

**Architectural-element analysis and depositional models for
pre-vegetation braidplain and braid-delta environments,
with modern analogues**

**A Dissertation Presented for the
Doctor of Philosophy
Degree
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DEDICATION

To Mom, for always steadying my ladder,

to Dad, for helping me cross rivers,

and

to Jeff Trop, who inspired my career in less than 82 minutes.

Thank you.

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I could not have found a better mentor than Chris Fedo, who has guided me through two degrees, four major research projects, and uncountable trials inside and outside the UTK doctoral program. For over seven years, we have developed grant proposals, trekked across the Mojave Desert in search of outcrops, flown to international conferences, debated each other in research meetings, adapted to all manner of adversity, and celebrated successful publications. Chris imparted valuable lessons in geology, field work, advising, teaching, public speaking, and writing, but beyond his profession capacity we have shared many a spirited conversation as friends. Committee members Jeff Moersch, Colin Sumrall, Alessandro Ielpi, and John Schwartz lent their time toward ensuring a successful dissertation. Assistance throughout my time in the department came from both faculty, current and emeritus, and office staff Angie, Diane, Melody, and Theresa. Overlapping lab-group members Latisha Brengman, Sam Gwizd, and Kristan Watkins provided comradery and scientific evaluations. I thank my parents and family for years of support and understanding while I focused on my degree. Much credit is owed to friends made at UTK and elsewhere, including Jonathan Algeo, Erin Donaghy, Keenan Golder, Miles Henderson, Cameron Hughes, Ashley Manning-Berg, and numerous other graduate students, professors, and acquaintances with whom I have intersected. Research would not have been possible without generous funding from the National Aeronautics and Space Administration (NASA), the Geological Society of America (GSA), the Society for Sedimentary Geology (SEPM), the International Association of Sedimentologists (IAS), the University of Tennessee, and the Department of Earth and Planetary Sciences.

ABSTRACT

Pre-vegetation landscapes that blanketed the continents before the emergence vascular plants in the late-Silurian are proposed habitats for the earliest terrestrial biota and are analogous to martian setting thought to have potentially hosted life. Analysis of the middle member of the Wood Canyon Formation, a Cambrian age sandstone, reveal new details about terrestrial pre-vegetation environments. In fluvial middle-member stratigraphy, units are defined by stacking patterns of three facies associations (FA1-3). In FA1, stacked cosets, interpreted as braidplain barforms and channel fills, preserve vertical- and downstream-accretion elements under unimodal paleoflow. Floodplains, represented by FA2, include red-orange intervals of fine- to medium-grained sandstone and thinner sets of cross-bedding than FA1. Possible aeolian beds of FA3 preserve broad festooned trough cross-strata that average 23 centimeters in thickness. A nearby stratigraphic section of middle member preserves the development of a fluvial-dominated braid delta at the terminus of the braidplain. In contrast to other pre-Devonian braid-delta strata that are largely absent mudrock, the majority of the braid-delta system contains over 5% mudstone. The 20 meters of braidplain-to-delta transition strata (FA4) are largely similar to those of fluvial middle-member sections. Each braid-delta facies association (FA5-7) preserves high sinuosity paleocurrent indicators, 6–12% mudstone, and symmetrical sand waves. Fluid-mud deposits found primarily in FA6 indicate the presence of a maximum turbidity zone. Trace fossils found only in the most distal braid delta suggest metazoans could not tolerate fresh water or the variable salinity of the braid delta. Global surveying of 786 Holocene braid deltas provides an understanding of present-day, pre-vegetation analogues. Systems develop at all latitudes, with the exception of the Antarctic, but are densest in the periglacial latitude bands. A novel classification of braid-delta morphotypes, separates deltas by flow characteristics, dominance of wave, river, or tide modification, and confinement style. Wet, river-dominated, linear or radial morphotypes and wet or dry, wave-dominated, linear morphotypes represent two-thirds of the dataset. Geomorphic maps for each morphotype, 38 km² in total area, detail a range of possible facies components. Importantly, 63% of the observed braid deltas are not the distributary forms that are common in meandering-river deltas.

PREFACE

I have been lucky all through the years to work in the Basin and Range. The Basin and Range impresses me in terms of geology as does no other place in North America. It's not at all easy, anywhere in the province, to say just what happened and when. Range after range—it is mysterious to me.

A lot of geology is mysterious to me.

— Kenneth S. Deffeyes, in John McPhee, *Basin and Range*

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INTRODUCTION

Prior to the radiation of vascular plants in the Devonian (Steemans et al., 2009; Gibling et al., 2014; Friedman, 2017) and accompanying sediment stabilization provided by root systems (McMahon and Davies, 2018a), extensive braidplains mantled the exposed continents (e.g., Cotter, 1978; Eriksson et al., 1998; Long, 2011), forming the main conduits that shuttled surface water to sedimentary basins. The term braidplain describes a wide expanse of braided-fluvial sediment transport. Where braided rivers interface with base level, a delta forms, merging the depositional style of braided channels with marine or lacustrine processes. Consequently, although “common delta” today refers to the delta of a meandering river, braid deltas were for the majority of Earth history the most abundant variety. Despite the extensive publication record on fluviodeltaic settings, common deltas and the deltas of alluvial fans (fan deltas) have received more interest from the sedimentology and geomorphology communities (e.g., Soh et al., 1995; Giosan and Bhattacharya, 2005; Bhattacharya, 2010), whereas the deltas attached to braided rivers, termed braid deltas by McPherson et al. (1987), are underrepresented in geoscience literature. In modern river systems, braid-delta environments are common at all latitudes and every continent except Antarctica, tied to regions with high rates of sediment supply. Despite the importance of such systems in the ancient past, a full depositional model has not been developed, and sedimentology texts and depositional environment compilations overlook braid deltas. Investigations of Holocene braid deltas are remarkably limited (McGowan and Sturman, 1997; Hart, 2007; Bell, 2009; Bendixen et al., 2017) and frequently do not include “braid delta” as a keyword. Without detailed study of both modern systems and pre-vegetation strata, a facies model for braid deltas will remain elusive.

Chapter I provides a detailed paleoenvironmental assessment of the Cambrian (Terreneuvian) middle member of the Wood Canyon Formation, first identified as the preserved expression of a braided fluvial system by Diehl (1979) and later by Fedo and Cooper (1990, 2001) and Fedo and Prave (1991). The work focuses on a near-continuous exposure in the Marble Mountains of southeastern California (Fig. 1.1). Digital outcrop models (DOM), made using both small unmanned aircraft systems (sUAS) and handheld cameras, capture the multiple scales required for analysis of braidplain stratigraphy. Mapping the fine-scale sedimentary architecture allows for bedform reconstructions and planform interpretation of the fluvial system, by providing details of bar accretion. On an outcrop scale, investigation of fluvial architecture permits documentation of changes in sedimentation style and preservation during deposition of the middle member. Specific aims of this study included: (1) description of barform, channel fill, and sandy bedform architecture in the middle member, (2) tracing the large-scale architecture of facies associations where possible, (3) reconstruction of depositional subenvironments and braidplain architecture, and (4) assessment of metazoan habitability. Major outcomes include evidence for deposits that represent overbank environments, including floodplains and aeolian sand sheets, and architecture that suggests perennial streamflow in braided channel belts.

Chapter II includes stratigraphic architecture results for a section of the middle member of the Cambrian Wood Canyon Formation previously interpreted as a braid-delta deposit by Fedo and Cooper (1990). Primary goals of this study included: (1) classifying the lithofacies and architectural elements of the proposed braid-delta environment, (2) distinguishing fluvial sedimentary features from those that are marine in origin, (3) developing a depositional model for the middle member Wood Canyon Formation beyond the first-order findings of Fedo and Cooper (1990) at the selected site, and (4) assessing habitability potential of the braid-delta environment. The braid-delta strata represent a down-dip continuation of nearby, coeval, braidplain strata of the middle member documented in Chapter I. Together, the two locations capture the lateral extent of a distal fluvial system where it intersected the ancient coastline. Pairing Chapters I and II provides the opportunity to investigate what detailed facies-level changes occur when a pre-vegetation fluvial system is modified by marine processes. Because the strata of the feeding braidplain preserved no distinguishable body/trace fossils, the search for evidence of habitable conditions shifted toward the connected transitional-marine realm.

To better understand the braid-delta environment of the middle member Wood Canyon Formation, Chapter III documents modern braid-delta systems, utilizing extensive global surveying and detailed analysis to address the following objectives: (1) identify the distribution and geomorphology of braid deltas on Earth, (2) develop a classification scheme based on distinct morphotypes, (3) map type localities in order to detail the possible facies components of this understudied depositional setting, and (4) discuss the role of braid deltas in the sedimentary record. Results provide a quantification of the important role that braid deltas have in the present-day sedimentary system and provide insight into their larger role in pre-Devonian time. From this perspective, Chapter III integrates geomorphology with sedimentology, as such, presented classifications are intended to apply to modern braid deltas and to aid in the interpretation of ancient sedimentary rocks on Earth or other terrestrial planets. The hundreds of large, Holocene, braid deltas recognized by this study reveal their global occurrence, major morphological differences from other delta types, the transience of their features, and bring to the foreground prior misconceptions. Additionally, Chapter III serves as a first step toward a complete facies model for the braid-delta environment.

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CHAPTER I
ARCHITECTURE OF A DISTAL PRE-VEGETATION
BRAIDPLAIN: CAMBRIAN MIDDLE MEMBER OF THE WOOD
CANYON FORMATION, SOUTHERN MARBLE MOUNTAINS,
CALIFORNIA, USA

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Abstract

Architectural element analysis and detailed mapping of a 300 meter along-strike exposure of the middle member Wood Canyon Formation, southern Marble Mountains, California, USA, provides new evidence for extensive braided-fluvial channel-belt deposits with adjacent overbank environments. Three-dimensional models constructed using Structure-from-Motion techniques, combined with field-based observations, allowed interpretation of outcrop-scale trends, barforms, channel fills, and fine-scale features. The ~80-meter-thick member is divisible into five distinct units, including units M1-3 that form the bulk of the stratigraphy. Units are defined by stacking patterns of three facies associations, FA1-3, each representing the product of a subenvironment within the fluvial system. In FA1, stacked cosets, interpreted as low-relief fluvial bars and channel fills, preserve vertical- and downstream-accretion elements under unimodal NNW paleoflow, with minor lateral accretion near bar edges. Deposits of FA2-3, linked to overbank environments, are found only in unit M2, in the middle 27 meters of the middle member. Floodplains, represented by FA2, include crumbly red-orange intervals of fine- to medium-grained sandstone and thinner sets of cross-bedding than FA1, interbedded with thicker cross-stratification indicative of overbank splay or overland flow aggradation from adjacent channel belts during flood stage. Possible aeolian beds of FA3 preserve broad festooned trough cross-strata that average 23 centimeters in thickness; their small size, medium-grained sandstone, and iron oxide cement suggest a high water table. The diverse assemblage of interpreted subenvironments, paired with bedform and facies patterns, implies a perennial fluvial system that gradually built large sand bars as the channel belt migrated and avulsed across an unconfined braided-fluvial reach, leaving the overbank area on its flanks subject to weathering and aeolian transport. Despite the occurrence of strata deposited in low-energy and ponded settings, and a marine influence proposed for nearby sections of middle member, no ichnofossils were encountered.

Introduction

Prior to the radiation of vascular plants in the Devonian (Steemans et al., 2009; Gibling et al., 2014; Friedman, 2017) and accompanying sediment stabilization provided by root systems (McMahon and Davies, 2018a), extensive braidplains mantled the exposed

continents (e.g., Cotter, 1978; Eriksson et al., 1998; Long, 2011), forming the main conduits that shuttled surface water to the oceans. Here, the term braidplain describes an unconfined expanse of braided-fluvial sediment transport. With no extensive root-bearing plant communities in the terrestrial landscape until the middle Paleozoic, braidplains reached continental size (Rainbird et al., 1992, 2017), and have no modern analogues of similar scale. Smaller present-day braided rivers contain many of the same elements used to classify ancient systems (e.g., Long, 2006) and compare directly to the architecture of ancient pre-vegetation deposits. As fluvial morphology is directly linked to climate, slope, sediment supply, and available accommodation space (Schumm, 1981), additional documentation of numerous pre-Devonian braided stream systems is needed to evaluate their diverse architecture and to identify any specific features that are not apparent in modern systems. Each pre-vegetation braidplain deserves detailed study, as each preserves a different set of fluvial characteristics reflecting its geologic setting.

The relative abundance of braided river deposits in pre-Devonian strata, hypothesized by Schumm (1968), was documented by Hereford (1977), Cotter (1978), and Long (1978). These authors suggested that the evolution of root-bearing plants provided the basis for establishing the cohesive banks that they claimed were essential to allow river meandering, and argued that without plant stabilization, rivers developed almost exclusively braided morphologies. Beyond initial interpretations, the complexity of subenvironments in these systems warrants continued detailed architectural analysis (e.g., Marconato et al., 2014; Santos et al., 2014; Ielpi et al., 2018). Depositional subenvironments are small localized components of an overall depositional environment, for example a floodbasin in a braided river system. Recent investigations (Davies et al., 2011; Ielpi and Rainbird, 2016a; Santos and Owen, 2016) identified diverse facies associations that occur within braidplain strata, including evidence for interspersed aeolian dune fields, floodplains, overflow channels, and paleosol development (Sarkar et al., 2012; Ielpi and Rainbird, 2015; Mazumder et al., 2015; Ielpi et al., 2018).

This study provides a detailed paleoenvironmental assessment of the Cambrian (Terreneuvian) middle member Wood Canyon Formation, first identified as the preserved expression of a braided fluvial system by Diehl (1979) and later by Fedo and Cooper (1990, 2001) and Fedo and Prave (1991). Work presented here focuses on a near-continuous exposure in the Marble Mountains of southeastern California (Fig. 1.1). Digital outcrop models (DOM), made using both small unmanned aircraft systems (sUAS) and handheld cameras, capture the multiple scales required for architectural element analysis of braidplain stratigraphy. Mapping the fine-scale architecture allows for bedform reconstructions and planform interpretation of the fluvial system, by providing details of bar accretion. On an outcrop scale, investigation of fluvial architecture permits documentation of changes in sedimentation style and preservation during deposition of the middle member. Specific aims of this study included: (1) description of barform, channel fill, and sandy bedform architecture in the middle member, (2) tracing the large-scale architecture of facies associations where possible, (3) reconstruction of depositional subenvironments and braidplain architecture, and (4) assessment of metazoan habitability. Major outcomes include evidence for deposits that

represent overbank environments, including floodplains and aeolian sand sheets, and architecture that suggests perennial streamflow in channel belts.

Geologic Setting

Along the margin of western Laurentia, a Neoproterozoic-to-Paleozoic rift-to-drift sequence records the breakup of Rodinia, and subsequent formation of Laurentia (e.g., Prave, 1999; Fedo and Cooper, 2001; Karlstrom et al., 2018). By the latest Ediacaran (Levy and Christie-Blick, 1991), a mature passive margin developed along the (present day) western Laurentian margin at a near-equatorial latitude (Li et al., 2008). A continent-scale fluvial system prograded across Laurentia, depositing sediments that built the middle member Wood Canyon Formation (Fedo and Prave, 1991; Hogan et al., 2011; Schoenborn and Fedo, 2011; Schoenborn et al., 2012) and that thicken extensively to the northwest in response to post-rift subsidence and sediment loading (Stewart, 1970; Cooper and Fedo, 1993; Fedo and Cooper, 2001). The Wood Canyon Formation has three informal members: a shallow-marine lower member, an arkosic fluvial middle member, and a shallow-marine upper member overlain by the Zabriskie Quartzite (Fig. 1.1A; Stewart, 1966; Diehl, 1979; Prave, 1991; Fedo and Cooper, 2001). The middle member is constrained to the Terreneuvian (542-521 Ma) and lies between the Ediacaran-Cambrian boundary, which occurs in the lower member (Corsetti and Hagadorn, 2000), and Cambrian Series 2 fossils in the upper member (Mata et al., 2012).

On the craton, where the rocks of this study are located, an incompletely developed Wood Canyon Formation begins with the middle member nonconformably overlying ~1.4 and 1.7 Ga crystalline basement of the Mojave Province (Fig. 1.1A-B; Anderson and Bender, 1988; Fedo and Cooper, 1990; Farmer and Ball, 1997; Wooden et al., 2013). A widespread, meters-thick, weathering profile advanced into exposed bedrock and formed an essentially flat topographic surface just prior to deposition (Hogan et al., 2011). Locally derived Mojave Province detrital zircons occur only within the lowest several meters of the middle member, above which the primary source of zircon is overwhelmingly dominated by a 1.1 Ga age peak as observed across the Great Basin (e.g., Stewart et al., 2001; Schoenborn et al., 2012; Gehrels and Pecha, 2014; Muhlbauer et al., 2017). The 1.1 Ga ages are interpreted to indicate long-distance transport and rapid burial of a very low-relief, mature, geomorphic surface (Schoenborn et al., 2012; Muhlbauer et al., 2017). A distinct absence of incised paleovalleys developed on the underlying bedrock or within the middle member suggests deposition under limited accommodation space conditions, a concept supported by detailed sequence stratigraphic work on younger Cambrian units (e.g., Koerschner and Read, 1989; Montanez and Osleger, 1993) that accumulated in response to low-amplitude base-level oscillation.

Early investigations of the middle member described it as generally “shallow marine” (Stewart, 1970), or more specifically as a tidalite (deVries Klein, 1975). Later paleoenvironmental analysis indicated that at least part of the member was of braided-fluvial origin (Diehl, 1979). Fedo and Cooper (1990) provided a comprehensive facies-level interpretation of the middle and upper members of the Wood Canyon Formation, recognizing a fluvial-to-marine transition both vertically and laterally in the southern

Marble Mountains. Foster (1991) revisited the tidalite interpretation based on the apparent occurrence of bimodal-bipolar foreset orientations, although these results were shown to be an artifact of measuring opposing limbs of trough cross-stratification by Fedo and Cooper (1991), an exchange that underscores the importance of understanding the three dimensionality of trough cross-beds when observed in oblique cross-sections (e.g., DeCelles et al., 1983).

A single, large, cliffside outcrop (Fig. 1.1B) of middle member Wood Canyon Formation in the southernmost Marble Mountains of southeastern California, USA (Fig. 1.1C-D) was selected for analysis of fluvial architecture. Situated approximately ~6 km cratonward of a middle member section interpreted as the product of a braid delta environment (Fedo and Cooper, 1990), the location represents the most distal reaches of the fluvial system, sensitive to even minor changes in base level. Mapped area measures approximately 300 meters along strike by 80 m in stratigraphic thickness. Exposures are oriented near-perpendicular to bedding, along a north-south trend. Outcrop geometry displays oblique longitudinal and transverse cross-sectional cuts through the fluvial system, with 3D exposure enhanced by fracture sets at approximately 000/30W, 330/60W, and 060/60N (Fig. 1.1D; Appendix A-4, Table 4.1; Fedo and Cooper, 1991). Stratigraphic exposure is near continuous, from the basal nonconformity to the contact with the upper member. Scree slopes coupled with high-angle, low-displacement, oblique faults obscure and dissect a small part of the outcrop. Preexisting data from the site, including a detailed stratigraphic column with paleocurrent analysis (Fedo and Cooper, 1990), detrital-zircon provenance results (Schoenborn et al., 2012; Muhlbauer et al., 2017), and characterization of the lowermost stratigraphy up to a prominent discontinuous conglomerate (Hogan et al., 2011) provide context for new work.

Methods

Recent evaluation of sedimentary architecture has progressed with advances in digital photography and consumer electronics. Photomosaic techniques limit studies to well-exposed, tectonically undeformed strata found in planar exposures (e.g., Almeida et al., 2016b; Ielpi and Rainbird, 2016a; Lebeau and Ielpi, 2017). Structure-from-Motion (SfM), especially if implemented through the use of a sUAS, allows new perspectives, capturing stratigraphy at a larger scale and over complex topography (cf. Ghinassi and Ielpi, 2018). Current SfM techniques align thousands of images using photogrammetric software (Fabuel-Perez et al., 2009; Clapuyt et al., 2016; Chesley et al., 2017), generating a high-resolution 3D model of the target area. A DJI Phantom 3 Professional sUAS collected images of the site, flying a horizontal grid pattern oblique to the outcrop face. More than 4000 images cover the full exposure of the middle member with suitable overlap, from its unconformable base to its inferred contact with the upper member. Pix4Dmapper™ software assembled a georeferenced SfM model of the field area, providing a base map for locating areas of interest and facilitating tracing of large-scale features. Vertical resolution of the DOM is 6-7 cm, with a spatial resolution is 2-3 cm. In a separate SfM approach, images collected using a smartphone camera were imported into Agisoft™ Metashape to generate ultra-high resolution DOMs, suitable for detailed stratigraphic studies. Construction of each architectural panel required tracing of bounding surfaces in

the field, collecting true dips of these bounding surfaces and primary fracture sets, determining lithofacies, and measuring a suitable stratigraphic column. Orientation measurements were restored to horizontal via stereonet to correct for a tectonic tilt of 50° to the east, determined from depositionally flat mudstone units in the upper member of the Wood Canyon Formation and the dip slope of the overlying Zabriskie Quartzite (Fig. 1.1D; Muhlbauer et al., 2020, Appendix A-4, Table 4.2).

Facies Associations and Subenvironment Interpretations

Stratigraphic stacking patterns of facies associations provide boundaries that divide the middle member into five units (Fig. 1.1A), including the three major units detailed in this study named M1, M2, and M3. Units X1 and X2 that represent the lowest ~4.5 m of stratigraphy directly above to the nonconformity, were described by Fedo and Cooper (1990) as Facies C, and are not discussed herein. Subsequent sections describe three facies associations, recognized as FA1, FA2, and FA3 (Fig. 1.1A), with photographs, stratigraphic panels, and corresponding stratigraphic columns that illustrate distinctive features. Within the depositional system, FA1-3 each correspond to specific subenvironments and together represent the majority of Wood Canyon Formation braidplain sedimentation as part of units M1-3.

Lithofacies and Architectural Elements

Facies associations are assigned based on the identification of lithofacies and mapping of architectural elements in the field. Nine lithofacies were recognized in the middle member of the Wood Canyon Formation (Fig. 1.2), using terminology introduced by Miall (1985) and Tucker (2003). At the Marble Mountains the middle member is dominated by trough cross-stratification (St; Fig. 1.2A), low-angle cross-stratification (Sl; Fig. 1.2B), and planar tabular cross-stratification (Sp; Fig. 1.2C). Figure 1.2D shows a rare example of ripple cross-lamination (Sr) in sandstone. Grain sizes below fine sand are present locally as mm- to cm-scale layers of finely laminated mudstone (Fl; Fig. 1.2E), and as mudstone intraclasts (Fm; Fig. 1.2F). Hogan et al. (2011) documented the conglomerate, interstratified with beds and lenses of sandstone (GSh; Fig. 1.2G), that occurs near the base of unit M1. Horizontally laminated sandstone (Sh; Fig. 1.2H) and massive sandstone (Sm; Fig. 1.2I) are common in units X1 and X2, which Fedo and Cooper (1990) interpreted as sheet-flood deposits.

A summary of architectural elements recognized in the middle member Wood Canyon Formation is presented in Figure 1.3. Although most elements follow published work by Miall (1985, 1996) and Long (2006, 2011), several were developed specifically for this study, namely vertical accretion (VA), floodplain (FP), and aeolian (AO). This study proceeds by classifying surface orders after Miall (1985). Foresets of both low- and high-angle (Fig. 1.4A) cross-stratification or cross-lamination represent 0th order surfaces. Scour surfaces at the base of cross-beds or plane-parallel beds are 1st order surfaces that range from near-horizontal to steeply dipping (Fig. 1.4B). Low-relief (Fig. 1.4C) 2nd order surfaces separate cosets of cross-stratification. Because most coset boundaries and higher-order surfaces in the Wood Canyon Formation are near horizontal, and fluvial channel belts are presumed much wider than the total along-strike extent of the outcrop, it

is difficult to reconcile existing categories of surface hierarchies (Miall, 1985; Kelly, 2006) with high-order bounding surfaces in middle member rocks. Facies-association boundaries (Fig. 1.4D), possible 4th or 5th order surfaces, are inferred based on distinct facies-level variability detailed in the following results.

Facies Association 1 (FA1)

Description: Lithology

Facies Association 1 (Figs. 1.5, 1.6; Table 1.1) comprises the overwhelming majority of middle member Wood Canyon Formation stratigraphy, forms the entirety of units M1 (excluding the meter-thick, medium-pebble conglomerate near the base) and M3, and makes up approximately half of unit M2. Meter-scale, ledge-and-cliff outcrops expose roughly parallel beds (Fig. 1.5A) that can be traced for ~10-50 meters along strike between small-scale faults. Throughout FA1, 20-110 cm cross-stratified cosets (Figs. 1.5A, 1.6A, 1.6F, 1.7A; Muhlbauer et al., 2020, Appendix S3) occur as part of multi-story gray-to-brown sandstone bodies (Fig. 1.5A-D). Boundaries between cosets commonly appear planar and horizontal, with dips similar to the local tectonic tilt (Fig. 1.5A). Only through bed tracing and detailed measurements can convex sandstone-body geometries (Fig. 1.5B-C) and relationships within cosets (Fig. 1.5D) be identified in outcrop.

Several types of distinct deposits floor the bases of cosets, in units ranging from a few mm to several cm thick, providing a basis for architectural mapping. Extensive single-clast-thick mud-chip horizons (Fig. 1.5E), reported by Diehl (1979) and Fedo and Cooper (1990), are embedded into the soles of some beds and can be followed along strike for up to tens of meters. One mud-chip horizon that crosses Fig. 1.5C can be traced along strike for approximately 50 m before it is lost under talus cover. Horizontal stratification is present in thin mudstone and fine-grained sandstone layers along certain coset boundaries (Fig. 1.6E). Mudstones are dominantly of silt grade. Exposed mudstones vary in color, and may be deep red, dark gray, or pale green. Other coset bases are lined with poorly sorted granule layers that may incorporate subrounded mud intraclasts or angular, flat mud chips.

Sets of cross-stratification, including St, Sp, and Sl (Fig. 1.2A-C; Table 1.1), average 10 cm in preserved thickness (Fig. 1.7B) and dominate FA1 stratigraphy (Fig. 1.6A-B). Longitudinal cross sections of trough cross-stratification appear tabular in places. Where fracture surfaces expose cross-beds transverse to flow direction, it becomes clear that St represents a vast majority of the observed cross-bedding (e.g., Fedo and Cooper, 1990). Architectural tracing in Figure 1.5D illustrates the effect along a well-exposed coset. Less abundant flow-related structures include: compound cross-stratification in tabular planar sets (Fig. 1.6C) and uncommon sinusoidal foresets (Fig. 1.6D). Asymmetric ripple marks and ripple cross-lamination occur rarely (Fig. 1.2D).

In thin section (Fig. 1.6G-H), FA1 is characterized by medium- to coarse-grained, poorly sorted, subarkosic sandstone, consistent with the findings of Fedo and Cooper (1990).

Abundant well-rounded monocrystalline quartz, polycrystalline quartz, orthoclase, microcline, and rare chalcedony grains occur. Less abundant rhyolite rock fragments and phenocrysts of volcanic derived quartz are present in each sample (Fig. 1.6G-H). Rare well-rounded and angular mudstone grains found in the samples represent a further mud component in the middle member (Fig. 1.6G). Sandstones are framework supported, with negligible matrix. Extensive syntaxial quartz cement can in some cases exceed the size of the nucleating grain (Fig. 1.6H). Minor chlorite and iron oxide cements occur as grain coatings.

Description: Architecture

Multiple architectural panels (Figs. 1.8-11), illustrating surface tracing and orientation measurements (Muhlbauer et al., 2020, Appendix S4) in each unit of the middle member, reveal the internal geometry, and hint at the external geometry, of the elements that form the middle member. Figure 1.8A illustrates the architecture of two cosets. Coset 1 (Fig. 1.8Ai) preserves high-angle tabular and compound cross-strata with set boundaries dipping to the northwest (Fig. 1.8Aiii). The tabular cross-stratification grades into troughs to the left of the diagram. The lower bounding surface of Coset 1 (Fig. 1.8Ai) dips steeply to the southwest and is floored by a gravel layer with embedded angular mud chips. Grain size within the coset is coarsest in the center, where very fine pebbly, very coarse-grained sandstone is found in cross-beds (Fig. 1.8Aii). Above, the 109 cm thick Coset 2 (Fig. 1.8Ai) preserves intricately stacked trough cross-bedding, typical of FA1. Foreset-dip azimuths trend to the northwest and northeast, whereas cross-set scours display no consistent pattern of dip directions (Fig. 1.8Aiii). A near-horizontal planar surface of laminated fine-grained sandstone forms the basal component of the coset. Orientation measurements on the upper boundary of the coset are also near-horizontal. The stratigraphic column (Fig. 1.8Aii) shows that grain size within the coset coarsens both in the core and in the gravel on the upper bounding surface.

Architecture outlined in Figure 1.8B incorporates three distinct cosets. In the lowest (Fig. 1.8Bi, Coset 1), trough cross-stratified medium- to very coarse-grained sandstone is floored by an extensive horizon of embedded mud-chips. Foresets dip to the northwest and cross-set scour surfaces exhibit no overall trend in dip orientation (Fig. 1.8Bii). Above, a 55 cm thick coset (Fig. 1.8Bi, Coset 2) of steeply dipping tabular cross-strata preserves a flow direction to the northeast. It scours into Coset 1, eroding it completely to the left of the image. In each set of tabular cross-strata, foresets decrease in thickness as grain size reduces to medium-grained sandstone of red color (Fig. 1.8Bii). Highest in the panel, a thin coset (Fig. 1.8Bi, Coset 3) with an irregular base scours into Coset 2 below, forming a concave-up erosional surface. Mud-chip casts line the base, and thin sets of trough cross-stratification indicate northward paleocurrent (Fig. 1.8Bii-iii).

Figure 1.9, illustrates the stratigraphy of seven cosets with trough cross-bedding in unit M1, where several beds can be observed to terminate laterally. Foresets dip to the north and northwest throughout (Fig. 1.9iii). Each coset has a relatively consistent grain size of medium- to coarse-grained sand, with dispersed very fine to fine pebbles (Fig. 1.9ii). Boundaries between cosets are marked by cm-scale intervals of siltstone, continuous

mud-chip horizons, or areas of cover that likely represent fine-grained deposits (Fig. 1.9ii). Cross-set scour dips in Cosets 1-3 show no systematic orientation (Fig. 1.9iii). Coset 4 contains an abundance of cross-set boundaries that dip steeply to the east (Fig. 1.9iii). Above, Cosets 5-6 are truncated by Coset 7, which displays a concave-up geometry (Fig. 1.9i). Cross-set scours dip to the west in Coset 5 and to the south in Coset 6 (Fig. 1.9iii). Coset 7 has northeast dipping set boundary surfaces (Fig. 1.9iii), a set of sigmoidal cross-stratification (Fig. 1.9i), and an upper very fine pebble conglomerate cross-bed (Fig. 1.9ii).

Additional features of FA1 are displayed in Figure 1.10 and Figure 1.11. At the base of FA1 in Figure 1.10, a 74 cm thick concave-up coset (Fig. 1.10i, Coset 1) with angular mudstone intraclasts scours into fine-grained sandstone below. Above, Coset 2 has foresets uniformly dipping to the north and changes from shallowly dipping set boundaries to steeply northward-dipping ($\sim 10^\circ$) set boundaries along a south-to-north trend (Fig. 1.10iii). Cosets 3-4 are bounded by cm-scale intervals of siltstone or fine-grained sandstone where not obscured by talus. Grain size within each coset is consistent (Fig. 1.10ii), except where interspersed very fine pebbles are present. Figure 1.11 depicts FA1 Cosets 1-5 with a low variability in grain size, floored by mud-chip horizons or thin intervals of medium-grained sandstone with low-angle stratification (Fig. 1.11ii).

Interpretation

Sedimentologic and architectural characteristics of FA1 indicate that broad channel belts deposited most of the middle member Wood Canyon Formation. Cosets and sandy sheet-elements (SE) previously described for the middle member (Fedo and Cooper, 1990; Davies et al., 2011) are here interpreted as segments of barforms and channel fills that built much of the braidplain (Fig. 1.12). Absence of differentiating facies throughout much of the middle member makes separation of individual channel belts based on high-order bounding surfaces problematic. Amalgamated channel-belt deposits likely form the majority of the repetitive and laterally extensive stacked sheets of cross-stratified beds found in the middle member. Based on the experimental bedform work of Leclair and Bridge (2001) that correlates the preserved thickness of cross-beds to the height of the original dune, and measurements of cross-set and coset thickness (Fig. 1.7A-B) across multiple stratigraphic panels, barforms in the braidplain had an estimated relief of only 0.6-3.2 meters. Hydraulic profiles of this thickness are correlated to a channel width of ~ 20 -105 meters in Precambrian deposits (Ielpi et al., 2017), but the near-absence of observable channel edges suggests they may have been wider. Vertical barform growth was limited by extensive erosion and sediment bypass in an accommodation-limited setting. The wide, shallow geometry of the channel belts and the small size of the outcrop compared to fluvial macroforms, which may reach 1000 m in lateral extent (Miall, 1996), preclude determination of the planform dimensions of macro-scale features.

In place of defining individual channel-belt deposits, this study documents unit bar and channel element segments using a methodology similar to that of Almeida et al. (2016a). Vertical accretion (VA) dominates the internal architecture of barforms and channel fills within FA1 stratigraphy (e.g., Fig. 1.8A, Coset 2; Fig. 1.9, Coset 2; Fig. 1.10, Coset 3;

Fig. 1.11, Coset 5). Vertical accretion is not commonly described for barforms in the ancient record but is found in modern braided rivers (Miall, 1977; Bristow, 1993a; Best et al., 2003; Okazaki et al., 2015). A majority of examined barforms (9 of 17 barforms observed, 53%) appear to have accreted vertically (e.g., Fig. 1.5A), with cross-set scour dips only defined by the convex-up bases of individual dunes, without a preferential dip direction. Vertical accretion occurs at the cores of barforms that span tens of square meters (Fig. 1.12) based on lateral bed tracing. When bankfull flow escaped channels and overtopped low-relief barforms (Fig. 1.12), aggradation occurred as 3D dunes moved sand along their planar tops (e.g., Bristow, 1993a; Best et al., 2003; Bridge and Lunt, 2006; Ielpi and Rainbird, 2015; Went and McMahon, 2018).

Downstream-accreting (DA) elements are abundant (8 of 23 architectural elements observed, 35%) in FA1 (e.g., Fig. 1.8A, Coset 1) and typify low-sinuosity sandy braided rivers (Long, 2011). As barforms migrate and accrete in the flow direction, the deposits at their downstream margin are buried and preserved. Typically, large tabular avalanche faces form at bar lees (Fig. 1.12), such as those imaged in the Rio Paraná (Sambrook-Smith et al., 2009). The extensive DA elements in Coset 2 of Figure 1.8B, Cosets 2 and 6 of Figure 1.10, and Coset 3 of Figure 1.11 illustrate this style of deposition. Coset 2 of Figure 1.8B preserves striking evidence of reactivation surfaces as dunes migrated down an angle-of-repose avalanche face in the lee of a DA unit bar (e.g., Reesink et al., 2014). Nearly all channel fills (CH) observed have internal downstream-accreting (DA) surfaces (e.g., Fig. 1.8A, Coset 1). Within channels, large dunes accreted in the direction of flow, traversing the braidplain at the edges of the partially subaerial barforms and macroforms (Fig. 1.12), a process inferred in other fluvial rocks (e.g., Bridge and Lunt, 2006; Ielpi and Rainbird, 2016b; Ghinassi and Ielpi, 2018; Went and McMahon, 2018) and observed in modern systems (Skelly et al., 2003). Channel margins are rarely preserved and have low angles of approximately 5-10° that can be difficult to identify in outcrop (Figs. 1.3, 1.5C; Fig. 1.9i, Coset 7).

Pervasive NNW paleocurrent observed in the southern Marble Mountains outcrop implies that most cross sections of the strata are approximately longitudinal to overall channel-belt paleoflow direction. Consequently, lateral accretion (LA) is difficult to discern without orientation measurements on bounding surfaces. Restored dips and dip directions of internal barform surfaces reveal (e.g., Almeida et al., 2016a) LA elements from longitudinal exposures of the braidplain (Fig. 1.9iii, Cosets 4-5; Fig. 1.10iii, Coset 4). Presumably occurring at the margins of large barforms (Fig. 1.12; Bristow, 1993b; Ghinassi and Ielpi, 2018), these deposits are not abundant, suggesting either limited lateral migration or poor preservation. Upstream accretion (UA) is possibly observed through limited measurements in a single coset (Fig. 1.9iii, Coset 6). High sediment supply and rapid aggradation is required to preserve UA elements (Bristow, 1993a; Long, 2006), providing evidence of moderate sediment supply during deposition.

True substrates (Tipper, 2015; Davies and Shillito, 2018) are rarely preserved in the middle member. Rippled surfaces, in-situ desiccation cracks, and paleosols are not observed. In this highly erosive and low-accommodation setting, nearly all exposed

surfaces would have been rapidly reworked. Absence of preserved stasis surfaces also indicates that very few preserved bedforms and barforms represent the full thickness of the original features. Although in-situ mud-cracked surfaces are not present, abundant evidence of desiccation occurs in the main channel belt as angular, commonly single-clast-thick mud-chips that form horizons representative of very minimal transport before burial (Fedo and Cooper, 1990). Desiccation chips and further transported subrounded mudstone intraclasts suggest that rapid avulsion or cutoff of channels in the active channel belt led to deposition and drying of suspended clays (Fig. 1.12). Thin siltstone and fine-grained sandstone lags at the bases of bars likely represent a separate process in which suspension fallout occurred in sheltered eddies downstream of large barforms (Fig. 1.12; e.g., Sambrook-Smith et al., 2009).

Facies Association 2 (FA2)

Description: Lithology

Interbedded between strata of FA1 in unit M2 are sandstone horizons with recessive weathering (Fig. 1.13A). Beds are commonly covered by talus blocks of FA1. Each interval is red-orange in color and thinly bedded (Fig. 1.13A-D); maximum cross-set thickness reaches only 16 cm (Fig. 1.7C; Table 1.1). The distinct appearance of the beds necessitates classification as FA2, despite representing only a minor component of the middle member. Scarcity and poor exposure of FA2 complicate lateral tracing and observation of relationships with other facies associations. Where visible, some FA2 contacts with FA1 appear sharp and planar (Fig. 1.13A), whereas others appear more gradational (Fig. 1.11i).

Where meter scale in thickness, FA2 intervals are organized into fining-upwards packages characterized by the transition from thick sets of St to thinly bedded St and Sr (Fig. 1.2; Fig. 1.11, Cosets 6-8; Table 1.1). Contacts between sets of cross-stratification appear sub-horizontal, rather than high-relief trough scour surfaces (Figs. 1.11i, 1.13B-C). Rare beds of plane-parallel stratification (Sh) occur in fine- to medium-grained sandstone (Fig. 1.11, Coset 6; Fig. 1.13B). Interbeds of cm-scale green or red mudstone (Fl) occur between sandstones (Fig. 1.2E), or as small weathered fragments beneath float blocks.

Strata of FA2 have an overall finer grain size than much of the middle member (Fig. 1.13E-F), with total absence of very coarse-grained sand and fine pebbles. Intervals of FA2 are poorly sorted, ranging from coarse-grained sandstone with granules to fine-grained sandstone. Weathered outcrop expressions are crumbly and mottled in appearance (Fig. 1.13D). Individual samples of sandstone are very poorly sorted, with silt to coarse-grained sand framework grains of quartz, orthoclase, microcline, and detrital muscovite (Fig. 1.13E-F). Discontinuous intervals of iron-rich mudstone with interspersed framework grains are present (Fig. 1.13E). Abundant hematite and chlorite contribute to the mottled texture and red-orange color of the rock (Fig. 1.13). Two distinct lithologies, fine- to medium-grained sandstone beds and coarser-grained cosets, comprise FA2. Finer beds contain pervasive hematite cement and clay matrix (Fig.

1.13E-F). Patches of hematite are mm-scale and in some cases stain chlorite grains (Fig. 1.13F). Coarser decimeter-scale cross-beds are medium- to coarse-grained subarkoses with large syntaxial quartz cements (Fig. 1.13E) and secondary chlorite.

Description: Architecture

Cosets 6-8 of the stratigraphic panel in Figure 1.11 form one of the most complete exposures of an FA2 interval found in the study location. The facies association is in sharp and planar contact with subjacent FA1. The upper contact with the base of an FA1 interval is potentially gradational but marked by increased grain size, thickness of cross-strata, and a change from red to tan color (Fig. 1.11ii). Where not covered by talus, beds preserve numerous thin sets of red-orange sandy bedforms (SB) with planar bounding surfaces that have an average thickness of 8 cm (Fig. 1.7C). Paleocurrent measurements (Fig. 1.11iii, Cosets 6-8) have a unimodal northward trend. Each coset is defined by ~1 m scale fining-upwards package of sediment (Fig. 1.11ii). Thin cross-bedded coarse-grained sandstones mark the base of observed fining upwards intervals.

Interpretation

Observations collected from FA2 suggest deposition in a floodplain subenvironment (FP; Table 1.1), similar to overbank splay and floodbasin rock-record examples in Ielpi et al. (2018). Absence of cross-sets over 16 cm and occurrence of fine- to medium-grained sandstone beds indicate minimal water-depths and low energy conditions (Labeau and Ielpi, 2017), sheltered from the active channel-belt on fluvial terraces (Fig. 1.12). Calm periods with shallow water and ponding occurred between flood-stage deposition from high-energy traction flows similar to those found in the channel belt (Ielpi and Rainbird, 2016a). Overbank flood inputs to the subenvironment built fining-upwards packages of sediment (e.g., Ielpi et al., 2018) that include plane-parallel and decimeter-scale trough cross-stratification grading to thin, finely bedded cross-strata (Fig. 1.11, Cosets 6-8). Although extensive desiccation chip horizons are not present, the occurrence of mud-chips implies that some suspension settling and desiccation occurred in the floodplain (Fig. 1.12). Thin laminated mudstone beds provide evidence of ponded water in abandoned channels formed before the channel belt migrated from the area (Fig. 1.12). No evidence of distinct channel banks or channel fills was found in FA2, an indication of the shallow depth of the channels and the scarcity of well-exposed examples.

