

^{PS} Architecture, Lithofacies, and Depositional Model for the Ballarat Sequence: a Mid-Pleistocene Fan-Delta Complex, Panamint Valley, Inyo County, California*

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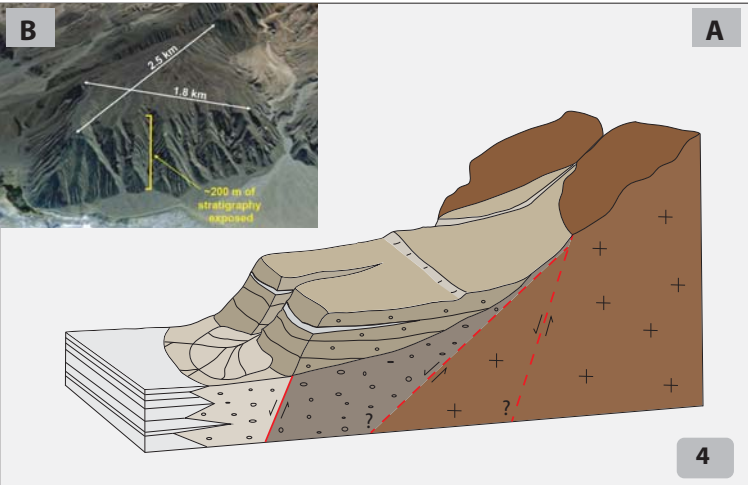
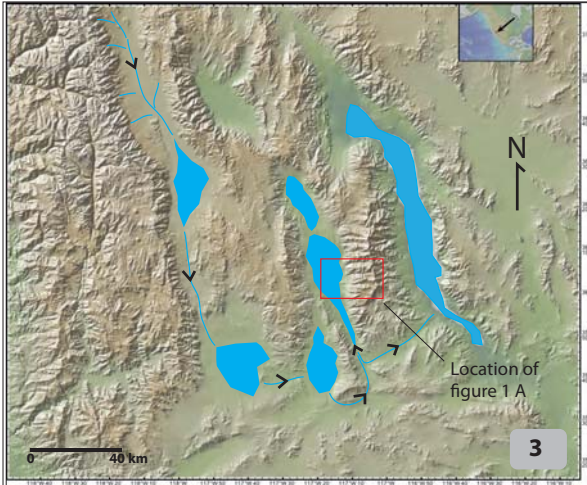
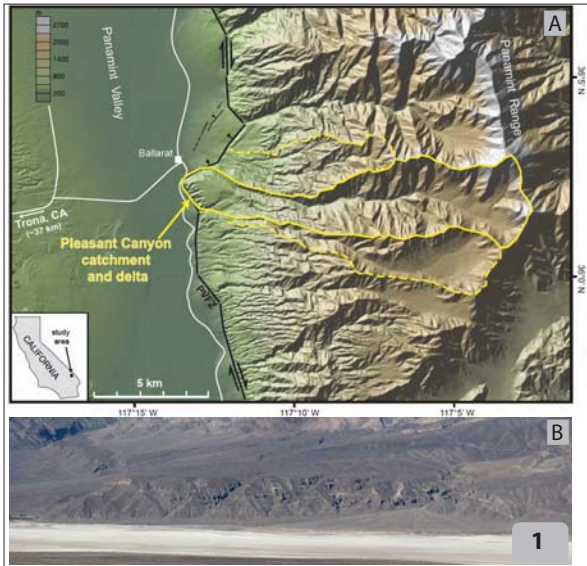
Abstract

A robust three-dimensional stratigraphic framework is required in order to understand the role sediment supply plays in the development of stratigraphic architecture. Such a high-resolution framework is essential for ongoing research into controls on stratigraphy and is the focus of this presentation. Here, we integrate data from measured lithologic sections, photomosaics, and high-resolution dGPS surveys of prominent stratigraphic surfaces to present a stratigraphic framework for this lacustrine fan-delta complex. During the early to mid-Pleistocene, a fan-delta sequence prograded from the Pleasant Canyon catchment in the Panamint Mountains westward into pluvial Lake Panamint, the penultimate endorheic basin in the Owens River system. Subsequent faulting along the Panamint Valley fault zone cut the fan-delta complex, uplifting the proximal segment relative to the subsiding basin, and post-abandonment incision and dissection have created exceptional outcrop exposures measure ~170 meters in thickness, 1.25 km along depositional strike, and 0.75 km along depositional dip. Measured sections through 170 meters of vertical succession allows for subdivision into three lithostratigraphic units defined by dominant internal lithofacies. Notable stratigraphic intervals are a basal sand- and gravel-dominated unit, a unit containing two light-colored fine-grained layers located approximately in the middle of the succession, overlain by a unit of sand- and matrix-supported gravel-dominated bedsets. The fan surface is composed of a 50-100 cm thick stage IV pedogenic carbonate, and a well-developed desert pavement cap. Thus the fan delta was constructed in at least three phases: 1) Gravel and sand in the base of the sequence accumulated as either subaerial or subaqueous debris flows, 2) a brief interval of paleosol formation followed by abrupt deepening of lake level represented by fine-grained light-colored calcareous strata, and 3) as lake level grew shallower the system responded by coarsening upward to subaerial debris flows near the surface of the sequence. This detailed stratigraphic framework aids

