (Nelson, 1967) confirm that several debris-chute sources feed each basin-floor location. The heterogeneous grain size and unsorted nature of the debris on the caldera wall and at the base of the caldera slope (Nelson, 1967) indicate that several types of gravity slides (rockfall, landslides, slumps) and sediment–gravity flows (debris flows, grain flows, turbidity currents) transport sediment down the caldera walls to the base-of-slope region of the caldera.

A wedge-shaped, base-of-slope cross section on seismic profiles (Fig. 4, B-B′), a lack of channels, decreasing bed thickness, and lower sand:shale ratios toward the lake center show that debris is funneled down numerous chutes to the base of the caldera slope by sediment–gravity flows and is resedimented as thick, coarse-grained layers on base-of-slope aprons (Figs. 1, 4, 5); the finer grained portion of the flows continues in sheet-flow turbidity currents out toward the basin center and is redeposited as fine-grained, well-sorted, and graded sand layers. The different mineralogy of sand layers (Nelson, 1967) suggests that each event is of local origin so that recurring channelized flow does not develop. Instead, lobe or sheetlike deposits spread across the base-of-slope aprons and basin floor.

The depositional facies patterns of Crater Lake basin cannot be considered a submarine fan system because no channel-levee complexes exist. Synthesis of seismic facies and core lithology shows that some elements of facies associations in submarine fans are present in the basin deposits and can be described by using a modified form of Mutti and Ricci Lucchi's

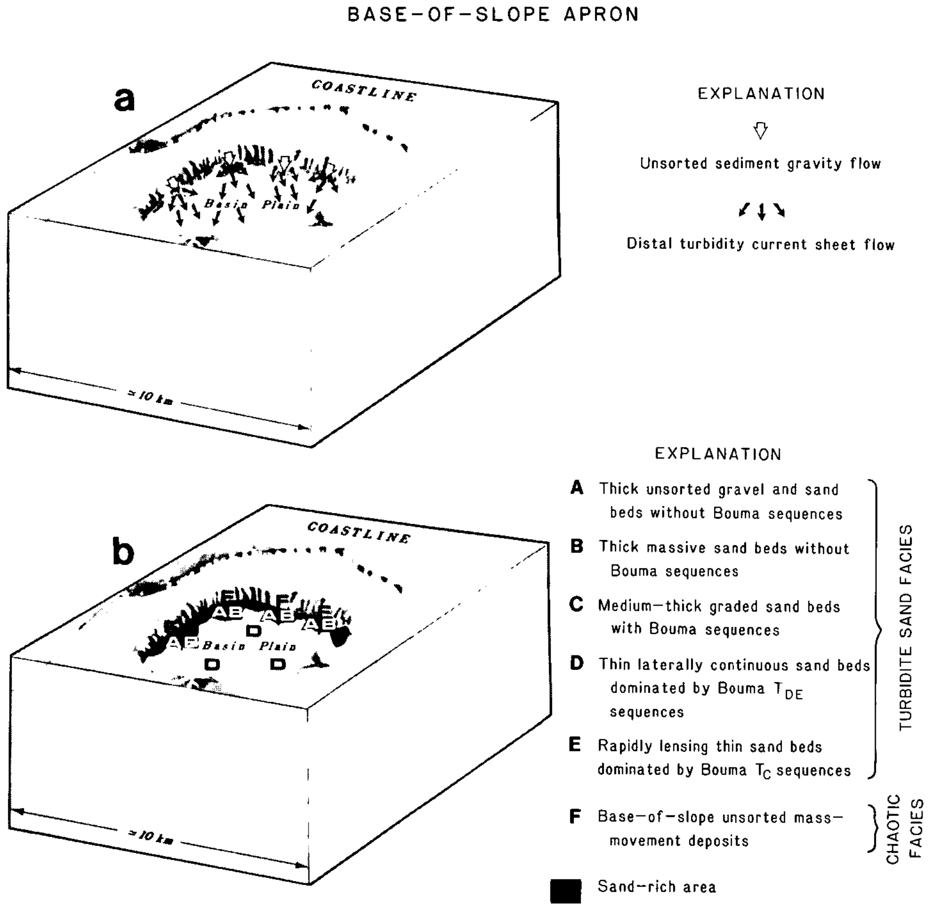

Figure 5. Generalized processes (a) and facies patterns (b) for nonchannelized, base-of-slope aprons in small restricted basins. Facies designations are modified from Mutti and Ricci Lucchi (1972) based on core lithology shown in Figures 3 and 4.

(1972) facies scheme (see Figs. 3–5). Facies-F chaotic deposits, from gravity slides and sediment–gravity-flow deposits, characterize the steep caldera walls. The proximal base-of-slope apron deposits also contain facies-F gravel units, but in distal apron areas they evolve to bedded gravel and massive sand layers of facies A and B (Figs. 1, 3–5). Thin-bedded and graded sand layers gradually evolve offshore from the base-of-slope aprons and cover most of the central basin plains as facies-D deposits (Figs. 1, 3–5).

GEOLOGIC SIGNIFICANCE

The facies patterns of the Crater Lake basin are an idealized example of patterns found in several other basins. Clastic turbidite facies in small basins on continental slope benches (Moore and Karig, 1976), basins bounded by line sources of carbonate platforms (Schlager and Chermak, 1979; Cook et al., 1983), and the smallest continental borderland basins (Field and Edwards, 1980; Nardin, 1983) all exhibit facies patterns similar to those of Crater Lake. These systems are comparable in that each has many sediment sources of heterogeneous grain size and no dominant sediment source to cause channelized fan deposition. The siliciclastic turbidite systems in small restricted basins (<10-km diameter) develop much simpler facies patterns than in larger basins with channelized fans (Nelson, 1983; Nelson and Nilsen, 1984). Nonchannelized base-of-slope aprons with F, A, and B facies form in base-of-slope environments and change gradually to broad, tonguelike deposits of rapidly thinning and fining facies-D turbidite sands in distal basin-plain environments (Fig. 5). Such complexes in small, siliciclastic basins are the simplest base-of-slope apron end member of turbidite depositional systems that fill basins (Nelson, 1983; Stow et al., 1983/1984; Nelson and Nilsen, 1984). The same processes and facies patterns, however, occur in carbonate clastic systems in much larger basins (Schlager and Chermak, 1979; Cook et al., 1983). Thus, the simple depositional process and facies patterns defined in the Crater Lake basin appear to be representative of many other modern and perhaps ancient basins (Fig. 5) (Stow et al., 1983/1984; Nelson and Nilsen, 1984).

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