Iron-rich fine-grained sandstone and mudstone is a common feature of floodplain deposits in pre-vegetation braidplain systems after the Great Oxidation Event (Fralick and Zaniwski, 2012; Ielpi and Rainbird, 2016a; Ielpi et al., 2018). Given the patchwork nature (Fig. 1.13F), the iron oxide present in FA2 is interpreted as the product of diagenesis; however, the timing of early versus late diagenetic redox reactions has not been studied in detail. Based on the consistent association between iron oxide and FA2 beds, some hematite may have formed early as part of interactions with a high water table. The chlorite is interpreted as a secondary phase, formed during burial diagenesis in the presence of iron and clays (Bartier et al., 1998; Chen et al., 2011). No clay cutans (e.g., Fralick and Zaniwski, 2012) or distinct paleosol horizons (e.g., Marconato et al., 2014) were identified in association with FA2, either because the high sediment input to

the system prevented pedogenesis or because high-energy flood events or wind easily stripped away fine-grained weathering products. Sets of trough cross-stratification in medium- to coarse-grained sandstone and less abundant hematite (Fig. 1.13E) provide evidence for sediment input during overbank flooding.

Facies Association 3 (FA3)

Description: Lithology

Interbedded horizons of FA3 are comparatively rare in the outcrop, found only in unit M2. Across the study area, the characteristics of this facies association are consistent and easily identifiable. Exposures of FA3 are rust-colored flaggy sandstones organized into broad, meter-scale, trough cross-beds (St) (Fig. 1.14A-C; Table 1.1). Many foresets are steeply dipping and evenly spaced (Fig. 1.14B-C), truncated at high angles (Fig. 1.14B-C), and characterized by mm-scale alternations in grain size and changes of accessory mineral content (Fig. 1.14D). Mudstone layers and mud-chip horizons are absent. Where exposed, upper and lower bedding contacts with FA1 appear sharp and erosional (Figs. 1.5B, 10i). Because of its distinctive appearance, the thickest bed of FA3 can be traced along-strike across the full extent of the outcrop, and shows no change in texture, composition, or overall sedimentary architecture.

Thin sections of FA3 show angular to subrounded grains of moderately to well sorted fine- to medium-grained subarkose (Fig. 1.14E-F). Well rounded mudstone intraclasts and granules of quartz occur rarely. Detrital iron oxides and variations in grain size form thinly laminated foresets that do not display internal grain size trends. A matrix of hematite-rich clay is present in some samples (Fig. 1.14E). Hematite-stained chlorite pseudomatrix and primary hematite are abundant, with hematite coatings common on grain boundaries (Fig. 1.14E). Patches of secondary hematite are present but less extensive than those found in FA2 (Fig. 1.14E-F).

Description: Architecture

Figure 1.10i illustrates a 3-meter-thick representative exposure of FA3. In this location, a sharp and planar basal contact separates the festooned medium-grained sandstone (Fig. 1.10ii, FA3) troughs of FA3 from the FA1 that occurs below, whereas above FA3 is scoured by FA1 (Fig. 1.10, Coset 1). Broad trough cross-beds characteristic of FA3 are dominant, with little evidence for horizontal high-order bounding surfaces that define cosets. The average thickness of troughs in the panel is 23 cm (Fig. 1.7D; Table 1.1). Foreset dips (Fig. 1.10iii, FA3) are high angle ($\sim 35^\circ$) to nearly bedding parallel, dependent on the part of the cross-set exposed in cross-section. Elsewhere on the outcrop, beds of FA3 display the same set of distinct features (Fig. 1.14A-D).

Interpretation

Although distinctive, the restricted overall thickness of FA3 places limitations on the extent to which it may be interpreted. Several observations support the concept that FA3 represents the product of localized overbank aeolian deposition (AO; Table 1.1), along the flanks of the active fluvial system (Fig. 1.12). Foresets are finely laminated and

evenly spaced, with pinstripe lamination (Fig. 1.14D; Fryberger and Schenk, 1988). Mud-chip horizons are not found within the cross-beds of FA3, indicating that surface waters rarely, if ever, flowed in this subenvironment. Absence of clear barform architecture, channel margins, and DA elements indicate that such features were not able to form. Instead, broad meter-scale troughs with upturned lees scour deeply into the cross-strata below (Fig. 1.10i, FA3; Fig. 1.14B). Moderately well-sorted medium sand grains with iron oxide coatings resemble those associated with pre-vegetation aeolian sediments (Lebeau and Ielpi, 2017). Although fine sand is generally associated with windblown deposits (Langford, 1989; Pye and Tsoar, 2009), aeolian sands sourced from proximal fluvial sediment are commonly not well sorted and are coarser, reaching medium- to coarse-grained sand in certain examples (Ielpi and Ghinassi, 2016; Lebeau and Ielpi, 2017). Texture, sorting, and composition are consistent across the outcrop and at all stratigraphic levels, a distinctive characteristic when compared to the variability expected from fluvial facies.

Uncertainties in the aeolian classification arise from several features of FA3 that do not fully align with those expected. Aeolian microforms, including adhesion ripples and wind ripples, are not identifiable on dune foresets. No evidence of interdune muds with desiccation structures or sands with adhesion warts is present. Paleocurrents in FA3 are dispersed, but overall unimodal northward (Fig. 1.10ii). Framework grains do not appear well rounded (Fig. 1.14E-F) and rare granules occur within the medium-grained sandstone. Nevertheless, coarsest grain sizes in dunes occur in toesets (Pye, 1982), where likelihood of preservation is highest, and examples of aeolian sediments with unexpectedly low textural maturity are recognized (e.g., Lea, 1990; Clemmensen and Dam, 1993). Despite uncertainties, the most plausible explanation of FA3 characteristics is deposition within incipient dune fields rather than a fluvial setting.

The presence of meter-thick sheets of aeolian sediment is consistent with dunes forming in a semiarid-to-humid environment with a high water table, where aeolian preservation occurs preferentially through interaction with high water tables and under increasing accommodation space (e.g., Eriksson et al., 1998; Davies and Gibling, 2010; Long, 2011). Water between sand grains limits the growth of dunes by increasing cohesion but increases their potential for accumulation and chance of preservation (Mountney and Russell, 2009). Iron cementation may occur when damp dunes are exposed to the surface for extended periods of time (e.g., Chakraborty and Chaudhuri, 1993). Increasing accommodation, possibly as part of minor base-level rise, reduces the stream power of the fluvial system even in low subsidence settings, sheltering dunes from later reworking. Based on relatively small-scale cross-beds and the minimal stratigraphic thickness of aeolian features compared to other pre-vegetation systems (e.g., Hadlari et al., 2006; Ielpi and Rainbird, 2016a; Lebeau and Ielpi, 2017), it is not likely that the area was arid. Fields of small dunes developed in sheltered areas of the braidplain under increasing, but still low, accommodation. Beyond the reach of overbank splays or overland flows (Fig. 1.12), they were rapidly stabilized from below by groundwater introduced by capillary action (e.g., Kocurek and Havholm, 1993; Mountney and Russell, 2009), limiting transport and preventing more distinct aeolian textures from forming.

Stacking and Geometry of Facies Associations: Defining Units M1, M2, and M3

Mapping of each facies association across the outcrop, displayed in Figure 1.15 alongside locations of the architecture panels discussed above, demonstrates the spatial extent of units M1, M2, and M3. Bed tracing reveals the lateral relationships of facies associations, and corresponding depositional subenvironments, in the middle member system.

Beginning above the basal units X1-2, units M1, M2, and M3 are 27 m, 27 m, and 18 m thick, respectively. Unit M2 has a consistently sharp base that separates braid bars of FA1 from aeolian dunes of FA3. The boundary between unit M2 and unit M3, defined by the last occurrence of FA2 or FA3, varies slightly in stratigraphic elevation along strike. A discontinuous bed of massive granule conglomerate with *Skolithos* burrows, up to 2 m in thickness, marks the contact with the upper member Wood Canyon Formation (Fig. 1.15). Possible drivers for the facies association stacking patterns that define units M1-3, whether allogenic or autogenic, are not the focus of the present study.

Occurrence of all three facies associations within unit M2 allows for further investigation of the external geometry of braidplain components. Although lateral terminations of facies associations could not be located, their exact distribution in unit M2 across the outcrop is not identical along strike, so terminations must be obscured by faulting and scree slope cover. Considering the low-displacement of the high-angle faults (Fig. 1.15), much of the along-strike distribution of facies associations is probably controlled by autogenic fluvial processes. Thick, continuous bands of FA1 dominate the middle member (Fig. 1.15), representative of extensive migrating channel belts. Laterally continuous beds of FA2 are present interbedded between bands of FA1. Intervals of FA3 are rare above the initial bed but can be located higher in unit M2. In several areas, FA2 and FA3 are observed in close contact and appear to interfinger, suggesting that aeolian and overbank fluvial environments occurred in close association (Fig. 1.15). The sharp contact at the base of unit M2 suggests an abrupt change in depositional parameters. Above, intervals of FA2 are thinner on average than those of FA1. With increasing stratigraphic elevation in unit M2, beds of FA1 and FA2 both reduce in thickness, until the last occurrence of FA2. Unit M2 represents a gradational change from preservation of facies association variability to the return of stacked sandy sheet-elements (SE) in unit M3.

Discussion: Depositional System Synthesis

Architectural element analysis and detailed mapping of the middle member Wood Canyon Formation, southern Marble Mountains, reveals three distinct facies associations that represent coeval subenvironments of the braidplain (Figs. 1.12, 1.16; Table 1.1): broad channel belts (FA1) with low-relief barforms, thinly-bedded (Fig. 1.7C) and finer-grained (Fig. 1.13E-F) floodplain terraces (FA2) that activated during flooding, and small aeolian dune clusters (FA3) far removed from stream flow. Splay or overland flow deposits of FA2 match FA1 in sedimentary structures (Fig. 1.13C), texture, and composition (Fig. 1.13E), indicating direct input between adjacent subenvironments. Channel belts may have swept across the braidplain and reworked both floodplain and aeolian deposits, evidenced by the scour of FA1 into FA3 illustrated in Figure 1.10*i*.

Along-strike mapping of facies association geometry (Fig. 1.15) provides the basis for the scale of braidplain barforms and channels in Figure 1.12. A hypothetical model at the kilometer scale, presented as Figure 1.16A, shows the overall small scale of the outcrop in comparison and the possible configuration of the braidplain relative to the paleo-shoreline. An average NNW (344°) dip direction of 382 foresets measured (Fig. 1.17) in five stratigraphic panels represents a more northerly paleocurrent when compared to results collected previously for the middle member (Fig. 1.17; Diehl, 1979; Fedo and Cooper, 1990), to overall westward regional paleoflow measurements recorded from time-averaged Cambrian fluvial rocks of the western Laurentian margin (e.g., Stewart, 1970, 2001; Fedo and Prave, 1991), and to provenance sources that lie to the east of the present location (Howard et al., 2015; Muhlbauer et al., 2017). Barring any unknown tectonic rotations, a complex shoreline geometry or channel belt orientation oblique to the coastline could explain local northward paleocurrent trends for the middle member in the Marble Mountains.

As the lateral extent of the outcrop does not expose full macroform cross-sections, developing such a diagram requires a suitable modern near-analogue on which to base the scale of braidplain features. Observations of the distal Skeiðarársandur outwash braidplain in southern Iceland help to calibrate the potential scale of subenvironments found in the middle member. Among the largest non-arid and minimally vegetated braidplains on Earth, Skeiðarársandur is generally comparable to a continent scale system. Within its multiple channel belts are channels typically 10s of meters across, similar to the 20- to 105-meter-wide channels approximated above by the equations of Ielpi et al. (2017) for the middle member Wood Canyon Formation system. The location shown in Fig. 1.16B suitably illustrates the scale and setting of proposed subenvironments. Sandy barforms (Boothroyd and Nummedal, 1978), tens of meters in longitudinal and lateral dimension, are elevated between multiple orders of shallow but high-energy unconfined channels. Outside of the main channel belt, channels are smaller, shallow ponds form in abandoned conduits, and more sediment is exposed to weathering processes at the surface. Beyond channel belt influence, braidplain sediments sit subaerially on low relief surfaces in areas analogous to those where Mountney and Russell (2009) reported aeolian features.

Middle member fluvial architecture demonstrates several characteristics suggestive of perennial flow in a system where below-bankfull discharge is capable of moving the bedload. Such a finding diverges from the work of Diehl (1979) and Fedo and Cooper (1990), studies that interpreted the middle member as having formed in a more ephemeral setting. Fluvial deposits with upper plane-bedding structures (Sh) and abundant interbedded aeolian dunes are typically ephemeral, experiencing monsoonal precipitation, with flashy hydrograph dynamics and unconsolidated sands causing rapid sediment movement during flood cycles (Long, 2011; Plink-Björklund, 2015; McMahon and Davies, 2018b). Data presented by Colombera and Mountney (2019) indicate that Sh most commonly occurs in channel deposits of dryland, not humid, vegetated fluvial systems. Fielding et al. (2018) proposed that rivers with the lowest coefficient of variation in discharge tend to preserve cross-stratification and barform bedding structures

similar to deposits of the middle member. In the channel belt, which represents the highest-energy setting in the braidplain, cross-stratification formed under subcritical flow, with foresets in excess of 25° dip (Fig. 1.4A). No upper flow-regime structures are found in FA1 other than rare sigmoidal cross-beds and S1 that represents transitional flow regime (Figs. 1.2B, 1.6D; Long, 2011). Even in the most active setting on the braidplain, most 3D dunes had low relief and barforms show evidence of incremental construction indicative of vertical and downstream accretion (Figs. 1.8-11). Poorly sorted sand deposits indicate changing energy conditions during the movement of sediments across bars (Figs. 1.8-11). Multiple barforms in FA1 are documented to progress from finer sandstone, to coarser, then return to finer grain sizes (Fig. 1.8A, Coset 1; Fig. 1.9, Coset 2; Fig. 1.10, Coset 3). Gravel bedforms (GB) occur on the upper surface of some bars (Fig. 1.8A, Coset 2; Fig. 1.10, Coset 4). Both cases represent complex changes in energy as barforms and channel fills are deposited through time, not the fining-upwards deposits expected from individual flooding events.

Additional characteristics of the middle member suggest deposition under perennial conditions that powered consistent stream flows in channel belts. Aeolian features are limited in scale and extent within the braidplain. No paleosol horizons, typical of long-lasting stasis, occur in the middle member. Deposits of mudstone, indicative of suspension settling in stagnant water, are rare and at most several centimeters thick (Figs. 1.2E, 1.6E). Abundant extensive desiccation clast layers (Fig. 1.5E), representative of minimally reworked flats of subaerial mud, indicate brief but common periods of drying before rapid burial. Perennial streamflow matches the inferred equatorial climate of the Wood Canyon Formation system (Li et al., 2008; Merdith et al., 2017) where precipitation, with no evidence for nearby orographic effects, should be high. Hafnium analysis of abundant 1.1 Ga detrital zircons in the middle member indicate derivation from the present-day Llano Uplift of Texas (Howard et al., 2015), a downstream transport distance of ~1500 km. At this scale, the south-north watershed would have intersected the Inter-tropical Convergence Zone (Syvitski et al., 2014), lending it intense rainfall and stable sediment yields. Other early Cambrian sandstones from Laurentia preserve evidence of intense tropical storm activity in coastal settings (Herbers et al., 2016). Two Precambrian braidplains investigated by Ielpi et al. (2017), with watersheds over 1000 km in length, display evidence of perennial streamflow attributed to the extensive size of the catchments. The perennial nature of the middle member braidplain supports provenance work that suggests a continent-scale drainage (Muhlbauer et al., 2017) and negates hypotheses that propose more local sources (Amato and Mack, 2012) or deposition within a Cambrian rift basin (Yonkee et al., 2014).

Sedimentary aspects of the middle member conflict with those proposed for the furthest downstream reaches of continent-scale pre-vegetation rivers. Ielpi et al. (2017) described narrow channels for distal alluvial plains in intracratonic basins. Almeida et al. (2016b) and Santos et al. (2017) suggested deeper and more sinuous channels (e.g., Santos and Owen, 2016) are most common in distal alluvial environments before vascular plant emergence, as elevated accumulation of cohesive fine-grained sediments occurred near coastal areas with slope values lower than 0.003. Despite deposition near the marine

realm (Fedo and Cooper, 1990), the middle member displays no deep, well-defined channeling (Fig. 1.7A). Mudstone is almost entirely absent from the stratigraphy, suggesting that the fine-sediment fraction bypassed the distal braidplain despite the low-gradient river profile. The deep channel-forms observed by Ielpi et al. (2017) in intratonic, rift, and foreland basins may not have developed on the slowly-subsiding passive margin of Laurentia. Limited subsidence in this on-craton setting (Fedo and Cooper, 2001; Hogan et al., 2011) prevented the deposition of thick successions of sediment and limited the depth of channelization in the middle member. Original barform thickness and topography were reduced and flattened by erosion and sediment bypass in the low-slope accommodation-limited setting.

Pathways and timing of metazoan terrestrial colonization remain a critical aspect of the coevolution of Earth and the biosphere. Conquering the transition from saltwater to freshwater was a necessary hurdle for marine organisms. Vertical trace fossils, discovered in off-craton exposures of basal middle member, were proposed by Kennedy and Droser (2011) to represent the Cambrian expansion of animals into the freshwater fluvial realm. After extensive and detailed examination of bedding tops and cross-sections in the southern Marble Mountains, this study identified no evidence of fossil traces in the distal fluvial environment. Such a conclusion reinforces the hypothesis that the reported trace fossils represent marine organisms that burrowed older fluvial sediments during periods of marine flooding (Davies and Gibling, 2012; McIlroy, 2012) and emphasizes the importance of gathering detailed architectural analysis and paleoenvironmental constraints when assessing the habitability of distal terrestrial environments. Near the coastline, braid deltas (McPherson et al., 1987) form tidally influenced areas of stagnant water that interfinger with the fluvial system and may harbor life (e.g., Hereford, 1977). Strata hypothesized to represent a tidally influenced braid delta with an ichnofossil assemblage, connected to the southern Marble Mountains middle member fluvial system, occurs ~6 km north of the study area (Fig. 1.16B; Fedo and Cooper, 1990).

Conclusions

Architectural element analysis and detailed mapping of the middle member Wood Canyon Formation, in the southern Marble Mountains, reveals the following:

1. Structure-from-Motion techniques generate 3D models that, once combined with field-based observation and measurement, allow interpretation of architectural elements from bedform to outcrop scale.
2. The ~80-meter-thick middle member divides into five distinct units (X1,2 and M1,2,3) Units M1-3, defined by the stacking patterns of facies associations FA1-3, make up the bulk of the braidplain strata.
3. In FA1, stacked cosets interpreted as low-relief fluvial bars and channel fills preserve vertical-, downstream-, and lateral-accretion elements as part of a channel belt with unimodal NNW transport.
4. Overbank subenvironments linked to FA2-3 are found only in the 27-meter-thick unit M2. Floodplains, represented by FA2, include crumbly red-orange sandstone

- with finer sand and thinner sets of cross-bedding than FA1. Interbedded thicker cross-beds indicate splay or overland flow input from the channel belt. Suspected aeolian beds of FA3 preserve broad festooned trough cross-stratification in medium-grained sand. Limited stratigraphic thickness and iron oxide cement suggest interaction with a high water table.
5. Documentation of multiple depositional subenvironments, paired with bedform and facies pattern observations, implies a perennial fluvial system that gradually built large sand bars on a continental-scale braidplain, where overbank sediments were subject to weathering and aeolian transport. Despite proposed marine influence for nearby sections of middle member, no ichnofossils are reported.

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Appendix A-1

Table 1.1: Summary of defining characteristics and interpretation of facies associations in the middle member of the Wood Canyon Formation.

Facies Association	Description	Lithotypes	Architectural elements	Cross-set thickness (cm)	Interpretation
FA1	Gray-brown medium- to coarse-grained sandstone, angular mud-clasts	St, Sp, Sl, Sh, Sr, Fl, Fm	CH, VA, DA, LA, UA, SB, GB	2-78, average 10	Channel belt; low-relief fluvial bars and channel fills; perennial streamflow
FA2	Red-orange, poorly-sorted sandstone, abundant chlorite	St, Sl, Sh, Fl	FP, VA, SB	2-16, average 8	Floodplain environment with splays or overland flows from channel belt
FA3	Red, festooned cross-beds, moderately- to well-sorted medium sandstone	St, Sl	AO	7-62, average 23	Suspected incipient aeolian dunes; preservation via high water table

Lithotype abbreviations defined in Figure 1.2; Architectural elements defined in Figure 1.3.

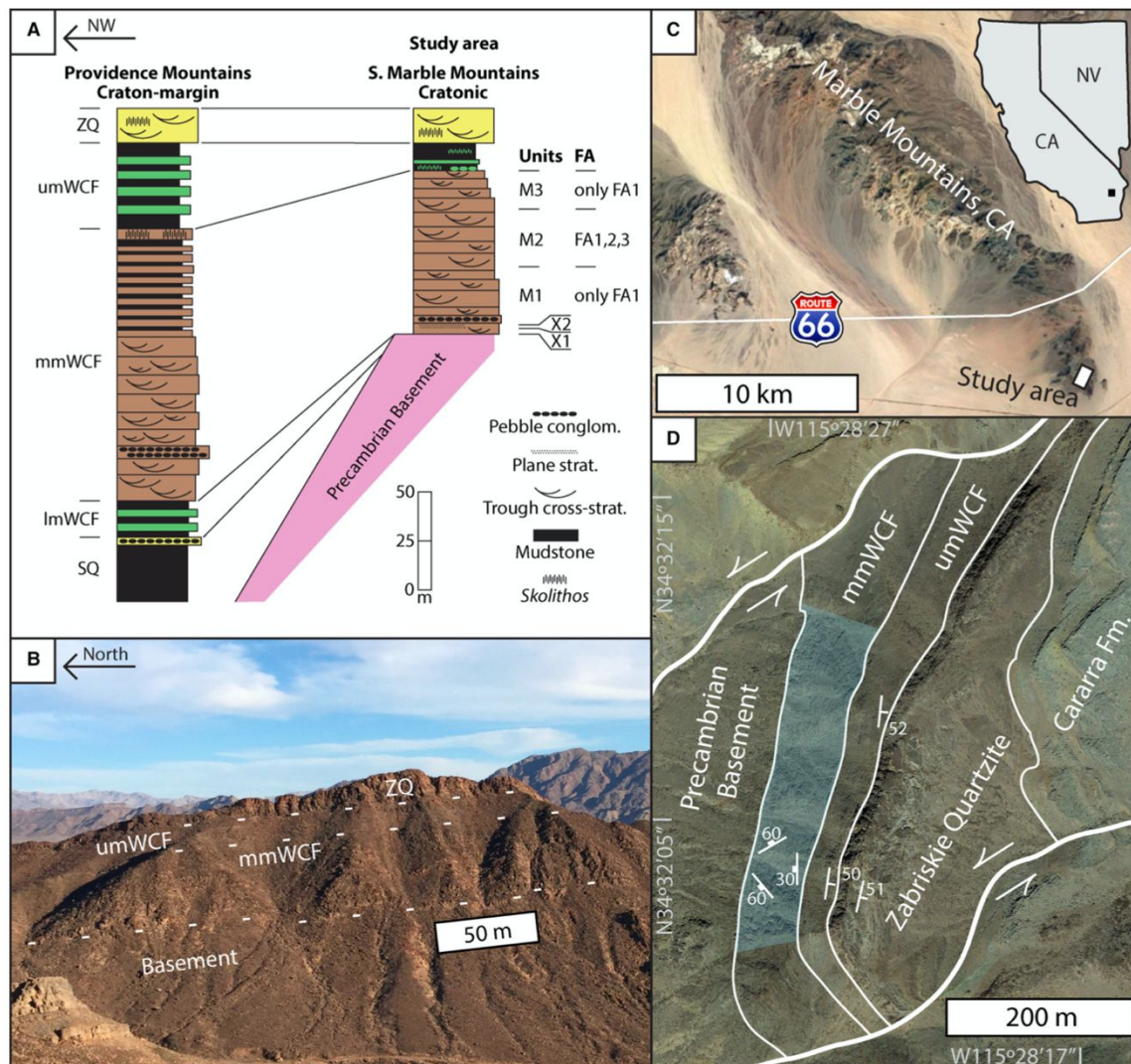


Figure 1.1: Images and stratigraphic context for the study locality. A) Stratigraphic columns of the southern Marble Mountains (Fedo and Cooper, 1990) and Providence Mountains (Fedo and Cooper, 2001) displaying the stratigraphic relationships between cratonic sections and those more basinward. The middle member Wood Canyon Formation lies nonconformably on bedrock in the study area. SQ – Stirling Quartzite; ImWCF, mmWCF, umWCF – lower, middle, and upper member Wood Canyon Formation; ZQ – Zabriskie Quartzite B) View of the well-exposed outcrop in the southern Marble Mountains, examined in this study. C) Location of the field area in the Marble Mountains, California (34.534421, -115.474391). D) Generalized geological map of the study area and surroundings, with strike and dip measurements on bedding planes and joint sets.

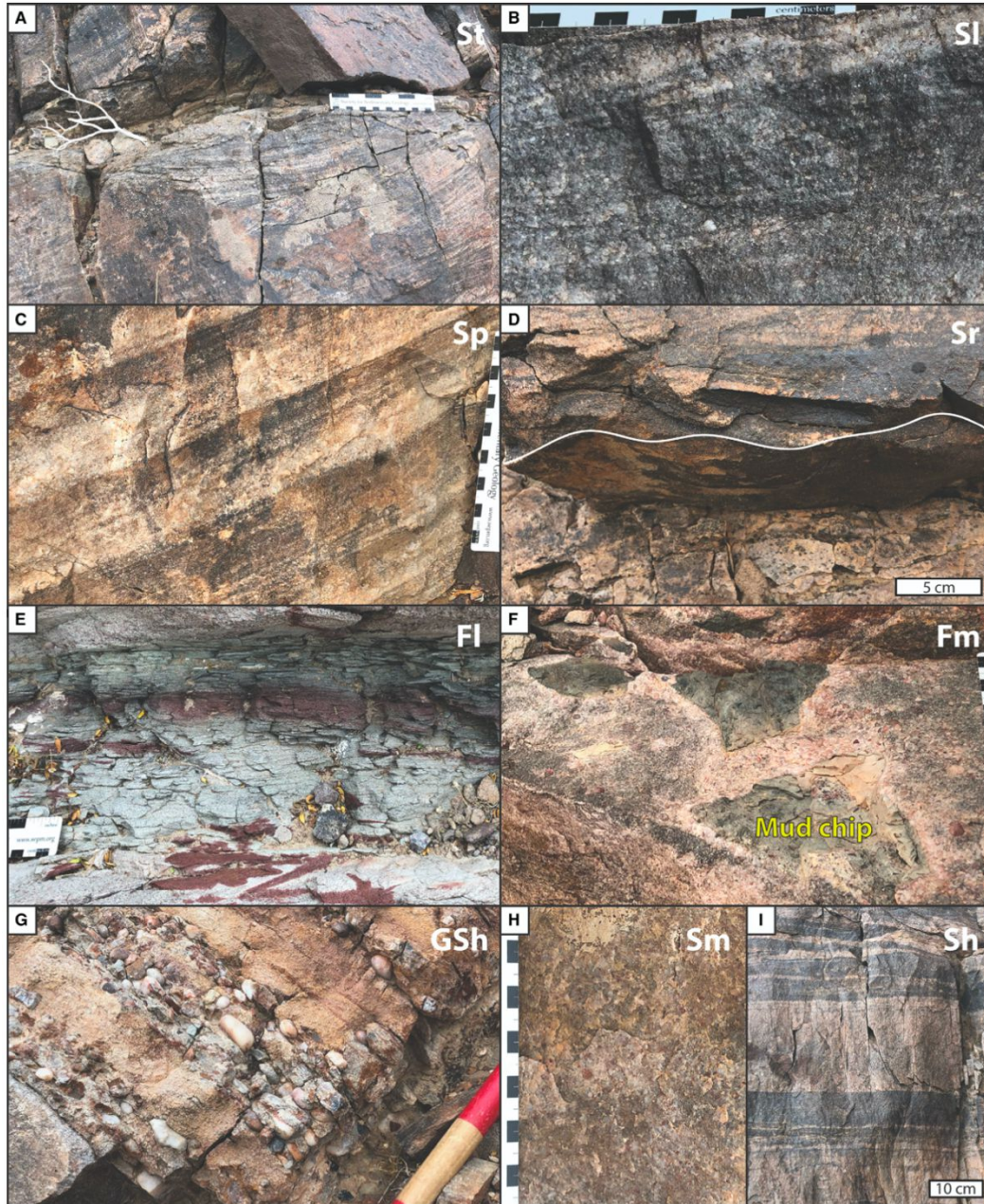


Figure 1.2: Lithofacies observed in the middle member, codes from Miall (1985) and Tucker (2003). Scale in cm unless otherwise noted. A) St – transverse exposure of trough cross-stratified sandstone, paleoflow toward viewer. B) Sl – close up of low-angle foresets in cross-stratification. C) Sp – tabular planar set of cross-stratification with distinctive banded foresets. D) Sr – ripple cross-lamination on bedding sole. E) Fl – laminated green and red siltstone horizon. F) Fm – massive mudstone as desiccation chips on a bedding top. G) GSh – basal conglomerate unit of the middle member displaying massive framework-supported pebble conglomerate with interbedded cross-stratified sandstone. White band on Jacob’s staff is 10 cm. H) Sm – massive sandstone near the base of the formation. I) Sh – horizontally stratified banded sandstone units.

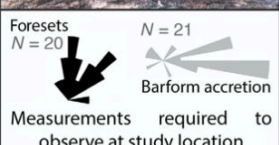
SE	Sandy sheet-element	Composite element, thickness:depth is > 20:1, amalgamated CH or barforms, sandy bedforms, may represent channel belts in the mmWCF		
CH	Channel fill	Multiple orders, concave-up or inclined lower bounding surface, filled with SB. May contain DA, UA, LA, and VA. Channels have low-angle margins		
Barforms and channels	DA	Downstream accretion unit bar	Foreset dip directions match internal bar surface dip directions ($\pm 30^\circ$), bars have convex-up geometry	
	UA	Upstream accretion unit bar	Foreset dip directions are opposite ($\pm 30^\circ$) to internal bar surface dip directions, bars have convex-up geometry	
	LA	Lateral accretion unit bar	Foreset dip directions are perpendicular ($\pm 30^\circ$) to internal bar surface dip directions, bars have convex-up geometry	 Foresets $N = 20$ $N = 21$ Barform accretion Measurements required to observe at study location
	VA	Vertical accretion unit bar	Internal bar surfaces do not have a distinguishable preferred dip direction, bars have convex-up geometry	
Overbank	FP	Floodplain	SB have finer average grain size than most mmWCF, some mudstone, poor sorting, includes VA, fining-upward cycles	
	AO	Aeolian	Metre-scale trough cross-beds, no barform/CH organization, moderately-sorted medium sandstone, pinstripe lamination	
Bedforms	SB	Sandy bedforms	Cross-stratification, dominantly trough, minimal tabular, sparse plane-parallel and sigmoidal, some laminated fine sands	
	GB	Gravel bedforms	Massive gravel, clast-supported, interbedded SB, localized to basal mmWCF	

Figure 1.3: Architectural elements found in the middle member Wood Canyon Formation at the study area, with representative images. Elements from Miall (1985, 1996) and Long (2006, 2011), except VA, FP, and AO. Scale in cm, white band on Jacob's staff is 10 cm.

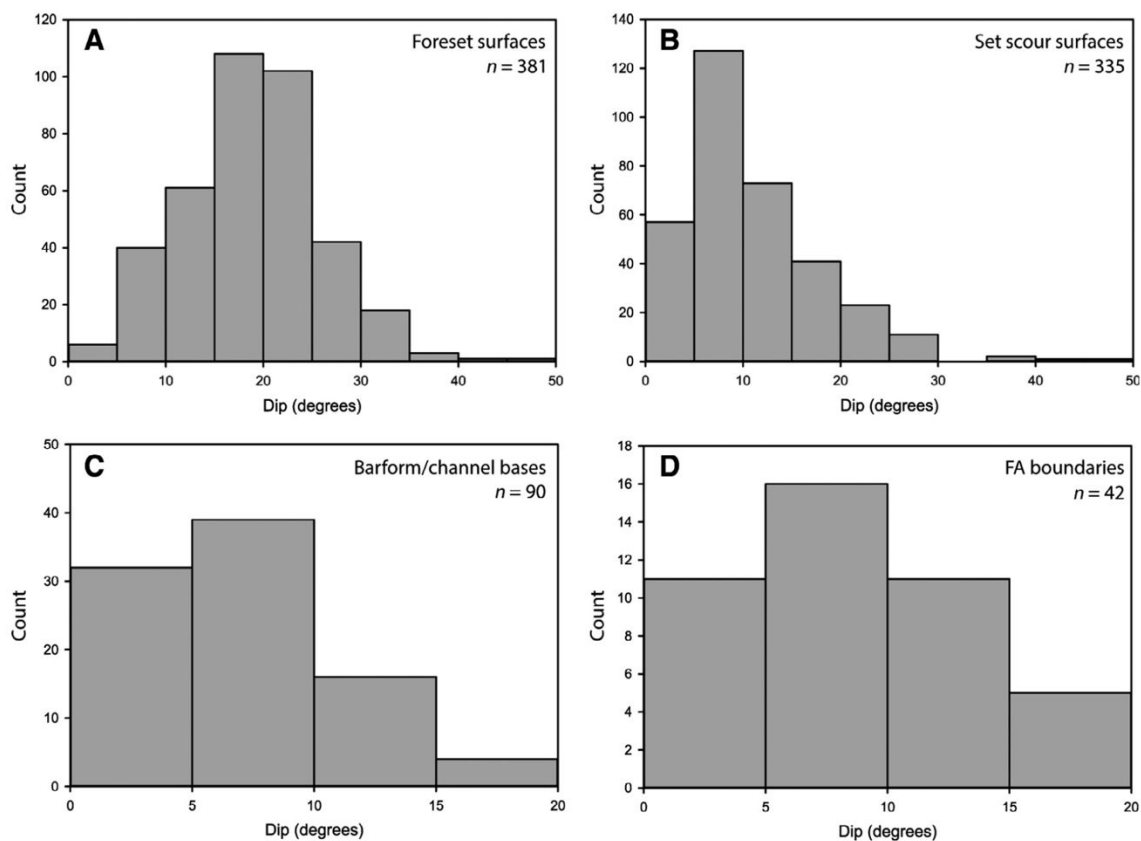


Figure 1.4: Histograms representing the distribution of original dip angle for each order of surface in the middle member (restored for tectonic tilt), including A) foresets, B) scour surfaces of cross-beds, C) Barform/channel fill bases, and D) Facies Association (FA) boundaries. All measurements are true dip, recorded on the outcrop using a geologic compass.



Figure 1.5: Images of large-scale strata and sedimentary features within FA1. Scale in cm, white band on Jacob's staff is 10 cm. A) Meter-scale cosets of trough cross-stratification, interpreted as longitudinal cross sections of unit bars. B) Erosional scour of FA1 into a finer grained interval of FA3 below. C) Outcrop of FA1 displaying lateral terminations of convex-up cosets of sandy bedforms (SB), interpreted as downstream-accreting (DA) barform edges, and a concave-up coset, interpreted as a small channel fill (CH). Imbedded desiccation clasts line the bedding plane that forms the base of the CH element. D) Comparison of longitudinal and transverse cross-sections of trough cross-stratification (white lines) in a single coset (yellow lines). E) Bedding plane (viewed from below) lined with angular decimeter-scale desiccation clast impressions.

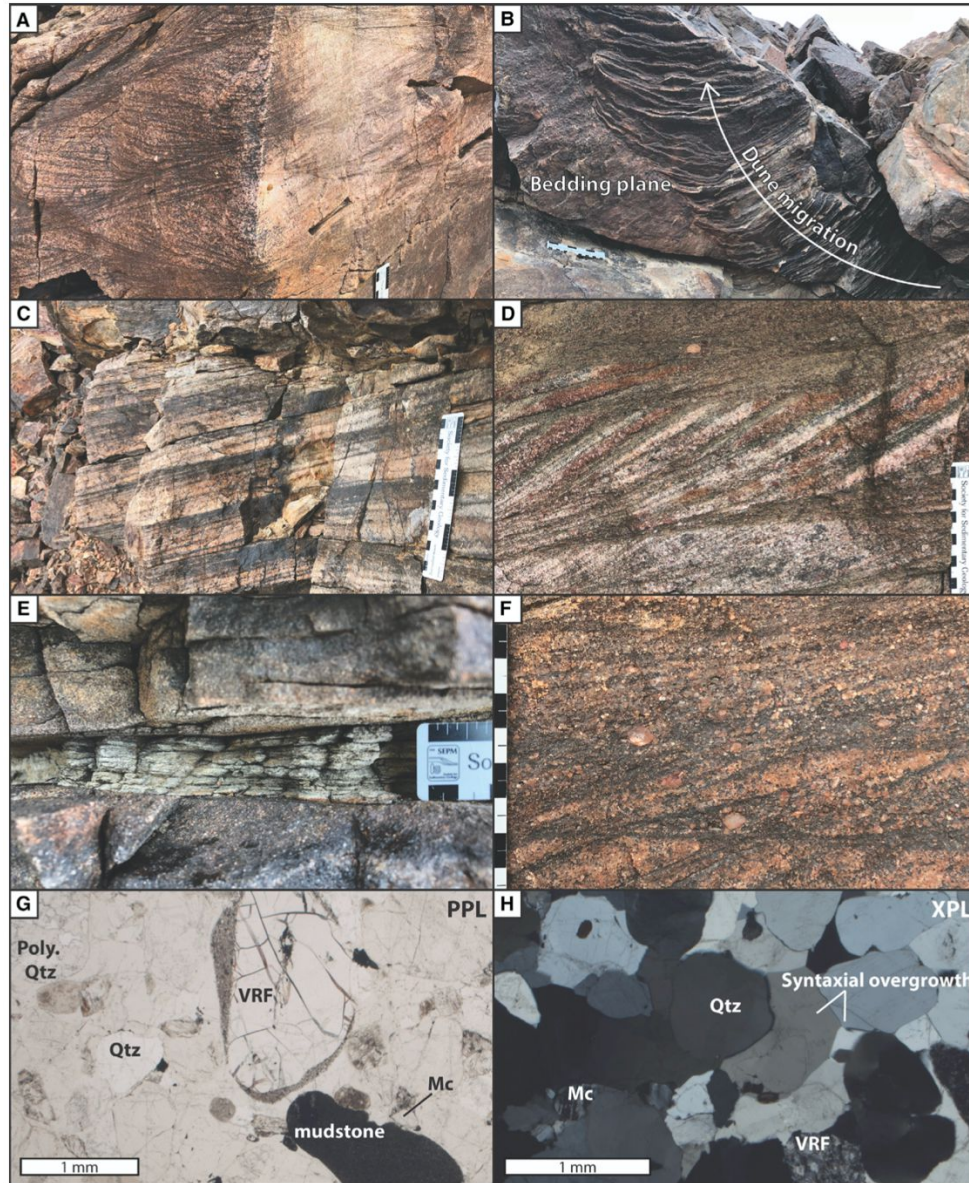


Figure 1.6: Images of fine-scale strata and sedimentary characteristics within FA1, including photomicrographs. Scale in cm unless otherwise noted. A) Decimeter-scale coset of trough cross-stratification, paleoflow toward viewer. B) Planform view of trough cross-stratification on a bedding plane formed by a lunate dune with changing direction of migration. C) Compound cross-stratification formed by dunes accreting in the downstream direction near the angle of repose. D) Sigmoidal foresets in a set of cross-stratification. E) Finely laminated interval of fine-grained sandstone and siltstone between two barforms. F) Characteristic texture of poorly sorted coarse-grained sand and granules in cm-scale FA1 cosets. G) Representative thin section (Sample MM517-1) of FA1 under plane-polarized light (PPL). Note the poor sorting, very coarse sand grains, abundant quartz (Qtz), microcline (Mc), large phenocryst in rhyolite (VRF), and well-rounded mudstone grain. H) Representative thin section (Sample MM517-12) of FA1 under cross-polarized light (XPL). Extensive syntaxial overgrowths on quartz filled a majority of the pore space in the sandstone.

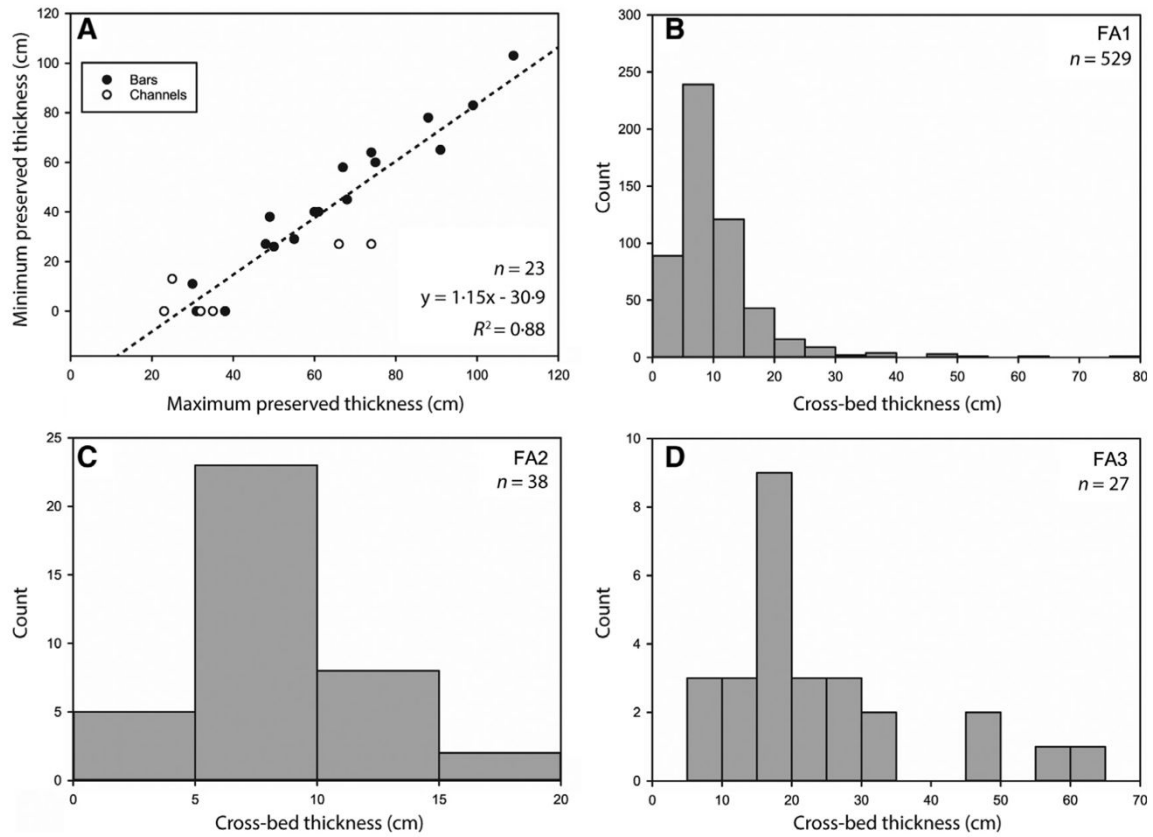


Figure 1.7: Thickness measurements of middle member architectural elements. A) Maximum and minimum preserved thicknesses of interpreted FA1 barforms and channel fills observed on stratigraphic panels. Maximum thicknesses range from 20-110 cm. Strong correlation suggests that most barforms will vary in thickness only ~10-30 cm when traced laterally. Histograms displaying the distribution of cross-set thicknesses in (B) FA1, (C) FA2, and (D) FA3 as measured from stratigraphic panels.