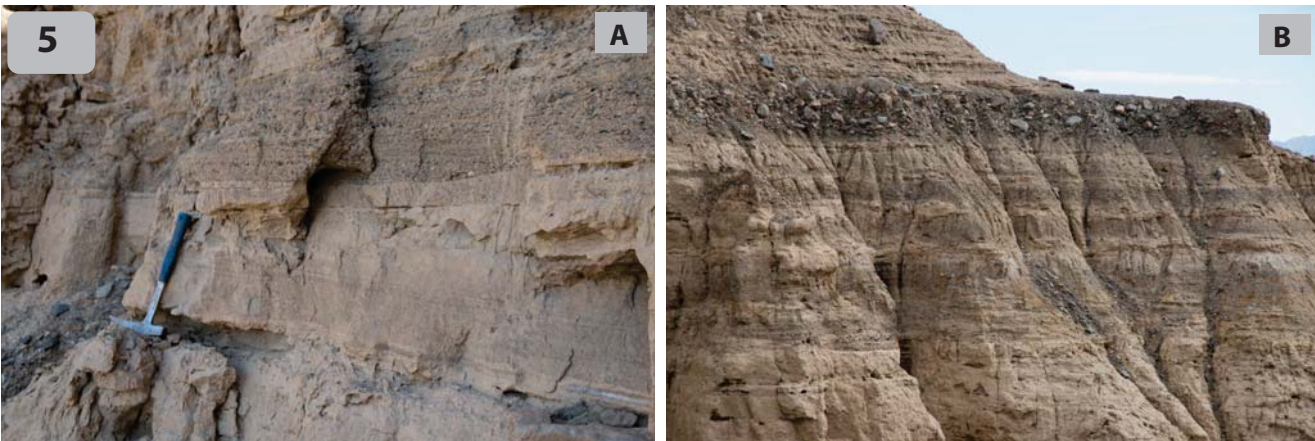
ongoing work to quantify sediment flux to the system using a novel cosmogenic nuclide approach.

ABSTRACT

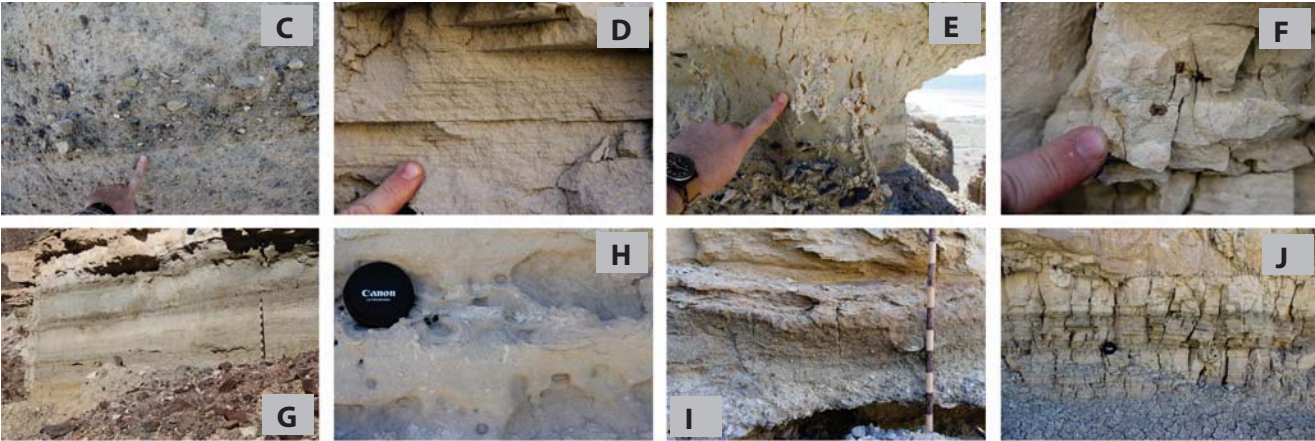
A robust three-dimensional stratigraphic framework is required in order to understand the role sediment supply plays in the development of stratigraphic architecture. Such a high-resolution framework is essential for ongoing research into controls on stratigraphy and is the focus of this presentation. Here, we integrate data from measured lithologic sections, photomosaics, and high-resolution dGPS surveys of prominent stratigraphic surfaces to present a stratigraphic framework for this lacustrine fan-delta complex. The Ballarat Sequence can be subdivided into five large-scale architectural elements (several -10s meters thick) that stack to form the overall stratigraphic architecture (100's meters). Starting with the base of the deposit: (1) alluvial fan / fan-delta (AFD), mostly covered by slope wash in outcrop, slope-forming, sub-horizontal to gently inclined interval, composed of matrix-rich to matrix-poor conglomerates and minor sands and silts, interpreted as subaerial alluvial fan/ fan-delta topsets and minor subaqueous foresets, (2) Fan Delta (FD), an interval of inclined progradational strata, with maximum apparent dips of ~8-15°, consisting of interbedded sands and conglomerates, interpreted to be fan-delta foresets, (3) Offshore lacustrine (OL), multiple intervals of stratified, calcareous fine-grained muds, silts and sands overlying white calcareous hardground. The fine-grained units bear a characteristic grey color, thicken basinward, and thin landward, and are interpreted to be offshore/distal lacustrine marls. Offshore/distal lacustrine units have a gradational contact with (4) nearshore lacustrine (NL), fine-coarse sands and minor granule-pebble rich zones, featureless, or cross- stratified, that grade into and form the base of, (5) Alluvial fan (AF), an overlying interval of repeated coarsening-upward sequences of sand-conglomerate couplets, composed of matrix-rich debris-flow deposits interbedded with sands, interpreted to be subaerial alluvial fan facies. This unit is truncated by an abrasion surface that forms the modern fan surface. Increased accommodation due to syn-sedimentary faulting, and possibly delta lobe switching in the south of the study area led to increased thicknesses of lacustrine sands and marls.