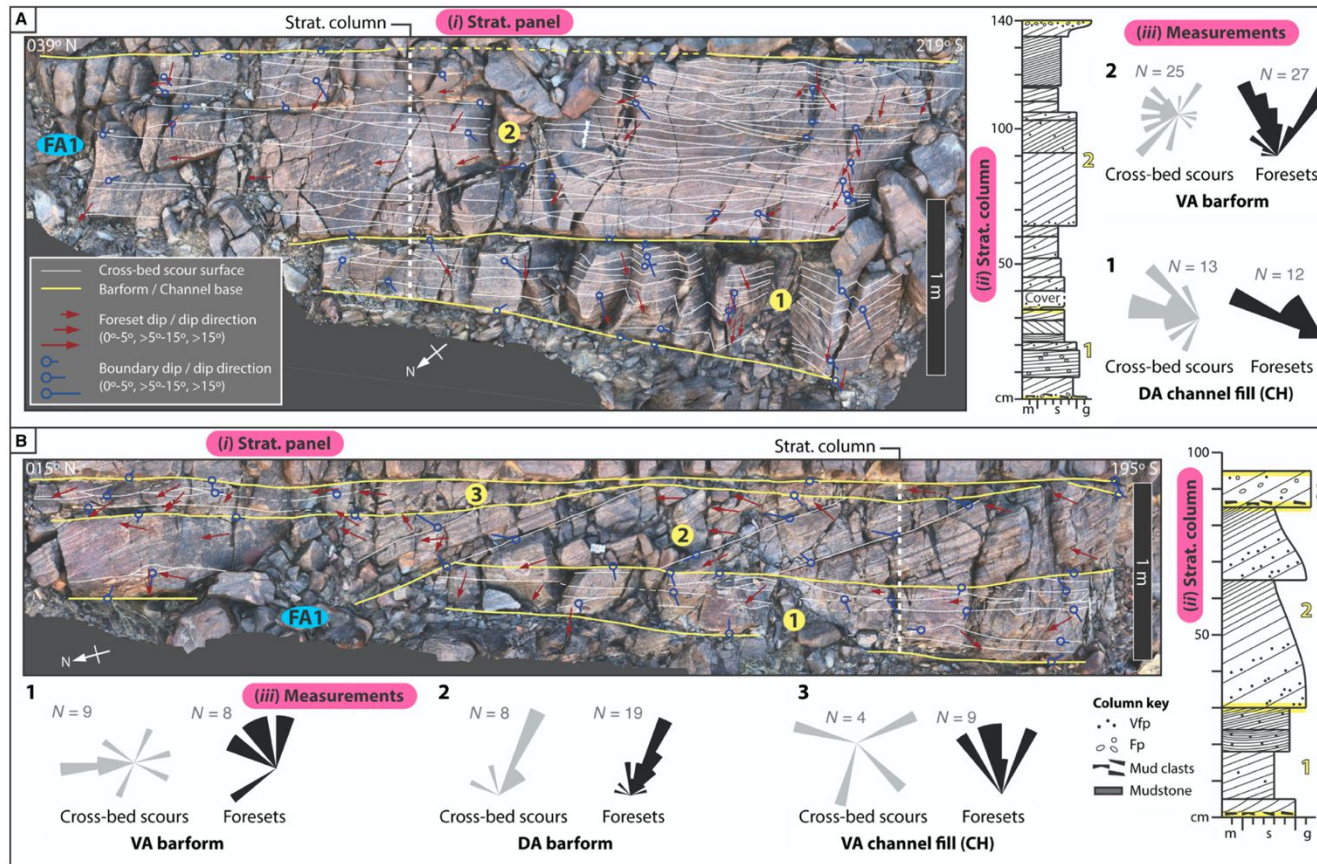


Figure 1.8: Facies Association 1 (FA1) locations (A) and (B) in unit M3 with stratigraphic panels (i) and corresponding stratigraphic columns (ii). Numbers in yellow circles on stratigraphic panels correspond to cosets (Cosets 1-2 on A, Cosets 1-3 on B), with matching yellow numbers labeling cosets on the stratigraphic columns. Interpretations are presented for each coset, based on displayed bounding surface orientations (iii). Restored measurements of dip direction on scour surfaces of cross-bedding displayed as gray rosettes, foresets displayed as black rosettes. Foreset dip directions approximate paleocurrent but may not represent a precise paleoflow, contingent on the measurement location relative to the trough axis of the three-dimensional dune. Panels are based on 3D outcrop models that are oriented with the primary face normal to the viewer.

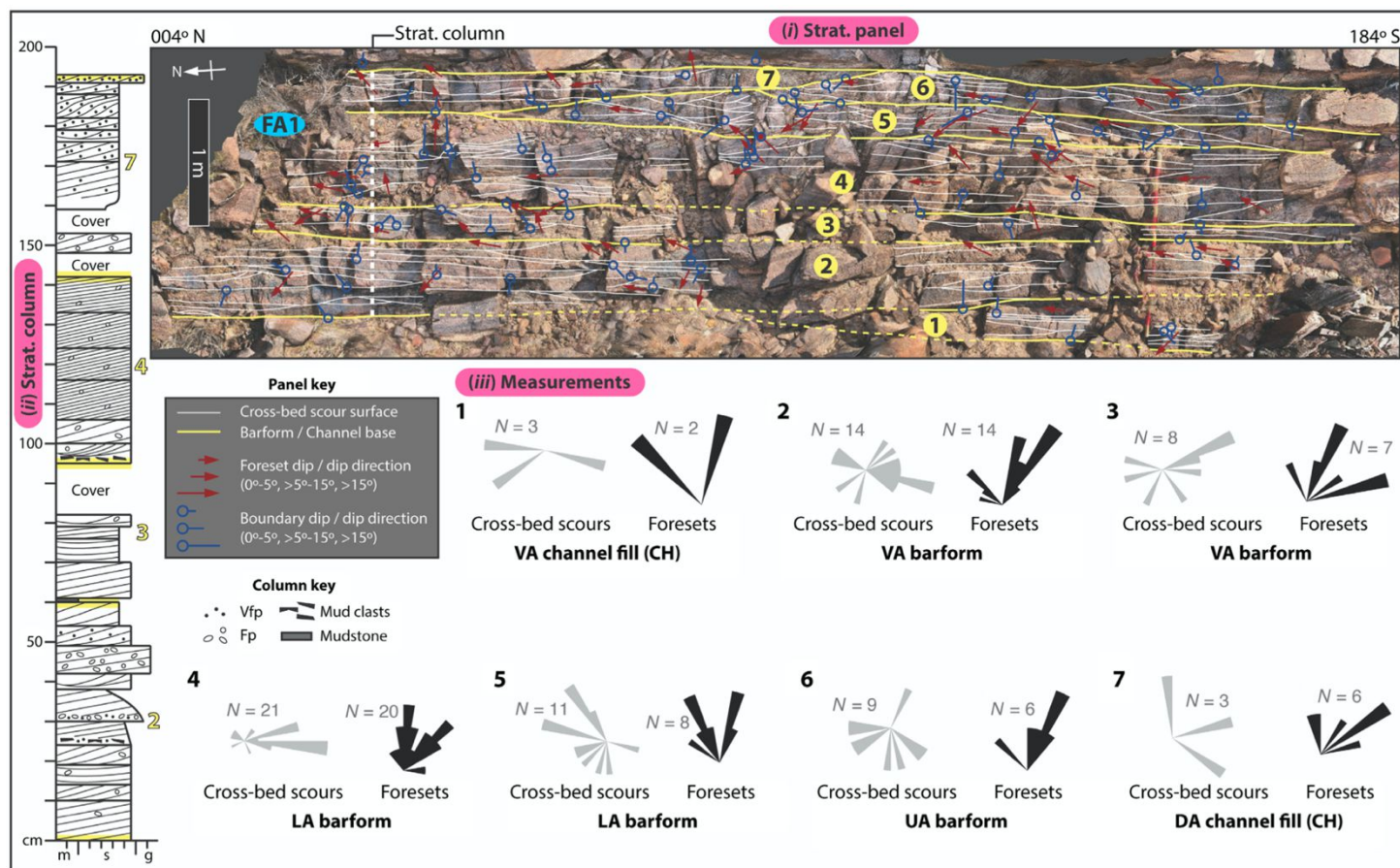


Figure 1.9: Stratigraphic panel (i) and corresponding stratigraphic column (ii) for FA1 in unit M1. Numbers in yellow circles correspond to Cosets 1-7, with matching yellow numbers labeling cosets on the stratigraphic column. Interpretations are presented for each coset, based on displayed bounding surface orientations (iii). Restored measurements of dip direction on scour surfaces of cross-bedding displayed as gray rosettes, foresets displayed as black rosettes. Foreset dip directions approximate paleocurrent but may not represent a precise paleoflow, contingent on the measurement location relative to the trough axis of the three-dimensional dune. Panel is based on a 3D outcrop model that is oriented with the primary face normal to the viewer.

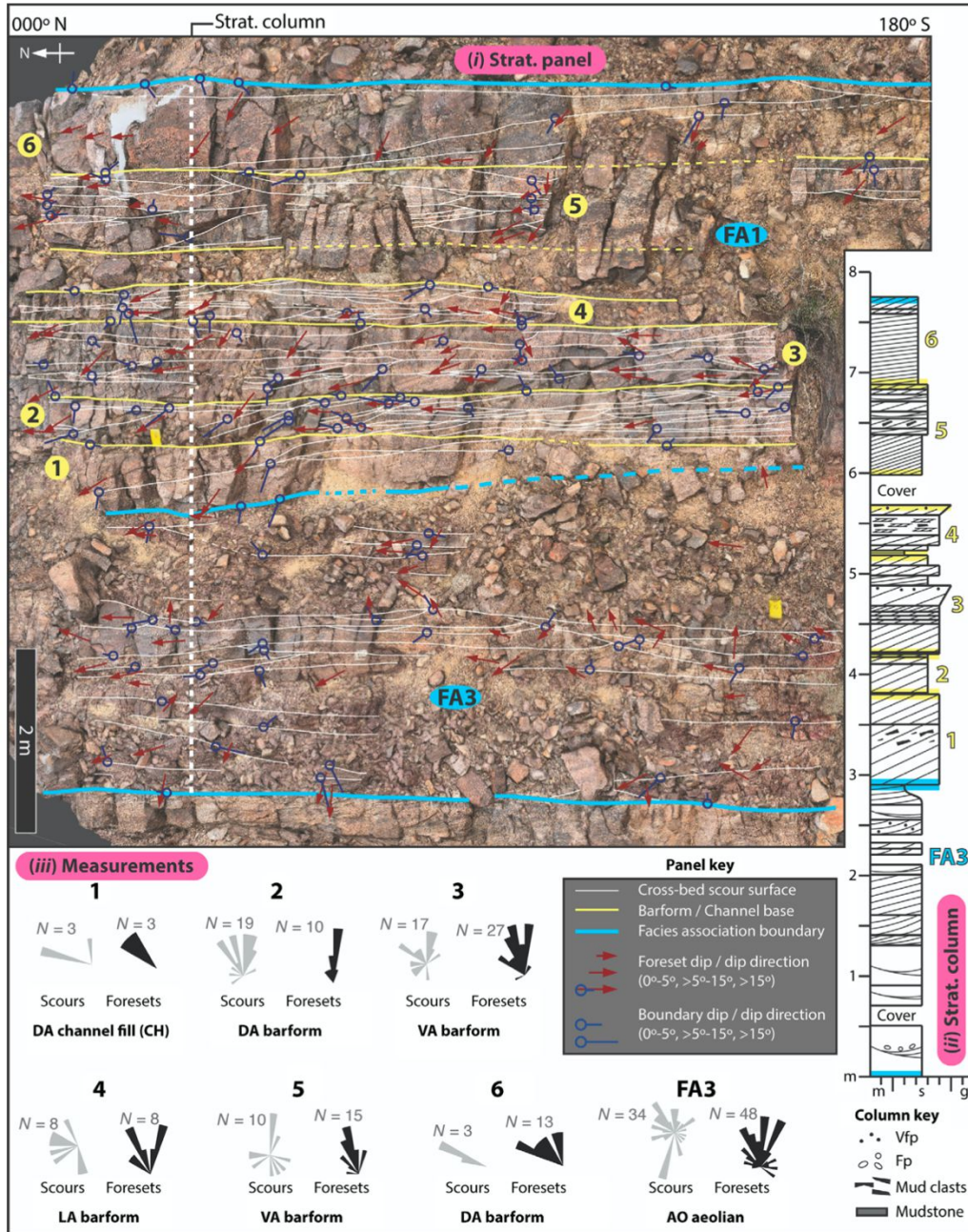


Figure 1.10: Stratigraphic panel (i) and corresponding stratigraphic column (ii) for FA1 and FA3 in unit M2. Numbers in yellow circles correspond to Cosets 1-6, with matching yellow numbers labeling cosets on the stratigraphic column. Cross-bedding in FA3 is labeled with a blue oval on the stratigraphic panel and in blue at the corresponding stratigraphic column location. Interpretations are presented for Cosets 1-6 and FA3, based on displayed bounding surface orientations (iii). Restored measurements of dip direction on scour surfaces of cross-bedding displayed as gray rosettes, foresets displayed as black rosettes. Foreset dip directions approximate paleocurrent but may not represent a precise paleoflow, contingent on the measurement location relative to the trough axis of the three-dimensional dune. Panel is based on a 3D outcrop model that is oriented with the primary face normal to the viewer.

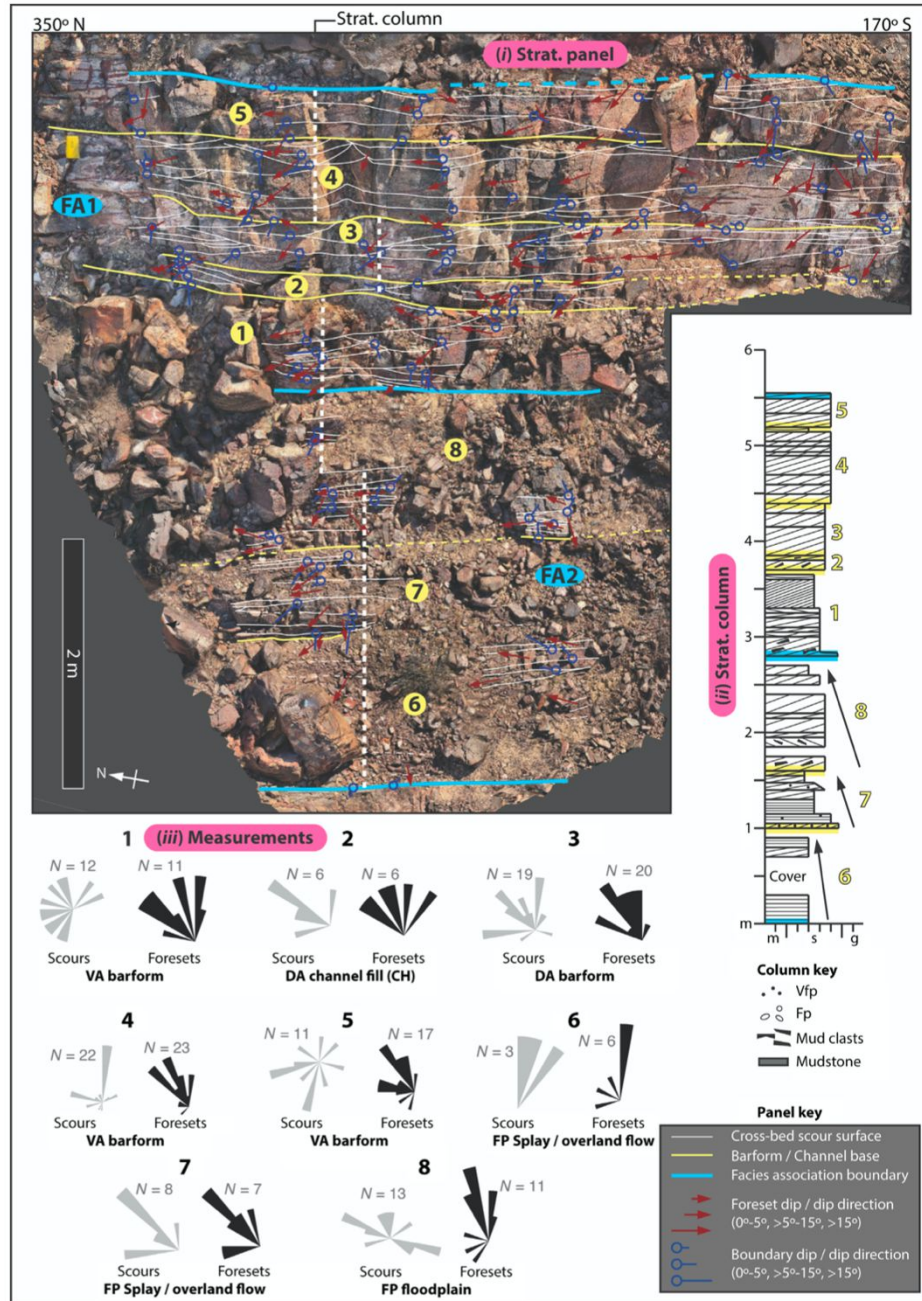


Figure 1.11: Stratigraphic panel (i) and corresponding stratigraphic column (ii) for FA1 and FA2 in unit M2. Numbers in yellow circles correspond to Cosets 1-5 of FA1 and 6-8 of FA2, with matching yellow numbers labeling cosets on the stratigraphic column. Interpretations are presented for Cosets 1-8, based on displayed bounding surface orientations (iii). Restored measurements of dip direction on scour surfaces of cross-bedding displayed as gray rosettes, foresets displayed as black rosettes. Foreset dip directions approximate paleocurrent but may not represent a precise paleoflow, contingent on the measurement location relative to the trough axis of the three-dimensional dune. Panel is based on a 3D outcrop model that is oriented with the primary face normal to the viewer.

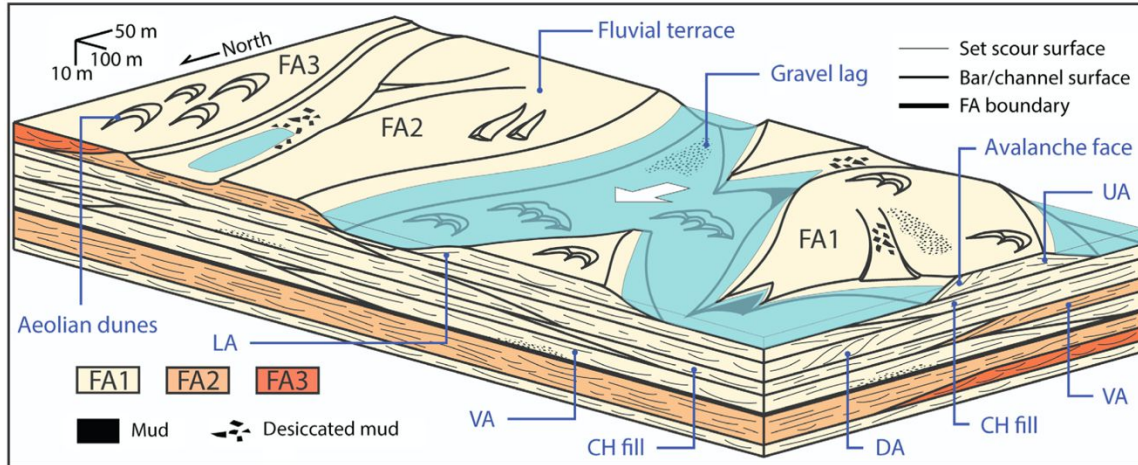


Figure 1.12: Block diagram of the middle member Wood Canyon Formation system at low discharge, including the subenvironments and representative features for each facies association (FA1-3). For architectural element abbreviations, see Figure 1.3. Approximate scale of diagram extent implied in top left.

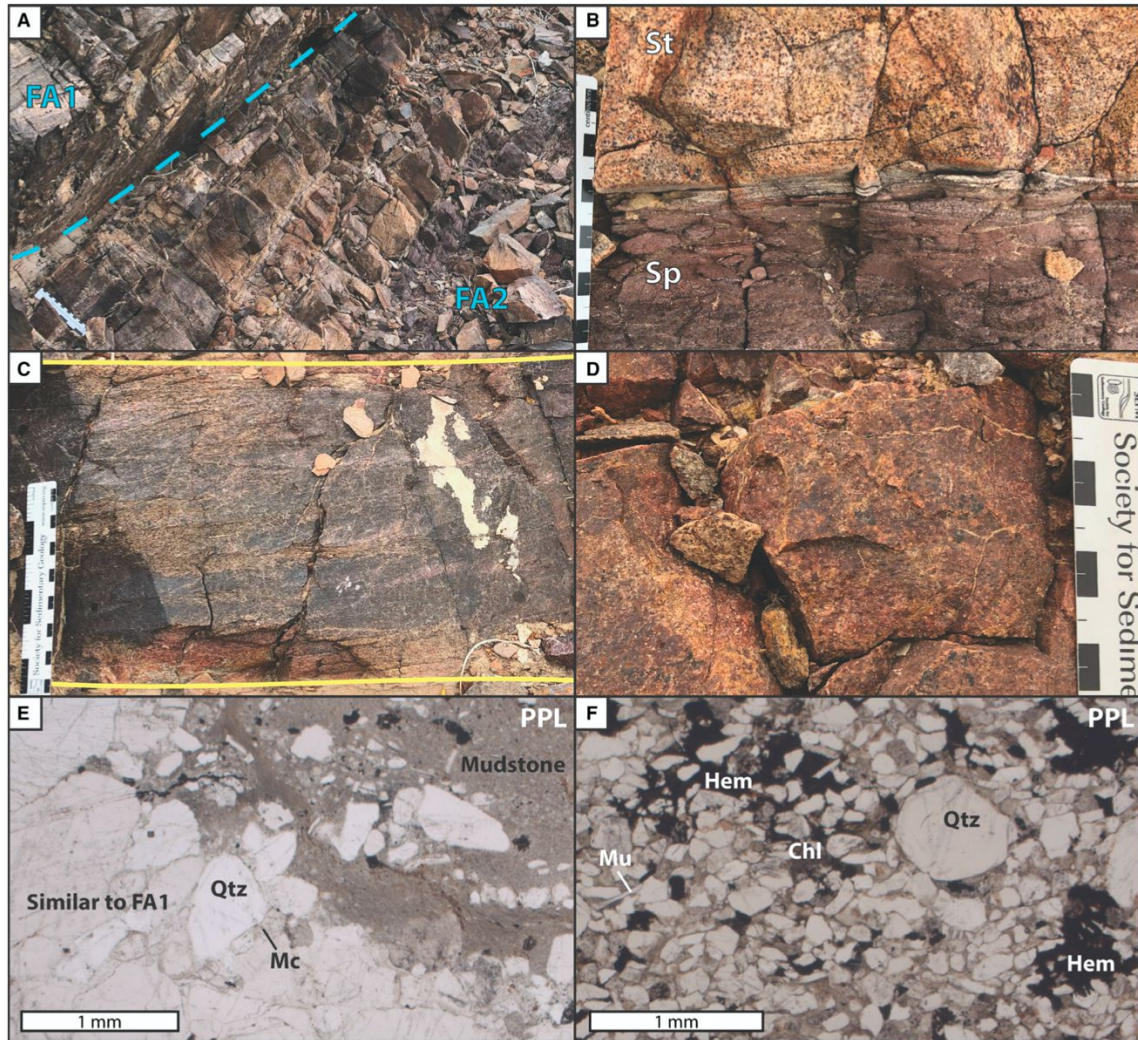


Figure 1.13: Images of FA2 strata and sedimentary characteristics. Scale in cm unless otherwise noted. A) Partially exposed interval of FA2 in sharp contact with FA1 above. Thinly bedded red-orange sandstone and low-relief weathering identifies FA2 in outcrop. B) Red plane-bedded (Sp) FA2 sandstone below, orange FA2 cross-bed (St) displays mottled appearance above. C) Coset of trough cross-stratification (St) in FA2, bounded by yellow lines, similar to FA1 in texture. Indicates the input of high energy traction flow in the FA2 subenvironment. D) Close-up view of FA2 sandstone in outcrop, with red coloration and mottled, crumbly appearance. E) Representative thin section (Sample MM517-5) of FA2 under plane-polarized light (PPL). At lower left, medium-to-coarse sand grains of quartz (Qtz) and feldspar (Mc) are cemented by syntaxial overgrowths of quartz, similar to FA1. In the top right, a layer of iron-rich mudstone and poorly sorted sand. F) Representative thin section (Sample MM517-8) of FA2 under plane-polarized light (PPL). Very poorly sorted texture with diagenetic chlorite (Chl), hematite (Hem), and detrital muscovite (Mu). Note iron-rich siltstone matrix and increased angularity of the finer grain-size fraction.

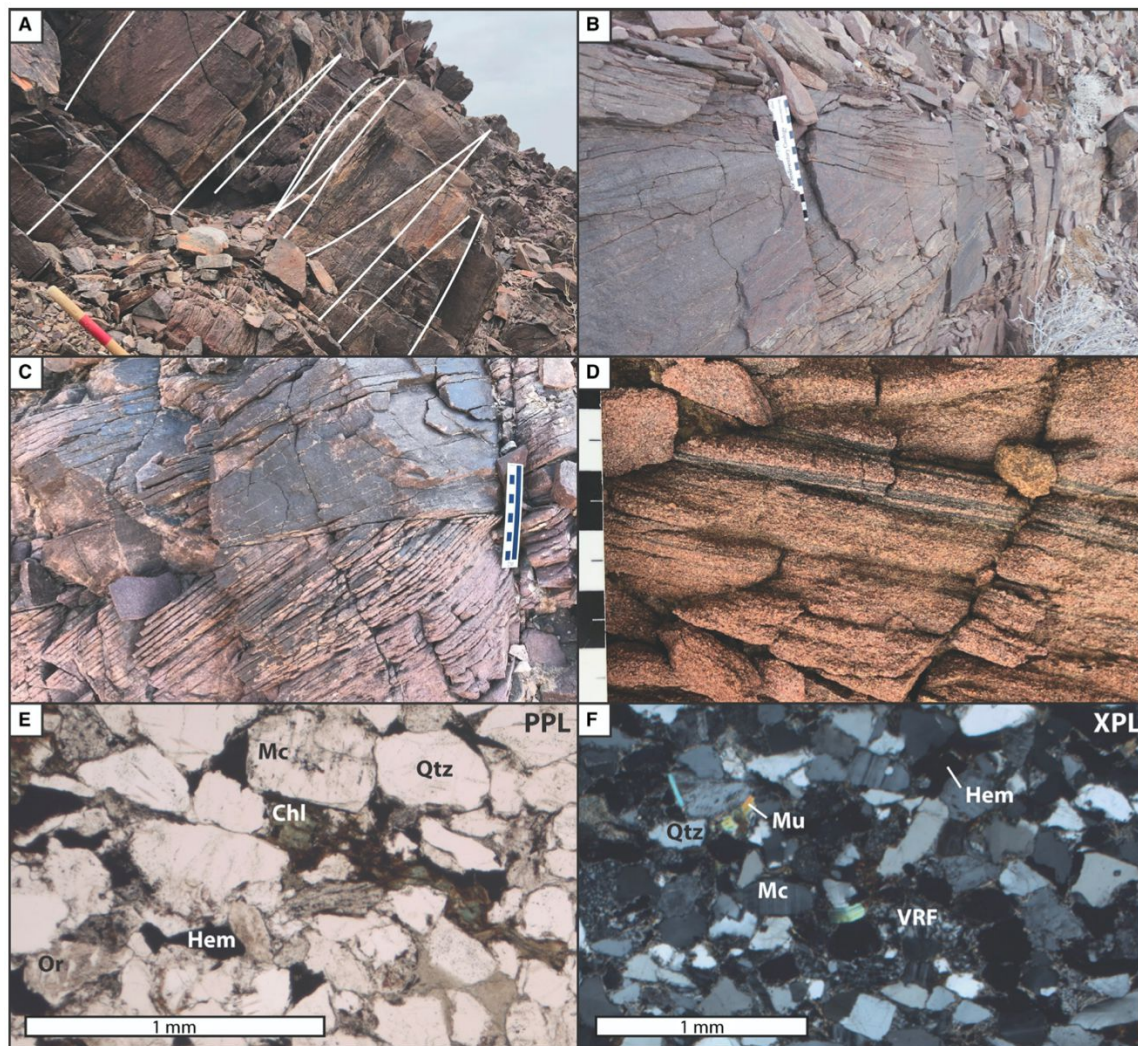


Figure 1.14: Images of FA3 strata and sedimentary characteristics. Scale in cm, white band on Jacob's staff is 10 cm. A) Approximately 3-m-thick interval of FA3 that marks the base of unit M2, with blocky weathering, rusty red-brown coloration, and large-scale trough cross-beds traced with white lines. B) Finely laminated and high-angle foresets of FA3 dune, truncated above by another set of trough cross-stratification. C) Evenly spaced, high angle tangential foresets in medium-grained sandstone. D) Close view of FA3 sandstone with foresets delineated by accessory mineral concentration that resembles pinstripe lamination in aeolian sediments. E) Representative thin section (Sample MM517-19) of FA3 under plane-polarized light (PPL). Quartz (Qtz) and feldspar (Or, Mc) framework grains of angular-to-subrounded, moderately sorted, fine- to medium-grained sand. Chlorite (Chl) pseudomatrix and clay matrix occur. Hematite (Hem) present both as primary detrital and secondary minerals. F) Representative thin section (Sample MM517-19) of FA3 under cross-polarized light (XPL). Moderately sorted fine-grained sandstone, framework grains of quartz (Qtz), microcline (Mc), rhyolite (VRF), and detrital muscovite (Mu).

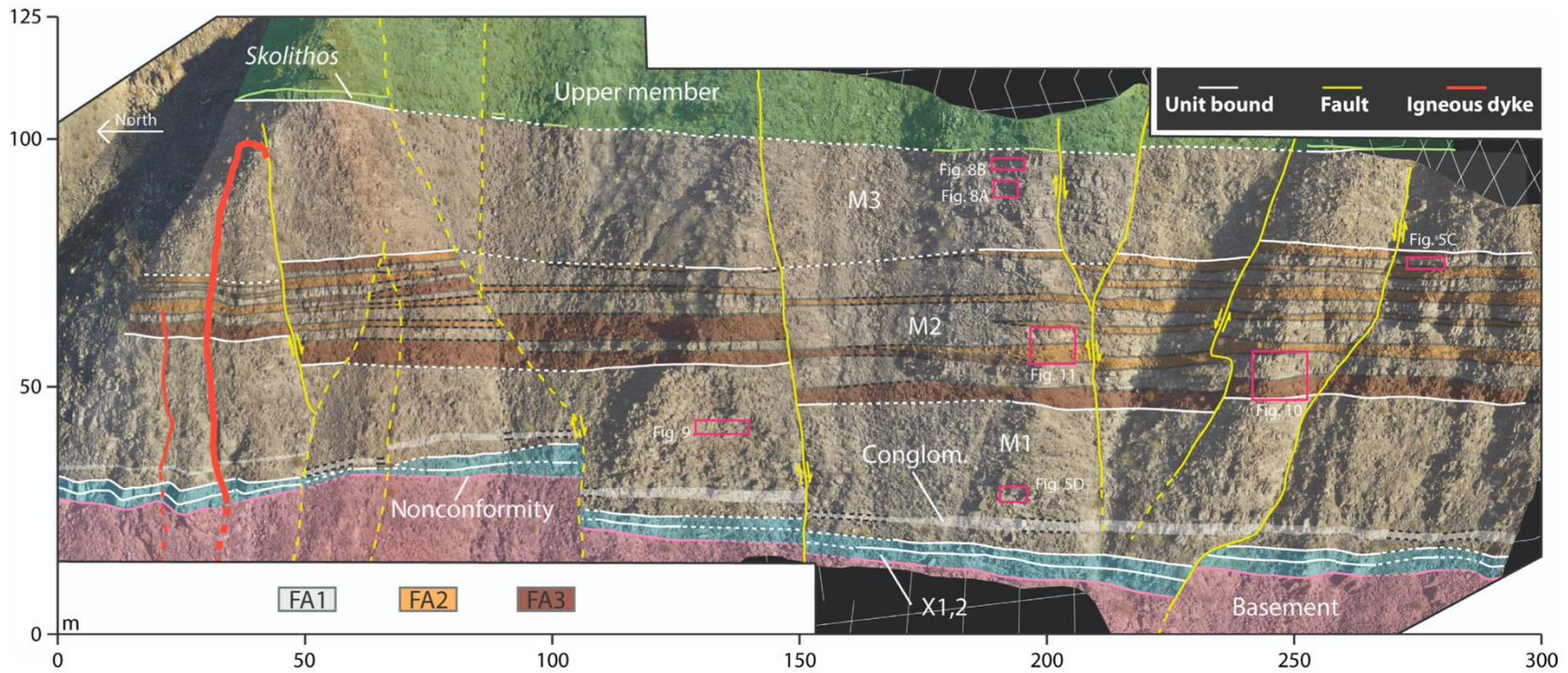


Figure 1.15: Facies association (FA1-3) mapping and delineation of depositional units (X1-2, M1-3) within the full outcrop of middle member Wood Canyon Formation surveyed in this study. Dashed lines are inferred. Panel is based on a 3D outcrop model, captured via sUAS, that is oriented with the primary face normal to the viewer. Pink boxes indicate the location and figure name of a more detailed stratigraphic panel presented herein.

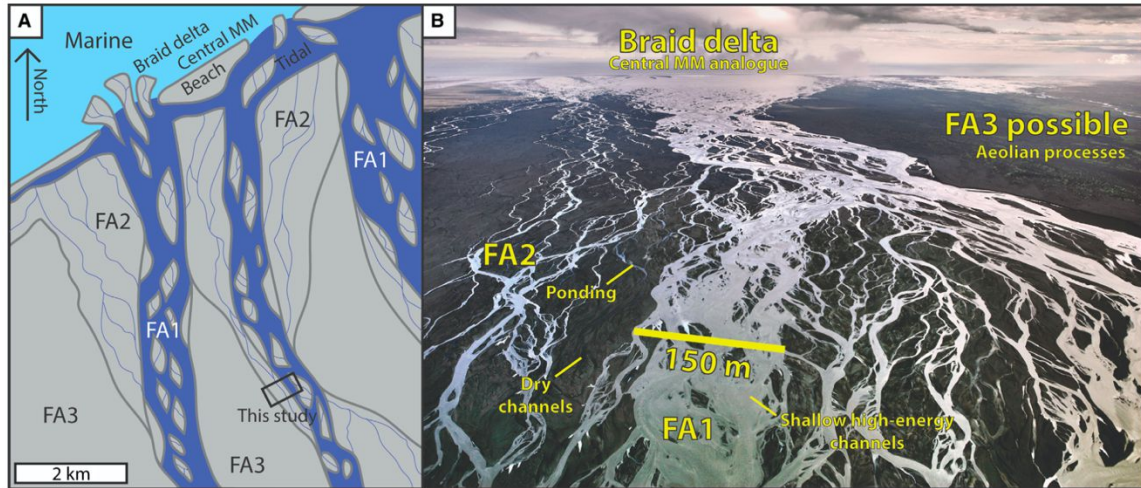


Figure 1.16: A) Hypothetical model of the larger system in which the studied strata were deposited; sediments in gray, water in blue. Corresponding facies associations (FA1-3) marked in each subenvironment. Scale modeled after modern braidplains, including the sandur plains of Iceland. Central Marble Mountains (MM), a site of future investigation, marked in the north of the diagram. B) Aerial view of Skeiðarársandur braidplain, Iceland, depicting subenvironment analogues for each facies association in a distal fluvial setting. Image courtesy of Phil Degginger, Degginger Photography.

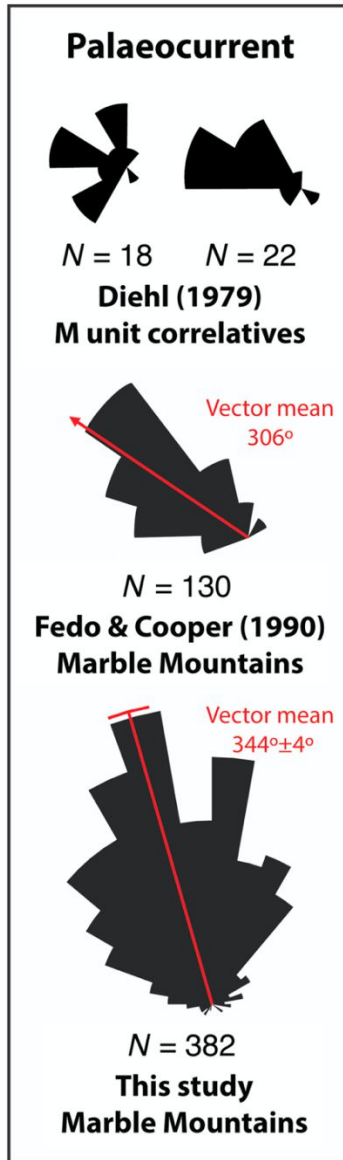


Figure 1.17: Middle member Wood Canyon Formation paleocurrent measurements from Diehl (1979), Fedo & Cooper (1990) collected in the study area, and this study recorded from stratigraphic panels. The new NNW paleocurrent data conflict with prior W–NW paleocurrent measurements.

CHAPTER II
ARCHITECTURE OF A RIVER-DOMINATED, WAVE- AND TIDE-
INFLUENCED, PRE-VEGETATION BRAID DELTA: CAMBRIAN
MIDDLE MEMBER OF THE WOOD CANYON FORMATION,
SOUTHERN MARBLE MOUNTAINS, CALIFORNIA, USA

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Abstract

Across the Mojave Desert of southeastern California, outcrops of the Cambrian middle member of the Wood Canyon Formation preserve the deposits of pre-vegetation braided-fluvial and braid-delta environments. One 78-meter-thick section in the southern Marble Mountains, documented here through detailed stratigraphic logging, facies analysis, architectural panels based on ‘Structure-from-Motion’ models, and a suite of paleocurrent and accretion-surface measurements, provides insight into the development of a fluvial-dominated, wave- and tidal-influenced braid delta at the distal end of a continent-scale braidplain. In contrast to other pre-Devonian braid-delta strata that are largely absent mudrock, the majority of the middle member system contains over 5% mudstone. Four facies associations, FA4-7, comprise the middle member section and represent (in order of stratigraphic height) a braidplain-to-delta transition (FA4), proximal braid delta (FA5), distal braid delta (FA6), and upper braid-delta front (FA7). The 20 meters of braidplain-to-delta transition strata are largely similar to those of fluvial middle member sections, containing approximately 2% mudstone, unimodal north-northwest paleoflow, and vertical, downstream, and downstream-lateral accretion elements representing compound barforms and channel-fills. Above, each braid-delta facies association (FA5-7) preserves high sinuosity paleocurrent indicators, 6–12% mudstone, and symmetrical, wave-formed sand waves. Decimeter-thick fluid-mud deposits found primarily in FA6 and less commonly in FA7 indicate the presence of a maximum turbidity zone that records brackish-water conditions in the distal braid delta. Trace fossils concentrated in FA7 suggest metazoans were confined the upper braid-delta front and could not tolerate the variable salinity of the braid delta. Increased marine influence with stratigraphic height requires gradual transgression during deposition of the middle member Wood Canyon Formation, possibly as part of a lowstand systems tract.

Introduction

Where braided rivers interface with base level, a braid delta forms, merging the depositional style of braided channels with marine or lacustrine processes. In modern river systems, braid-delta environments are common, but limited to arid and periglacial climates, or tectonically active areas with high rates of sediment supply. Each factor limits the establishment of rooting plant communities and allows for braided rivers to persist despite low slopes where vegetation typically stabilizes stream banks (Davies et

al., 2011; McMahon and Davies, 2018). Ancient pre-Devonian systems, deposited before the emergence of channel-confining vascular land plants (Gibling et al., 2014; Friedman, 2017), consisted of relatively unconfined braidplains (e.g., Cotter, 1978; Eriksson et al., 1998; Long, 2011) that commonly reached the coastline (Eriksson et al. 1998), developing in a clastic fringe of adjacent braid deltas. Consequently, although “common delta” today refers to the delta of a meandering river, braid deltas were for the majority of Earth history the most abundant variety.

McPherson et al. (1987) introduced the term “braid delta,” proposed alongside a continuum with common deltas and (alluvial) fan deltas. Discussion with modification came afterword in Nemec and Steel (1988), with few studies completed on the environment since, compared to their common- and fan-delta counterparts. Nevertheless, several papers documenting units of Precambrian or Phanerozoic age include the term. A review of Precambrian clastic systems by Eriksson et al. (1998) includes braid deltas and suggests that such systems were common at the terminus of continental-scale braidplain systems. Case studies that either directly or indirectly observe braid deltas in the rock record include Hereford (1977), Fedo and Cooper (1990), Soegaard (1990), Schreiber and Eriksson (1992); DiBona and von der Borch 1993; Eriksson et al. (1995; 2006), MacNaughton et al. (1997), Fedo and Cooper (2001), Zhu et al. (2017), Levell et al. (2019), and Went (2019), and in the modern, McGowan and Sturman (1997) and Hart (2007). Tidal processes are regularly associated with the transition from braided fluvial to braid delta in the sedimentary record (e.g., Bradley et al., 2018), at odds with the rarity of braided-tidal systems today, as a result of steep slopes that prevent channel stabilization (Dalrymple and Choi, 2007). Despite the importance of such systems in the past, a full depositional model has not been developed, and sedimentology texts and depositional environment compilations overlook braid deltas. Detailed studies, when conducted, document important information about the processes and evolution of distal braided rivers and their terminal deltas, determine criteria to distinguish them from fan deltas and other marginal-marine environments, and provide datasets that are the basis for building a braid-delta facies model.

The present study includes stratigraphic architecture results for a section of the middle member of the Cambrian Wood Canyon Formation (Mojave Desert, California, USA) previously interpreted as a braid-delta deposit by Fedo and Cooper (1990). Primary goals of this study include: (1) classify the lithofacies and architectural elements of a proposed braid-delta environment, (2) distinguish fluvial sedimentary features from those that may be marine in origin, (3) develop a depositional model for the middle member Wood Canyon Formation beyond the first-order findings of Fedo and Cooper (1990) at the selected site, and (4) assess habitability potential of the braid-delta environment. The braid-delta strata represent a down-dip continuation of nearby, coeval, braidplain strata of the middle member (Muhlbauer et al., 2020). Together, the two locations capture the lateral extent of a distal fluvial system where it intersected the ancient coastline. Pairing Muhlbauer et al. (2020) with the results presented here provides the opportunity to investigate what detailed facies-level changes occur when a pre-vegetation fluvial system is modified by marine processes. Because the strata of the feeding braidplain preserve no

distinguishable body/trace fossils, the search for evidence of habitable conditions must shift toward the connected transitional-marine realm.

Geologic Setting

Cropping out across the southern Great Basin of California, Nevada, and Arizona, the Wood Canyon Formation is a subarkosic sandstone deposited along the Cambrian margin of Laurentia in response to rifting or Rodinia (Stewart, 1970; Fedo and Cooper, 2001; Schoenborn et al., 2012; Muhlbauer et al., 2017). Three members comprise the formation (Fig. 2.1A; Stewart, 1966; Diehl, 1979; Fedo and Cooper, 2001): a marine-shelf lower member that preserves the Ediacaran-Cambrian boundary in a number of localities (Corsetti and Hagadorn, 2000), a fluvial-to-deltaic middle member, and a marine-shelf upper member that belongs to Cambrian Series 2 (Hollingsworth, 2005). Thus, biostratigraphic correlation of the *Fallotopsis* biozone (Mata et al., 2012; Peng et al., 2012) constrains the deposition of the middle member Wood Canyon Formation to the Terreneuvian (541-521 Ma), predominantly within Stage 2 (529-521 Ma). A vast braidplain, capable of transporting clastic sediment for hundreds to more than one thousand kilometers (Fedo and Prave, 1991; Hogan et al., 2011; Schoenborn and Fedo, 2011; Schoenborn et al., 2012; Muhlbauer et al., 2017), provided detritus that initially prograded across the craton-margin hinge zone following northwest (present day) paleoslope (Fedo and Cooper, 2001; Hogan et al., 2011) to build the middle member. As a result of differential post-rift subsidence and loading (Stewart, 1970; Cooper and Fedo, 1993; Fedo and Cooper, 2001), sections furthest northwest into the basin are thickest and most complete. Cratonic sections (Cooper and Fedo, 1993) thin significantly, with the lower member absent and the middle member lying nonconformable over 1.4 Ga granitic bedrock (Fig. 2.1A; Anderson and Bender, 1989; Farmer and Ball, 1997; Wooden et al., 2013).

A sequence stratigraphic framework by Fedo and Cooper (2001) presented the middle member Wood Canyon Formation as part of a transgressive systems tract (TST). Hogan et al. (2011) reinterpreted the middle member as falling stage (FSST) progressing to lowstand (LST) systems tract progradation under normal regression, placing it early within the Sauk Supersequence, but not at its base. Craton-hinge and off-craton sections, where the Wood Canyon Formation and subjacent units are thickest, heavily influenced sequence stratigraphic interpretations. Systems tract boundaries merge onto the craton compressing or eliminating stratigraphic units such that the middle member was deposited directly on a paleosol developed on Proterozoic granitic and gneissic bedrock (Anderson and Bender, 1989; Wooden and Miller, 1990) of the Mojave Province (Bennett and DePaolo, 1987). Given this relationship, there is a distinct likelihood that middle member deposition on the craton began during the LST, and only preserves the uppermost strata of basinward counterparts.

Near continental margins, an array of depositional environments and subenvironments interfinger across lateral distances of meter-to-kilometer scale; in the right conditions, such an array may produce comparable sedimentary sequences leading to difficulty in their interpretation. Unsurprisingly, much discussion over a marine (Stewart, 1970;

deVries Klein, 1975; Foster, 1991) or fluvial (Diehl, 1979; Fedo and Cooper, 1990; 1991) origin for the middle member has occurred through time, resulting in a need to evaluate paleoenvironments at each exposure in order to refine the depositional history of the unit. The most recent interpretation of the rocks studied here (Section N66; Fig. 2.1B), by Fedo and Cooper (1990), suggested that the lowest 5–6 m of strata represent the products of a proximal braid delta, followed by 11 m of tidal flat, and finally capped by ~75 m of distal braid delta.

In a stratigraphically up-dip direction 8 km to the south, facies and architectural analysis of the middle member by Muhlbauer et al. (2020; Section S66; Fig. 2.1B), revealed a distal, perennial, braided-fluvial system with no influence from marine deposition. Three facies associations were developed by mapping 80 meters of stratigraphic section exposed for 300 meters along-strike. Stacked, coarse-grained, cross-stratified, sandstone cosets in Facies Association 1 (FA1) are interpreted as the deposits of barforms in shallow channels with unimodal north-northwest paleoflow. Facies Associations 2 (FA2) and 3 (FA3) occur as comparatively thin, discontinuous intervals interbedded within FA1. The thinly bedded, fine- to medium-grained sandstone of FA2 is hematite-rich, likely deposited by flood-related overbank splay or overland flow on fluvial terraces. Meter-scale trough cross-beds in rare FA3 deposits resemble localized aeolian dunes, representing windblown sediments winnowed from the alluvial plain. Mudstone is nearly absent from each facies association, with polygonal desiccation-chip horizons comprising the bulk of the clay content. Several factors imply that this pre-vegetation braidplain experienced perennial streamflow, including incremental compound-bar construction with reactivation surfaces and minimal evidence for upper flow-regime structures (Fielding et al., 2018). Despite the distal-fluvial setting, no marine trace fossils are found within the middle member at this location. Thus, given the proximity to the braid-delta strata of Section N66, significant variation in depositional environment is preserved nearing the Cambrian coastline.

North of State Route 66 in the steep-sided southern Marble Mountains, southeastern California, Section N66 of the Wood Canyon Formation crops out in a series of low hills and escarpments (Figs. 2.1B, 2.2A). Relatively undeformed areas between large sinistral slip-strike faults tilt 50–55° to the east. One such fault-bounded block defines the study area mapped in Figure 2.2B, ensuring that a stratigraphic column (Fig. 2.3) could be measured confidently and utilized during fieldwork. Wood Canyon Formation strata are exposed in entirety, from the nonconformity with bedrock, through the middle and upper members, to the contact with the overlying Zabriskie Quartzite (Prave, 1991). Talus cover limits the visible outcrop area of the basal contact and overlying ~20 meters of sandstone compared to the rest of the middle member. Small slip-strike faults with sub-meter offset crosscut the area. Two primary sets of fractures, oriented approximately 070°/65°NW and 310°/60°NE, form faces normal to bedding (Appendix A-4, Table 4.3). Joint sets are also near-parallel or near-perpendicular to paleoslope, providing beneficial longitudinal and transverse cross sections of fluvial features. Lithologic observations and the general stratigraphic column presented in Fedo and Cooper (1990) provide context for

renewed high-detail study of the site. Work conducted for Muhlbauer et al. (2020) allows for comparative architectural analysis between Sections N66 and S66.

Methods

Pairing extensive bounding-surface tracing with 3D digital outcrop models (DOM; e.g., Ghinassi and Ielpi, 2018, Muhlbauer et al., 2020), entirely while in the field, allows the creation of high-detail architecture panels that most accurately reflect the strata. Generated by processing images collected with a handheld camera through Structure-from-Motion (Fabuel-Perez et al., 2009; Clapuyt et al., 2016; Chesley et al., 2017) software package Agisoft™ Metashape (Agisoft LLC, St. Petersburg, Russia), DOMs provide sub-cm spatial resolution for meter-scale exposures. Creating stratigraphic panels required extensive field-based tracing of bounding surfaces, collection of thousands of paleocurrent and bounding surface orientations with a geologic compass, documentation of lithofacies, grain size, and sedimentary structures, measurement of the face orientation of the panel, and correction for local tectonic tilt via stereonet. The average orientation of planar beds of mudstone found across the site determined that the strike and dip of the Marble Mountains is 50° to 55° to the east depending on the location in the field area (Appendix A-4, Table 4.4). A DJI Mavic 2 Pro (DJI, Shenzhen, China) small unmanned aircraft system (sUAS) conducted additional reconnaissance of the field area. Images from this platform facilitated construction of a 3D basemap (Fig. 2.2B) for the field area using Agisoft™ Metashape and provided rapid assessment of ideal locations for detailed stratigraphic panels.

Facies Associations

A stratigraphic column (Fig. 2.3), detailed architectural panels, and field observation recognized four facies associations, FA4–7, in Section N66 of the middle member Wood Canyon Formation (Fig. 2.2). Muhlbauer et al. (2020) previously described FA1–3 at Section S66 (Fig. 2.1). The stratigraphic column (83 m thick) was measured bed-by-bed in centimeter increments, ensuring the documentation of fine-scale sedimentary structures and thin mudstone beds. Stratigraphic logging marked a sharp break in slope at 78 m (Fig. 2.3), where dark colored-sandstone and increased mudstone abundance mark the onset of the upper member Wood Canyon Formation. Images of each lithofacies identified in the study area are provided in Figure 2.4. Tables 2.1 and 2.2 provide further definitions of the lithofacies and architectural elements discussed herein, respectively.

Description: Facies Association 4 (FA4)

Comprising the lowermost unit in the study area, FA4 represents the first 20 meters of the middle member above the basement nonconformity (Fig. 2.3; Table 2.3). Multistory, brown, gray, or white beds of sandstone are primarily parallel-bedded and show convex or concave geometries where terminations are located. Cosets of cross-stratified, coarse-grained subarkose (Fig. 2.5A, B), occur bounded by planar or low-amplitude sinuous surfaces (Fig. 2.5B) and are between 20–60 cm (n=34) in thickness for over 50% of examples (Table 2.3). Paleocurrent indicators observed in cross-beds are uniformly north-northwest directed. Trough cross-stratification (St; Figs. 2.4A, 2.5A), tabular cross-

stratification (Sp; Fig. 2.4B) and low-angle cross-stratification (Sl; Fig. 2.4C) are most abundant (Table 2.1), minor lithofacies include crudely bedded sandstone (Sm; Fig. 2.4F), crudely bedded conglomerate (Gm; Fig. 2.4G), horizontal-bedded conglomerate (Gh; Fig. 2.4H), and trough cross-bedded conglomerate (Gt; Fig. 2.4I). Approximately 2% of the facies association is mudstone (Fl and Fm; Fig. 2.4J), predominantly siltstone, present between cosets and along set boundaries (Fig. 2.5B, C; Table 2.3). Mudstone layers are discontinuous and range from millimeter-scale veneers (Fig. 2.5B, C) to beds 5 cm in thickness. Between cosets, laminated beds of very fine- to fine-grained sandstone (Table 2.3), less than 5 cm in thickness, appear similar in outcrop appearance to mudstones because of desert varnish. Polygonal “bowtie-shaped” mudstone intraclasts were deposited within cross-beds (Fig. 2.5D), gravel layers, and along coset-bounding surfaces. Millimeter-scale layers of conglomerate, commonly single-clast-thick, line the soles and tops of cosets (Fig. 2.5C; Table 2.3), or comprise cross-sets. Because of the co-location of mudstone and gravel between sandstone cosets (Fig. 2.5C), the two lithologies may be paired by process, positioning mudstone lenses between layers of conglomerate in some examples.

Thin section photomicrographs (Fig. 2.5E, F) of FA4 samples confirm the characterizations from the stratigraphic column (Fig. 2.3) and provide additional details. Modal mineralogy of sandstone is similar to that previously reported for the Wood Canyon Formation (Fedo and Cooper 1990), including abundant quartz (monocrystalline and polycrystalline), microcline, and orthoclase, with microcrystalline quartz, rhyolite volcanic rock fragments, magnetite, and muscovite (Fig. 2.5E, F). Patchy hematite and epidote formed as epigenetic minerals. Coarse- to very coarse-grained sandstones are commonly cemented with syntaxial quartz overgrowths (Fig. 2.5E) that preserve original grain boundaries. Clay minerals are present as matrix in poorly sorted sandstones (Fig. 2.5F), especially those with framework grain sizes between very fine- and medium-grained sand. Some samples contain up to 10% clay-mineral matrix. Centimeter-scale mudstone layers are normal-graded siltstone, with clays and interbedded very-fine sandstone.

Architecture

Figure 2.6A and B, a representative architectural panel of FA4 oriented longitudinal to paleoslope, illustrates cosets with abundant trough cross-stratification (St) and tabular cross-stratification (Sp) in sandstone. Minor lithofacies components include mudstone (Fl), crudely bedded sandstone (Sm), crudely bedded conglomerate (Gm), horizontal-bedded conglomerate (Gh), and trough cross-bedded conglomerate (Gt). The sandstone and conglomerate lithofacies form sandy bedform (SB) and minor gravel bedform (GB) architectural elements (Table 2.2) that comprise each coset. Coset boundaries are marked by the presence of thin, discontinuous mudstone layers, angular mudstone clasts, and Sm, Gm, Gh, and Gt lithofacies (Fig. 2.4; Table 2.1). Each coset-bounding surface exhibits a low-amplitude wavy appearance. Paleocurrent measurements for all sets (Fig. 2.6C) are unimodal and consistently to the north-northwest, at an average of 329° ($n=77$). Rosettes illustrate that cosets in areas 2 and 3 (Fig. 2.6B, C) have no systematic orientation of set dip-directions, a characteristic of vertical accretion (VA; Table 2.2). Cross-sets of areas

4–8 (Fig. 2.6B, C), each part of a single coset, are alternating intervals of Sp and St, with steeply inclined set boundaries, downlapping foresets, and at least one inclined mudstone bed between sets. Paleoflow orientations of the tabular cross-beds (areas 5, 7; Fig. 2.6B, C) are northward, parallel to the accretion direction of the sets, defining a downstream accretion (DA) element (Table 2.2). Trough cross-stratified sets (area 6), layered between the tabular sets (Fig. 2.6B), have northwest foreset dip-directions (Fig. 2.6C) that suggest paleocurrent at an oblique angle to overall DA element migration, indicating downstream-lateral accretion (DLA; Table 2.2) and a change in current direction across the accretion face. Trough cross-beds in areas 4 and 8 (Fig. 2.6B, C) have no systematic orientation to set dip-directions, preserving VA alongside the DA element (Table 2.2) in a compound barform.

Description: Facies Association 5 (FA5)

Distinct facies and architecture over an interval of 20–38 meters, as measured on the stratigraphic column (Fig. 2.3), encompass FA5 (Table 2.3). The majority of sandstone cosets are parallel bedded, but wedge-shaped and convex geometries also occur. A wide sweep of paleocurrent orientations, from west to east, diverges up to ~90° from the inferred direction of paleoslope. Approximately 50% of cosets fall between 20–60 cm (n=28) in thickness (Table 2.3). Brown coloration is most common in outcrop, although white-colored units of coarse-grained sandstone represent approximately 25% of the facies association strata (Fig. 2.7A; Table 2.3). Sandstone lithofacies (Fig. 2.4; Table 2.1) are dominated by trough (St) and low-angle (Sl) cross-bedding, with planar cross-bedding (Sp), ripple cross-lamination (Sr), planar-bedding (Sh), and rare crudely-bedded sandstone (Sm). Ripple cross lamination (Fig. 2.4D) appears in association with horizontal-bedded (Sh), fine- to medium-grained sandstones (Fig. 2.7B), but ripple marks are nearly absent from bedding tops. Possible symmetrical sand waves with ~5 cm amplitudes occur draped by mudstone or fine-grained sandstone. Mudstone (Fl and Fm) comprises 6% of FA5 (Table 2.3) as mm-thick veneers and wedge-shaped to laterally continuous beds typically 3–10 cm in thickness (Fig. 2.7C). A mud-veneered sandstone surface with desiccation cracks (Fig. 2.7D) intersects the stratigraphic column (Fig. 2.3) at 34 m and potentially extends for 150 m along strike. Polygonal “bowtie-shaped” (Fig. 2.5D) and smaller, rounded mud clasts are found throughout FA5, either within sets of cross-stratification or along coset-bounding surfaces. Uncommon, very fine- to fine-pebble conglomerate (Gh) lines the soles and tops of several cosets (Table 2.3).

Thin-section photomicrographs from FA5 samples provide further insight into the sandstone and mudstone beds of the interval (Fig. 2.7E, F). Rounded to well rounded, poorly sorted, subarkosic sandstones form the framework-grain mineralogy of the middle member (Fedo and Cooper, 1990), with approximately 10% clay matrix (Fig. 2.7E). Grain-size details of each thin, black-colored bed (Fig. 2.7C) are difficult to assess on the outcrop because of ubiquitous desert varnish. Thin-section analysis of representative samples reveals a range of grain sizes, from clay to medium-grained sand (Fig. 2.7E), that form the dark-varnished beds. Mudstones are silty, with interbedded fine sand. The dark color of the layers is owed to patchy, diagenetic iron oxide and magnetite growth in

matrix (Fig. 2.7E). White-colored sets are moderately sorted and coarse-grained sandstone, with negligible matrix and pervasive syntaxial quartz cement (Fig. 2.7F).

Architecture

Strata of FA5 in Figure 2.8A and B, approximately 30 meters above the nonconformity, comprise a stratigraphic panel oriented transverse to paleoslope. Planar or wedge-shaped cosets contain sandy bedforms (SB; Table 2.2) and are bounded by sharp erosional surfaces, mudstone veneers (Fm), or cm-thick siltstone layers (Fl). Cosets of trough cross-stratification (St) are common, but not dominant; low-angle cross-bedding (Sl; Fig. 2.8B; areas 2, 3, 5, 6, 10) occurs in equal proportion. Paleocurrent results for low-angle cross-beds (Fig. 2.8C) are inconclusive, as the measurements are strongly affected by tectonic tilt estimates and foresets are obscured by desert varnish. Trough cross-sets have both east (area 4) and west (areas 7, 8) paleoflow directions (Fig. 2.8B, C), with no systematic orientation of set boundaries, defining vertical accretion (VA) elements (Table 2.2). At the base of the panel (Fig. 2.8B; area 1), a horizontally stratified (Sh) bed of fine- to medium-grained sandstone preserves millimeter-scale interlayers of smeared-out ripple cross-lamination (Sr; Fig. 2.7B). A meter-thick set of white, coarse-grained sandstone with several tangential foresets and abundant cm-scale mudstone intraclasts (Fig. 2.8B, C; area 9) may represent an eastward moving DA element, but internal surfaces are too limited to make a definitive assessment. Featureless, massive sandstone (Sm) floors the base of the area 5 coset (Figs. 2.4F, 2.8B). Planar mudstone units (Fig. 2.8B; below areas 3, 4, 7, 8) appear alongside those with sinuous, load-deformed, bounding surfaces (below area 10). Beneath area 9 (Fig. 2.8B), a concave-up unit of Fl comprises a channel-fill element (CH; Table 2.2) that is 20 cm in thickness and floored with ripple marks.

Description: Facies Association 6 (FA6)

Lithofacies diversity is highest within FA6, which crops out between meters 38–60 on the stratigraphic column (Figs. 2.3, 2.9; Table 2.3). Parallel-bedded, wedge-shaped, and convex cosets of sandstone are between 20–60 cm (n=35) in thickness in 55% of measured examples (Table 2.3). Prominent sandstone lithofacies (Fig. 2.4; Table 2.1) are trough (St) and tabular (Sp) cross-bedding, with secondary low-angle cross-bedding (Sl), planar bedding (Sh), and crudely bedded intervals (Sm). White, coarse-grained sandstone, approximately 20% of FA6, interbeds with brown or tan subarkose (Table 2.3). Some white-colored sandstones are observed to display sand-wave geometries (Fig. 2.10A, B; Table 2.3), with flat bases and sinuous upper bounding surfaces commonly encased in mudstone. Paleocurrents display a primary north-northwest trend (349°, n=244), but outcrop observations reveal divergence from the direction of paleoslope. Additionally, rare tabular cross-sets have foresets that dip to the southeast (Fig. 2.10C, D), indicating paleoflow opposite of the overall system. Black, medium-grained sandstones comprise beds of ripple cross-lamination (Sr) and low-angle cross-stratification (Sl) throughout the facies association (Fig. 2.4). Horizontally bedded (Sh) fine-grained sandstones, up to 40 cm in thickness, are interbedded between coarser deposits (Table 2.3). Bedding tops preserve abundant symmetrical and interference oscillation ripple marks (Fig. 2.9A), with 16 examples recorded along the measured stratigraphic column (Table 2.3). Measurements of ripple crest orientations indicate both bidirectional east-west (100°–

280°) paleocurrent and bidirectional southeast-northwest (160°–340°) paleocurrent. An occurrence of asymmetrical ripples was noted within the FA6 interval elsewhere on the outcrop. Mudstone layers (F1 and Fm), a maximum of 30 cm in thickness (Fig. 2.9B, C), make up 12% of FA6 strata (Table 2.3). Upper bounding surfaces of mudstone packages may be planar, rippled to wavy, or display evidence of deformation by loading (Fig. 2.9C). Additionally, 5–10-cm-thick intervals of highly deformed, elongate, mudstone intraclasts occur in white-to-tan, pebbly, coarse- to very coarse-grained sandstone (Fig. 2.9D; Table 2.3). Intraclasts reach up to 25 cm in long-axis dimension. Figure 2.10E demonstrates that sand injection into underlying cohesive, but unlithified, mud caused lamination disruption and formation of mud clasts. Crudely bedded, fine- to medium-pebble conglomerate (Gm) within FA6 is commonly associated with mudstone beds (Figs. 2.9B, 2.10F; Table 2.3) in a variety of relationships that include deposition subjacent, superjacent, or adjacent to mudstones, thin interbeds between mudstone layers, or pod-shaped agglomerations within mudstones.

Thin-section analysis of samples collected within FA6 provide additional petrographic information. Sandstone composition aligns with the reported framework-grain mineralogy for the middle member (Fig. 2.9E; Fedo and Cooper, 1990). Framework grains of very fine- to medium-pebble conglomerates are primarily quartz, microcline, orthoclase, chalcedony, and volcanic rock fragments of rhyolite (Fig. 2.9F). Tan-to-brown sandstones have 5–15% clay matrix with hematite stain (Fig. 2.9E) that is absent from separate, white-colored, coarse-grained sandstones. Two types of mudstone deposits are documented in FA6: those that are silty, with interbedded fine-grained sandstone, and others composed of claystone with iron-oxide stain (Fig. 2.9F).

Architecture

Two stratigraphic panels, oriented longitudinal to paleoslope, trace the features of FA6. Figure 2.11A and B, located approximately 45 m above the nonconformity, depicts four trough cross-bedded (St) cosets with minor planar-bedded (Sh), crudely bedded (Sm), and low-angle cross-bedded (Sl) sandstone (Fig. 2.4, Table 2.1). Cosets of areas 1 and 2 (Fig. 2.11B) pinch out against each other with concave-down bounding surfaces that expose the margins of middle member barforms. Above, a coset in area 3 is bounded by roughly parallel bedding-planes (Fig. 2.11B). The concave-up basal surface of the coset in area 4 (Fig. 2.11B) defines it as a channel fill (CH) element. Each coset is bounded by load-deformed and scoured layers of mudstone (Fm and F1), up to 12 cm thick, rip-up chips, crudely bedded (Sm) sandy bedforms (SB; Table 2.2), or discontinuous, crudely bedded (Gm) gravel bedforms (GB; Table 2.2). Foreset orientations record a range of paleoflow directions from northwest to northeast (Fig. 2.11C). Sets of horizontally stratified sandstone (Sh) are interbedded within the area 3 coset (Fig. 2.11B). At the base of area 4, a white, low-angle, cross-bedded sandstone (Sl) with faint foresets forms a series of 10-cm-thick sand waves with embedded mudstone intraclasts (Fig. 2.11B). The upper surfaces of all mudstone layers appear convolute, and in certain locations (Fig. 2.11B; between areas 2 and 3; between areas 3 and 4), preserve rip-up formation or are reduced to mud-clast horizons. Enigmatic, rounded agglomerations of crudely bedded conglomerate (Gm) line the coset-bounding surface above area 2 (Fig. 2.11B).

Near the upper boundary of FA6, the internal complexity of the facies association is well illustrated (Fig. 2.12). The majority of the panel is comprised by three cosets of trough (St) and tabular (Sp) cross-stratification (Fig. 2.4) and two extensive intervals of mudstone in contact with pebble conglomerates. At the base of the panel, a 30-cm-thick mudstone bed contains a concave-up package of conglomerate that defines a channel-fill (CH) element (Fig. 2.12A, B; Table 2.2), though its featureless character (Gm) prevents assessment of paleoflow direction. Another gravel layer occurs within the convex-up coset of area 4 (Fig. 2.12A, B), overlain by a 30-cm-thick mudstone bed. The meter-thick coset in the center of the panel, formed by cross-sets of areas 1–3 (Fig. 2.12B), preserves a compound barform in which vertical accretion (area 1) gives way to downstream accretion (area 2) toward the north-northwest (Fig. 2.12C; Table 2.2). The DA element (area 2) is built from light-colored, tabular cross-bedded, coarse-grained sandstone, with downlapping foresets that are overlain by the trough cross-beds of area 3 (Fig. 2.12A, B). Irregular bounding-surface geometry at the base of area 1 appears to erode the thin mudstone layer above the conglomerate CH element (Fig. 2.12B), leaving only mudstone intraclasts. Several sets of southeast- and east-dipping cross-strata in area 4 indicate assembly of sandy bedforms (SB) under multiple current directions (Fig. 2.12B, C; Table 2.2). Area 5, located at the top of the panel, contains trough cross-beds (St) and intervals of ripple cross-lamination (Sr) in medium-grained sandstone (Fig. 2.12B). Set boundaries are planar and show no preferential orientation, suggesting vertical accretion (VA; Fig. 2.12C; Table 2.2).

Description: Facies Association 7 (FA7)

Facies Association 7, the upper 60–78 meters of middle member, is subjacent to the contact with the upper member Wood Canyon Formation (Fig. 2.3; Table 2.3). Sandstones are brown, tan, and white, with 65% of parallel-bedded and wedge-shaped cosets between 40–80 cm (n=22) in thickness (Table 2.3). None of the measured cosets were 10–20 cm thick. White-colored sandstone cross-sets represent 45% of observed strata (Table 2.3). Trough (St) and tabular (Sp) cross-sets (Fig. 2.4), and ripple cross-lamination (Sr), are common through the facies association (Fig. 2.4; Table 2.1). Although Sr is pervasive (Fig. 2.13A), preserved oscillation ripple marks with centimeter-scale wavelengths were identified only four times while measuring the stratigraphic column (Figs. 2.3, 2.13B). Flat-based symmetrical sand waves occur with mudstone drapes (Table 2.3). Foreset measurements indicate east and west paleoflow that diverged approximately 90° from primary north-northwest trending cross-strata that migrated down-slope. The base of the facies association on the stratigraphic column is marked by 1.5-meter-thick bed of massive medium-grained sandstone (Sm) that extends for 10s of meters along the outcrop before termination at faults (Fig. 2.13C). Continuous-to-discontinuous mudstone beds (Fm and Fl), up to 20 cm in individual thickness, comprise approximately 6% of FA7 (Table 2.3). Small, deformed and rounded, mudstone intraclasts were deposited with cross-bedded sandstones. Sparse conglomerate layers (Gm and Gh) line the tops and soles of cosets and pair rarely with mudstones. Ichnofossils are abundant within FA7 on the bedding planes of mudstone and fine-grained sandstone packages (Fig. 2.13D).

In thin section, samples of FA7 allow further characterization of the rocks observed on the stratigraphic column and panel. Subarkoses and pebble conglomerates reflect the framework grain mineralogy typical of the middle Wood Canyon Formation (Fig. 2.13E; Fedo and Cooper, 1990). Tan- to brown-colored sandstones are poorly sorted and contain 10–15% hematite-stained clay matrix, whereas white-colored beds are cemented by quartz cement that is absent of matrix. Chlorite, hematite, and magnetite comprise the diagenetic mineral assemblage of the collected samples. Mudstones are predominantly claystone (Fig. 2.13F), with interbedded quartz, feldspar, and muscovite silt-sized grains. Platy magnetite crystals, 10–20 μm in long axis measurement, are found throughout mudstone units (Fig. 2.13F).

Architecture

Figure 2.14A and B displays strata near the base of FA7 in transverse cross-section to paleoslope, including numerous trough (St) and tabular (Sp) cross-bedded cosets (Fig. 2.4; Table 2.1). Paleocurrent and accretion direction in the cosets is highly variable, ranging from east to west (Fig. 2.14C). Two tabular cross-bedded cosets (Fig. 2.14B, C; areas 4, 8) have paleocurrent directions divergent from paleoslope, as do trough cross-bedded cosets in areas 3 and 5 (Fig. 2.14B, C). Cosets of areas 1, 2, 5, 6, and 7 aggraded vertically (VA; Table 2.2), cosets of areas 3, 8, and 9 represent downstream accretion (DA; Table 2.2), and area 4 contains a thick DA element (Table 2.2) overlain by the sandy bedforms (SB) of a trough cross-bedded VA element (Fig. 2.14B, C; Table 2.2). Units of ripple cross-laminated, fine-grained sandstone (Sr; Fig. 2.13A), marked with green on Figure 2.14B, are interbedded in cross-bedded cosets or between coset boundaries (above and below area 3). Intervals of Sr were deposited both near the tops (areas 8, 9) and bases (area 7) of cosets (Fig. 2.14B). Continuous, planar mudstone beds and discontinuous, wavy mudstone layers, up to 6 cm in thickness, occur between cosets (Fig. 2.14B). At the base of the panel, a thick mudstone bed exhibits load deformation. Mudstone drapes and rounded mudstone intraclasts are present within trough cross-sets (Fig. 2.14B; areas 1, 7). Two gravel bedforms (GB; Table 2.2) of horizontally stratified conglomerate (Gh) are illustrated, one along the top surface of area 2, another at the base of area 4 in contact with a mudstone bed below (Fig. 2.14B). A bilobate trace fossil (cf. *Aulichnites*), pictured in Figure 2.13D, is preserved in negative epirelief on a bedding plane within trough cross-stratified, fine-grained sandstone (Fig. 2.14B). The ichnofossil may represent a gastropod grazing trail that is known from rocks of Ediacaran and Cambrian age (Crimes, 1992; MacNaughton and Narbonne, 1999).

Environmental Interpretation

FA4: Braidplain-to-delta Transition

Several lines of evidence indicate that FA4 strata preserve the transition from braidplain to braid delta (Fig. 2.15A, B), each with a relatively stable hydrograph during deposition. Facies and fluvial architecture in the strata are similar to the active braidplain subenvironment proposed by Muhlbauer et al. (2020) for intervals of Facies Association 1 (FA1) at Section S66, 8 km south of the study area (Fig. 2.1A, B). Low sinuosity (Fig.

2.15B), recorded by unimodal foreset dip-directions trending toward the north-northwest (329°; Fig. 2.6C) that resemble the measurements of paleocurrent in FA1 intervals (344°), suggests minimal change in the direction of paleoflow or fluvial style. Cosets of tan, brown, and gray subarkose organized into VA, DA, and DLA elements, reported in FA1, are also found within FA4 (Fig. 2.6B) and represent cross-sections of compound barforms or channel fills (e.g., Almeida et al., 2016a). Composed of repetitive trough and tabular cross-beds, cosets are the deposits of barforms and channel fills generated through multiple events of subcritical flow. Floodplain (FA2) and aeolian (FA3) environments reported by Muhlbauer et al. (2020) do not occur in the study area, so either development of stable, dry surfaces was limited, or not preserved near the coastline. Although angular desiccation chips are found within FA4 sandstone (Figs. 2.5D, 2.6B), extensive pavements of *in situ* polygonal mud clasts, found in FA1, are absent between cosets. Both properties are consistent with a stable, perennial hydrograph for a wide reach of active braided channels (Fig. 2.15A, B).

The primary difference between FA4 and FA1 is silty mudstone beds that make up 2% of FA4 strata (Fig. 2.5B; Table 2.3), whereas mudstone is present only at sub-percentage levels in the braidplain (FA1). Additionally, poorly sorted, coarse-grained sandstones contain up to 10% clay matrix (Fig. 2.5F), a characteristic not reported in the typically quartz-cemented middle member (Stewart, 1970; Fedo and Cooper, 1990). Throughout the rocks of the study area, authigenic clay growth is evident in sandstones and siltstones where framework grain boundaries are concave and forced apart by intruding clay matrix (Fig. 2.5F). However, total added volume of clay is minimal and not expected to unevenly impact the reported percentages of mudstone. Elevated mudstone is likely related to backwater effects that reduced flow velocity as the braided system approached base level (Colombera et al., 2016; Fernandes et al., 2016; Wu and Nitterour, 2019). Mud-draped foresets (Fig. 2.6B) indicate slackwater events during the migration of sandy bedforms (SB), when fine-grained sediments could fall from suspension. More extensive normal-graded siltstones between cosets (Fig. 2.5B) may form during channel avulsion or cutoff, on bar tops during waning flow, or in areas of localized flow expansion (Fig. 2.15B). The pairing of conglomerate and mudstone, specifically mudstone veneers between conglomerate (Fig. 2.5C), is explained by the development of gravel lags (e.g., Miall, 1977) along channel floors and gravel-armored surfaces formed on bar-tops during bankfull floods. During channel abandonment, a layer of suspended silt settled over fine pebbles formerly in the channel thalweg. Migrating barforms may cover the mudstone below with a gravel lag, trapping a thin layer of mudstone between conglomerates. Via common fluvial processes, the preservation of thin interbedded mudstones and conglomerates that represent multiple depositional events may be expected between sandstone cosets.

FA5: Proximal Braid Delta

Within FA5, occurrences of specific features require marine influence in a braid delta, proximal to the fluvial system (Fig. 2.15A). Figure 2.8 preserves highly sinuous paleoflow, in which multiple bedforms and DA elements migrated perpendicular to the overall north-northwest paleoslope (Fig. 2.15C). Despite high sinuosity, there are no

obvious lateral-accretion (LA) elements (Miall, 1985) reported. Absence of LA elements and clear floodplain deposits support that the system remained a sandy braided river (Long, 2011), with channel segments, or links (Egozi and Ashmore, 2008), taking on higher sinuosity (Fig. 2.15C). The channel-fill in Figure 2.8B reveals that some channels in the system were shallow and, in some cases, filled with silt after abandonment (Fig. 2.15C). Conversely, a meter-thick set of tabular cross-bedding in Figure 2.8B (area 9) requires a channel several meters deep. The sinuosity increase in the system likely lowered flow-velocities locally, evidenced by the thick siltstone beds and fine- to medium-grained, planar-bedded to rippled sandstones found throughout FA5 (Figs. 2.7B, C, 2.8B, 2.15C; Table 2.3). Subaerial muds were desiccated in the system (Fig. 2.15C), evidenced by polygonal rip-up chips and one extensive bed of *in-situ* desiccation cracks (Fig. 2.7D). Rare symmetrical ripple surfaces imply transport of sand by low-energy, wave-driven processes (Fig. 2.8B; Table 2.3). Large cm-amplitude symmetrical sand waves (Table 2.3; Allen, 1980; Leckie, 1988) suggest reworking of sediments by waves in deeper water before burial beneath siltstone or fine-grained sandstone that indicates energy reduction in the fluvial system.

FA6: Distal Braid Delta

The presence of a maximum turbidity zone (Uncles et al., 2006; Dalrymple and Choi, 2007), located within the distal braid delta (Fig. 2.15A), is recorded in the strata of FA6. With a diverse facies assemblage (Figs. 2.9, 2.10; Table 2.3) uncommon to the Wood Canyon Formation, FA6 marks a definitive change from the braidplain depositional environment proposed by Muhlbauer et al. (2020). Vertical accretion and downstream-accreting avalanche faces (Reesink et al., 2014) are common in cross-bedded cosets. Architecture panels in Figures 2.11 and 2.12 record compound barform and channel-fill morphologies in cross section. Based on paleoflow measurements, sinuosity of this subenvironment remained high compared to the braidplain (Fig. 2.15D). Although both architecture panels record few paleocurrents migrating perpendicular to paleoslope (Figs. 2.11C, 2.12C), they do preserve localized instances of DLA and east- or west-dipping foresets. Variable paleocurrents are observed in several locations within the FA6 stratigraphic interval, including an area of the outcrop with several, meter-thick, tabular cross-sets with southeast-dipping foreset directions (Fig. 2.10C, D), indicating a reversal of flow in the system that may be tidal in origin. The structures are likely not antidunes (Plink-Björklund, 2015; Massari, 2017), as mudstone layers separate each set of southeast-trending cross-strata. The mudstone represents brief periods of hiatus that would not occur during a single, large, flooding event capable of generating standing waves.

Decimeter-thick beds of mudstone that make up 12% of the stratigraphic interval (Table 2.3) are the most distinctive feature of FA6, often found interbedded with pebble conglomerate between sandstone cosets (Figs. 2.9B, 2.10F, 2.12B). Repeated co-location of the finest and coarsest grain sizes in the system requires a process-based explanation. Fluidization of mud (Kineke et al., 1996; Dalrymple et al., 2003; Ichaso and Dalrymple, 2009; Peng et al., 2018), associated with transitional-marine environments, best explains the paired mudstone and conglomerate beds. In tidal, deltaic, and shelf systems, fluid

muds form cohesive substrates at the bases of channels or on muddy flats, as a result of interactions between fresh and saline water (Ichaso and Dalrymple, 2009). Where the density-driven salt wedge forms in the system, turbidity is elevated due to enhanced flocculation driven by increased salt content and by trapping of particulate between the density gradient (Uncles et al., 2006; Dalrymple and Choi, 2003; 2007). This area, known as the maximum turbidity zone, occurs in brackish water where present-day salinity is approximately 20 ‰ (seawater is ~35 ‰; Dalrymple and Choi, 2007, Collins et al., 2020). Thus, with reasonable certainty, the distal braid-delta plain (Fig. 2.15D) preserved in the middle member had substantial area flooded with brackish water. The mudstones are clay-rich, with silt layers, typical of fluid mud examples reported by Ichaso and Dalrymple (2009) and Mackay and Dalrymple (2011). Fluidized muds are known to be structureless and thick compared to mudstones from suspension fall, over 5 millimeters for individual layers (Dalrymple et al., 2003; Ichaso and Dalrymple, 2009), consistent with those found in FA6 (Fig. 2.9F). No rhythmic patterns are observed in the inferred fluid-mud deposits, confirming that a tidal origin is unlikely (Gugliotta et al., 2015). Additionally, the presence of sandstones with 5–15% mud matrix (Fig. 2.9E) reveals that abundant suspended fines were transported in the turbid system and may have limited bedform height (Baas et al., 2015; Schindler, 2015). Figure 2.10E includes a location where sandstone deposited by traction flow appears injected into subjacent fluidized mud deposits, deforming them. Numerous, load-deformed upper bounding surfaces of mudstone beds (Fig. 2.9C) require soft, wetted mud before burial. Large blocks of mudstone, in coarse-grained sandstone, were scoured from the bed and plastically deformed (Figs. 2.9D, 2.16; Table 2.3), clearly indicating that they were not desiccation chips but rather rip-ups of bottom-hugging muds (Longhitano, 2012). Fluidized muds are commonly associated with pebble conglomerate, as both occupy channel floors (Figs. 2.15D, 2.16) where the thalweg transports coarse-grained material alongside muddy soupgrounds (Ichaso and Dalrymple, 2009). Pebbly gravel bedforms (GB) migrating into fluid muds may have been captured by the viscous material, forming the patchy agglomerations of conglomerate (Figs. 2.9B, 2.10F, 2.12B) that are found associated with FA6 mudstones.

Symmetrical and interference oscillation ripple marks (Fig. 2.9A; Table 2.3), observed in abundance on bedding planes in FA6, require reworking by wave processes in shallow water. Much of FA6 was likely submerged at all times, even when fluvial flow was locally reduced. Ripples may have formed on bar tops or within shallow channels (Fig. 2.15D). Large symmetrical sand waves (Allen, 1980; Leckie, 1988), floored or draped with mudstone, indicate that waves in deeper water also modified the sediments in the distal braid delta (Figs. 2.10A, B, 2.15D; Table 2.3). Representing preserved bedforms, sand waves are often white to tan, coarse- to very coarse-grained subarkose (Fig. 2.11B), with negligible clay matrix. Some white-colored cross-sets within FA6 (Table 2.3) may be linked to wave transport of sediments resuspending and removing clays from the sands of the system. Others, however, are likely formed via high-energy traction flows and on barform avalanche faces that deposited only bedload sediments. The occurrence of sand waves superjacent to thick mudstone intervals (Fig. 2.10A, B) suggests wave processes built sandy bedforms (SB) that migrated across in-channel fluidized muds (Fig. 2.15D).