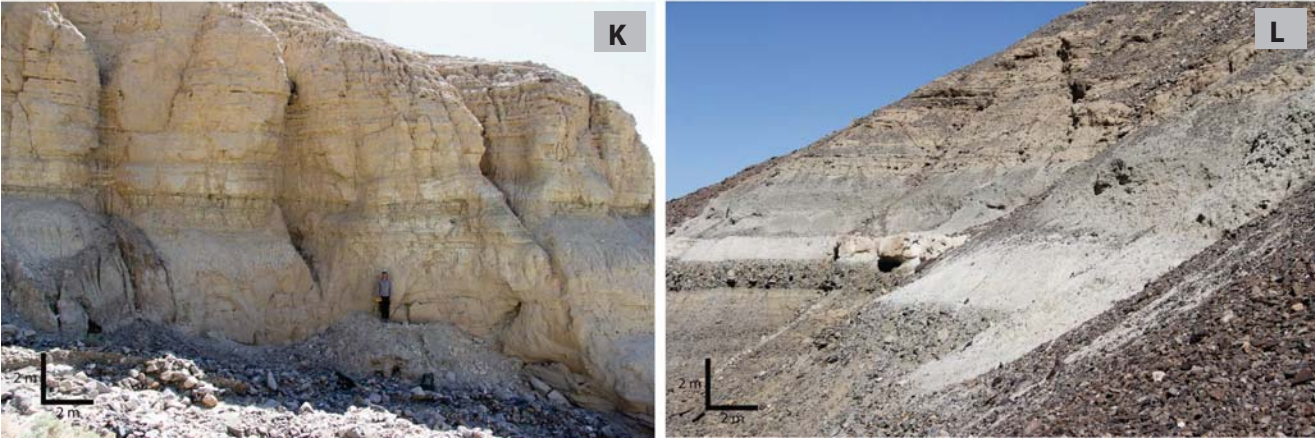
alluvial fan



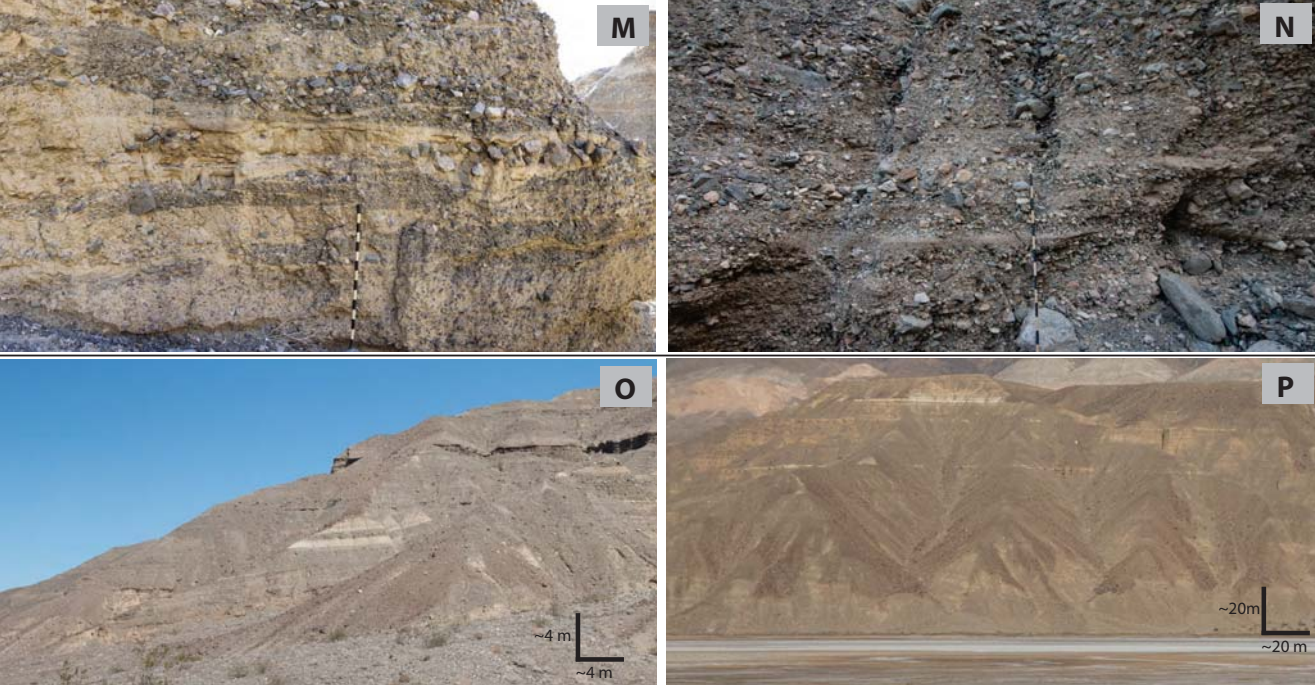
offshore / nearshore lacustrine



fan delta



alluvial fan / fan delta



INTRODUCTION

The Ballarat Sequence is a beheaded Pleistocene fan-delta complex, exposed on two sides by normal faults, and internally exposed by a number of small canyons incising headward into the deposit. During the Pleistocene, Panamint Valley was hydrologically linked to the eastern Sierra Nevada by ephemeral rivers and pluvial lakes (Figure 3). Paleo-lake Panamint was fed by melt water from the Paleo-Owens River system during wetter glacial times, and desiccated during drier interglacials, leading to numerous fill-desiccation cycles over Milankovitch timescales (~100 ka cycles) (Jayco et al., 2008). Pleistocene lake-filling events occurred at: (1) 1.3-1.0 Ma, (2) 0.75 - 0.6 Ma, (3) 0.5 - 0.4 Ma, (4) and 0.13 - 0.1 Ma (Jannick et al., 1991). A basal unit contains ~0.9 - 0.6 Ma volcanic zircons (Vogel et al., 2002). Wave-cut shorelines truncate the deposit, and are likely MIS 6 or ~150 ka (Jayco, et al., 2008). This evidence suggests a maximum timespan for deposition of the fan-delta sequence of ~600 - 150 ka.