FA7: Upper Braid-delta Front

Observations collected from FA7 place its deposition at the braid-delta front (e.g. Soegaard, 1990; MacNaughton et al., 1997; Levell et al., 2019; Went, 2019), along the shoreface of the system (Fig. 2.15A, E). Fluvial features typical of the middle member Wood Canyon Formation, including VA and DA elements (Fig. 2.14; Table 2.3), form as bars accrete through aggradation or migration with paleoflow. Greater coset thicknesses imply deeper water depth during deposition than elsewhere on the braid delta (Table 2.3). Sinuosity in FA7 is high, measured from bedforms that, in some examples, migrated perpendicular to paleoslope (Fig. 2.14B). Mouth bars (e.g., Harrison et al., 2017), possibly reworked by wave processes or longshore current, may explain the variation in paleocurrent (Fig. 2.15E). The 1.5-meter-thick bed of massive (Sm) medium-grained sandstone at the base of the facies association (Fig. 2.13C) resembles sandstones in the upper member Wood Canyon Formation (Fedo and Cooper, 1990) that may preserve large, longshore sand bars. Ripples formed between dunes that deposited trough cross-bedded medium-grained sandstones with ripple cross-laminated toesets (Fig. 2.13A). Symmetrical sand waves are identified (Allen, 1980), some draped with mudstone, but few bedding-top ripple marks are observed (Table 2.3), indicating wave reworking of sediments in shallow water that submerged much of the sediment during deposition. Despite the transitional-marine setting (Fig. 2.15A), definitive tidal sedimentary structures are not observed, consistent with the drop in tidal energy that occurs on delta fronts (Dalrymple et al., 1992; Dalrymple and Choi, 2007). With 6% mudstone (Table 2.3) and minor conglomerate-mudstone pairs or deformed rip-ups, fluidized mud production was limited seaward of the maximum turbidity zone. Numerous horizontal trace fossils (Fig. 2.13D), found throughout the field area in FA7, require an abundant metazoan community structure during sedimentation. However, unlike other sites (including Section S66; Fedo and Cooper, 2001; Muhlbauer et al., 2020) in which the top of the middle member is marked by a thick, heavily bioturbated pavement of *Skolithos*, no vertical trace fossils are present. The ichnofossils suggest that the salinity level of FA7 was close to that of seawater, because the vast majority of Cambrian-age metazoans were not adapted to survive brackish conditions (Buatois et al., 2005).

Discussion

Depositional Model

Taken together, the four facies associations identified in the study locality inform the depositional model, illustrated in Figure 2.15, that depicts the wide variety of subenvironments possible within Cambrian-age pre-vegetation braid deltas. Because the strata progress from transitional with the braidplain feeder system to upper braid-delta front, the depositional model is applicable to transgressive systems, distinguishing it from other braid-delta examples that are progradational (e.g., Counts et al., 2016). At the transition from braidplain to braid delta (FA4), sandstone strata show little change from the fully fluvial setting at Section S66. The difference is instead marked by a backwater-driven (Fernandes et al., 2016; Wu and Nitterour, 2019) increase in mudstone from negligible volume to 2% of the strata (Table 2.3), and the disappearance of extensive desiccation-chip pavements. Proximal braid-delta deposits (FA5) present strata that

preserve clear differences from braidplain settings, most notably 6% mudstone content (Table 2.3). Beyond the increase in fine-grained deposits, paleocurrent and architectural-element orientations indicate increased channel sinuosity (Fig. 2.8B, C), conglomerate lags are uncommon (Table 2.3), white-colored, coarse-grained sandstone cross-sets represent ~25% of the strata (Fig. 2.7A; Table 2.3), and bedding planes with sand-wave geometry occur (Table 2.3). However, desiccation cracks (Fig. 2.7D) and polygonal mud-chips require that the proximal braid delta was not entirely submerged. Distal braid delta strata (FA6) are distinct from the braidplain and even other braid-delta subenvironments. Mudstones make up 12% of the strata (Table 2.3), commonly in decimeter-thick beds that are more clay-rich than FA4–5. The thickness of the mudstones, interbedded conglomerate within mudstone intervals, sand injection into subjacent mudstone layers, increased clay matrix in sandstones, and abundant, deformed rip-up clasts provide strong evidence that fluidized-mud processes (Dalrymple and Choi, 2007; Longhitano, 2012) operated in the turbid water of the distal braid delta (Figs. 2.9, 2.10). Symmetrical and interference oscillation ripple-marked bedding planes (Fig. 2.9A; Table 2.3) require that much of the setting was drowned beneath shallow water. Rare sand waves composed of white-colored sandstone (Figs. 2.10A, B, 2.11B) indicate that larger waves could have transported sediments. Tidal processes, preserved in several sets of cross-strata migrating opposite paleoslope (Fig. 2.10C, D), may have taken a minor role in reworking the delta. Increased abundance of pebble conglomerate (Table 2.3) within the strata may be related to elevated energy in the system from tidal currents (Dalrymple and Choi, 2007). The braid-delta front (FA7) appears similar to the proximal braid delta, with key differences. Cross-bedded cosets are thicker than the other facies associations (Table 2.3), suggesting deposition in deeper water than elsewhere on the braid delta. Sets of white-colored coarse-grained sandstone increase from ~25% in FA5–6 to 50% in FA7 (Table 2.3), lending credence to the possibility of marine, wave-induced formation. Finally, trace fossils (Fig. 2.13D) on bedding planes above mudstone or fine-grained sandstone record the activity of metazoans that occupied the saline water of the braid-delta front. The consistent architectural-element assemblage of the Wood Canyon Formation in the Marble Mountains, including channel-fill, VA, DA, and DLA elements of coarse-grained sandstone that comprise the bulk of the strata (Tables 2.2, 2.3), define a fluvial-dominated braid delta (Galloway, 1975; Liangquing and Galloway, 1991) with minor influence from wave and tidal processes, similar to deltas described from the Paleoproterozoic Burnside Formation (McCormick and Grotzinger, 1993) and Mesoproterozoic Açuruá Formation (Magalhães et al., 2015).

Perennial freshwater input into the delta is required to form the observed strata. Throughout the stratigraphy, in each location on the braid delta, there are examples of episodic accretion of compound barforms, changes in flow direction around barforms, mudstone lags within accretion surfaces, and an absence of upper flow regime structures. Such features are common to fluvial systems in which deposition is primarily controlled by bankfull floods, as opposed to larger floods in flashy, ephemeral systems (Fielding et al., 2018). Furthermore, desiccation structures and polygonal mud-clasts are rare in the distal braid delta and delta front, whereas ripple marks and symmetrical sand waves are common (Table 2.3), indicating near-complete submergence where the system

approached the coastline. To develop the documented fluidized muds, a stable salt wedge must be maintained (Dalrymple and Choi, 2007; Longhitano, 2012), requiring consistent freshwater input.

Figure 2.17 depicts the perennial, non-vegetated, fluvial-dominated braid delta of the Pukaki River at Lake Pukaki, NZ, a near-analogue for the proposed middle member Wood Canyon Formation braid-delta system. Although periglacial and prograding into a controlled lake where no tidal modification is possible, the general scale and morphology of the delta mirror that observed in facies associations FA4–7 and presented in Figure 2.15A. The area representative of FA4 is a braidplain, generally not influenced by deltaic processes (Fig. 2.17). In the FA5 analogue zone, in-channel ponding occurs as a result of backwater effects in the proximal braid delta. Partial submergence of the distal braid delta characterizes FA6, whereas the fully submerged mouth bars on the braid-delta front resemble hypothetical FA7 bedforms.

Major differences between the middle-member braid-delta strata and other pre-vegetation examples are apparent after detailed facies and architectural analysis. Systems of similar age and older are commonly reported as nearly absent of delta-plain or delta-front mudstone (Went, 2019) and preserving clear tidal (Eriksson et al., 1995; Bradley et al., 2018; Levell et al., 2019) or wave (Plummer, 1990) influence represented in sedimentary structures. Examples commonly preserve mudstone facies interpreted as prodelta deposits (e.g., Junilla and Young, 1995; Røe, 1995; Stutenbecker et al., 2019) that are not found in the Wood Canyon Formation. Consequently, prevailing hypotheses suggest that braid deltas typically lack mudstone in the sedimentary record, similar to their fluvial counterparts (Long, 2011; Almeida et al., 2016b). Findings from the middle member Wood Canyon Formation do not support that all pre-vegetation braid deltas are without significant mudstone deposits or that fluvial dominance of ancient braid deltas is uncommon. The stable hydrograph of the fluvial system may result in both differences. Steady input of fresh water from an active channel belt caused the development of backwater effects (Fernandes et al., 2016; Wu and Nitterour, 2019) that forced the deposition of suspended fines. Density differences between fresh and saline water, paired with tidal processes (Nichols, 1984; Walsh and Ridd, 2008), formed a maximum turbidity zone (Dalrymple and Choi, 2007). Fluvial energy from the perennial system dominated deposition on the braid delta, overwhelming the influence of tide- and wave-driven processes that could actively rework sediments were the system an ephemeral one.

Sequence Stratigraphic Implications

The sequence stratigraphic framework for the middle member Wood Canyon Formation has positioned the base within a falling-stage systems tract (FSST) that progresses to a lowstand system tract (LST; Hogan et al., 2011). The gradual transgression recorded within the middle member in the studied section does not appear to align with prior findings that would expect progradation of the braid delta. The most plausible explanation for the discrepancy with prior interpretations is that the middle member is time transgressive, where southern Marble Mountains stratigraphic sections sitting landward of the craton-hinge zone (Cooper and Fedo, 1993; Cooper and Fedo, 2001), are

marginally younger than those deposited further basinward (Fig. 2.1A). In the basin, middle member sections have gradational contacts with subjacent highstand systems tract (HST) lower member sediments (Fig. 2.1A), supporting progradation during the FSST (Hogan et al. 2011). But, once deposition began on the craton at the present-day Marble Mountains, sea level may have already reached the lowstand systems tract (LST). In this scenario, the braidplain at the Marble Mountains developed primarily under slow sea-level rise (Dalrymple, 2010), forming the observed transgressive facies patterns (Fig. 2.3).

Bridging Sections N66 and S66 (Fig. 2.1) is an important step of understanding the systems but is unfortunately interrupted by Cenozoic faulting, erosion, and rhyolitic flows covering the area between the localities (Fedo and Cooper, 1990). Still, broader stratigraphic order, basic lithology, and consistent overall paleoflow directions (Fig. 2.18) between the fluvial (FA1; 344°), braidplain-to-delta transition (FA4; 329°), and braid delta (FA5–7; 354°) indicate that each represent part of the same fluvial system. Although facies-association variability occurs at Section S66 (Fig. 2.18; Muhlbauer et al., 2020), it cannot be linked conclusively to the transgression recorded in the braid delta. Blum and Törnqvist (2000) suggested that change in marine base level is the primary control driving preservation a few tens of km upstream from the river mouth, the area occupied by the braid delta. Therefore, much of the facies heterogeneity found in Muhlbauer et al. (2020) likely resulted from autogenic processes in the braidplain, possibly migration of active channel belts (Hajek and Wolinsky, 2012). The absence of strata with FA4–7 characteristics at Section S66 (Fig. 2.18), specifically near the contact with the upper member, implies an abrupt change from fluvial to marine depositional environments. This complete drowning of the fluvial system was rapid enough that there was not time for deltaic deposition before the major transgression in the upper member. In Section N66, the transgression from the middle to upper member is gradational, as the braid delta was fully established by gradual sea-level rise before the time of the major transgression.

Habitability Assessment

Definitive trace fossils in the middle member, including cf. *Aulichnites*, are restricted to bedding planes above mudstone to fine-grained sandstone beds within FA7, the upper 18 m of the braid delta nearest to the marine upper member of the Wood Canyon Formation (Fig. 2.3; Table 2.3). The bedding-plane subparallel ichnofossils, and the fine-grained nature of the sediment, is indicative of organisms foraging for nutrients at the sediment-water interface in the delta front. No recognizable trace fossils are found within the braid delta, interpreted by fluidized-mud deposits to have contained brackish water, so the organisms that made the preserved traces on the braid-delta front were apparently not adapted to survive reduced or variable salinities (Buatois et al., 2005). Because braid deltas with perennial freshwater input can be expected to contain brackish water, adaptation to such conditions is a major barrier to ancient metazoans surviving in fresh water on the continents. Even in present-day deltaic and estuarine settings, the variable-salinity, high-turbidity zones of the system have the lowest biodiversity (Buatois et al., 1997; Dalrymple and Choi, 2007). Combining the salinity problem with rapid sedimentation, strong current, and high turbidity created a harsh environment for

metazoan life attempting to traverse braid deltas in the early Cambrian. Reports of trace fossils within the middle member Wood Canyon Formation in the northern Nopah Range and Kingston Range of California, proposed by Kennedy and Droser (2011) to represent life adapted to survive fresh water, are concentrated near mudstone layers and the gradational boundary with the marine lower member. It is likely that these organisms were active in areas where marine salinity encroached into the fluvial system at its most distal reaches (Davies and Gibling, 2012; McIlroy, 2012), possibly within a braid-delta front setting (e.g., Fig. 2.15A).

Conclusions

Detailed stratigraphic logging, facies analysis, and stratigraphic panels of the middle member Wood Canyon Formation, north of Rt. 66 in the southern Marble Mountains, are presented herein. The following points improve on prior descriptions of depositional environment for the member and hold significance for the classification of other pre-vegetation distal fluvial or deltaic systems.

1. A zone a braidplain-to-delta transition is recorded in FA4 above a nonconformity with basement rock, progressing through 20 m of the strata. Vertical, downstream, and downstream-lateral accretion of barforms and channel-fills remain similar to the corresponding braidplain but are distinguished by 2% siltstone in veneers or beds up to 5 cm in thickness.
2. Between 20–38 meters, lithofacies and architecture in FA5 record more apparent marine influence in a proximal braid delta, including 6% mudstone, mud-cracks, elevated sinuosity recorded from paleocurrents, and bounding surfaces that display sand-wave geometry.
3. In FA6, the strata between 38–60 meters, a variety of unique facies relationships represent a distal braid delta. Mudstone percentage is the highest in the middle member, at 12%, comprising decimeter-thick beds that show evidence for deposition as fluidized muds within the brackish waters of a maximum turbidity zone, a process not previously reported in pre-vegetation braid deltas. Abundant symmetrical and interference oscillation ripples indicate submergence of the distal braid delta beneath shallow water, and rare bedforms migrating opposite paleoslope may preserve minor tidal modification.
4. The 18 meters of FA7 strata below the boundary with the marine upper member Wood Canyon Formation were deposited on a submerged braid-delta front. Increased coset thickness, wave-formed structures, horizontal trace fossils, and abundant sandstone beds without clay matrix resulted from deposition in submerged mouth bars.
5. Bedding-plane subparallel ichnofossils discovered in FA7 on bedding planes of mudstone and fine-grained sandstone are traces of Terreneuvian organisms that lived on the braid-delta front in water of oceanic salinity. Unable to survive the brackish and turbid setting of the distal braid delta, metazoans did not migrate into the fluvial system.
6. Progression from more fluvial to more marine settings with increasing stratigraphic height requires that the middle member experienced gradual sea-level rise during deposition, separating the strata from braid delta examples

- deposited under regression. Likely Cambrian Series 2 in age, the Marble Mountains sections of the Wood Canyon Formation may represent deposition during slowly rising sea levels in a lowstand systems tract. Additionally, the clear transgression in the study area suggests that facies level variability in connected fluvial strata 8 km to the south is linked to autogenic processes, as the stratigraphy does not record the same transgressive pattern.
7. Unlike many other pre-vegetation braid deltas, the middle member Wood Canyon Formation system records significant mudstone landward of the delta front, over 10% of the strata in some intervals, and hosts few tidal sedimentary structures. In the case of perennial fluvial input, braid-delta strata can be distinguished from their fluvial counterparts through increases in mudstone deposition, sinuosity, coset thickness, and oscillatory flow structures. Upcoming study should focus on identifying similarities to middle member strata in other similar-age or older distal-fluvial formations and in modern analogues.

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Appendix A-2

Table 2.1: Lithofacies code definitions.

Lithofacies code	Facies / Sedimentary structures
Gm	Very fine- to medium-pebble conglomerate, clast-supported, massive or crudely bedded. Massive
Gh	Very fine- to medium-pebble conglomerate, clast-supported, crudely bedded. Horizontal beds
Gt	Very fine- to medium-pebble conglomerate, clast-supported, stratified. Trough cross-sets
Sm	Very fine- to very coarse-grained sandstone, $\pm$ granules. Massive or faint lamination
Sh	Very fine- to very coarse-grained sandstone, $\pm$ granules. Horizontal lamination, parting lineation
St	Fine- to very coarse-grained sandstone, $\pm$ granules. Trough cross-sets
Sp	Fine- to very coarse-grained sandstone, $\pm$ granules. Tabular cross-sets
Sl	Fine- to very coarse-grained sandstone, $\pm$ granules. Low-angle cross-sets (less than 15° foreset dip angle)
Sr	Very fine- to coarse-grained sandstone, $\pm$ granules. Ripple cross-lamination
Fm	Claystone or siltstone. Massive, desiccation cracks
Fl	Claystone or siltstone. Fine lamination, small ripples

Representative images in Figure 2.4. From Miall (1985).

Table 2.2: Architectural element (AE) code definitions.

AE code	AE	Description
CH	Channel fill	Multiple orders, concave-up or inclined lower bounding surface, filled with SB or GB. May contain VA, DA, or DLA elements. Channels have low angle margins
VA	Vertical accretion	Set boundaries within a coset do not have systematic dip-direction orientation, barforms have convex-up geometry
DA	Downstream accretion	Foreset dip directions match set-boundary dip directions within a coset ($\pm 30^\circ$), barforms have convex-up geometry
DLA	Downstream-lateral accretion	Foreset dip directions are oriented 30° – 60° oblique to set-boundary dip directions within a coset, barforms have convex-up geometry
SB	Sandy bedform	Bed of very fine- to very coarse-grained sandstone; St, Sp, Sl, Sh, Sm, or Sr lithofacies
GB	Gravel bedform	Bed of very fine- to medium-pebble conglomerate; Gm, Gh, or Gt lithofacies

From Miall (1985, 1996), Long (2006), and Muhlbauer et al. (2020).

Table 2.3: Summary of facies association (FA) characteristics found in the middle member of the Wood Canyon Formation at the study area, based on detailed stratigraphic logging.

FA	Stratigraphic interval (m)	Coast thickness range (cm)	% mud-stone	% fine-grained sandstone	# of conglomer. beds	# chaotic mud-clast beds	# ripple mark surfaces	% white sandstone beds	# of sand waves	Paleocurrent trends	Lithofacies	AE	Interpretation
FA7	60–78 (18 m)	20–155	6	2	6	2	4	46	3	Variable	St, Sp, Sr, Sm, Fm, Fl, Gm, Gh	DA, DLA, VA, CH, SB, GB	Braid-delta front
FA6	38–60 (22 m)	15–128	12	5	13	11	16	23	3	Variable	St, Sp, Sl, Sh, Sm, Sr, Fl, Fm, Gm	DA, DLA, VA, CH, SB, GB	Distal braid delta; turbidity maximum zone
FA5	20–38 (18 m)	15–130	6	3	5	0	1	27	2	Variable	St, Sl, Sp, Sr, Sh, Sm, Fl, Fm	DA, DLA, VA, CH, SB	Proximal braid delta
FA4	0–20 (20 m)	12–98	2	2	17	2	1	6	0	Unimodal NNW	St, Sp, Sl, Sm, Fl, Fm, Gm, Gh, Gt	DA, DLA, VA, CH, SB, GB	Braidplain-to-delta transition

Lithofacies abbreviations defined in Table 2.1; Architectural elements (AE) defined in Table 2.2. The complete dataset is available in the included Appendix A-4.

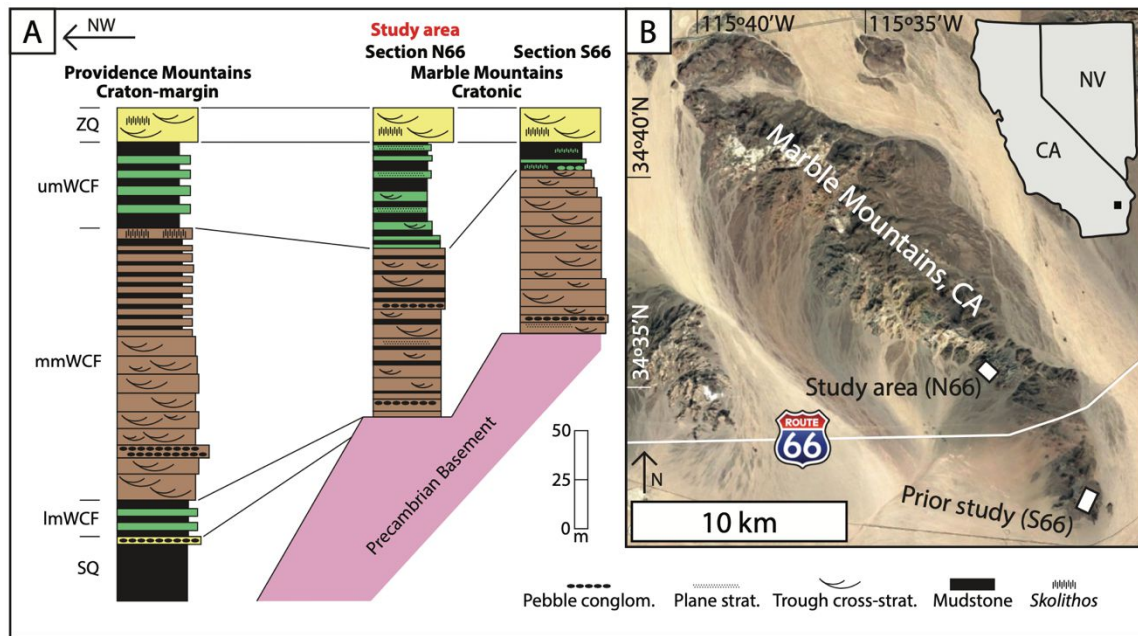


Figure 2.1: Stratigraphic and geographic context for the study locality. A) General stratigraphic columns illustrating the lateral relationship between the southern Marble Mountains (Fedo and Cooper, 1990) and Providence Mountains (Fedo and Cooper, 2001). Note the basal nonconformity and thinning of the middle member in the Marble Mountains. lmWCF, mmWCF and umWCF– lower, middle, and upper member Wood Canyon Formation, respectively; SQ– Stirling Quartzite; ZQ– Zabriskie Quartzite. B) Location of Sections N66 (this study) and S66 (Muhlbauer et al., 2020) in the Marble Mountains, California, USA. Image from Google™ Earth.

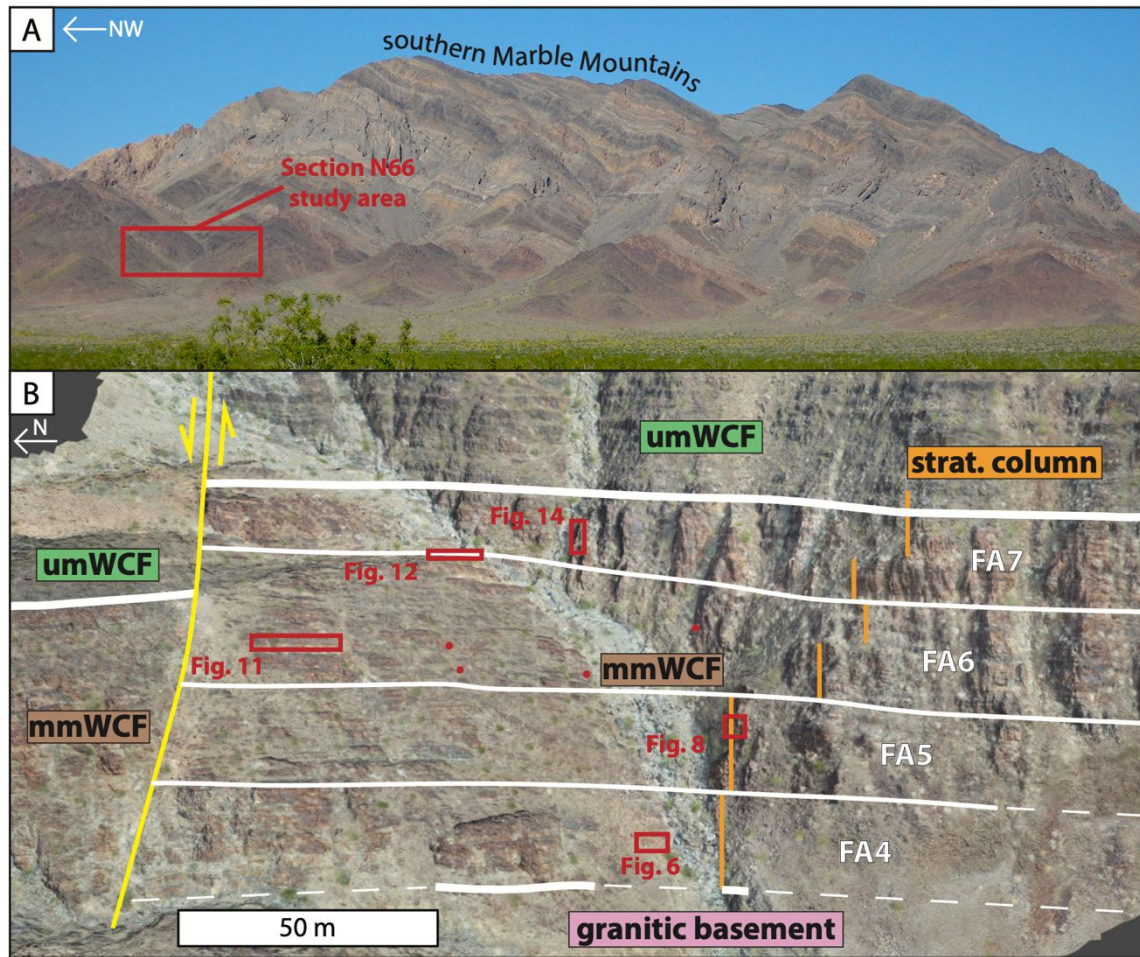


Figure 2.2: Images showing the study area and locations of recorded observations. A) Photograph of the southern Marble Mountains including the location of Section N66. B) Structure-from-Motion digital outcrop model of Section N66, with bedding oriented normal to the viewer. mmWCF and umWCF– middle and upper member Wood Canyon Formation, respectively; strat. column– stratigraphic column. White lines (solid or dashed) separate each facies association (FA4–7). Stratigraphic column (Fig. 2.3) logged along the orange lines. Trace of a large, left lateral, strike-slip fault is mapped with a yellow line. Locations of stratigraphic panels for each facies association are marked with red boxes. Red dots record the location of images presented in Figure 2.10.

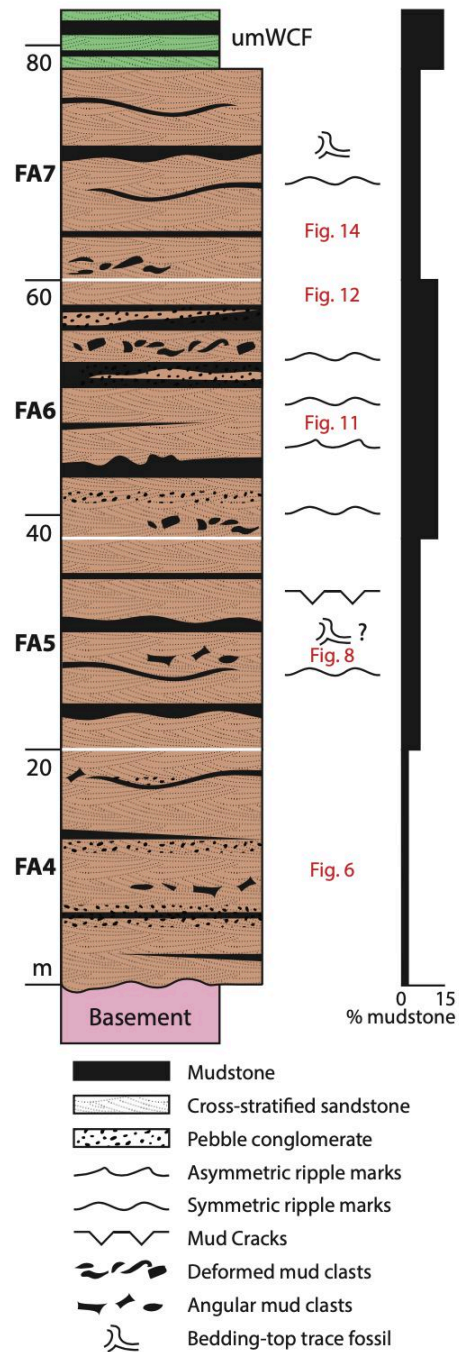


Figure 2.3: Simplified stratigraphic column of Section N66, including the stratigraphic thicknesses of each facies association (FA4–7), sedimentary structures, and mudstone percentage calculated for each interval. Constructed via bed-by-bed stratigraphic logging; see additional information in Table 2.3.

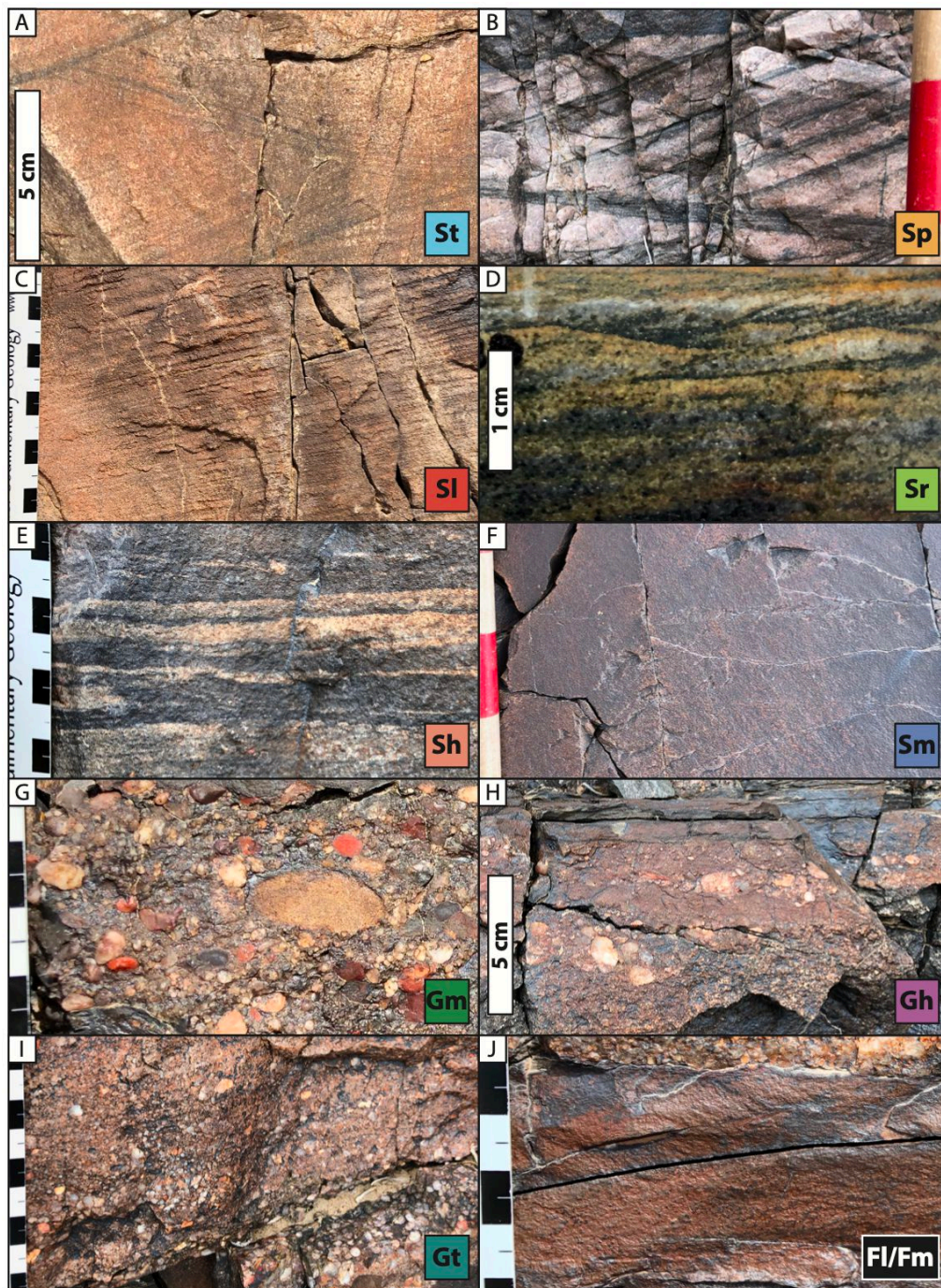


Figure 2.4: Representative images for each lithofacies identified at Section N66 in the Marble Mountains, and corresponding codes (defined in Table 2.1). Fill colors correspond to those used to illustrate stratigraphic panels in this study (Figs. 2.6, 2.8, 2.11, 2.12, 2.14). Scale in cm; Jacob's staff increments are 10 cm.

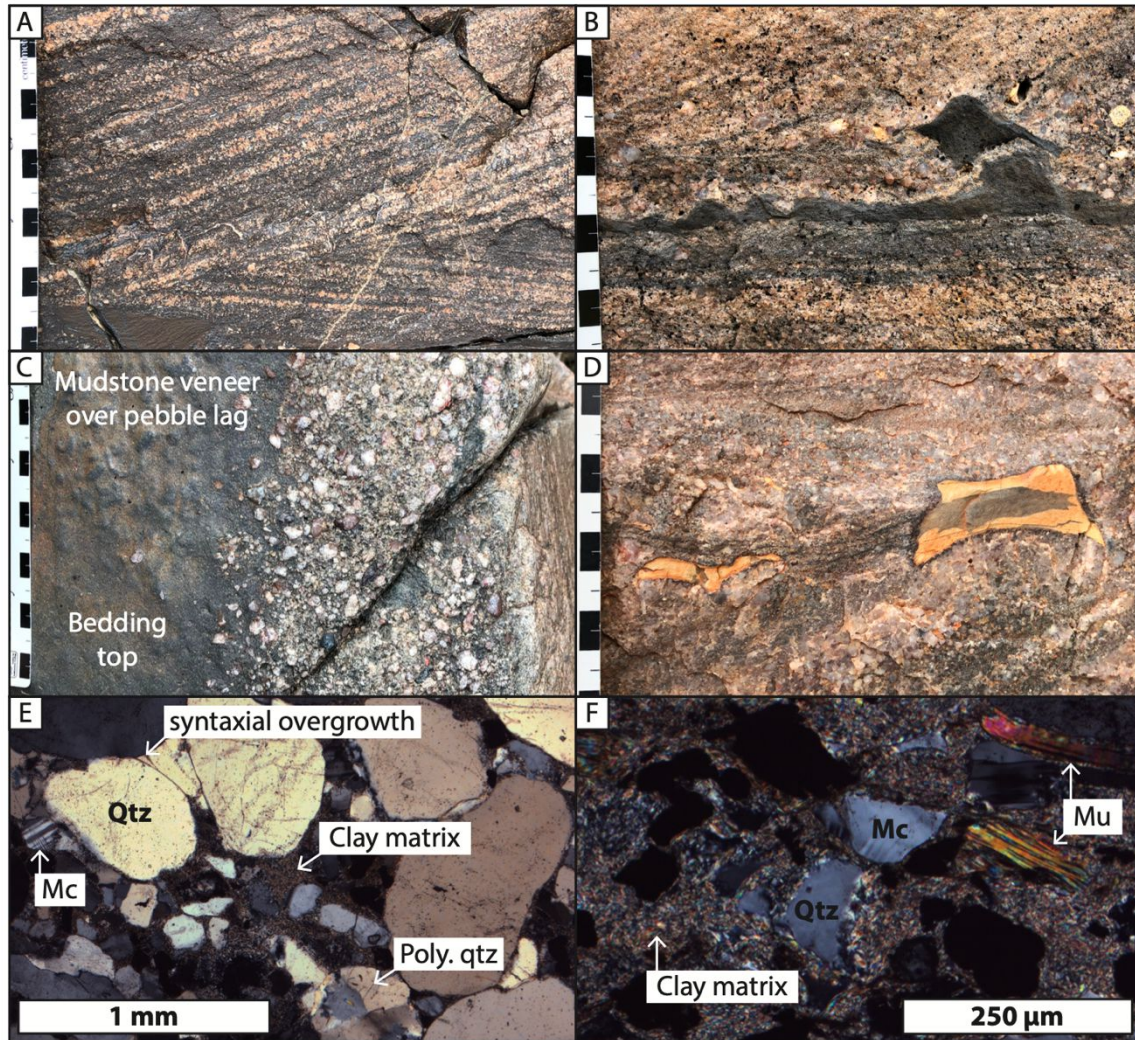


Figure 2.5: Images and photomicrographs of characteristic FA4 strata. Scale in cm unless otherwise noted. A) Trough cross-bedded (St), brown-to-tan, coarse-grained subarkose common to the middle member Wood Canyon Formation. B) Siltstone (Fl) layer with possible flame structures and a preserved rip-up clast inside a granular, cross-bedded, coarse-grained sandstone lag at the base of a coset. C) Bedding-top view of a mudstone veneer deposited over a pebble layer (Gh) at the top of the subjacent coset. D) “Bowtie-shaped” polygonal desiccation chips in cross-stratified, very coarse-grained subarkose. E) Poorly sorted, coarse-grained sandstone with monocrystalline and polycrystalline quartz (Qtz), microcline (Mc), syntaxial overgrowths on well-rounded quartz grains, and clay in matrix. Sample MM219-05. F) Fine-grained sandstone with quartz (Qtz), microcline (Mc), muscovite (Mu), and abundant clay in matrix. Concave grain boundaries on quartz indicate possible infill of authigenic clays between framework clasts. Sample MM219-28.

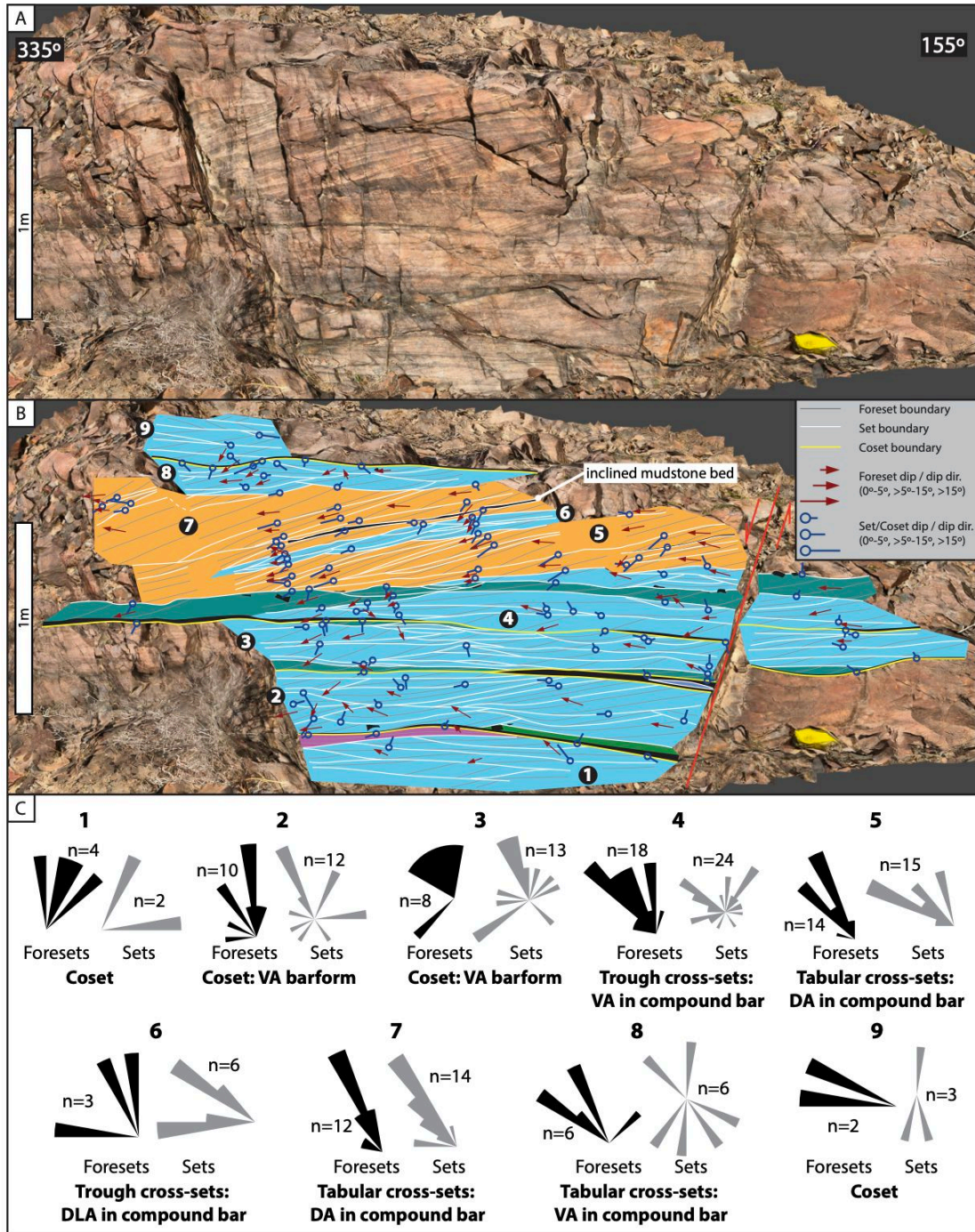


Figure 2.6: Stratigraphic panel representative of FA4 strata with corresponding orientation data. A) Three-dimensional digital outcrop model with bedding oriented normal to viewer. Orientation of the rock face noted in degrees. B) Stratigraphic panel with fill colors corresponding to lithofacies in Fig. 2.4 and described in Table 2.1. Fault with cm-scale offset marked in with a red line. Numbers correspond to C) areas 1–9 of restored orientation-measurement rosettes for foreset- and set-boundary (if any) dip directions, with interpretations where data permit. Data available in Muhlbauer and Fedo (2020) supplemental file.

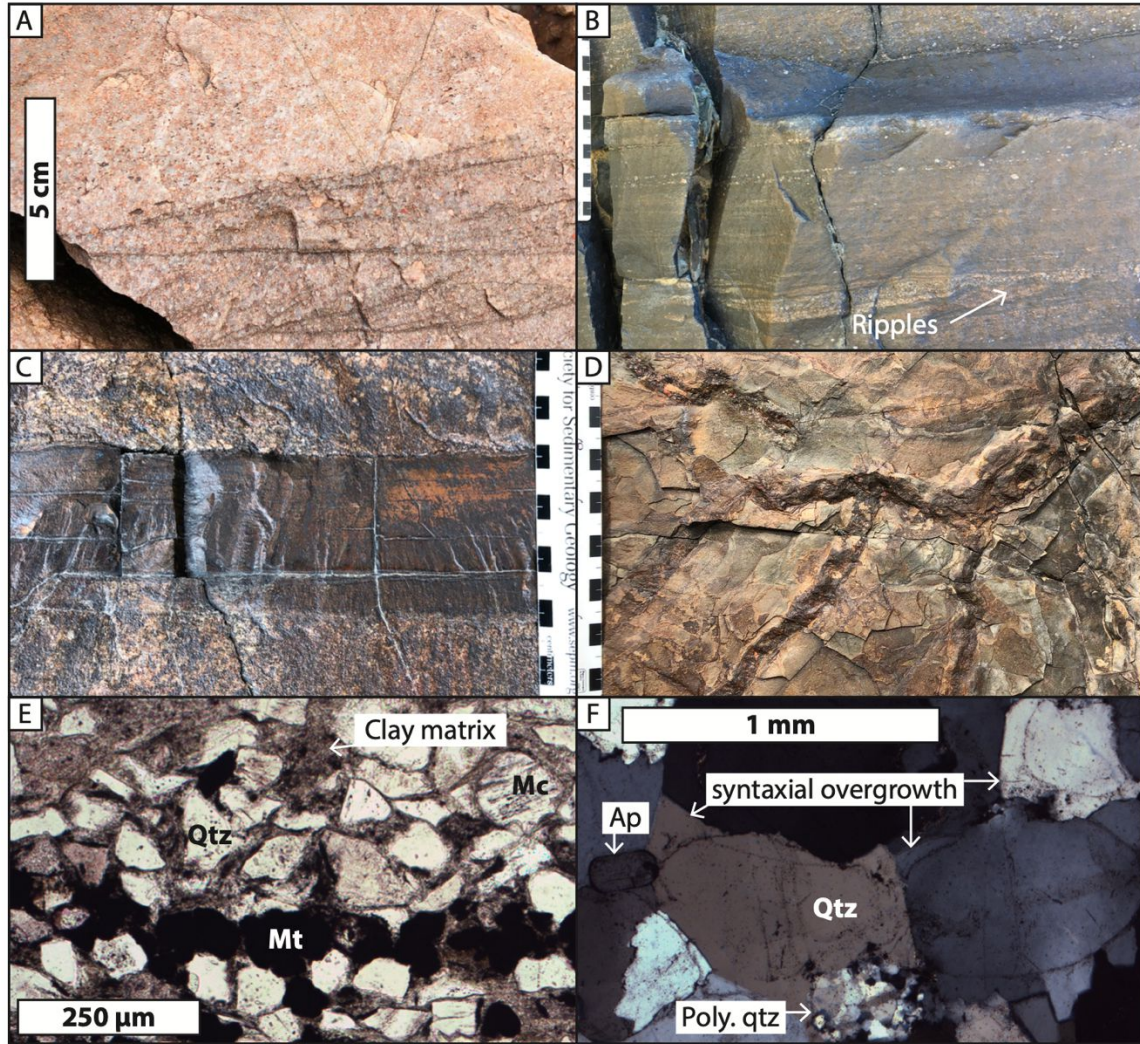


Figure 2.7: Images and photomicrographs of characteristic FA5 strata. Scale in cm unless otherwise noted. A) White, quartz-cemented, coarse-grained subarkose with trough cross-sets (St). B) Horizontal-bedding (Sh) and ripple cross-lamination (Sr) in fine- to medium-grained sandstone. C) Planar siltstone bed (Fl) bed between two cosets. D) Curvilinear desiccation cracks in a mudstone veneer. E) Photomicrograph of fine-grained subarkose with quartz (Qtz), microcline (Mc), primary and diagenetic magnetite (Mt) in a heavy-mineral lag, and hematite-stained clay matrix. Bed was dark-brown in outcrop. Sample MM219-13. F) Monocrystalline and polycrystalline quartz (Qtz) with extensive syntaxial cement and apatite (Ap), in coarse-grained sandstone. Bed was white colored in outcrop. Sample MM219-12.

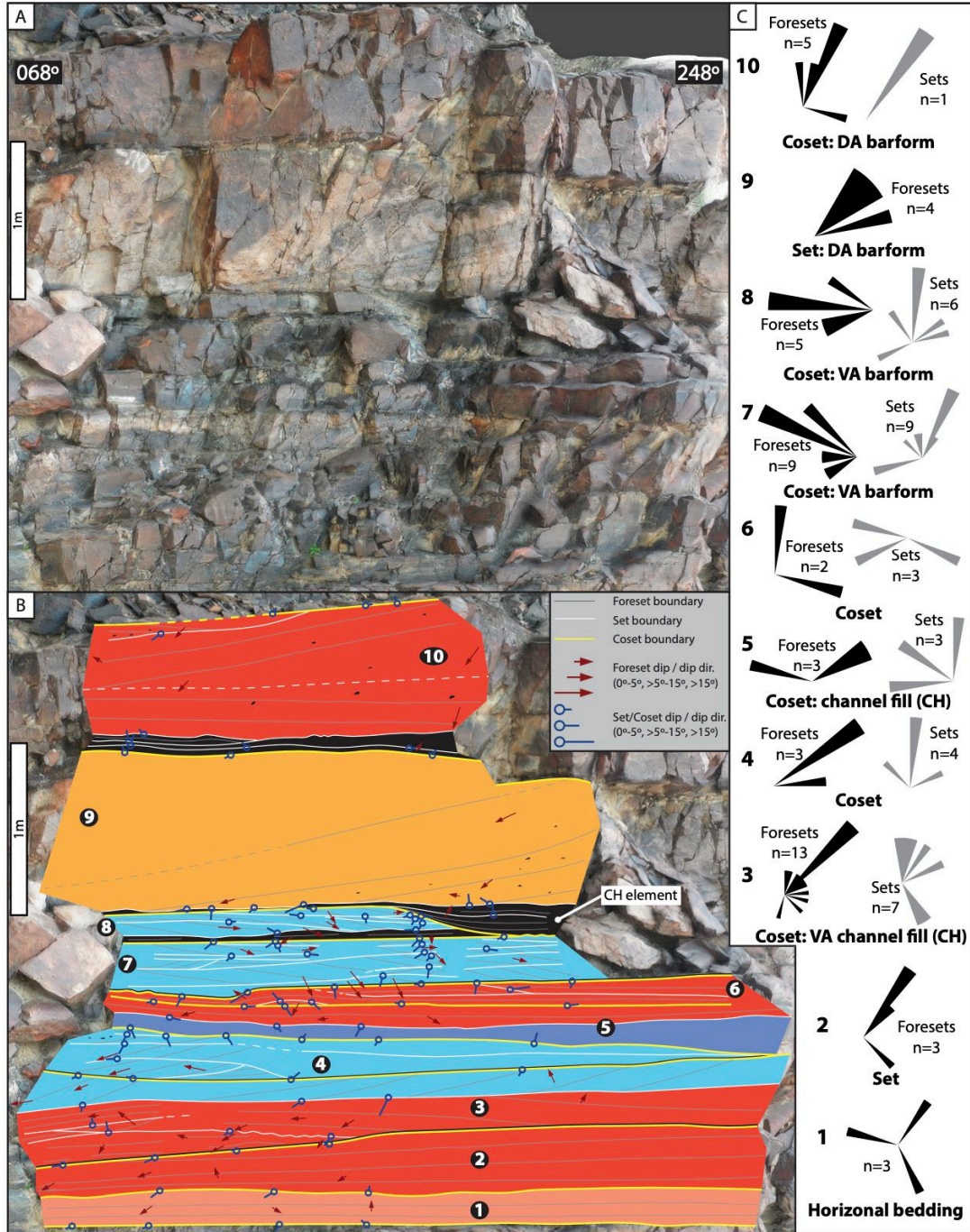


Figure 2.8: Stratigraphic panel representative of FA5 strata with corresponding orientation data. A) Three-dimensional digital outcrop model with bedding oriented normal to viewer. Orientation of the rock face noted in degrees. B) Stratigraphic panel with fill colors corresponding to lithofacies in Fig. 2.4 and described in Table 2.1. Numbers correspond to C) areas 1–10 of restored orientation-measurement rosettes for foreset- and set-boundary (if any) dip directions, with interpretations where data permit. Data available in Muhlbauer and Fedo (2020) supplemental file.

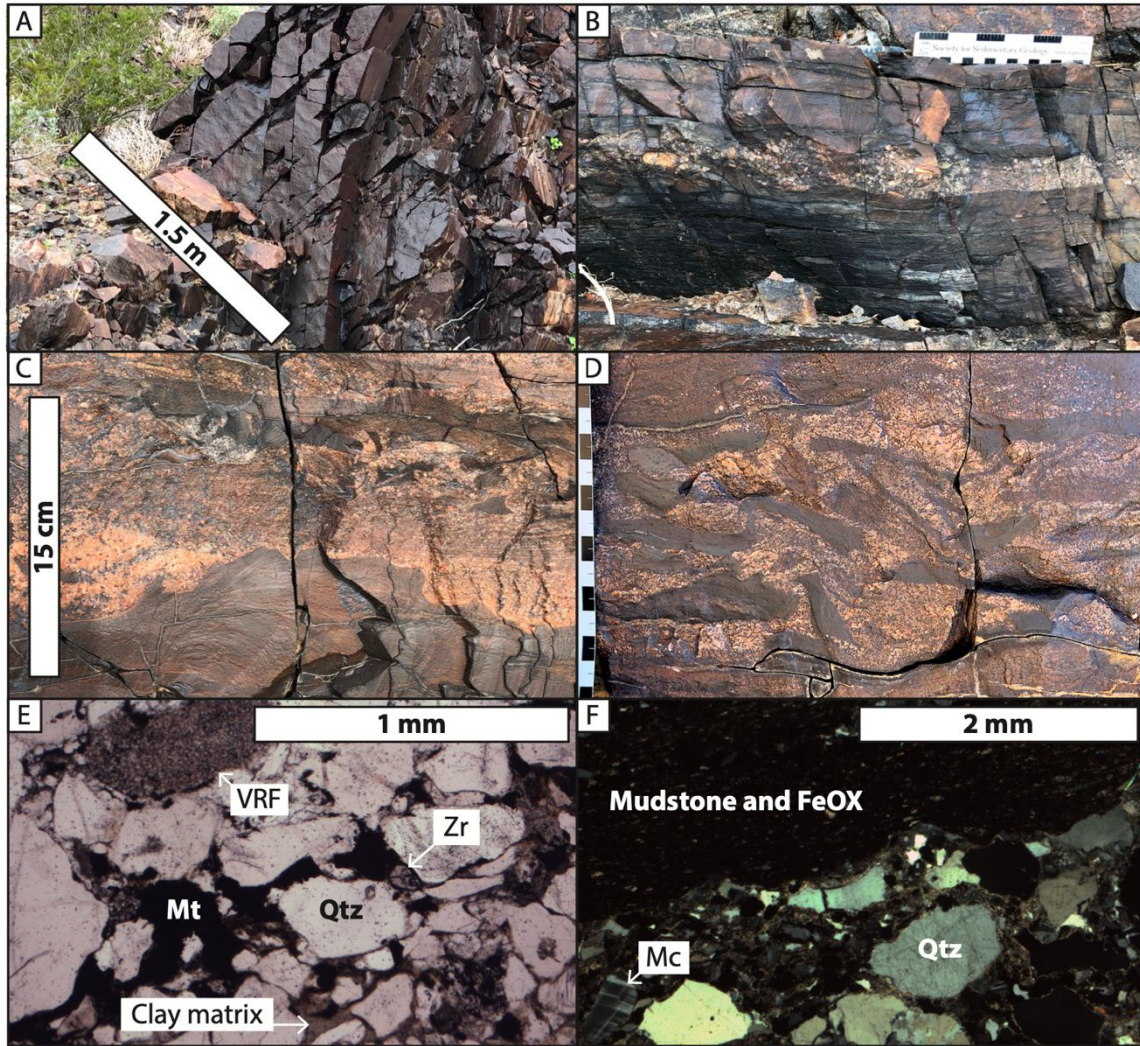


Figure 2.9: Images and photomicrographs of characteristic FA6 strata. Scale in cm unless otherwise noted. A) Symmetrical, oscillatory ripple marks resulting from east-west paleocurrent. B) Fluid-mud deposit with interbedded lens of fine- to medium-pebble conglomerate (Gm). C) Load-deformed mudstone (Fm) beneath a sandstone coset. D) Highly deformed mudstone rip-up clasts that were transported with tan, coarse-grained sand. E) Medium- to coarse-grained subarkose with quartz (Qtz), volcanic rock fragment (VRF), zircon (Zr), and diagenetic magnetite (Mt). Clay matrix is present between framework grains. Sample MM219-18. F) Sharp contact between a fluid mud layer (iron-stained mudstone) and a fine-pebble conglomerate interval with quartz (Qtz) and microcline (Mc) clasts. Note the pointed, concave grain boundaries on quartz clasts, similar to those in Figure 2.4F. Sample MM219-17.

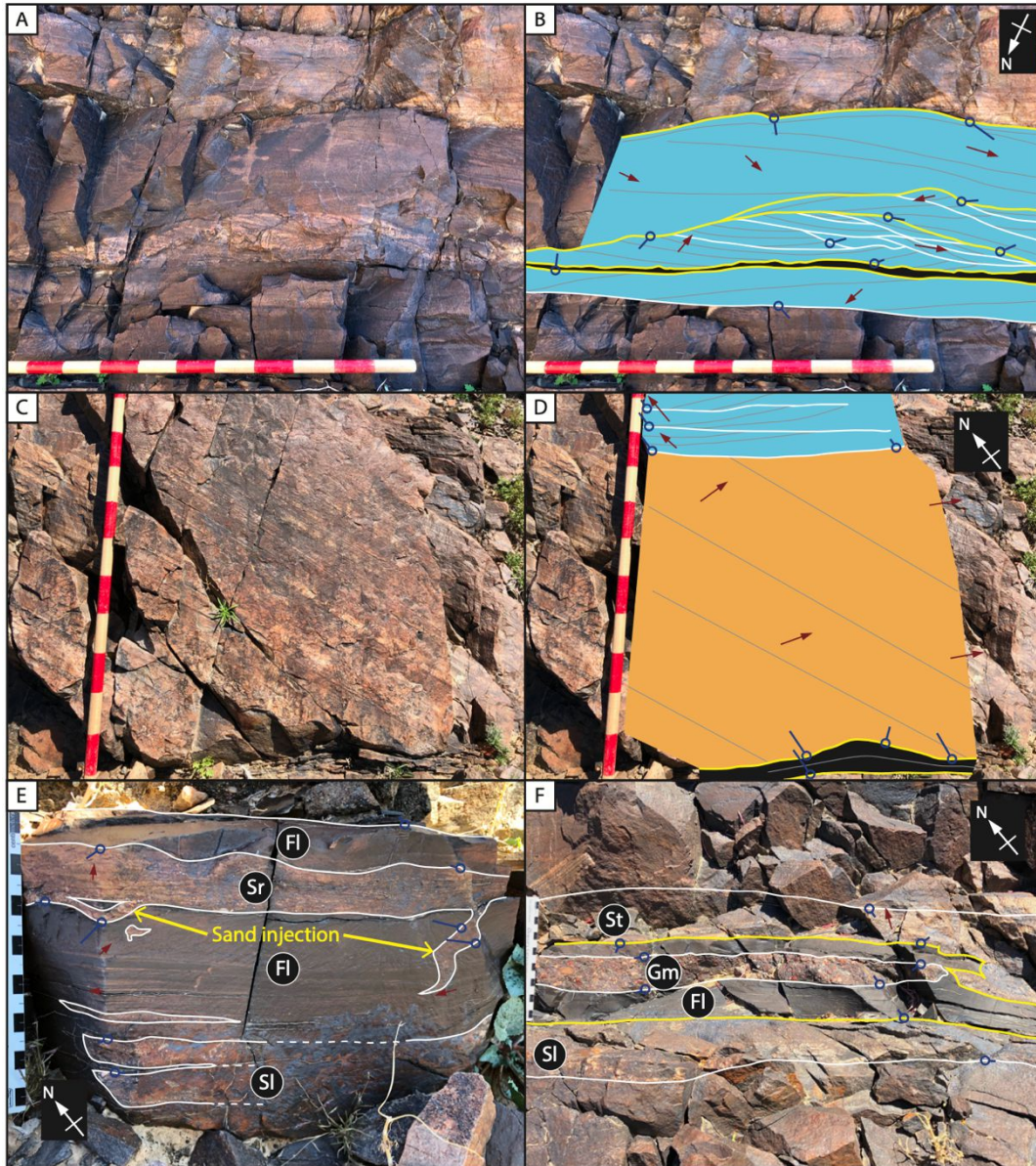


Figure 2.10: Stratigraphic panels of sedimentary structures and facies relationships found within FA6. Scale in cm; Jacob's staff increments are 10 cm. Panel notation defined in Fig. 2.6. Colors match the lithofacies codes on Fig. 2.4. Data available in Muhlbauer and Fedo (2020) supplemental file. A-B) Symmetrical sand wave in white-colored sandstone, with internal complexity in paleocurrent and accretion directions. C-D) Tabular cross-set (Sp) with southeast dip-direction of possible tidal origin. Overlying trough cross-beds have northward paleoflow indicators. E) Rippled sandstone (Sr) that injected into underlying fluid-mud deposit (Fl), deforming bedding planes. Below, mudstone is interbedded with fine-grained, horizontal-bedded sandstone (Sl). F) Pebble conglomerate (Gm) between two planar fluid-mud deposits (Fl). The interval is located between cosets of trough cross-sets (St) and low angle cross-bedding (Sl). Note that the upper fluid mud was scoured on the right of the image, removing both mudstone and subjacent conglomerate.

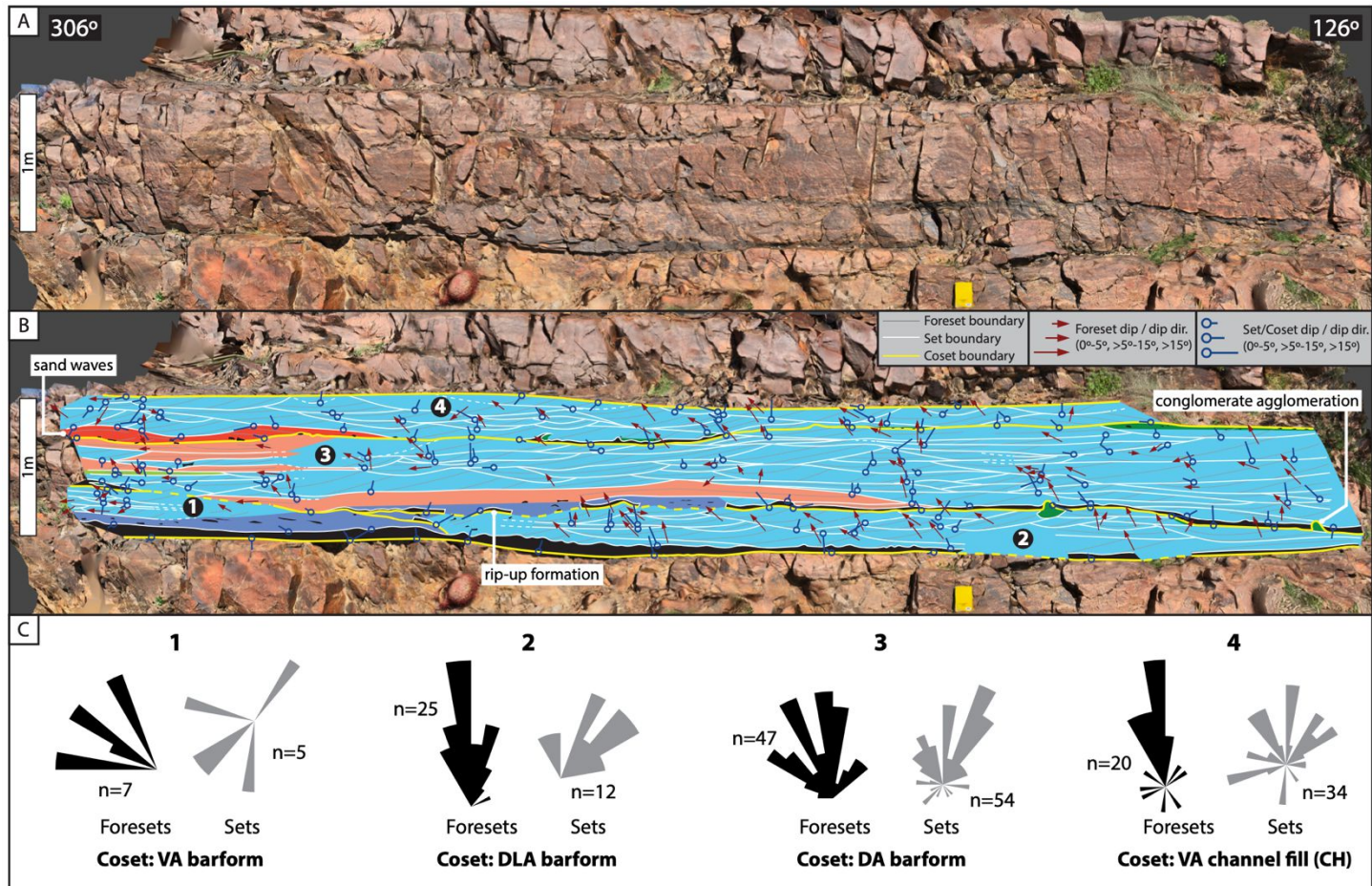


Figure 2.11: Stratigraphic panel representative of FA6 strata with corresponding orientation data, located at a stratigraphic height of 45 meters on the stratigraphic column. A) Three-dimensional digital outcrop model with bedding oriented normal to viewer. Orientation of the rock face noted in degrees. B) Stratigraphic panel with fill colors corresponding to lithofacies in Fig. 2.4 and described in Table 2.1. Numbers correspond to C) areas 1–4 of restored orientation-measurement rosettes for foreset- and set-boundary dip directions, with interpretations. Data available in Muhlbauer and Fedo (2020) supplemental file.

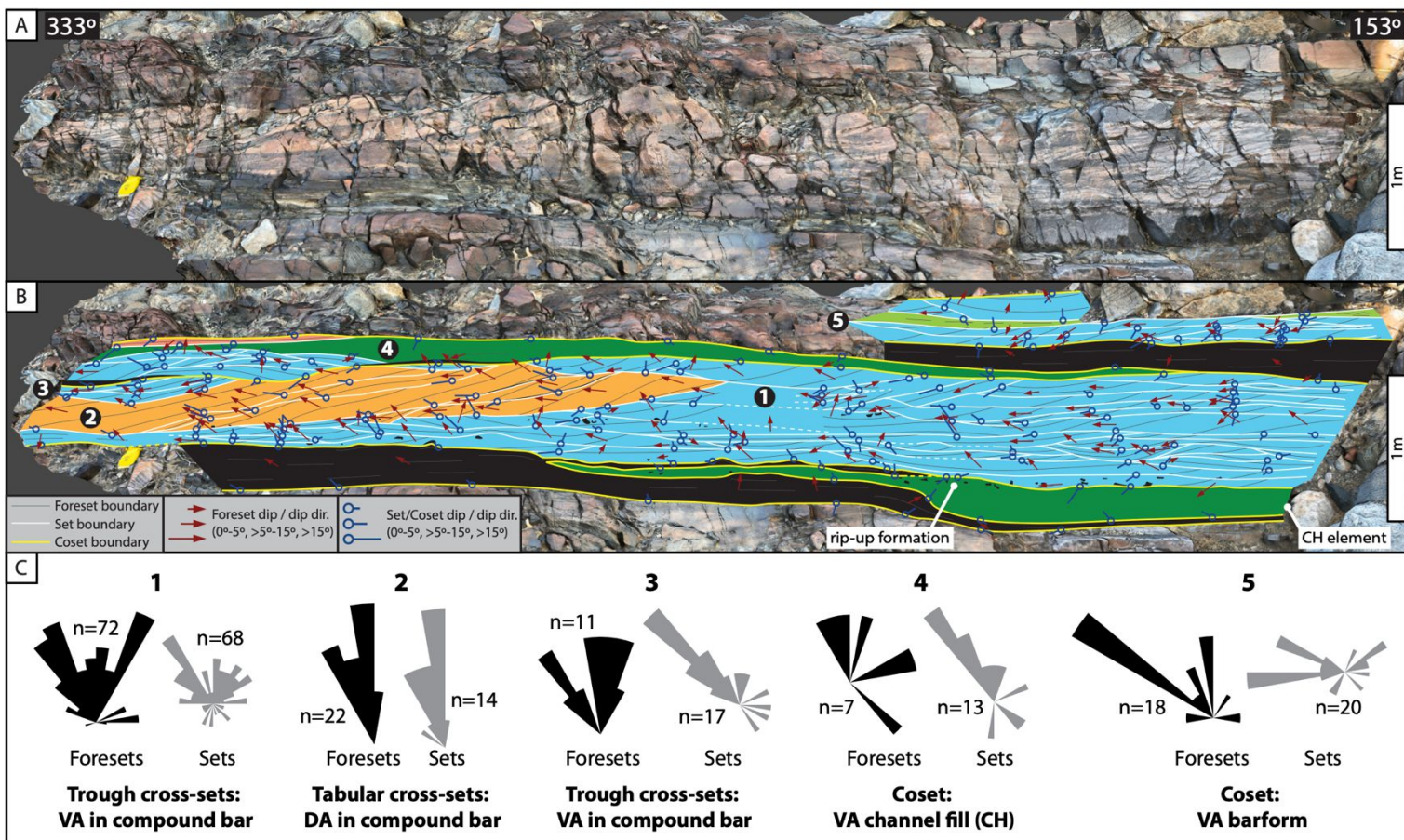


Figure 2.12: Stratigraphic panel representative of FA6 strata with corresponding orientation data, located near the upper boundary of the facies association. A) Three-dimensional digital outcrop model with bedding oriented normal to viewer. Orientation of the rock face noted in degrees. B) Stratigraphic panel with fill colors corresponding to lithofacies in Fig. 2.4 and described in Table 2.1. Numbers correspond to C) areas 1–5 of restored orientation-measurement rosettes for foreset- and set-boundary dip directions, with interpretations. Data available in Muhlbauer and Fedo (2020) supplemental file.

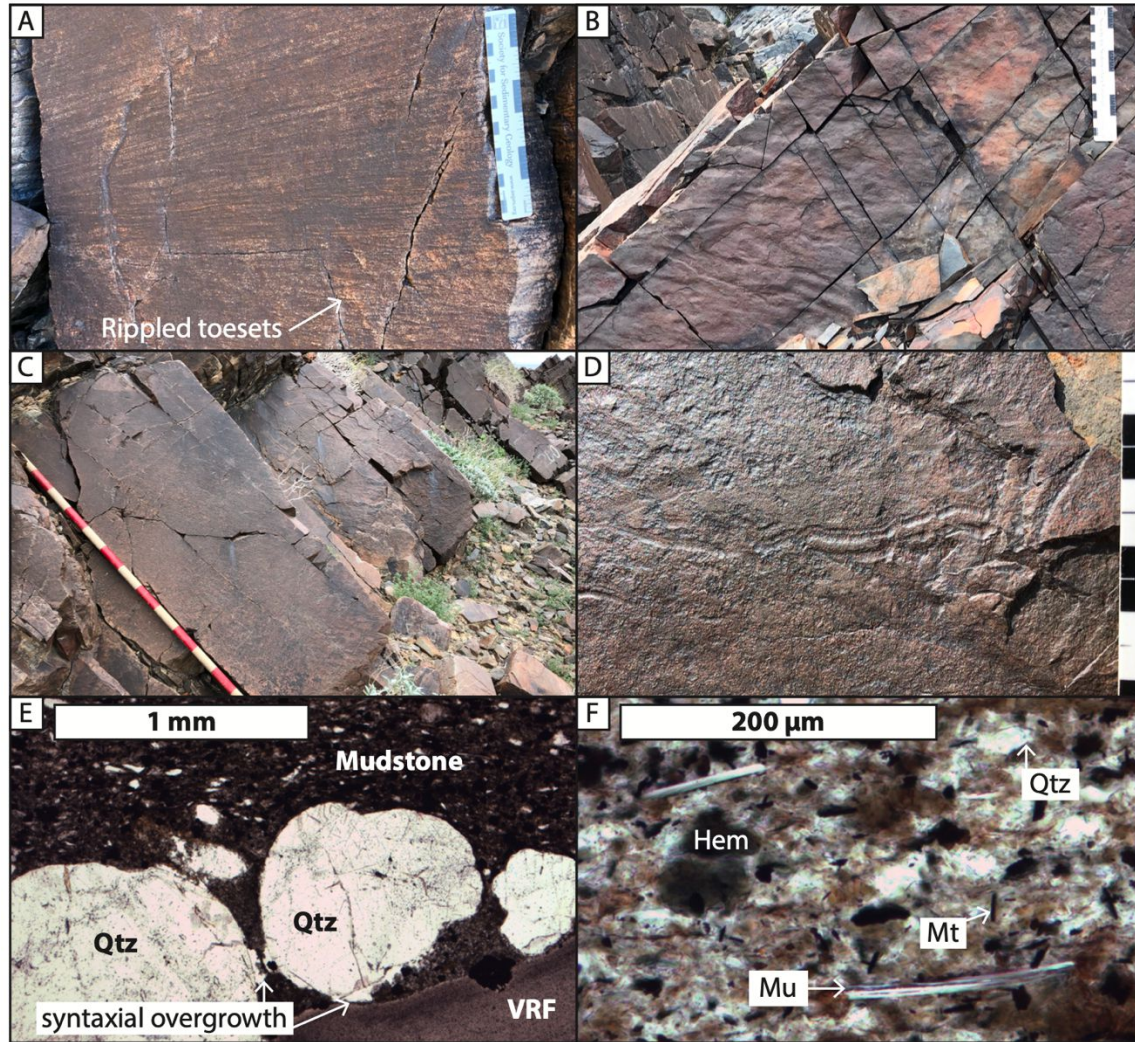


Figure 2.13: Images and photomicrographs of characteristic FA7 strata. Scale in cm; Jacob's staff increments are 10 cm. A) Trough cross-bed of medium-grained sandstone (St) with rippled toesets and finely laminated foresets. B) Symmetrical ripple marks preserved on fine-grained sandstone bedding plane. C) Featureless medium-grained sandstone (Sm) bed at the base of FA7, 1.5 meters thick. D) Representative cf. *Aulichnites* trace fossil on a bedding plane of fine-grained sandstone. E) Hematite-stained mudstone and coarse-grained sandstone contact, with quartz (Qtz) and volcanic rock fragment (VRF). Clay matrix and syntaxial quartz overgrowths occur between framework grains. Sample MM219-21. F) Mudstone with quartz (Qtz) silt, muscovite (Mu), patchy hematite, and diagenetic magnetite (Mt) crystals. Sample MM219-24.

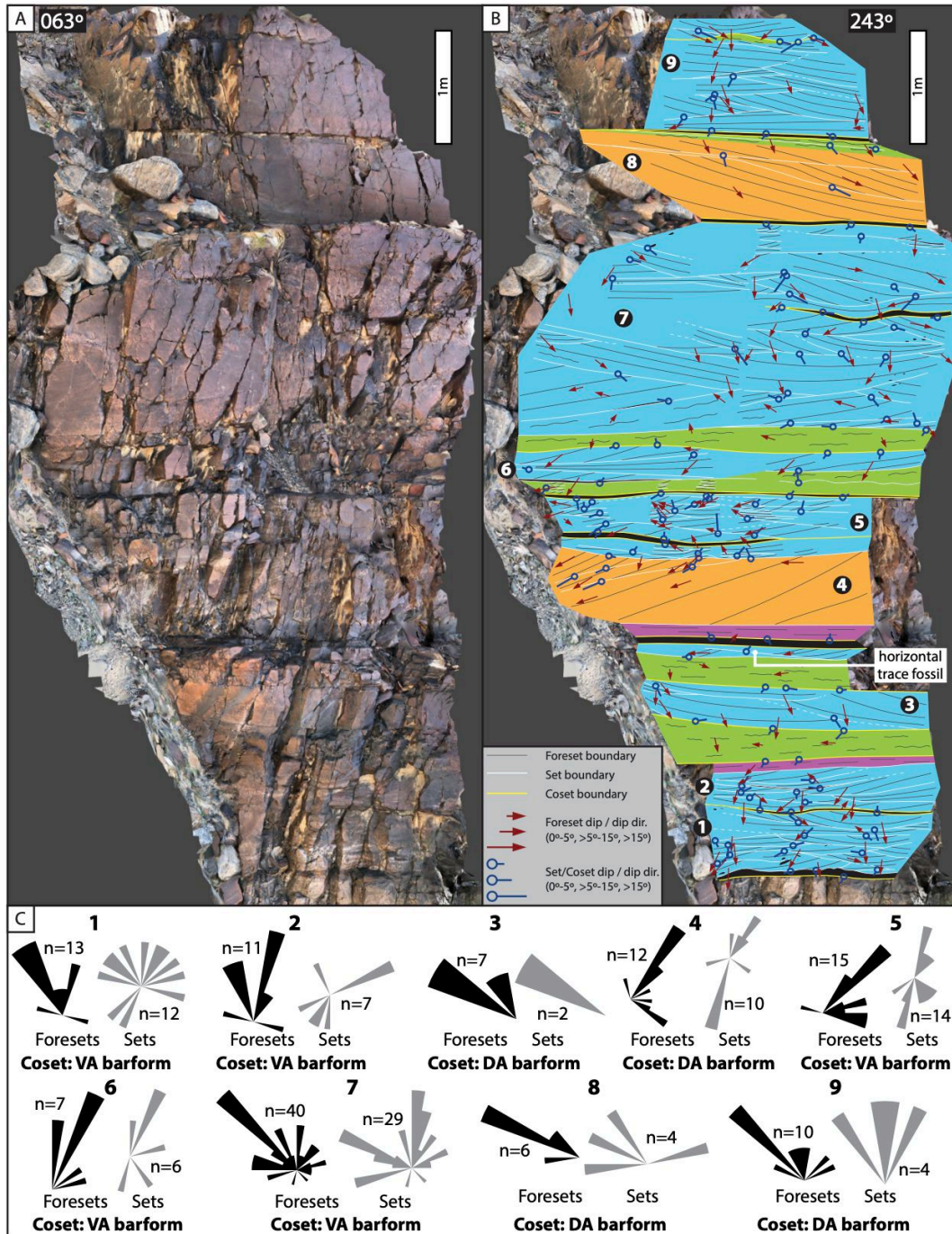


Figure 2.14: Stratigraphic panel representative of FA7 strata with corresponding orientation data. A) Three-dimensional digital outcrop model with bedding oriented normal to viewer. Orientation of the rock face noted in degrees. B) Stratigraphic panel with fill colors corresponding to lithofacies in Fig. 2.4 and described in Table 2.1. Numbers correspond to C) areas 1–9 of restored orientation-measurement rosettes for foreset- and set-boundary dip directions, with interpretations. Data available in Muhlbauer and Fedo (2020) supplemental file.

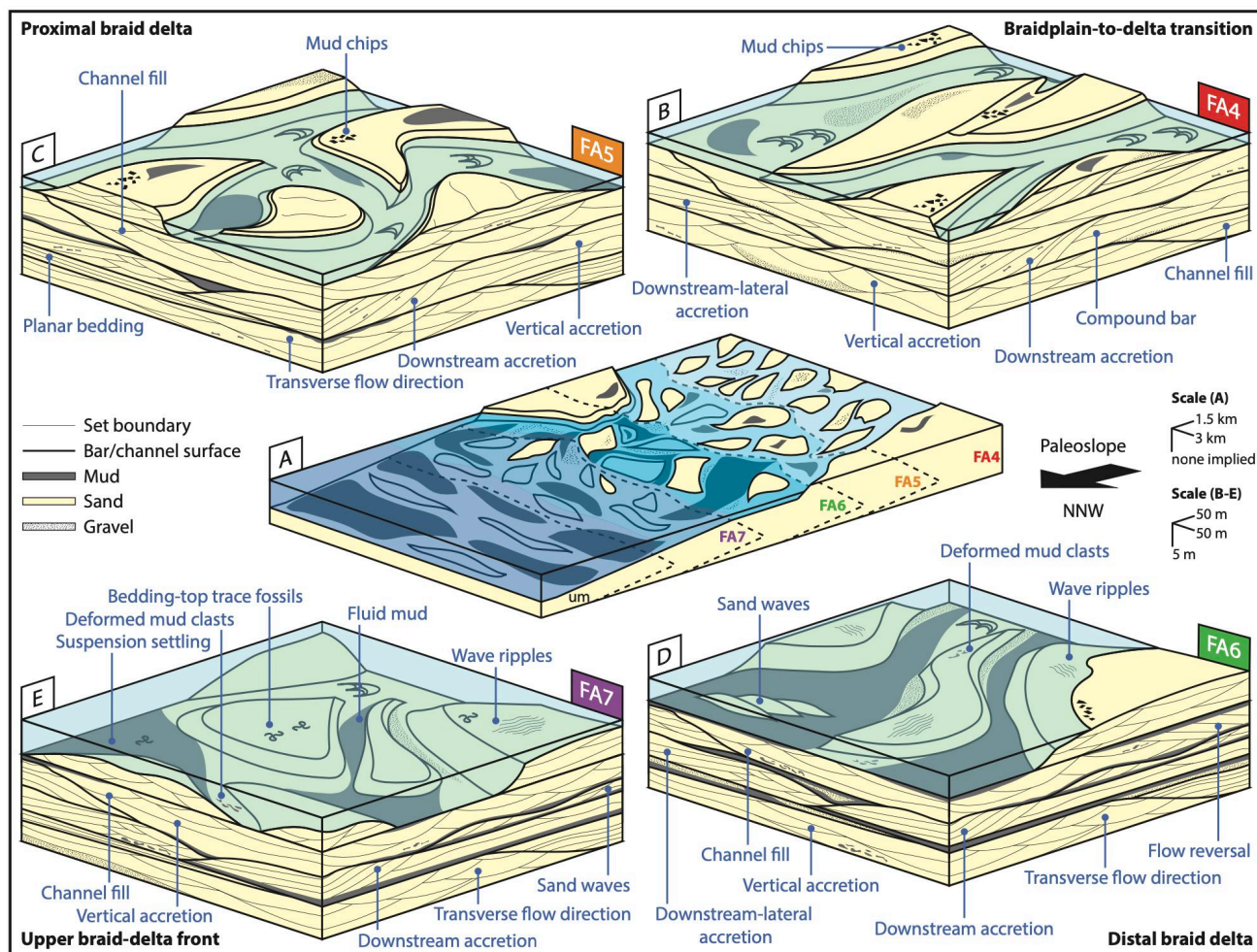


Figure 2.15: Block diagram of A) the overall middle member Wood Canyon Formation braid-delta system preserved at Section N66, with detailed environmental block diagrams of B) FA4, C) FA5, D) FA6, and E) FA7. See Table 2.2 for architectural element definitions.

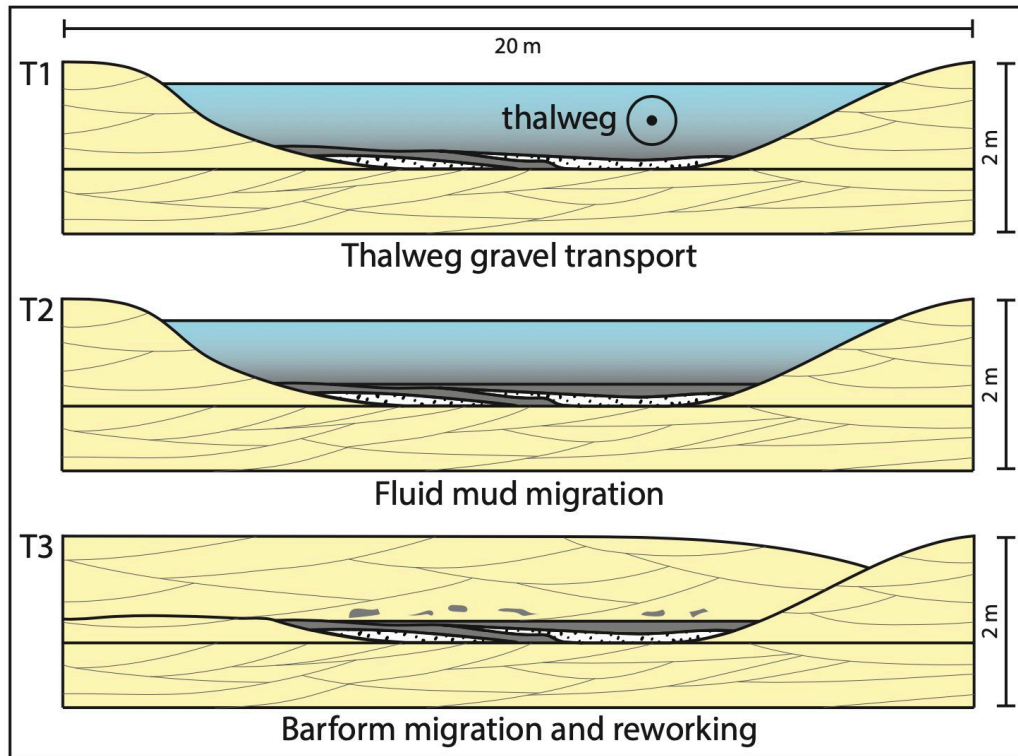


Figure 2.16: Proposed fluidized-mud processes in the turbidity maximum zone, leading to the formation of thick mudstone beds with interbedded very fine- to medium-pebble conglomerate in FA6 and rarely in FA7 (e.g., Figs. 2.9B, 2.10F, 2.12B). A) In-channel fluidized mud alongside gravels transported by a high-energy thalweg. B) Fluid-mud migration over stranded gravels. C) Burial by subsequent barform migration that scours and deforms clasts of fluid mud before incorporation into the overlying sandstone coset.