METHODS

Measured stratigraphic sections were utilized to document stratigraphic thicknesses, mean grainsize, and bedforms. Master sections and smaller sections were measured ~1 km apart in (1) the north, and (2) the south of the area of interest (see figure 8 A) to document lateral and vertical facies changes. Illustrated digital photomosaics were used for reconnaissance level correlations and documentation of facies on steep, untouchable outcrop exposures, as well as at scales larger than mapping on foot allows. dGPS surveys were used to aid in correlations (data not presented here).

LITHOFACIES

Lithofacies and corresponding codes were constructed using the scheme of Miall (1985) (see Figure 5, and table 1) where the first capitol letter in the code signifies grainsize, and the second or third lowercase letter denotes bedform or other important characteristics.

ARCHITECTURE

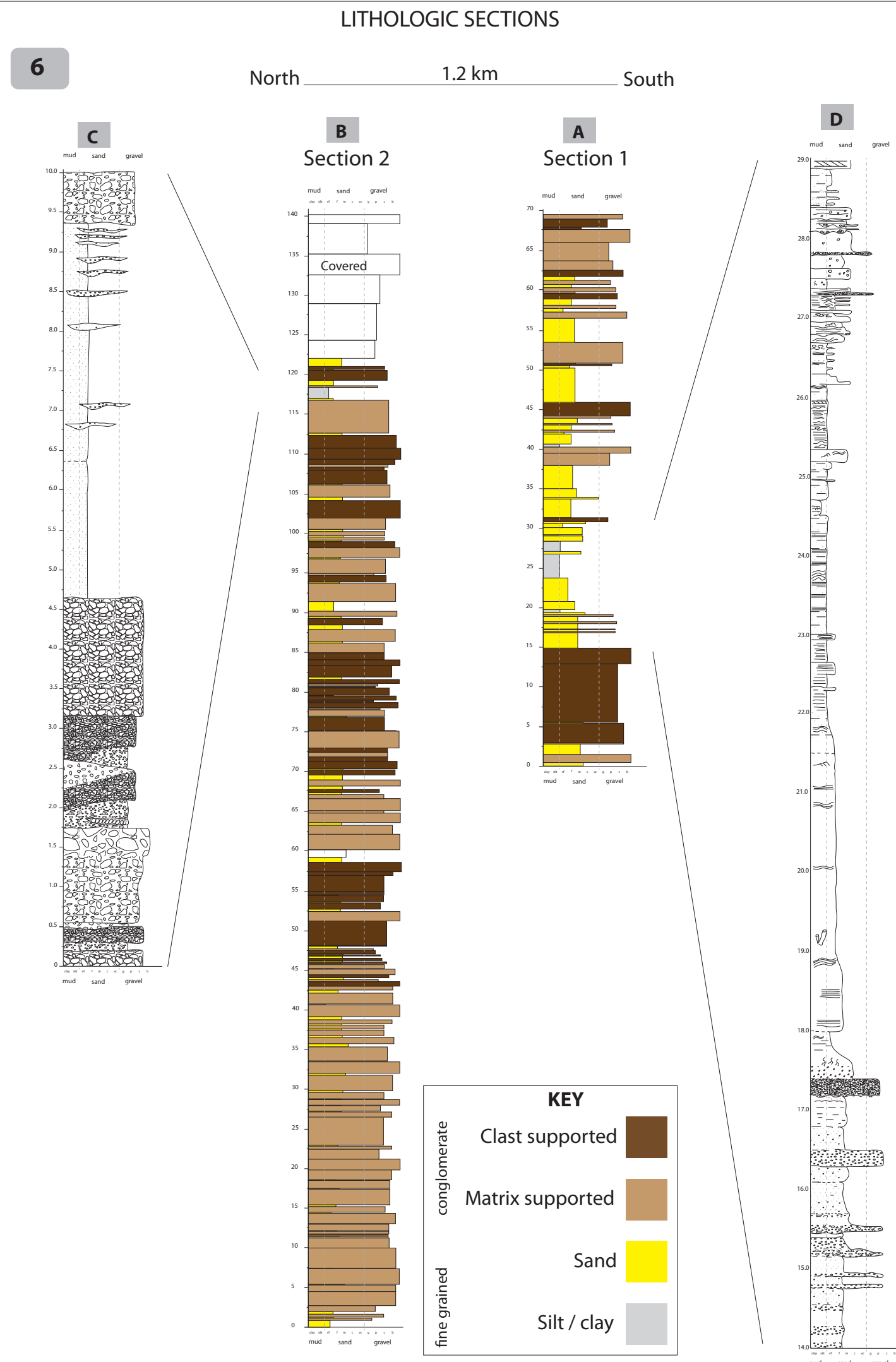
Individual lithofacies are grouped to form lithofacies associations, which in turn are grouped together here to form the largest scale architectural elements, and include interpretations of depositional environemnt (*sensu* Johnson and Graham, 2004).