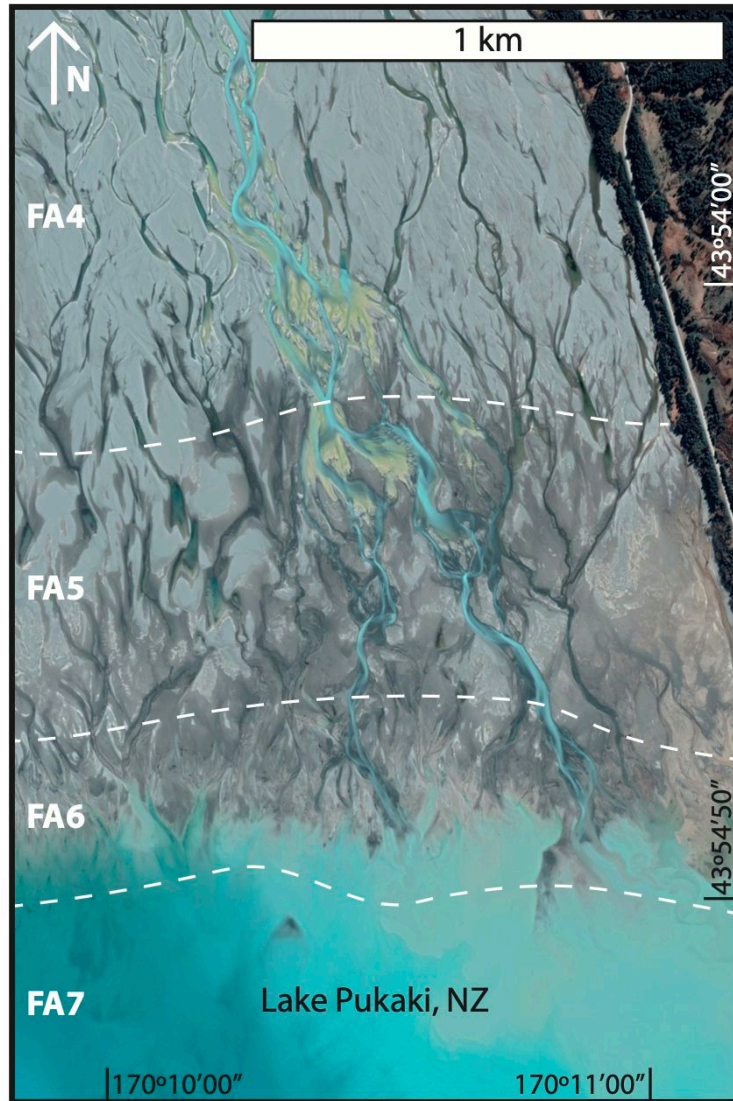


Figure 2.17: Fluvial-dominated braid delta of the Pukaki River at Lake Pukaki, NZ. Dashed lines in white divide the setting into zones that resemble each middle member Wood Canyon Formation facies association (FA4–7). Image from Google™ Earth, captured September 18, 2019.

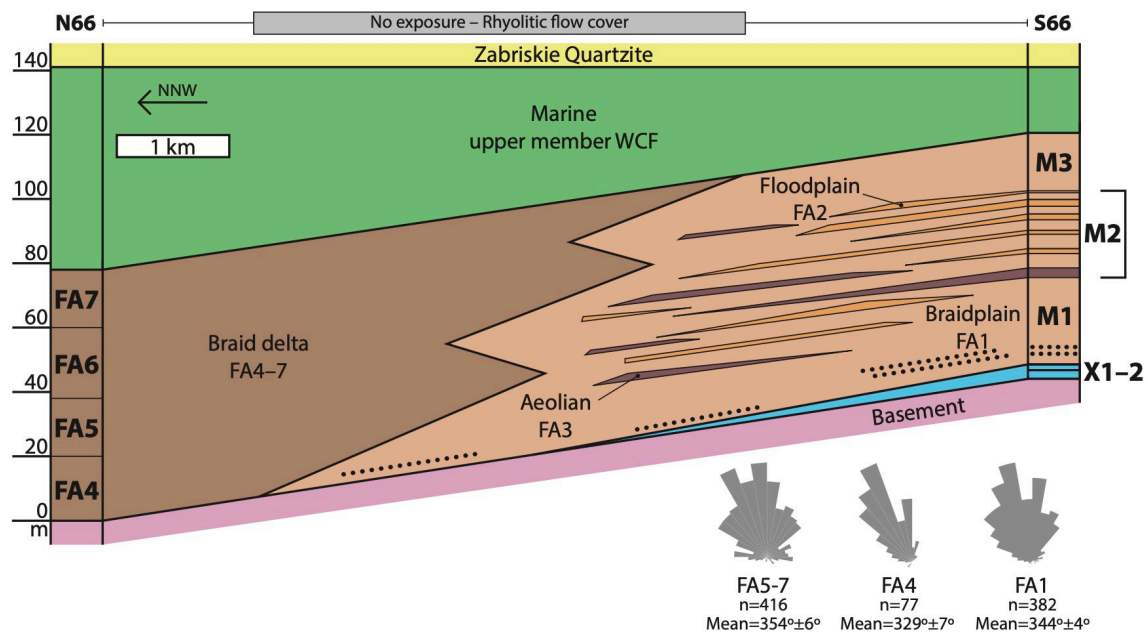


Figure 2.18: Lithostratigraphic panel linking Section N66 (Fig. 2.1) of the middle member Wood Canyon Formation (WCF), studied herein, to Section S66 (Fedó and Cooper, 1990; Muhlbauer et al., 2020) and associated paleocurrent data. Stratigraphic columns are hung on the base of the Zabriskie Quartzite. Units X1–2, M1–3 are based on facies-association stacking patterns at Section S66 (Fig. 2.1), described in Muhlbauer et al. (2020). The boundary between the braid delta and braidplain environments is hypothetical, as the relevant strata between the two sections are covered by rhyolitic flows.

CHAPTER III
GLOBAL DISTRIBUTION OF 800 HOLOCENE BRAID DELTAS
WITH NOVEL MORPHOTYPE CLASSIFICATION AND
APPLICATIONS TO THE SEDIMENTARY RECORD

This chapter is from a manuscript in preparation by Jason G. Muhlbauer and Christopher M. Fedo:

Jason G. Muhlbauer and Christopher M. Fedo. “Global distribution of 800 Holocene braid deltas with novel morphotype classification and applications to the sedimentary record” *Sedimentology* (2021).

The following chapter will be published with modification in a peer-reviewed journal. Christopher M. Fedo advised work on the project.

Abstract

Braid deltas, a depositional environment that forms where braided rivers prograde into standing water, are more important on Holocene Earth than previously understood. Worldwide surveying efforts identified 786 braid deltas with feeder rivers greater than 500 meters in width and gradients less than 2°. Systems develop at all latitudes, with the exception of the Antarctic, but are densest in the periglacial -45° to -60° and 60° to 90° latitude bands. Sediment supply is the dominant control on braid-delta generation, with clustering in mountain belts, extensional terranes, the Arctic Circle, and large islands. Still, some develop along passive margins, including the coasts of southern Africa. Of the total sample, 72% are marine associated and the remainder are lacustrine. A novel three-part classification of braid-delta morphotypes, separates deltas by the flow characteristics of the feeder system, dominance of wave, river, or tide modification, and change in confinement along the delta plain. Given the above information, the scheme can predict geomorphology and facies components of 9 observed braid-delta types. Perennial/intermittent, river-dominated, linear or radial morphotypes and perennial/intermittent or ephemeral, wave-dominated, linear morphotypes represent two-thirds of the dataset. Geomorphic maps of type localities for each morphotype, 38 km² in total area, detail a range of possible facies components that could enter the sedimentary record. Channel-counting braid indices for each site decrease to 0-17 channels per km of transect less than 150 meters from base level. Importantly, 63% of the observed braid deltas are not distributary forms and 165 have tributary channel patterns that are not possible in meandering-river common deltas. Results of this study begin construction of a braid-delta facies model for Earth and Mars, provide details about the pre-vegetation fluviodeltaic environments through which life migrated onto the continents, and may be instrumental in monitoring future climate-driven changes in sediment flux and flooding hazards.

Introduction

Deltaic environments, in ancient rocks or observed near present-day coastlines, represent invaluable records of the interplay between marine and terrestrial sedimentary processes. Deltas capture evidence for fluctuations in sea-level, changes in climate, and the migration of biology between saline and fresh water conditions. As a result, much attention has focused on the sedimentology of river deltas across the span of geologic time, on both Earth (e.g., Reading and Collinson, 1996; Bhattacharya, 2010) and more

recently on Mars (Moore et al., 2003; Pondrelli et al., 2008; Goudge et al., 2017; Goudge et al., 2018; Lapôtre and Ielpi, 2020). Despite the extensive publication record on deltas, their recognition in the geologic record and in modern systems remains fraught with complications and overlapping terminology that has obscured important aspects of fluviodeltaic settings. Notably, the deltas of meandering rivers (common deltas) and the deltas of alluvial fans (fan deltas) have received interest from the sedimentology and geomorphology communities (e.g., Soh et al., 1995; Giosan and Bhattacharya, 2005; Bhattacharya, 2010), whereas the deltas attached to braided rivers, termed braid deltas by McPherson et al. (1987), are underrepresented in geoscience literature. Braided rivers were the dominant fluvial form for the majority of Earth history before the emergence of vascular plants (Gibling et al., 2014; Friedman, 2017), so braid deltas were similarly abundant for billions of years. On a wetter, non-vegetated Mars, development of braided streams is plausible and so should be the eroded remnants of their deltas.

Galloway (1975) established the enduring delta-classification ternary based on the dominance of wave, river, or tide modification on a system. More than a decade afterward, McPherson et al. (1987) proposed three distinct types of deltas that correspond to the style of feeder system delivering clastic input to a coastline: common deltas, fan deltas, and braid deltas. Xue and Galloway (1991) recognized McPherson et al. (1987) and integrated the two classifications. Figure 3.1 provides further context for how each type of delta may relate to a classification of coastlines (Boyd et al., 1992). Competing classification schemes (e.g., Postma, 1990) for deltas were critical of the emphasis on feeder type without assessment of subaqueous delta segments. Other classifications are equally valid, including the lake-associated Gilbert-type delta (Church and Gilbert, 1975) and coarse-grained deltas detailed by Nemec (1990), the McPherson et al. (1987) scheme holds important benefits for sedimentology because it links facies generated by processes that span alluvial and delta environments.

Focus on feeder systems makes possible the prediction and interpretation of sedimentary structures, fluvial architecture, and facies relationships that define the depositional environment of the delta and laterally interfingering settings. For this reason, braid deltas are inferred from the ancient record, especially in Proterozoic and Archean pre-vegetation systems (Eriksson et al., 1998), but modern examples receive much less attention. Researchers interpret braid deltas as wave-, river-, or tide-dominated (Plummer, 1990; Eriksson et al., 1995; Bradley et al., 2018) and based on extent propose continent-scale “unconfined” braidplains (Rainbird et al., 1992, 2017) that could terminate in braided-river-dominated coasts. Recent studies continue to progress towards a full understanding of braid-delta architecture and depositional processes (Went, 2019; Levell et al., 2019; Muhlbauer and Fedo, 2020). But investigations of Holocene braid deltas that serve as the best approximation for similar settings in the past, despite the current abundance of plant life, are remarkably limited (McGowan and Sturman, 1997; Hart, 2007; Bell, 2009; Bendixen et al., 2017) and frequently do not include “braid delta” as a keyword. Without detailed study of modern systems, a facies model for braid deltas will remain elusive.

To begin documenting and understanding modern braid-delta systems, this paper utilizes extensive global surveying and detailed analysis to address the following objectives: (1) identify the distribution and geomorphology of braid deltas on Earth, (2) develop a classification scheme based on distinct morphotypes, (3) map type localities in order to detail the possible facies components of this understudied depositional setting, and (4) discuss the role of braid deltas in the sedimentary record. Results provide a quantification of the important role that braid deltas have in the present-day sedimentary system and provide insight into their larger role in pre-Devonian time. From this perspective, the paper integrates geomorphology with sedimentology, as such, presented classifications are intended to apply to modern braid deltas and to aid in the interpretation of ancient sedimentary rocks on Earth or other terrestrial planets. The hundreds of large, Holocene, braid deltas recognized by this study reveal their global occurrence, major morphological differences from other delta types, the transience of their features, and bring to the foreground prior misconceptions. Additionally, the research serves as a stepping stone to a complete facies model for the braid-delta environment.

Study Rationale

The morphometric braid-delta classification proposed herein derives from both quantitative and qualitative metrics extracted from a global, planform survey. A wide variety of researchers using remote images may deploy the scheme for rapid assessment of braid-deltas and prediction of certain parameters useful in paleoenvironmental reconstruction of ancient deposits (e.g., Muhlbauer and Fedo, 2020). More information about the influence of measurable external factors on classified morphotypes will accumulate from subsequent research and database expansion. For this study, preliminary analysis of external controls is primarily qualitative and limited to the discussion.

A diverse global database (Appendix A-4, Table 4.4) inherently includes multiple examples of every likely control, suitable for the testing of future hypotheses. Differences in watershed surface area, altitude of the basin, stream profile, hydrology, stream power, and main-stem length all presumably influence braid-delta morphology. Altitudes of the examined deltas range from sea level (BD1159) to over 5 kilometers above sea level on the Tibetan Plateau (BD2336). Multiple localities in the five Köppen-Geiger main climatic zones are represented (Kottek et al., 2006), including polar (BD0545), cold (BD1807), temperate (BD0787), arid (BD0655), and tropical (BD0304). Locations occur in divergent (BD1709), collisional (BD0061), transform (BD0412), and passive (BD1481) tectonic settings. Tidal ranges, from microtidal (BD0401) to macrotidal (BD0258), are surveyed (Shriver et al., 2012). Grain size, sediment sorting, and other textural characteristics are at least partly controlled by bedrock geology, possibly impacting aspects of resultant braid-delta deposits. Database sites are derived from felsic (BD0426) to mafic (BD1654) bedrocks upon both continents (BD0023) and volcanic arcs (BD1220). The numerous characteristics above may control various aspects of braid-delta settings, but the purpose here is a first-order assessment of an environment for which the publication record is limited relative to their abundance throughout Earth history.

Methods

Global survey of marine and lacustrine, Holocene, braid deltas with Google Earth

Coordinates of Holocene, coastal and lacustrine braid deltas, located by worldwide visual survey of shorelines, generated a preliminary database of 2,393 possible sites identified with the most recent available Google™ Earth Pro imaging (Fig. 3.2). Systematic scanning of coastlines, large lakes, and orogenic settings, recorded on the global map, ensured inclusion of all regions. Coordinates derived from a database of continental sedimentary basins published by Weissmann et al. (2010) provided further candidate localities in lakes. Reducing the list of inferred braid-delta candidates began with the removal of feeder-system channel belts less than 500 m across as a means to select larger and more permanent features. Measurements of width (w) were collected transverse to the braided channel belt at the boundary between observable fluvial and deltaic features (Fig. 3.3A). In braid deltas with distributive morphology, w was measured at the observed apex of avulsion (Fig. 3.3A). After recording width, Google™ Earth Pro data provided the slope of each feeder river to confirm the braided-fluvial origin of the delta. The slope of each channel belt was calculated over a distance of twice the recorded width ($2w$), beginning at the location of w measurement (Fig. 3.3A). Exclusion from the database occurred where the feeder system at $2w$ exceeded an average slope of 2° , entering the range of gradient more associated with alluvial fans (Blair and McPherson, 1994). Rejection by w had the greatest impact on reducing the size of the dataset. Only 37 slope-based rejections were made, an indication that braid deltas are visually distinct from fan-delta counterparts in most settings. Several further rejections, made where available elevation data were too poor to consider estimation of channel-belt slope, completed reduction of the initial survey. The final database includes 786 Holocene braid deltas that span the globe (Fig. 3.2; Appendix A-4, Table 4.4).

Qualitative data that facilitate classification of each of the 786 examples are hydrology, dominant energy, confinement characteristics, and marine or lacustrine basin type. Hydrology was noted as flow characteristics, either perennial/intermittent or ephemeral, based on the visual appearance of the river, presence of surface water in historical images, and the climatology of the location. Perennial (continuous flow) and intermittent (seasonal flow) are grouped for rapid assessment of aerial images and because of the difference in depositional processes when compared to ephemeral (flow resulting only from precipitation) settings (Sophocleous, 2002). Dominance of common, diagnostic, geomorphic and sedimentary features allowed distinction between river-, wave-, and tide-influence (Galloway, 1975). Cases that displayed no clear dominant style were recorded as “mixed” energy.

Confinement characteristics of the paired feeder river and braid delta, recorded as increasing, neutral, or decreasing confinement, permitting rapid communication of the overall delta shape. Decreasing-confinement braid deltas undergo a reduction of confinement on the channel belt approaching a shoreline, resulting in a radial morphology. Neutral-confinement braid deltas have no change in channel belt width between the fluvial and deltaic settings, whereas braid deltas with channel belts that are

constricted by coastal sedimentary or bedrock landforms have increasing confinement at the delta, resulting in a tributary nature at the mouth of the system. For simplicity and clarity in this study, decreasing-confinement braid deltas are named radial braid deltas and both neutral- and increasing-confinement braid deltas are grouped as linear braid deltas, owing to the linear coastal trace of their delta plain (Fig. 3.3A). No braided systems are “unconfined” because all channel belts experience some control on lateral growth. For further studies and for those in the geoscience community, the database contains visual estimates of vegetation amount, degree of anthropogenic alteration, and primary formational control.

Geomorphic mapping of type localities with ArcGIS

To further develop a proposed classification, type-locality braid deltas with high-resolution image quality in Google™ Earth, selected from the database, are presented as detailed maps. Nine mapped locations correspond to the number of braid-delta morphotypes observed on present-day Earth. Efforts focused on areal measurement of geomorphic features that may generate different facies or architectural elements in the sedimentary record and on calculation of braid intensity for deltaic and fluvial channel belts at each locality. Mapping completed in Esri™ ArcGIS outlined each component of the fluviodeltaic system with coded feature classes that are easily queried for geodesic area or distance, comparable to any measurements made in Google™ Earth. Base maps for each site were exported from Google™ Earth Pro and georeferenced in Esri™ ArcMap. Shapefiles map channels and the channel belt, multiple barform and macroform types, wave-reworked sediments and lagoons, tidal features, floodplain and abandonment landforms, aeolian activity, and ponding.

A common braid index, channel count (Egozi and Ashmore, 2008; Surian, 2015), is applied to type localities to investigate changes as each braided river develops into a delta. Maintaining consistency and reducing bias necessitated a detailed plan, illustrated in Figure 3.3B, in which the placement of transects used to attain channel counts differs depending on whether or not the braid delta is linear or radial. For linear deltas, transects are spaced at intervals of 300 meters beginning at the mouth of the delta to ensure that each site has over 5 transects (Fig. 3.3B), with one exception: the extensive Tuxedni River site required 2 km spacing. In radial deltas, a circle tracing the subaerial delta plain served as a guide for the initial transect (Fig. 3.3B). The radius (r ; Fig. 3.3B) of the circle decreases by 300 meters to form further transects, until the r of the circle no longer intersects the channel-belt border. Upstream of the last curvilinear transect, those further upstream are linear. Transects are the shortest line capable of traversing the channel belt at the set interval. A test on the Rangitata River site determined that random variations in the placement of transects did not notably affect the location of the channel-belt midline or channel counting results (Appendix A-4, Table 4.5, Fig. 4.1). Certain sites have additional transects less than 300 meters from the coastline. Each channel that intercepted a transect was counted and normalized to the length of that transect, facilitating comparison where the channel-belt width is variable. The exercise also made possible a systematic division of the deltaic setting from the fluvial realm (Fig. 3.3B). Circles set over each radial delta provide an origin (O ; Fig. 3.3B) where the apex of distribution is

located, used to place a transect separating each depositional environment. Linear deltas, lacking any such apex, are divided from the feeder river using a linear transect placed at the last upstream occurrence of a deltaic landform.

Results

Description: braid-delta dataset

A global dataset of Holocene braid deltas, available in Microsoft™ Excel and Google™ Earth formats (Appendix A-4, Table 4.4), forms the foundation of this study. Charting the parameters of the 786 deltas sampled is necessary before drawing inferences about this unique depositional environment. Figure 3.4 provides visualization of the width and slope parameters that identified the selected braid deltas. Measured widths range from 0.5 km, the lower cutoff, to 21.7 km, where a linear regression shows no correlation between width and slope values (Fig. 3.4). Slopes of braid-delta feeder rivers (Fig. 3.4) range from 0°, gradients that cannot be detected by the vertical resolution of available elevation data, to 1.96° near the upper cutoff established by Blair and McPherson (1994). A majority of examples (71%) measured less than 0.5° in slope across the measured reach (Fig. 3.4). Additionally, 58 of the braid deltas (7%) were visually classified as heavily influenced by anthropogenic modification (Appendix A-4, Table 4.4), including proximity to urban centers or extensive flood-control structures, ensuring that the morphology of nearly all deltas in the dataset is either free from, or minimally impacted by, human engineering in the study area.

Figure 3.5 displays latitude data from the survey of braid deltas, normalized to present-day land mass within each 15° interval of latitude (Mendez, 2011). Normalization is necessary, as a simple histogram of braid deltas per latitude is heavily influenced by differences in area between high and low latitudes, and by the uneven distribution of continental crust between the southern and northern hemispheres. Displaying both hemispheres in the histogram (Fig. 3.5), instead of using the absolute value of latitude, exposes nuance in the latitude data and reveals Antarctica as a continent without large braid deltas. Examples are most densely distributed in the -45° to -60° and 60° to 90° latitude bands, with a smaller mode between 30° to 45° latitude. Excluding Antarctica, the depositional environment occurs across all latitudes and on every continent.

The culmination of the survey, a global map of the braid deltas, is displayed in Figure 3.6 and provides further context for their Holocene distribution on Earth. Most data points are clustered in collisional mountain belts, including the American Cordillera in Alaska and the Andes, the Zagros Mountains, the Himalaya and Tibetan Plateau, the Mongolian Altai Mountains, the Kolyma Range in Russia, and the Southern Alps of New Zealand. Additional large populations occur in the Arctic Circle and regions of crustal extension in the Afar Triple Junction, the Basin and Range Province, and Baja California. Further clusters are found on Iceland, Madagascar, Taiwan, the Philippines, and the Kerguelen Islands, and the passive margins of southern Africa. Remaining braid deltas are widely scattered across the continents (Fig. 3.6). With few exceptions, examples are not near major centers of human development.

Organizing the metadata collected alongside braid-delta locations (Table 3.1; Fig. 3.7) allows further exploration of the resultant dataset. Of the 786 braid deltas, 562 formed at an interface with the marine realm, whereas 224 are in lacustrine settings. Table 3.1 organizes numerical data for the remaining major qualitative parameters that describe each delta, with a first-order division into perennial/intermittent or ephemeral hydrology. Two-thirds of the braid deltas are perennial or intermittent. In terms of energy, river-dominated (391 deltas) and wave-dominated (280 deltas) examples are most common, whereas those with identifiable tidal dominance are rare (8 deltas). For the remaining 107 braid deltas, energy dominance could not be distinguished without further information. Assessment of the confinement style of each delta reveals linear braid deltas to be more common in the sample than those with radial morphology, at 63% of the dataset. Figure 3.7 further divides the recorded parameters, revealing that wave-dominated braid deltas are mostly marine and linear morphotypes, the majority of river-dominated localities are fed by perennial or intermittent streams, and the few observed tidal-dominated settings are exclusively perennial/intermittent and linear morphotypes.

Interpretation: geomorphic classification of braid deltas

Distinct from common deltas that are described by the Galloway (1975) classification, three parameters are required to categorize the range of braid-delta geomorphology. A new classification, illustrated in Figure 3.8, merges the hydrology, dominant energy, and confinement characteristics of a braid delta into a scheme that can predict associated landforms and depositional facies. First, braid deltas with consistent fluvial discharge are separated from those that form under ephemeral conditions (Fig. 3.8), as rare flow events, flashy discharge, and aeolian or wave reworking cause a major process-geomorphic break between the two types of systems. Because arid conditions favor braided-river development by functionally increasing bedload (Schumm, 1985; Zhu et al., 2019), ephemeral braid deltas are more prevalent than ephemeral common deltas and must be specifically addressed.

Second, the Galloway (1975) ternary is incorporated (Fig. 3.8), splitting deltas by river, wave, or tide dominance based on characteristic geomorphic elements. Unlike common deltas, in which tidal dominance is easily recognized and common (Galloway, 1975; Hori et al., 2002; Dalrymple et al., 2003), braid deltas with indications of tide dominance represent only 1% of those in this study. Confinement characteristics form the final part of the classification as linear and radial morphotypes (Figs. 3.3, 3.8). Meandering streams typically split into terminal distributary channels that form common deltas (Olariu and Bhattacharya, 2006), but braided rivers by definition begin as multi-channel systems. Consequently, braided rivers may not disperse near base level (linear), or may become distributive (radial), a property that necessitates the inclusion of confinement in the new braid-delta classification. Figure 3.8 diagrams the nine morphotypes that occur on present-day Earth. Three other tidal varieties are predicted by the classification but not observed. Each of the 12 possible types are presented in Table 3.1 alongside their abundance in the database. Four of the most common are the perennial/intermittent, river-dominated, linear or radial braid deltas; the perennial/intermittent, wave-dominated,

linear braid deltas; and the ephemeral, wave-dominated, linear braid deltas that together represent two-thirds of observed examples.

Description: Type-locality mapping

To better document the nine braid-delta morphotypes in the database, and how each can transfer to the sedimentary record, nine corresponding type localities, mapped with Esri™ ArcGIS (Figs. 3.9, 3.10; Appendix A-4, Figs. 4.2–4.28), are included as part of this study and described below. Traced features and even the distinct morphotype of each location are certainly transient, but the instantaneous snapshots imported from Google™ Earth depict the recognizable planform geomorphology and facies components of each categorized type. Table 3.2 summarizes the results of the feature mapping and Figure 3.11 plots channel-count braid index for each site.

Perennial/intermittent, river-dominated, linear braid delta: Kerguelen Islands

An unnamed, glacier-fed, fjord-bounded river located in the Kerguelen Islands (French Southern and Antarctic Lands) of the southern Indian Ocean provides an example of a braid delta with year-round discharge that drives river dominance and forms a linear morphotype (Fig. 3.9A). Geomorphic mapping of the delta and feeder river (1.44 km² of mapped area; calculated $w = 540$ m) reveals that the channel belt in both the river and deltaic areas hosts channels, macroforms, and small unit bars (Bridge and Lunt, 2006). A floodplain, adjacent to the channel belt, is formed from subaerial terrace sediments and carved by flood-overflow channels. Fringing the floodplain along the interface with base level, ~40,000 m² of sediments within the tidal range are exposed. Ponding occurs both on macroforms in the channel belt and within abandoned floodplain channels, whereas no ponded water is identified in the ~100,000 m² deltaic area. Using tidal range as an indication of marine influence, the division between the fluvial and deltaic realm is 134 m from the mouth of the delta, close to base level (Fig. 3.9A, 3.11). The percentage of barforms within the channel belt decreases from 54% in the braided river to 12% in the delta (Table 3.2). Channel counting, spaced every 300 meters from the coast with an additional transect at 150 meters, ranges from 11 to 37 channels per 1 km transect, where the lowest channel density is nearest to base level (Fig. 3.11).

Perennial/intermittent, river-dominated, radial braid delta: Turkwel River, Kenya

In the Kenyan Rift Valley, the Turkwel River progrades into Lake Turkana (Fig. 3.9B), forming a seasonally active (Stave et al., 2003), river-dominated braid delta with a radial morphotype (0.89 km² of mapped area; calculated $w = 220$ m; calculated $r = 700$ m). An apex of distributary morphology occurs 722 meters from the mouth of the delta (Figs. 3.9B, 11) where the channel belt initially widens. Upstream of the delta plain, the channel belt is primarily filled by submerged channels, with macroforms, bank-attached macroforms, and unit bars (Fig. 3.9B). Bordering the channel belt are aeolian dunes and a ~40,000 m² splay feature visible through the surrounding forest cover. Channels, macroforms, and unit bars continue into the braid delta, with a reduction in total channel area. Barforms represent 46% of the fluvial channel belt and increase to 77% in the deltaic channel belt (Table 3.2). The delta itself is formed from the same barform types as the fluvial channel, with the addition of a ~200,000 m² inactive delta lobe. Historical

images in Google™ Earth confirm that the system avulses rapidly, so the lobe is included within the active channel belt for this study. At the interface with Lake Turkana, thin beaches of wave-reworked fluvial sediments with a total area of $\sim 10,000 \text{ m}^2$ predominantly line the inactive lobe of the braid delta, where they shelter small lagoons that comprise 1.5% of the deltaic channel belt (Fig. 3.9B; Table 3.2). Channel counting, spaced every 300 meters from the coast with an additional transect at 150 meters, ranges from 7 to 39 channels per km, where the lowest channel density is at the delta mouth (Fig. 3.11).

Perennial/intermittent, wave-dominated, linear braid delta: Rangitata River, New Zealand

Transporting sediment from the Southern Alps of New Zealand, the perennial Rangitata River (Browne, 2008) intersects a wave-dominated coast and develops a linear braid delta (1.90 km^2 of mapped area; calculated $w = 500 \text{ m}$). In the river, the channel belt is lined by forested floodplain and contains channels, macroforms, bank-attached macroforms, and unit bars (Fig. 3.9C). Small ponds develop on macroforms, totaling $\sim 1,200 \text{ m}^2$. Similar components, absent ponding, are found within the channel belt of the braid delta. Barforms represent 75% of the fluvial system and 51% of the braid delta (Table 3.2). From the feeder stream to the delta, unit bars increase from 2.7% to 5.6% and channels increase from 25% to 47% (Table 3.2). Notably, the width of the channel belt decreases near the coast as braided channels become tributary, a change associated with a $150,000 \text{ m}^2$ barrier beach developed along the front of the delta (Fig. 3.9C). Sheltered by the beach, isolated lagoons form adjacent to the channel belt with a total area of $\sim 96,000 \text{ m}^2$. The propagation of the lagoons inland provides the basis for a division between the deltaic and fluvial realms of the system, which occurs 440 m from the coastline (Fig. 3.11). Channel counting, spaced every 300 meters from the coast with additional transects at 25, 50, 75, and 100 meters, ranges from 9 to 44 channels per km, where the lowest channel density is at the delta mouth (Fig. 3.11). Highest channel density is associated with the narrowing of the deltaic channel belt where braided channels first merge into a single outflow.

Perennial/intermittent, wave-dominated, radial braid delta: Rio Ocoa, Dominican Republic

Rio Ocoa is sourced from a mountainous, dry region of the Dominican Republic and experiences seasonal flow that terminates at a wave-dominated and radial braid delta (1.50 km^2 of mapped area; calculated $w = 515 \text{ m}$; calculated $r = 1,100 \text{ m}$). The image utilized for mapping is at low flow-stage, revealing more of the sediment in the river. Macroforms, bank-attached macroforms, and unit bars make up the features associated with the feeder-river channel belt (Fig. 3.9D). Ponding in abandoned channels is visible in both the fluvial and deltaic portions of the mapped area. Within the delta itself, which extends 1174 m from the coast (Figs. 3.9D, 3.11), vegetated and stabilized swaths of floodplain occur between braided distributary channels. Each distributary, where abandoned, fills with a small lagoon that is protected by the barrier beach lining the edge of the radial braid delta. Lagoons account for $\sim 13,000 \text{ m}^2$ of mapped area to the $\sim 100,000 \text{ m}^2$ of beach (Table 3.2). Where the most active braided distributary channel meets the

shoreline, it punctures the barrier beach, forming a confined outlet. Total barform area within both the fluvial and deltaic reaches of the system is nearly identical, approximately 83% of the channel belt (Table 3.2). Channel counting, spaced every 300 meters from the coast with an additional transect at 150 meters, ranges from 0.7 to 23 channels per km, where the lowest channel density is at the delta mouth (Fig. 3.11).

Perennial/intermittent, tide-dominated, linear braid delta: Tuxedni River, Alaska, United States

Glacially sourced, the perennial Tuxedni River produces a linear, bayhead, braid delta (Fig. 3.9E) as part of a macrotidal (Hayes and Michel, 1982) estuary in Cook Inlet, Alaska (26.4 km² of mapped area; calculated $w = 780$ m). Capturing the transition from braided river to braid delta required more extensive mapping than other locations, approximately 18 km of reach length of which ~10 km are deltaic (Figs. 3.9E, 3.11). The feeder river contains minimal subaerial barforms, including macroforms, bank-attached macroforms, and unit bars that comprise 29% of channel-belt area (Table 3.2). The deltaic system is marked by elongate tidal macroforms, visible in the low-tide image, that replace fluvial macroforms and unit bars. Tidal macroforms are incised by sinuous tidal channeling and host approximately 34,000 m² of superimposed low-tide ponding. Extensive tidal macroform scale increases the percentage of barform area within the delta to 40% of the channel belt (Table 3.2). Swaths of channelized intertidal sediment line both the delta and lower reaches of the braided river, developing a tidal flat adjacent to the braid delta. Channel counting, spaced every 2 km from the coast, ranges from 0.7 to 14 channels per km, where the lowest channel density is at the delta mouth and the highest is furthest upstream (Fig. 3.11).

Ephemeral, river-dominated, linear braid delta: Panamint Valley, California, United States

Panamint Valley is an endorheic basin (Jayko et al., 2008) in the Mojave Desert where an underfilled lake and associated salt flat periodically receive floodwater from the surrounding alluvial fans and braided rivers. Based on evidence from historical images, minor sediment redistribution occurred in the system during a post-1995 event. An axial, ephemeral, braided river progrades into the lake from the south, forming a fluvial-dominated and linear braid-delta morphotype (0.93 km² of mapped area; calculated $w = 780$ m). Components of the feeder river include abundant macroforms, unit bars, and a dense network of channels (Fig. 3.10A). Several bank-attached macroforms occur in the channel belt. Braid-delta features begin 162 m upstream of the mouth (Figs. 3.10A, 3.11) and are further simplified, consisting of only macroforms, unit bars, and channels. Contrasting with the feeder river, unit bars have a greater areal percentage than macroforms within the braid delta and preserve lunate morphology (Fig. 3.10A; Table 3.2). Barforms decrease from 61% of the fluvial channel belt to 16% of the deltaic reach (Table 3.2). Channel counting, spaced every 300 meters from the shore with an additional transect at 150 meters, ranges from 17 to 81 channels per km, where the lowest channel density is at base level (Fig. 3.11).

Ephemeral, river-dominated, radial braid delta: Tonopah, Nevada, United States

Near the boundary between the Great Basin Desert and Mojave Desert, near Tonopah, Nevada, an inflowing ephemeral braided river builds a fluvial-dominated and radial braid delta on the margin of a salt flat (0.90 km² of mapped area; calculated $w = 360$ m; calculated $r = 870$ m). More recently than 2011, channels experienced active water flow. Formed simply from macroforms, unit bars, and channels, the braided river becomes distributary approximately 866 m before reaching the evaporative basin (Figs. 3.10B, 3.11). Similar components comprise the braid delta, with the addition of degraded, thinned sediments near base level that make up 24% of the channel belt and apparent jet-plume deposits at the termini of inflow channels (Fig. 3.10B; Table 3.2). Percentage of barforms within the channel belt increases from 73% in the fluvial reach to 79% in the radial braid delta (Table 3.2). Channel counting, spaced every 300 meters from the shore with an additional transect at 150 meters, ranges from 9 to 29 channels per km, where the lowest channel density is at the delta mouth (Fig. 3.11).

Ephemeral, wave-dominated, linear braid delta: Al Ghaydah, Yemen

In western Yemen, east of the city of Al Ghaydah, an ephemeral braided river crosses the arid landscape before emptying into the Arabian Sea. The braid delta is linear in morphotype along the strongly wave-dominated coast (2.35 km² of mapped area; calculated $w = 1,170$ m). In addition to macroforms, bank-attached macroforms, unit bars, and channels, a class of superimposed bars is necessary to describe the geomorphic features of the feeder system (Fig. 3.10C). Because of the exposed dry riverbed, smaller barforms are preserved migrating over larger macroforms. Over 200,000 m² of superimposed bars (Table 3.2) provide additional information about sediment transport and channelization during flood activity, requiring their addition to feature mapping. An island of stabilized floodplain sediment occurs well upstream of the braid delta in the locality. Within the braid-delta, the same feature classes as the feeder system are identified alongside a beach and lagoon settings that fill dry channels (Fig. 3.10C). The lagoons comprise 7% of the channel-belt area in the deltaic setting and extend a maximum 498 m from the shoreline (Table 3.2; Fig. 3.11). No outlet channels through the beach are preserved, disconnecting the delta from the marine realm. Barform area within the channel belts of both the fluvial and deltaic areas are nearly identical, at ~73% (Table 3.2). Channel counting, spaced every 300 meters from the coast with an additional transect at 150 meters, ranges from 0 to 16 channels per km (Fig. 3.11), where the lowest channel density at the delta mouth as wave activity erases channel features.

Ephemeral, wave-dominated, radial braid delta: Bosaso, Somalia

West of the city of Bosaso, Somalia, along the coast of the Gulf of Aden, a wave-dominated braid delta (Fig. 3.10D) with a radial morphotype develops at the mouth of an ephemeral system (2.03 km² of mapped area; calculated $w = 820$ m; calculated $r = 1,270$ m). Partially confined by coastal mountains, the channel belt of the river contains macroforms, bank attached macroforms, unit bars, channels, and superimposed barforms visible with no flowing water present. Where the channel belt of the delta expands 1,271 m from the coast (Figs. 3.10D, 3.11), it displays the same features as the river with the addition of a ~90,000 m² unbroken fringing beach (Table 3.2) that shelters lagoons within

dry channels. Lagoons fill 4.4% of the channel belt in the deltaic area (Table 3.2). The western border of the delta is bounded by a floodplain terrace, preserving evidence of previous avulsion before further incision of the prograding braid delta. Barform area (Table 3.2) is greater in the delta (77%) than in the more confined feeder system (38%). Channel counting, spaced every 300 meters from the coast with an additional transect at 150 meters, ranges from 0 to 16 channels per km (Fig. 3.11), where the lowest channel density at the delta mouth as wave activity reworks fluvial channels.

Interpretation: braid-delta facies components

Organizing the possible facies components of Holocene braid deltas on Earth is crucial in working toward a facies model applicable to the sedimentary record and potentially to deltaic deposits on Mars. Fluvial components of braid deltas, including macroforms, unit bars, and channels (Fig. 3.12A), are similar to those of braided rivers, and therefore difficult to distinguish without additional data. Distributary and more widely variable paleocurrent patterns than coeval fluvial systems are commonly used to invoke deltaic environments (Fielding, 2010). Braid deltas with radial morphotypes (Fig. 3.8) do become distributary and may preserve inactive delta-lobe facies (Fig. 3.12B) which can become stabilized floodplains, as in the case of Rio Ocoa (Fig. 3.9D). But, this study clarifies that radial braid deltas represent a minority (Table 3.1), whereas most do not form distributary channels and undergo no expansion of the channel belt near base level. Linear braid deltas, such as the Rangitata River or Kerguelen Islands sites (Figs. 3.9A, C), are expected to be more difficult to identify in the sedimentary record because their areal extent as low as $\sim 100,000 \text{ m}^2$ (Table 3.2). Processes that rework fluvial sediments generate landforms that are crucial to recognizing braid deltas, including subaerial, intertidal, and nearshore environments that were the focus of Esri™ ArcGIS mapping.

Wave and tide processes have large roles in modifying braid deltas. Where waves generate barrier beaches (e.g., Hart, 2007) of sediment along the coast, braid deltas respond by narrowing in channel belt width, eventually into a single channel associated with barrier spits (Hoyt, 1967) exemplified by the 45-meter-wide outflow of the Rangitata River braid delta (Fig. 3.12C). The tributary nature of such deltas near the marine/lacustrine interface provides the discharge required to erode the barrier beach. In some cases, braid deltas divert for kilometers parallel to the coast before reaching an outlet. Of the dataset, 165 wave-dominated or mixed-energy deltas preserved tributary morphologies related to increased confinement by beaches. River-mouth lagoons (Hart, 2007) represent the majority of standing water adjacent to the channel belt in wave-dominated braid deltas (Fig. 3.12C), over $90,000 \text{ m}^2$ in the Rangitata River (Table 3.2; Fig. 3.12C). Within the sedimentary record, wave-dominated braid deltas should preserve fluvial barforms and deep channels with shore-parallel paleoflow, interbedded with beach sands or gravels, extensive lagoonal mudstones with metazoan fossils, washover deposits, and shoreface facies. Considering macro-scale features, tide-dominated braid deltas like the Tuxedni River site transition from braided barforms to $\sim 8 \text{ km}^2$ of tidal macroforms (Table 3.2; Fig. 3.12D) elongate perpendicular to the coast (e.g., Dalrymple and Choi, 2007). At low tide, ponding occurs on the surfaces of tidal macroforms, tidal flats, and other intertidal settings (Fig. 3.12D) alongside dense tidal channeling. Between high-

energy fluvial input and rapidly changing salinity, the channel belts of tide-dominated braid deltas likely host a low diversity of life (Dalrymple and Choi, 2007).

Braid deltas fed by ephemeral rivers preserve some facies components common in all morphotypes with additional features specific to arid settings. Smaller barforms superimposed on macroforms may be mapped (Fig. 3.12E), preserving evidence of high-water flood conditions that are subject to aeolian winnowing. On the borders of ephemeral, underfilled lakes, barforms are observed as degraded, eroded remnants of sediment thinned and redistributed by shallow waves or wind (Fig. 3.12F). Additionally, floodwaters that debauch into salt flats create plumes of sediment resulting in jet-plume deposits (Fig. 3.12F), where each individual channel becomes unconfined and sediment falls from suspension as current energy disperses (Ernst et al., 1996; Wellner et al., 2005). Nine jet-plume deposits line the Tonopah braid delta (Fig. 3.10B), in variable states of degradation by erosive forces in the salt pan.

Discussion

Controls on global distribution of braid deltas

Observation of Holocene braid-delta clusters worldwide indicates that several conditions are most favorable for their formation. Sediment supply appears to be the largest control on braid-delta occurrence. Collisional mountain belts and areas of crustal extension generate uplift and elevated sediment loads that in-part cause river braiding (Schumm, 1985). Coincidental growth of the Basin and Range Province and Tibetan Plateau between 30° to 45° latitude causes elevated braid-delta density in Figure 3.5. Especially where uplifted regions are near the ocean or other sedimentary basins, braided rivers transporting high sediment loads may reach base level. Alpine glaciers in uplifted regions serve to further increase physical erosion and provide meltwater that increases braided-river abundance. In the Arctic Circle, or along its border, glacial comminution supplies the sediment in braided rivers that reach the coast. Combined with limited vegetation in recently deglaciated regions (Klaar et al., 2016), a dense concentration of braid deltas occurs surrounding the Arctic Ocean (Fig. 3.6). High topography or glaciation close to the coastline is most notable on numerous islands from equatorial to polar, causing dense populations of braid deltas. Examples visible in Figure 3.6 include Iceland, Greenland, Svalbard, Baffin Island, the Aleutian Islands, Wrangel Island, Madagascar, the Kerguelen Islands, Taiwan, and the Philippines. Although aridity is known to drive erosion and functionally increase bedload, forming braided rivers (Schumm, 1985; Zhu et al., 2019), the results of this study indicate that the abundance of ephemeral braid deltas in the Basin and Range, the Afar Triple Junction, and the Tibetan Plateau (Fig. 3.6) are linked to uplift and enhanced erosion rather than solely climate. Extremely arid regions with low topography, including the Sahara Desert, the Karakum Desert bordering the Caspian Sea, and the Australian Outback generate few braid deltas. Because arid locations are commonly cited as pre-Devonian analogues because of their limited vegetation (Long, 2011; Santos et al., 2019), it is important to note that even tropical regions can develop possible modern analogues for braid-delta settings.