1	Facies code (from Miall, 1985)	Facies name	Description	Interpretation	Depositional environment
	Gm	Matrix supported conglomerate	Brown colored fine sand matrix, poorly sorted clasts range from pebble to boulder, lacks bedding or grading, or may contain faintly organized beds	Pseudoplastic debris flows, unconfined, or channelized (?)	Channelized or unconfined fan surface, upper fan to distal fan
	Gc	Clast-supported pebble to boulder conglomerate	Disorganized or faintly stratified with imbricated clasts, may contain bedload traction structures, fine sand matrix poor or absent	Debris flows, or sieve deposit (?)	Gravel bars in channels on fan surface
	Sh	Horizontally laminated sand	Very fine to lower medium sand showing planar lamination	Sheetfloods, waning stage (?)	Unconfined fan surface
	Sf	Featureless very fine to medium beds of sand	Lacks organization		
	Sg	Granule-pebble rich sand	Granule-pebble rich or poor sand, diffuse or faint horizontal stratification of coarse fraction	Density currents, gravity flows, sandy mud flows	Distal fan (subaqueous?)
	Sd	Deformed sand beds	Contorted beds of fining upward sand, often present in repeating packages	Sandy turbidites, density currents	Subaqueous delta front (?)

Table 1: facies codes, descriptions, and interpretations

2	Architectural code	Depositional system / environment
	AF	Alluvial fan
	NL	Nearshore lacustrine
	OL	Offshore lacustrine
	FD	Fan delta
	AFD	Alluvial fan / fan delta

Table 2: Architectural codes and interpreted depositional system or environment

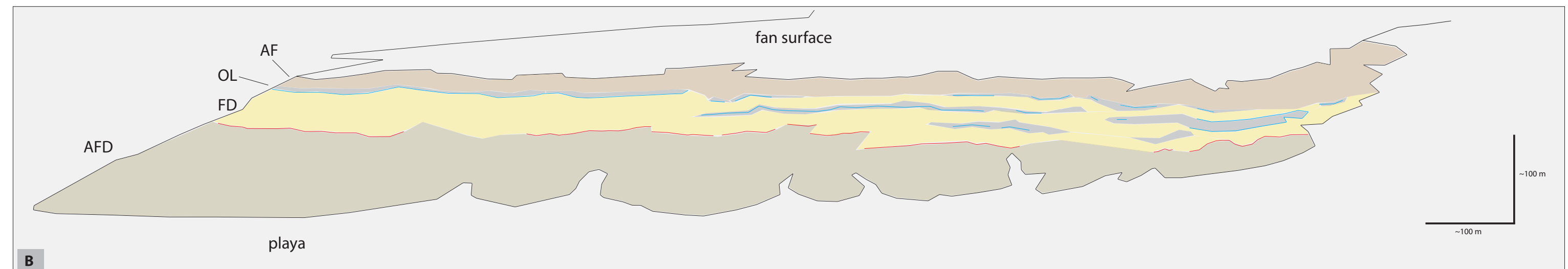
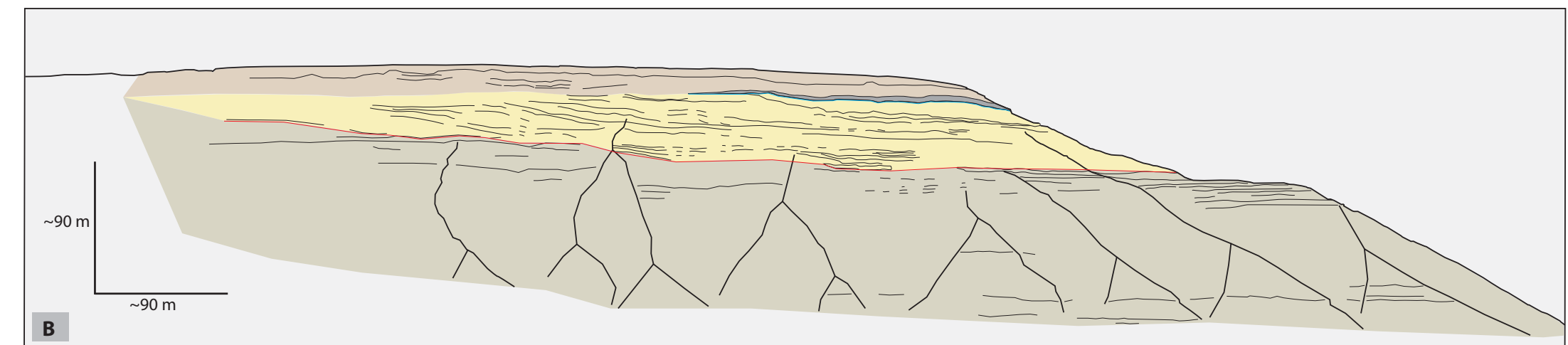
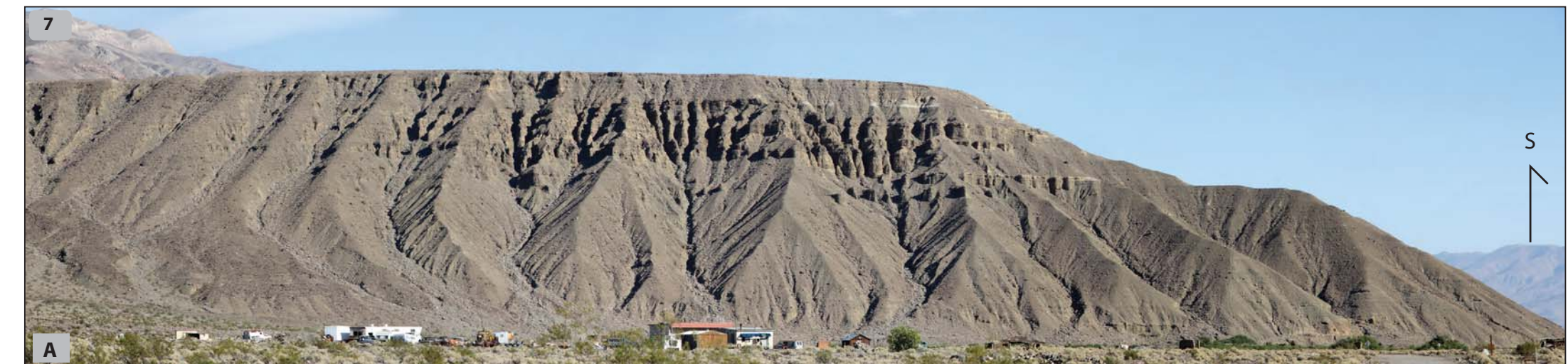
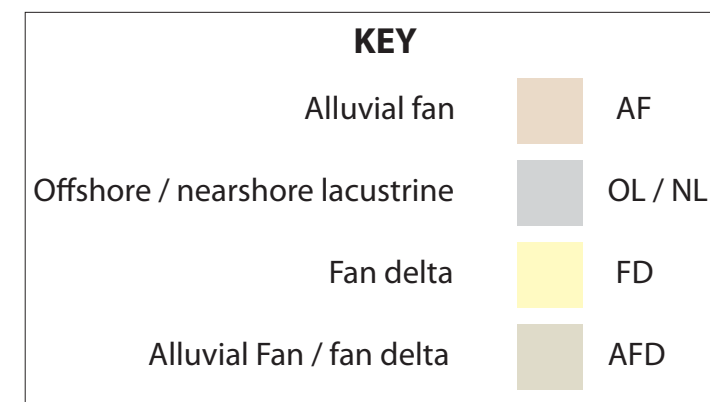


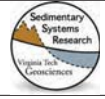
ARCHITECTURE OF MIXED ALLUVIAL FAN / FAN DELTA

Figure 6: Lithologic sections (locations noted on figure 8A)
A) section 1, B) Section 2, C and D) detailed sections from lacustrine intervals (OL/NL).

Figure 7: A) photomosaic and B) interpreted stratigraphic architecture of north-facing fan-delta outcrop.

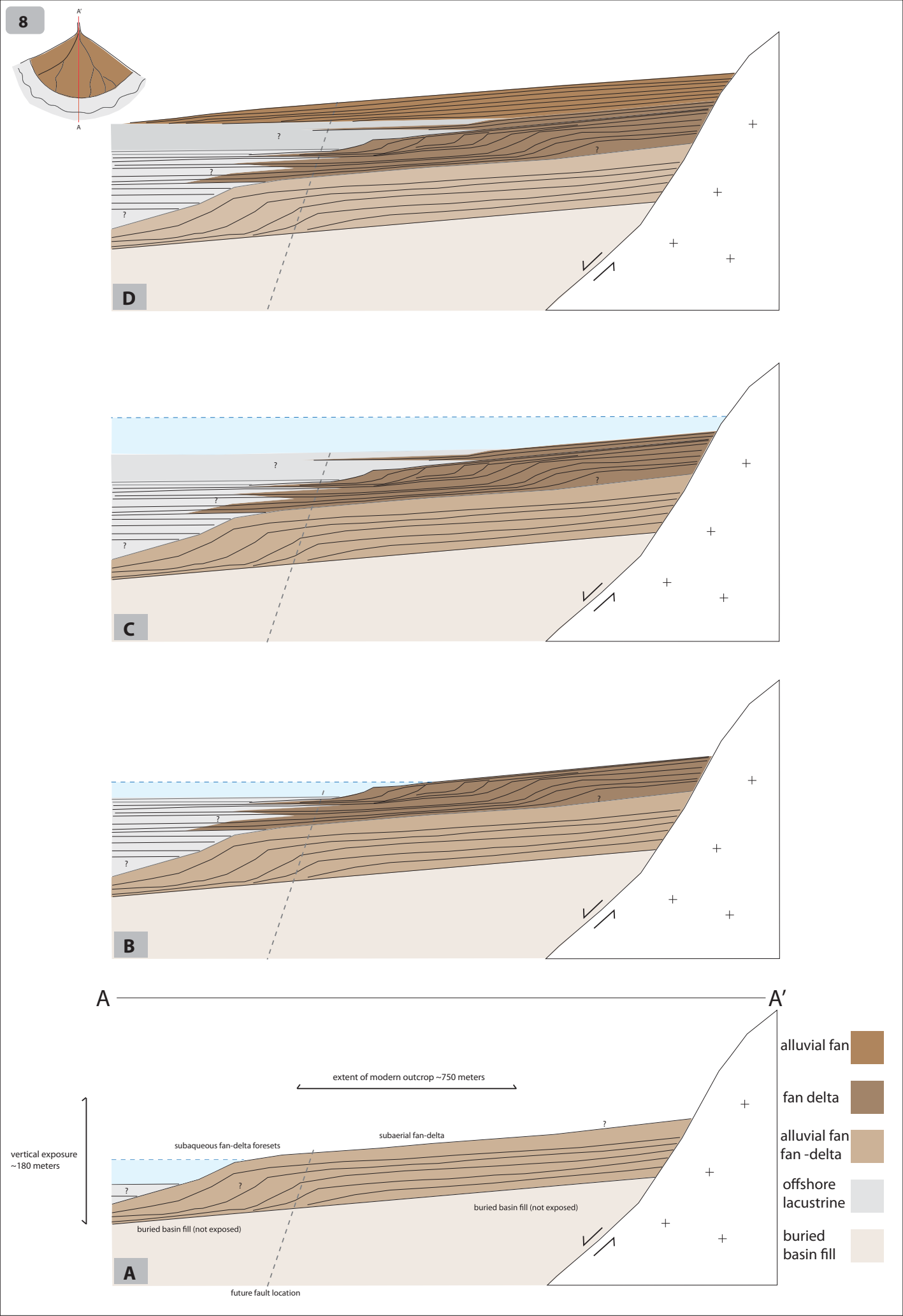
Figure 8: A) Photomosaic and B) interpreted stratigraphic architecture of southwest facing outcrop.





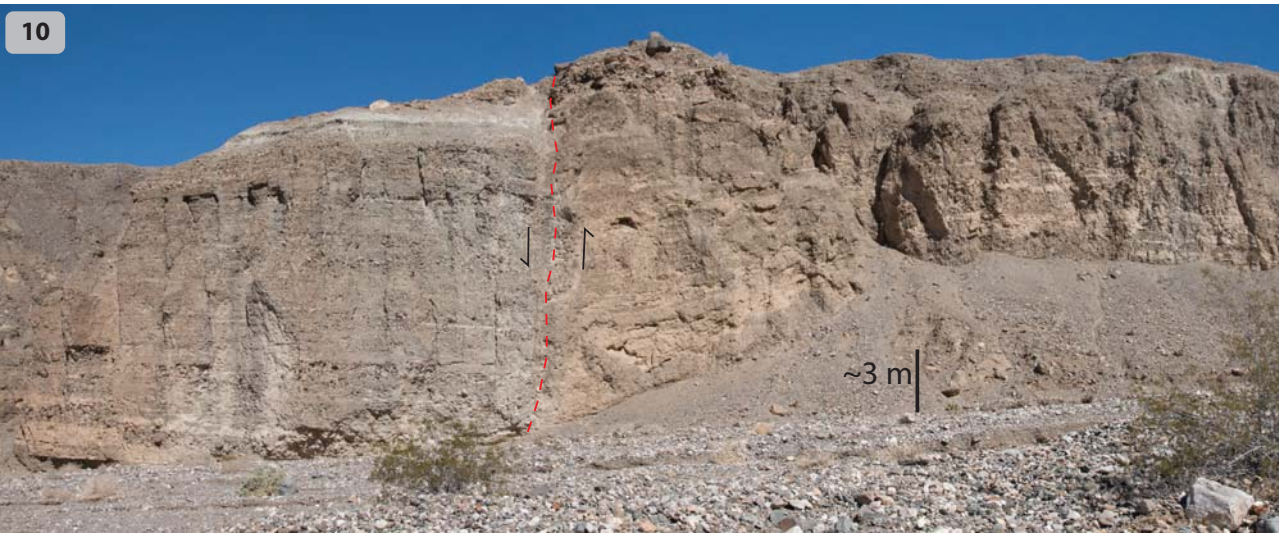
Architecture, lithofacies, and depositional model for the Ballarat sequence: a mid-Pleistocene fan-delta complex, Panamint Valley, Inyo County, California

DEPOSITIONAL MODEL



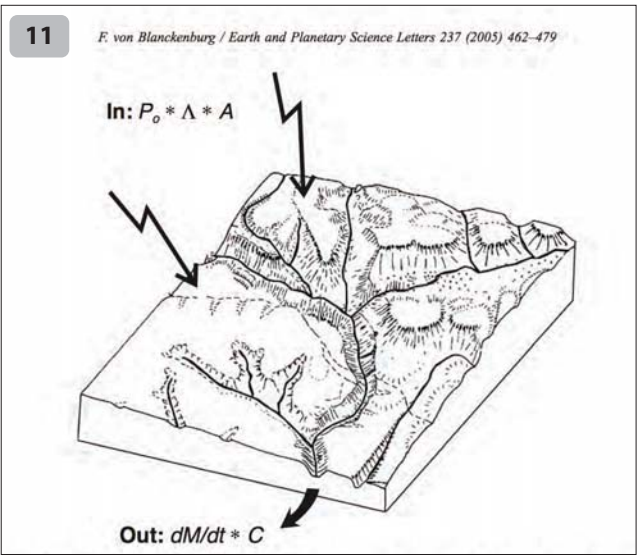
INCREASED ACCOMMODATION

Offshore / nearshore lacustrine facies stratigraphic thicknesses increases from north to south by an order of magnitude (figure 6 A, D). Synsedimentary faults in close proximity to the thickened lacustrine unit in the south likely account for the expanded fine-grained section (Figure 8 below). Another possibility for systematic increase in accommodation from north to south may be paleotopography related to either: 1) channelized fan-delta foresets, or 2) topography related to delta lobe switching, or 3) the paleo-Middle Park catchment outlet may have formed a channel in a similar location as the modern wash location. However, we see no major channelforms in the stratigraphy (> 1.5 m vertical), thus at this time we surmise the main force driving differential accommodation is synsedimentary faulting in the fan delta.



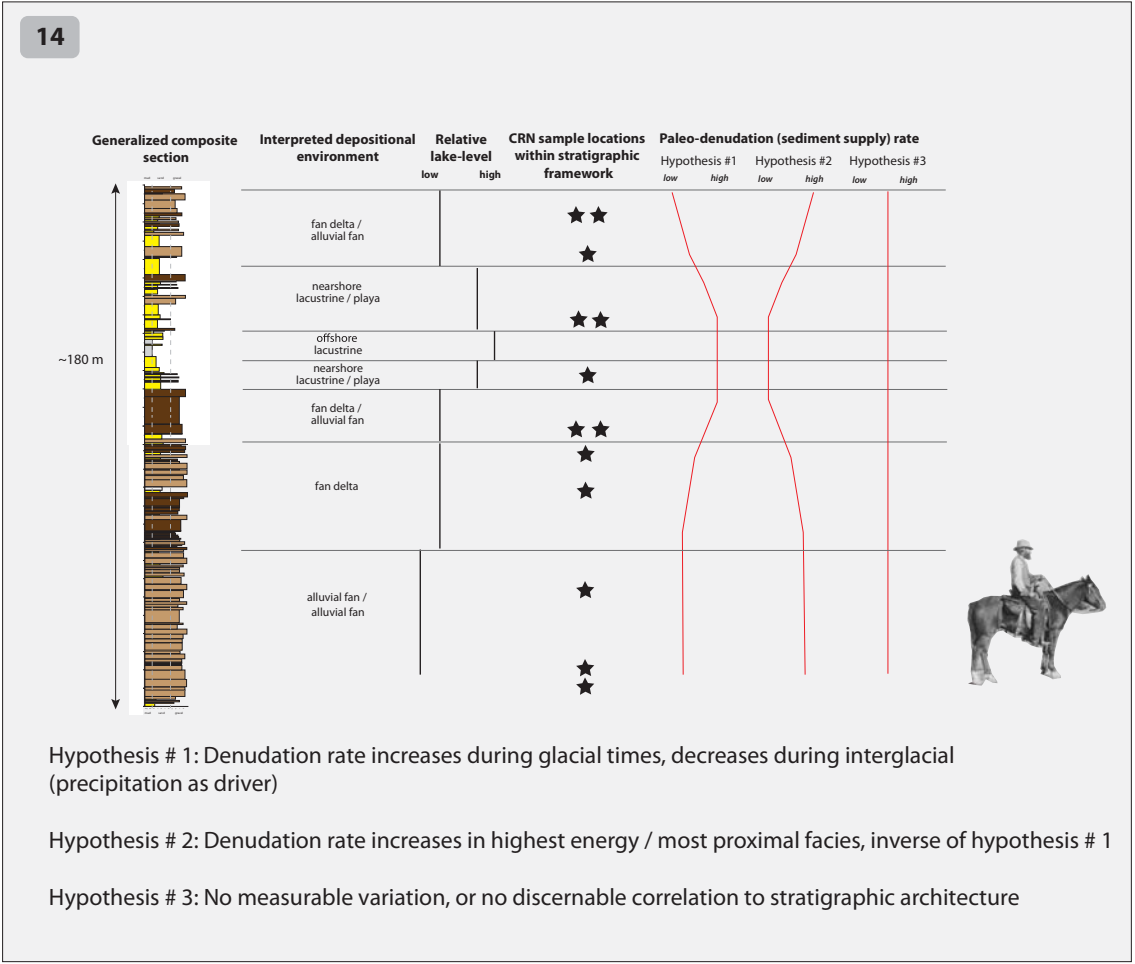
Captions: Figure 8: depositional model for the construction of the fan-delta sequence at Ballarat, A-D) time steps, old to youngest.
Figure 9: Photomosaic of synsedimentary fault in south of field area.
Figure 10: Photomosaic of synsedimentary fault in south of field area.
Figure 11: Illustration of the “Let nature do the averaging” technique for cosmogenic catchment-averaged denudation rate (Von Blanckenburg, 2005).
Figures 12, 13: Photographs of sampling buried alluvium to be used for our paleodenudation rate study. Tools and sampling techniques are illustrated.
Figure 14: Composite section, interpreted environments, sample locations within framework, hypotheses regarding paleodenudation rates, and G. K. Gilbert on horseback.

PALEO-DENUDATION RATES



FUTURE WORK

The overarching goal for this study is to quantify sediment supply (Q_s) to the catchment-fan system through time, using ^{10}Be ; a terrestrial cosmogenic nuclide (TCN) produced in quartz near the Earth surface, then link rates to stratigraphic architecture. ^{10}Be is used as both an exposure and burial chronometer by those investigating Earth-surface processes, and increasingly, has been used to quantify catchment-averaged denudation rates. In modern river sediment, measured ^{10}Be concentrations are inversely proportional to spatially averaged denudation (erosion + chemical weathering) rate in the catchment, and thus yield Q_s (Figure 11). We build on the technique by using measurements of ^{10}Be in buried alluvium to determine paleo-catchment-averaged denudation rates. Measuring ^{10}Be in buried sediment and subtracting the effects of radiogenic decay, and post-burial production yields paleo-denudation rates, or paleo-mass flux, a proxy for Q_s . The steep, linked catchment-fan minimizes exposure to cosmic-ray flux during sediment transport to the depositional segment (transport, storage, reworking) making this location ideal for testing hypotheses regarding sediment supply and stratigraphic architecture. We hypothesize that denudation rates varied over timescales less than or equivalent to time represented in preserved stratigraphy, and that the paleo-denudation rates will vary systematically with either stratigraphic architecture and / or with climatic regime (inferred through lake level history preserved in stratigraphy (Figure 14). In March 2014 we acquired a preliminary suite of samples from within the stratigraphic framework presented here that should help address questions of how mass flux is related to stratigraphic architecture and help to detangle accommodation vs supply (A / S) in natural systems.



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