Braid-delta morphotype comparison

Comparing the morphotypes in the database reveals why certain braid delta varieties are most abundant in the Holocene, and why others appear rare or transient. Just four morphotypes represent two-thirds of the dataset: perennial/intermittent, river-dominated, linear or radial morphotypes and perennial/intermittent or ephemeral, wave-dominated, linear morphotypes (Fig. 3.8; Table 3.1). Perennial/intermittent, river-dominated, radial morphotypes form as a result of consistent, high-energy flow where the fluvial system progrades and becomes distributary near base level. Expectations that the radial morphology is most common for river-dominated braid deltas are incorrect, as the dataset reveals that linear morphotypes are present in higher numbers (Table 3.1).

Perennial/intermittent, river-dominated, linear braid deltas develop where the delta is limited to the same confinement as the feeder river. Multiple causes of delta confinement are observed, contributing to their abundance. Bounding fjord walls, observed in the Kerguelen Islands site (Fig. 3.9A), are primary confining features, commonly associated with braid deltas fed by glacial melt from alpine regions or ice sheets. Other confinements of fluvial-dominated, braid-delta channel belts include fluvial terracing, natural levees, and dense vegetation. Both perennial/intermittent and ephemeral varieties of wave-dominated, linear morphotypes are common on Earth and nearly exclusive to marine basins (Fig. 3.8; Table 3.1). Their development hinges on wave energy overpowering river input, forming persistent beaches (Fig. 3.12C) and flattening sediment lobes against the coastline. Marine waves are capable of constraining fluvial channels even in deltas fed by large rivers, where barrier beaches confine the entire channel belt to a single outflow channel (Figs. 3.9C, 3.12C). Ephemeral feeder systems, without consistent flow, are completely cut off from the marine realm by beaches of wave-reworked fluvial sediment (Figs. 3.10C, D, 3.12E), except in rare cases after flooding briefly develops a new outflow.

Other uncommon morphotypes are equally important to unraveling the controls on braid-delta geomorphology. Ephemeral, river-dominated linear and radial morphotypes occur primarily in dry-lake settings (Table 3.1; Fig. 3.12F), because wave-reworking in underfilled basins is limited. Wave-dominated, radial deltas represent disequilibrium features and are observed only in marine settings in low numbers (Table 3.1). The radial nature of a braid delta is inherently a fluvial feature, thus wave dominance of a distributive geomorphology suggests recent change in energy conditions. If wave energy persists, it may flatten a radial pattern, contributing to the rarity and transience of this morphotype. Tidal dominance, observed only with perennial fluvial input as part of linear morphotypes (Table 3.1; Fig. 3.7), is rare based on macro-scale features. Radial morphotypes are unlikely to exist alongside tide dominance, a process that develops barforms elongate perpendicular to the coast and estuarine geomorphology with limited progradation (Dalrymple et al., 1992; Dalrymple and Choi, 2007). Although the specific abundances of each morphotype are expected to vary given changing global conditions across geologic time, the observations made here are useful in interpreting present-day distributions and further develop the proposed classification for application to lithified braid-delta deposits.

Braid deltas in the sedimentary record

Distinguishing braid-delta morphotypes in the sedimentary record is an intended function of the proposed classification (Fig. 3.8) and guided the mapping of each type locality. Combining the level of variability in facies components and morphologies between sites with a temporal understanding that braid deltas may shift between morphotypes based on changing conditions, identifying ancient braid deltas requires detailed stratigraphic documentation. All braid deltas have channel belts with sedimentary features similar to braided rivers: channels flowing between macroforms, bank-attached macroforms at the edge of the channel belt, and simple unit bars (Figs. 3.12A, B). Each feature, if preserved, will form components of fluvial architectural, including channel fills, accretion elements, and compound bars (Miall, 1985; Long, 2011). Channel counting as a braid-index metric for each type locality indicates minimal change in all braid deltas until a decrease to 0-17 channels per km that occurs less than 150 meters from the coast (Fig. 3.11). Channel density, then, is a difficult metric to employ for recognizing of deltaic influence.

Identification largely relies on the interfingering facies components previously detailed, formed by wave, tide, aeolian, and distributive processes. The terrestrial extent of delta-plain features is dependent on morphotype, as indicated by the mapped braid-delta sites. River-dominated, linear morphotypes (of any hydrology) extend only 100-200 meters from the coast (Fig. 3.11), juxtaposing fluvial and marine features with little transition. Wave-dominated, linear morphotypes (of any hydrology) extend further from the coast, 400-500 meters (Fig. 3.11), as a result of lagoon infilling. All radial braid deltas cover a more extensive area than linear counterparts, because the apex of their distributary channel pattern is located 700-1300 m from the shoreline (Fig. 3.11). And finally, large braid deltas with tidal dominance may propagate as much as 10 km (Fig. 3.11) from the open ocean if, like the Tuxedni River site (Fig. 3.9E), gradient approaches zero degrees. Applying the proposed geomorphic classification to strata, which limits lateral assessment of landforms but adds temporal information, entails sedimentary analysis of the complete stratigraphic package, assessing individual beds to determine flow characteristics, energy dominance, and planform extent.

A comparison of changes in barform area in the channel belt across the boundary between braided river and braid delta (Table 3.2), for each site, reveals that linear deltas experience a decrease or no change in barform area within the delta. Radial deltas cause an increase, or no change, in observed bar extent (Table 3.2). The tidal setting in the Tuxedni River site, in which bar volume increases within the linear delta (Table 3.2), is an exception produced by the expansive tidal macroforms visible at low tide. In the sedimentary record, barforms of radial braid deltas may be extensive and show evidence of stabilization when compared to the strata of the feeder system. Linear braid deltas could preserve the opposite: extensive channel fills and minimal evidence of large subaerial barforms. Although the observations are preliminary and require further data collection to assess, they represent a method by which morphotypes may be classified from strata.

Reliance on distributive paleocurrent patterns to identify deltaic influence may not detect the majority of ancient braid-deltas. Holocene, linear, braid deltas are 63% of the dataset (Fig. 3.7; Table 3.1) and would not develop a broader range of unidirectional paleocurrent over a large area near base level. However, tens of meters from the coast, linear systems are likely to record shore-parallel paleocurrents in fluvial deposits, a result of channel belt diversion by barrier beaches (Fig. 3.12C). The areal extent of shore-parallel channels is limited and proximity to shoreface facies may overprint or otherwise render them indistinguishable. The changes between braided river, linear braid delta, and shoreface are subtle and may appear as a change from terrestrial to marine strata without accepted common-delta facies (e.g., Muhlbauer and Fedo, 2020).

Braid delta misconceptions and implications for distributive fluvial systems

Global survey of braid deltas reveals several misconceptions held about the depositional environment. In McPherson et al. (1987), the braid delta is diagrammed as distributive, similar in shape to a common delta. However, the results presented herein provide evidence that the majority of braid deltas are not distributive, or radial, morphotypes (Table 3.1). Instead, they are linear, in which the delta is either the same width as the feeder river, or further confined by wave processes. Because pre-vegetation braided rivers are typically associated with arid climates (Long, 2006, 2011), braid deltas are expected to form as a part of ephemeral systems in stratigraphic studies (Fedo and Cooper, 1990; Eriksson et al., 1995). However, worldwide data suggest that approximately two-thirds of braid deltas are formed by perennial or intermittent rivers (Table 3.1) that are fed by rainfall, snowmelt, or glacial sources. In terms of density per land mass, most braid deltas form in mid-to-high latitudes as originally proposed by McPherson et al. (1987), but hundreds of braid deltas also form in the lower latitudes (Fig. 3.5) and contribute to those that are categorized as perennial/intermittent in hydrology. Oddly, despite the sedimentology preconception that most braid deltas should form in areas with limited rainfall, braid deltas that prograde into dry lakes are understudied. In McPherson et al. (1987), ephemeral systems are not considered, whereas alluvial fans in arid regions are discussed.

Certain terminology surrounding braid deltas, deltas in general, and distributive sedimentary systems, is inconsistent, contradictory, and based on prior assumptions, which is limiting to the dissemination of research on the subject. An update to the naming in McPherson et al. (1987), changing fan delta, braid delta, and common delta to alluvial-fan delta, braided-river delta, and meandering-river delta, respectively, could increase consistency and limit the furthering of misconceptions. Changing each term may balance the perceived importance of the three delta types in geomorphology and sedimentology publications. Figure 3.6 clearly identifies abundant braid deltas across all latitudes where common deltas form. Furthermore, clarifying the “fan delta” as “alluvial-fan delta” holds enhanced importance. Every type of delta may be fan-shaped (distributive) or not, depending on confinement (e.g., confined fans; Nemec and Steel, 1988). A recent paper covering braid deltas in Greenland (Bendixen et al., 2017), labeled some as “open fan-shaped deltas.” The term “fan delta” is similar enough that confusion can easily result. When referring to deltas with distributive morphology, the term “radial”, not “fan”,

removes the potential for dual use of the term. Additionally, distributive fluvial systems (DFS; Nichols and Fisher, 2007; Hartley et al., 2010; Weissman et al., 2010), share similar terminology and appearance to braid deltas in some cases, indicating that perhaps many DFS classified in the literature are misidentified. Researchers investigating the role of DFS in deposition should not only confirm that a DFS has multiple contemporaneous active channels as clarified by Fielding et al. (2012), but also verify that it does not terminate in a standing body of water or dry lake, as such a feature is a braid delta.

Reconciling modern surveying with ancient, tidal, braid-delta strata

Low numbers of observed braid deltas with evidence of tide dominance, just 8 examples (Figs. 3.6, 3.7; Table 3.1), may at first inspection imply that tidal processes are not a common control on sedimentation in the environment. Such a major sedimentary process remaining absent from braid deltas is improbable and likely related to the limitations of remote global survey. Whereas the large-scale features left by fluvial and wave processes leave extensive subaerial deposits, tidal features are often submerged and viewing them is dependent on capturing images at low tide. Tidal bars, such as those mapped in the Tuxedni River in Figure 3.9E, are rare in braid deltas. Tidal channels and flats are observed adjacent to braid deltas but rarely within the boundaries of the channel belt itself, indicating that a delta is not tide dominated. Furthermore, bedforms and sedimentary structures, including tidal bundles and herringbone cross-stratification (Dalrymple and Choi, 2007; Longhitano, 2012), that are obvious with fine-scale observation of a depositional environment, are not visible at the scale of aerial photography. At the macro-scale, the geomorphology of a braid delta may appear entirely fluvial, hiding superimposed meter-scale tidal bedforms invisible at current resolutions. That tides can have a large role in braid-delta sedimentation is supported by the strata of ancient braid deltas, including Precambrian examples, that preserve abundant tidal sedimentary structures and interfingering tidal flats (Bradley et al., 2018). Although some of the abundance can be attributed to enhanced tidal range in the past (Eriksson et al., 2006), some amount is also related by the ease of identifying diagnostic tidal features in outcrop. Such evidence may only be observed in modern settings via field observation, trenching, and geophysical methods that are beyond the scope of this paper. Still, macro-scale tidal bedforms may be expected to be uncommon in ancient braid deltas based on the presented database of modern analogues.

The role of climate change and transgression in Holocene braid-delta geomorphology

The current state of eustatic sea-level change on Earth is one of transgression, driven in the Holocene by both natural, and more recently, severe anthropogenic warming of the atmosphere (Jevrejeva et al., 2009; Hamlington et al., 2014; Slangen et al., 2016). Transgressive intervals favor wave-dominated coasts and tidal estuaries (Boyd et al., 1992), reflected in our dataset by the abundance of wave-dominated, linear, braid deltas that represent ~40% of the marine examples (Figs. 3.6, 3.8; Table 3.1). Tide-dominated braid deltas are uncommon in general, but as explained above, several biases may contribute to a reduction in locations. Present-day global transgression undoubtedly has a large influence on the population of deltas and their characteristics. However, by specifically surveying lacustrine environments (Figs. 3.9B, 3.12B) and high-latitude

regions undergoing isostatic rebound, braid deltas that have formed in normal- or forced-regressive conditions reveal the morphotypes expected during base-level highstand or regression. Of the 118 lacustrine braid deltas with perennial/intermittent feeder streams, 86% are river dominated with a 1:0.79 ratio of linear to radial braid deltas, representing an increase in radial morphologies when compared to the 1:0.6 ratio of the full dataset. In periods of eustatic sea-level fall, evidence suggests that river-dominated braid deltas (Fig. 3.8) are most likely to form, and that radial morphologies (Fig. 3.8), built as deltas prograde rapidly, increase in abundance.

High density of braid deltas in the mid-to-high latitudes and in alpine regions (Figs. 3.5, 3.6), areas associated with recent ice-sheet or glacial melting, is reason to suspect that the warming climate will result in an increasing abundance of braid deltas. Sourced from meltwater in periglacial settings that will begin with negligible plant life, braid deltas will develop within fjords or coastal sandur plains as glacial debris is reworked. Such systems are observed in all locations with actively melting glaciers and ice sheets, including Greenland, Iceland, the Kerguelen Islands, and alpine regions found in the mountain chains of Alaska, the Andes, the Southern Alps of New Zealand, and the Himalaya (Fig. 3.6). As the melting of Antarctic ice sheets progresses over the coming centuries (DeConto and Pollard, 2016), development of numerous braid deltas in southern latitudes will begin. The most suitable analogues for these future systems are those found in Greenland, Iceland, Svalbard, and the Kerguelen Islands (Figs. 3.6, 3.9A, 3.11A); studies of these islands can predict the sedimentary environments and sediment flux from a deglaciating Antarctic. Based on the proposed classification (Fig. 3.8), numerous intermittent, river-dominated, linear braid deltas will form.

Conclusions

Nearly 800 Holocene braid-delta systems, fed by braided rivers over 500 meters in width, represent a depositional environment that is found across all latitudes and every continent except Antarctica. Additional research into smaller braid deltas, if completed, would only add to the list of recognized localities. A novel classification, utilizing flow characteristics, wave-, river-, or tide-dominance, and radial or linear morphology, predicts twelve morphotypes, nine of which occur under present-day conditions. Importantly, the majority of braid deltas are not distributive systems as initially depicted by McPherson et al. (1987), contributing to the current deficiency in their geomorphic recognition. The most abundant braid deltas are those with perennial/seasonal fluvial input and those dominated by river or wave energy. Each distinct morphotype produces its own diagnostic facies components, flow patterns, and channel-belt extent, illustrating the need for detailed observation of modern analogues to identify braid deltas in sedimentary strata on Earth, or on Mars.

This paper is a contribution towards a facies model for braid deltas, a goal that requires further database additions, stratigraphic study, and field-based investigations of multiple Holocene examples each representing the most common morphotypes. Importantly, common-delta and fan-delta facies models cannot adequately describe braid-delta strata, nor can the facies models for braided rivers or Gilbert deltas. Applications of an accurate

facies model are not limited to gaining context for the migration of marine life into fresh water, or to the martian sedimentary cycle. Deltaic environments are intricately linked to eustatic sea-level and climatic change and braid deltas in particular are sensitive to ice-cap and glacial melt, changes in vegetation, and the balance between humid and arid conditions. As the Earth warms, a detailed depositional model of braid deltas will inform calculations of sediment flux to the oceans and predict hazards to human infrastructure resulting from climate-driven change to braid-delta morphotypes. Large Holocene braid deltas, now fully catalogued, are a target for continued geomorphic study and represent suitable analogues for the pre-vegetation, Quaternary, and planetary sedimentology communities.

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Appendix A-3

Table 3.1: Count of braid-delta morphotypes based on surveying of large, Holocene, braid deltas.

Energy - Confinement Type	Perennial/Intermittent Braid Delta	Ephemeral Braid Delta
River - Linear	167 (66% marine)	48 (2% marine)
River - Radial	119 (63% marine)	55 (15% marine)
Wave - Linear	137 (97% marine)	88 (89% marine)
Wave - Radial	14 (100% marine)	41 (88% marine)
Tide - Linear	8 (100% marine)	0
Tide - Radial	0	0
Mixed - Linear	35 (89% marine)	7 (71% marine)
Mixed - Radial	46 (83% marine)	19 (84% marine)

Table 3.2: Feature-class area of braid-delta facies components in each identified braid-delta morphotype.

Feature class in m² (% in channel belt)	Kerguelen Islands	Turkwel R.	Rangitata R.	Rio Ocoa	Tuxedni R.	Panamint Valley	Tonopah	Al Ghaydah	Bosaso
<i>Feeder river</i>									
Channel belt	1,339,434	424,462	1,786,354	854,233	5,779,345	800,167	327,688	1,833,677	674,675
Channels	612,182 (45.7%)	228,095 (57.3%)	441,959 (24.7%)	136,123 (15.9%)	4,099,691 (70.9%)	308,705 (38.6%)	88,008 (26.9%)	521,039 (28.4%)	421,179 (62.4%)
Macroform	689,589 (51.5%)	109,808 (25.9%)	1,075,131 (60.2%)	398,870 (46.7%)	1,051,485 (18.2%)	332,821 (41.6%)	212,935 (65.0%)	628,946 (36.8%)	14,540 (2.2%)
Bank-attached macroform	–	74,542 (17.6%)	220,357 (12.3%)	287,596 (33.7%)	283,876 (4.9%)	43,245 (5.4%)	–	544,095 (29.7%)	215,667 (32.0%)
Unit bar	37,663 (2.8%)	12,017 (2.8%)	48,907 (2.7%)	31,644 (3.7%)	344,293 (6.0%)	115,397 (14.4%)	26,744 (8.2%)	93,566 (5.1%)	23,289 (3.5%)
Superimposed bar	–	–	–	–	–	–	–	219,180*	61,678*
Splay	–	42,346	–	–	–	–	–	–	–
Aeolian	–	7,575	–	–	–	–	–	–	–
Ponding	1,060*	–	1,199*	2,775*	2,329*	–	–	–	–
% bars / channel belt	54.3%	46.3%	75.3%	84.1%	29.1%	61.4%	73.1%	71.6%	37.6%
<i>Braid delta</i>									
Channel belt	100,821	465,463	112,923	640,787	20,606,429	126,254	575,520	513,205	1,357,362
Channels	88,282 (87.6%)	98,899 (21.2%)	52,621 (46.6%)	113,241 (17.7%)	12,295,414 (59.7%)	106,497 (84.4%)	118,925 (20.7%)	97,416 (19.0%)	249,895 (18.4%)
Macroform	10,428 (10.3%)	144,799 (31.1%)	23,154 (20.5%)	254,928 (39.8%)	101,351 (0.5%)	5,544 (4.4%)	267,256 (46.4%)	362,819 (70.7%)	670,315 (49.4%)
Bank-attached macroform	–	1,472 (0.3%)	27,869 (24.7%)	270,835 (42.3%)	6,850 (<0.1%)	–	–	3,098 (0.6%)	306,905 (22.6%)

Table 3.2: Feature-class area of braid-delta facies components in each identified braid-delta morphotype. Continued.

Feature class in m ² (% in channel belt)	Kerguelen Islands	Turkwel R.	Rangitata R.	Rio Ocoa	Tuxedni R.	Panamint Valley	Tonopah	Al Ghaydah	Bosaso
Unit bar	2,111 (2.1%)	4,715 (1.0%)	6,273 (5.6%)	1,782 (0.3%)	17,369 (0.1%)	14,213 (11.3%)	49,822 (8.7%)	11,800 (2.3%)	71,076 (5.2%)
Superimposed bar	—	—	—	—	—	—	—	36,498*	290,397*
Lagoon	—	6,873 (1.5%)	95,604 (2.7%)	12,884	—	—	—	38,073 (7.4%)	59,172 (4.4%)
Beach	—	10,926 (0.1%)	156,022	98,835	—	—	—	93,448	90,012
Tidal macroform	—	—	—	—	8,185,446 (39.7%)	—	—	—	—
Intertidal sediment	42,359	—	—	—	—	—	—	—	—
Inactive lobe	—	208,377 (44.8%)	—	—	—	—	—	—	—
Degraded surface	—	—	—	—	—	—	145,698 (23.5%)	—	—
Jet-plume deposit	—	—	—	—	—	—	4,427 (0.8%)	—	—
Ponding	—	—	—	3,472*	34,136*	—	—	—	—
% bars / channel belt	12.4%	77.2%	50.7%	82.3%	40.3%	15.6%	79.3%	73.6%	77.2%

*Features superimposed on other landforms in the channel belt; not included in the calculation of percentages relative to total channel-belt area.

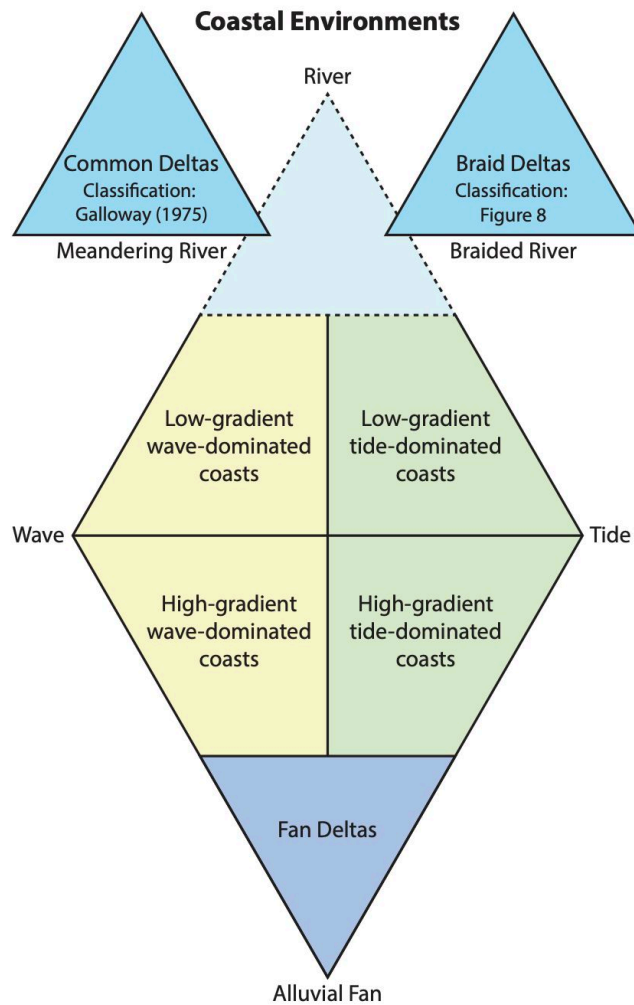


Figure 3.1: A coastal classification combining the work of Boyd et al. (1992) and McPherson et al. (1987). River, wave, tide, and alluvial-fan clastic coasts may develop based on local conditions. River dominated coasts form associated with meandering rivers that generate common deltas, or with braided rivers that prograde into standing water as braid deltas.

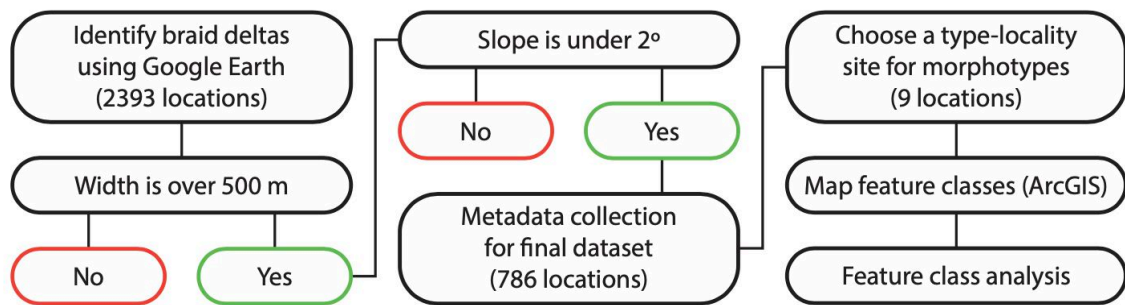


Figure 3.2: Methodology chart detailing the research design of this paper, including surveying, measurement, classification, and mapping of type localities.

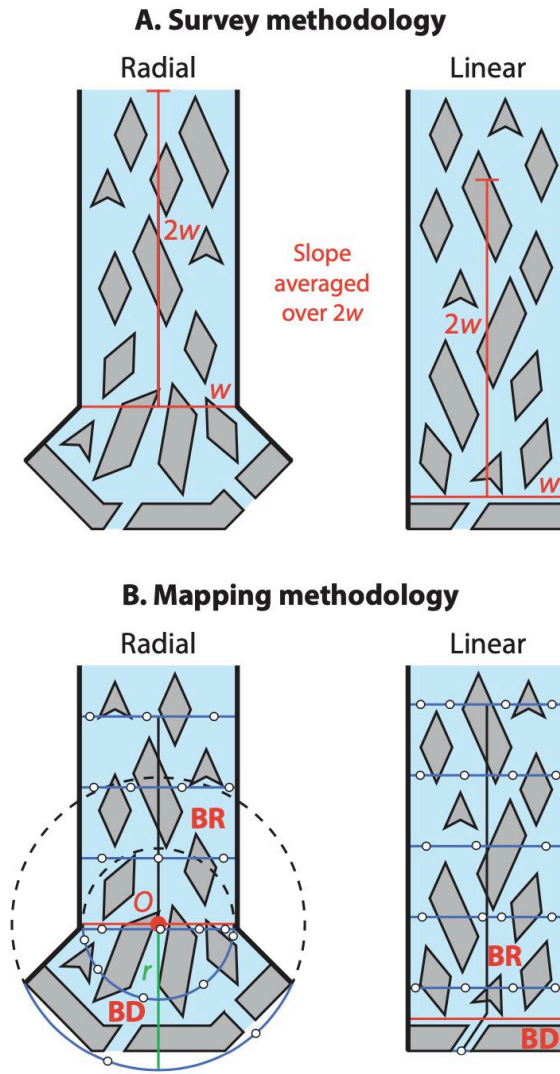


Figure 3.3: Diagrams illustrating methods of data collection to quantify braid deltas. **A)** Width (w) and slope measurement methodology for the feeder rivers of radial and linear braid-delta morphotypes. **B)** Channel-count methodology developed to extract braid index from mapped examples of braided systems, for both radial and linear braid-delta morphotypes. The interval between channel-count transects is 300 meters. Each red line indicates the division between braided-river (BR) and braid-delta (BD) environments. For radial braid deltas, the origin (O) of a circle fitted to the coastal trace of the delta plain provides the location to divide BR from BD. Channel belt – bounded by bold black lines, channels – light blue, barforms – gray, channel-count transects – dark blue lines, white circles – indication of a counted channel, green line – radius (r) of the radial braid delta.

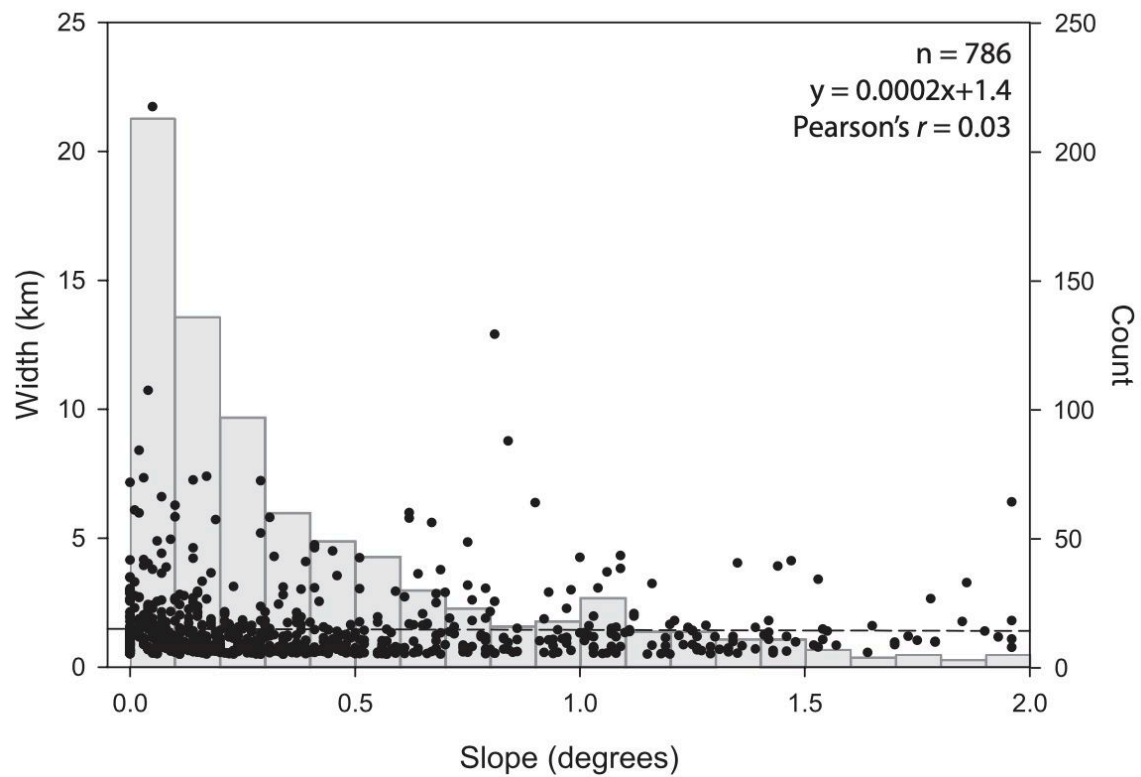


Figure 3.4: Slope (degrees) vs. width (km) scatter plot and histogram displaying each of the 786 braid-delta feeder rivers in the final database. A linear fit and near-zero Pearson's r suggest no correlation between the two variables. A skew of the data toward low values provides evidence that alluvial-fan feeder systems are not present in the surveyed locations.

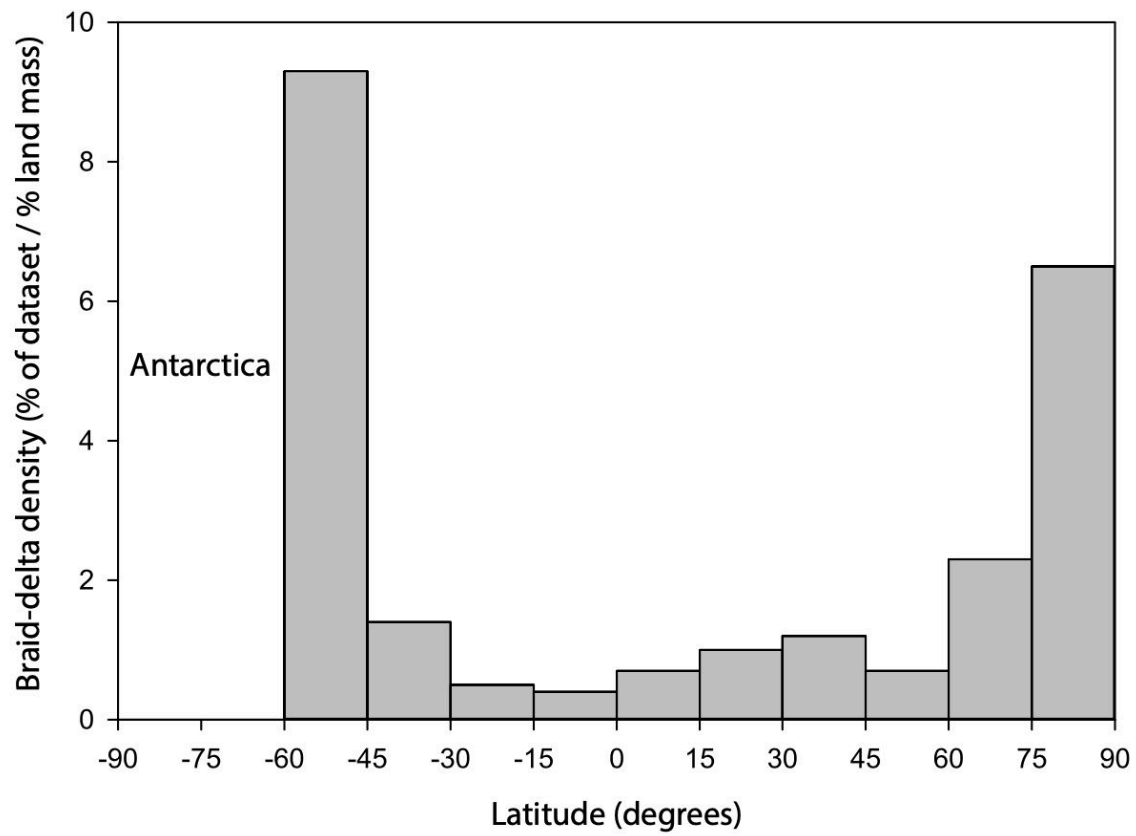


Figure 3.5: Histogram displaying the density of braid deltas per latitude, calculated as the percent of the dataset in each 15° bin divided by the percent land mass (Mendez, 2011) in that bin. Elevated densities occur in the highest latitudes, where land mass is low and glaciation generates increased sediment yield. Antarctica, represented by -60° to -90° latitudes, hosts no braid deltas.

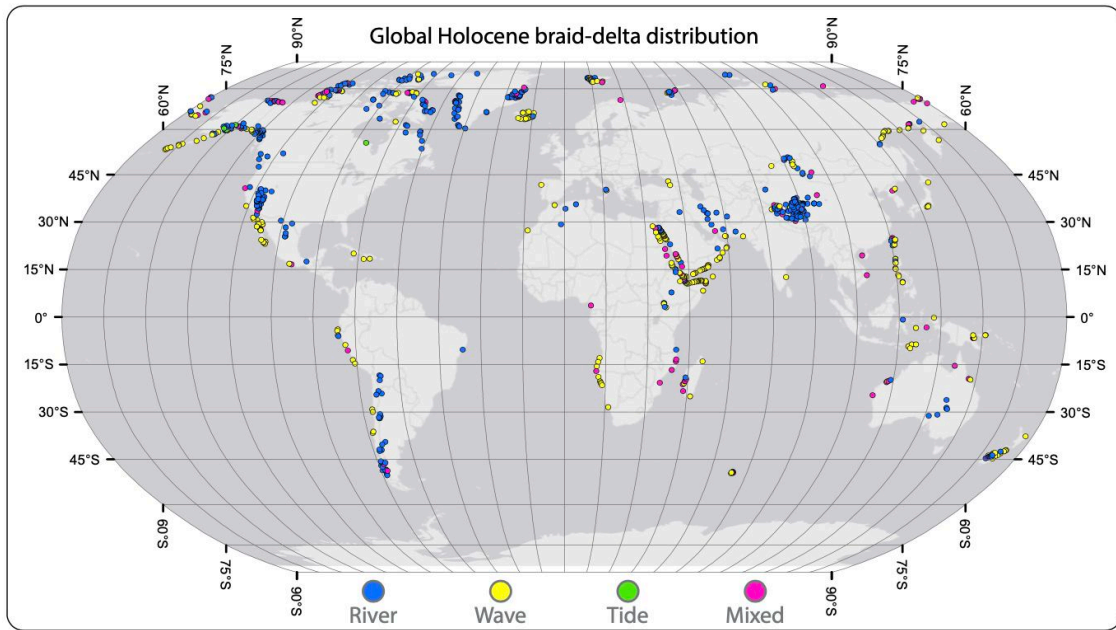


Figure 3.6: The global distribution of Holocene braid deltas on Earth, produced via systematic survey of shorelines. Colors correspond to the dominant energy control on each braid delta. Database files are available in Appendix A-4, Table 4.4.

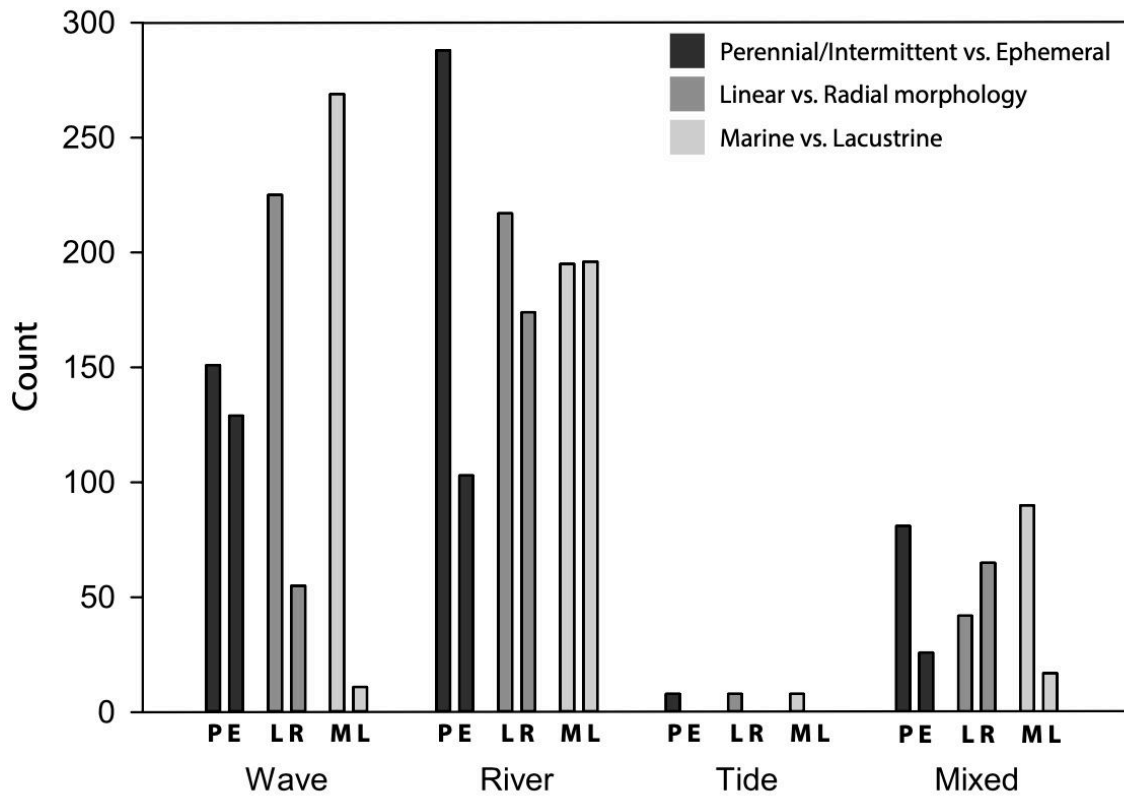


Figure 3.7: Bar chart displaying observed parameters for braid deltas with wave, river, tide, and mixed energy dominance. Wave-dominated braid deltas are evenly split between perennial/intermittent and ephemeral flow, largely linear in morphotype, and mostly marine. Perennial/intermittent feeder systems are abundant for river-dominated braid deltas that are otherwise evenly distributed between linear or radial and found equally in marine or lacustrine settings. Tide dominance is only observed in marine, perennial, linear braid deltas. Additional numerical data are included in Table 3.1 and Appendix A-4, Table 4.4.

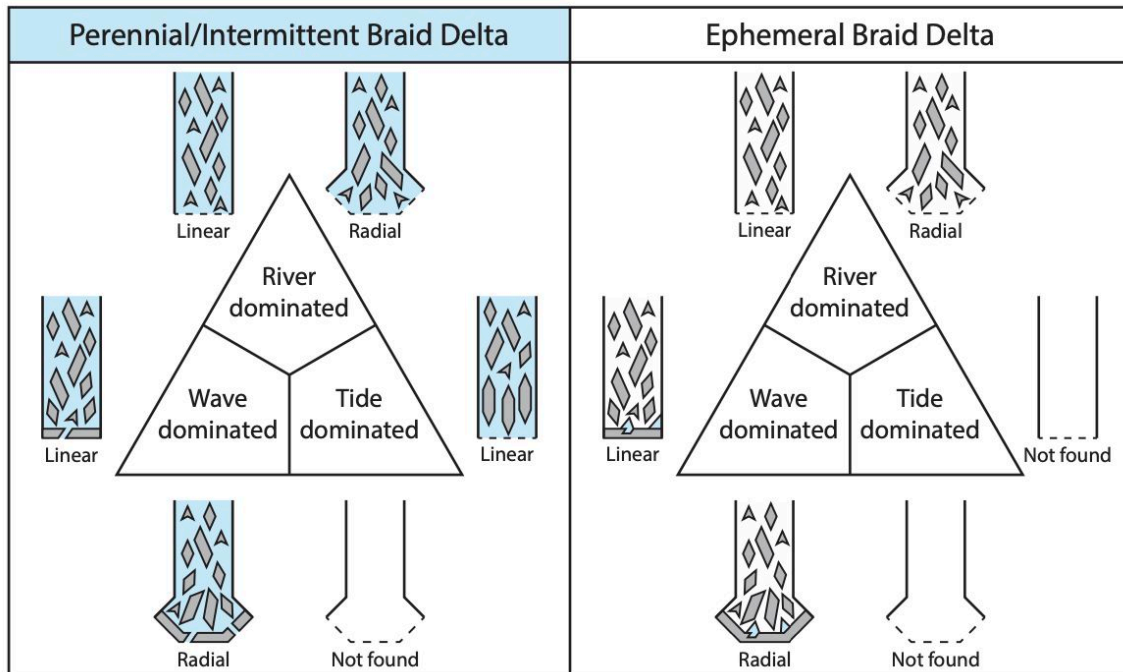


Figure 3.8: Novel, three-part classification of Holocene braid-delta morphotypes based on global observations (Fig. 3.6). Braid deltas are divided into those with perennial/intermittent and ephemeral flow, then classified as river, wave, or tide dominated, and finally identified as linear or radial in confinement characteristics. Diagrams illustrate each of the nine morphotypes observed in the dataset with colors corresponding to those in Figure 3.3. Empty diagrams associated with tide dominance are hypothetical morphotypes not discovered during surveying. Additional numerical data for each morphotype are included in Table 3.1 and Appendix A-4, Table 4.4.

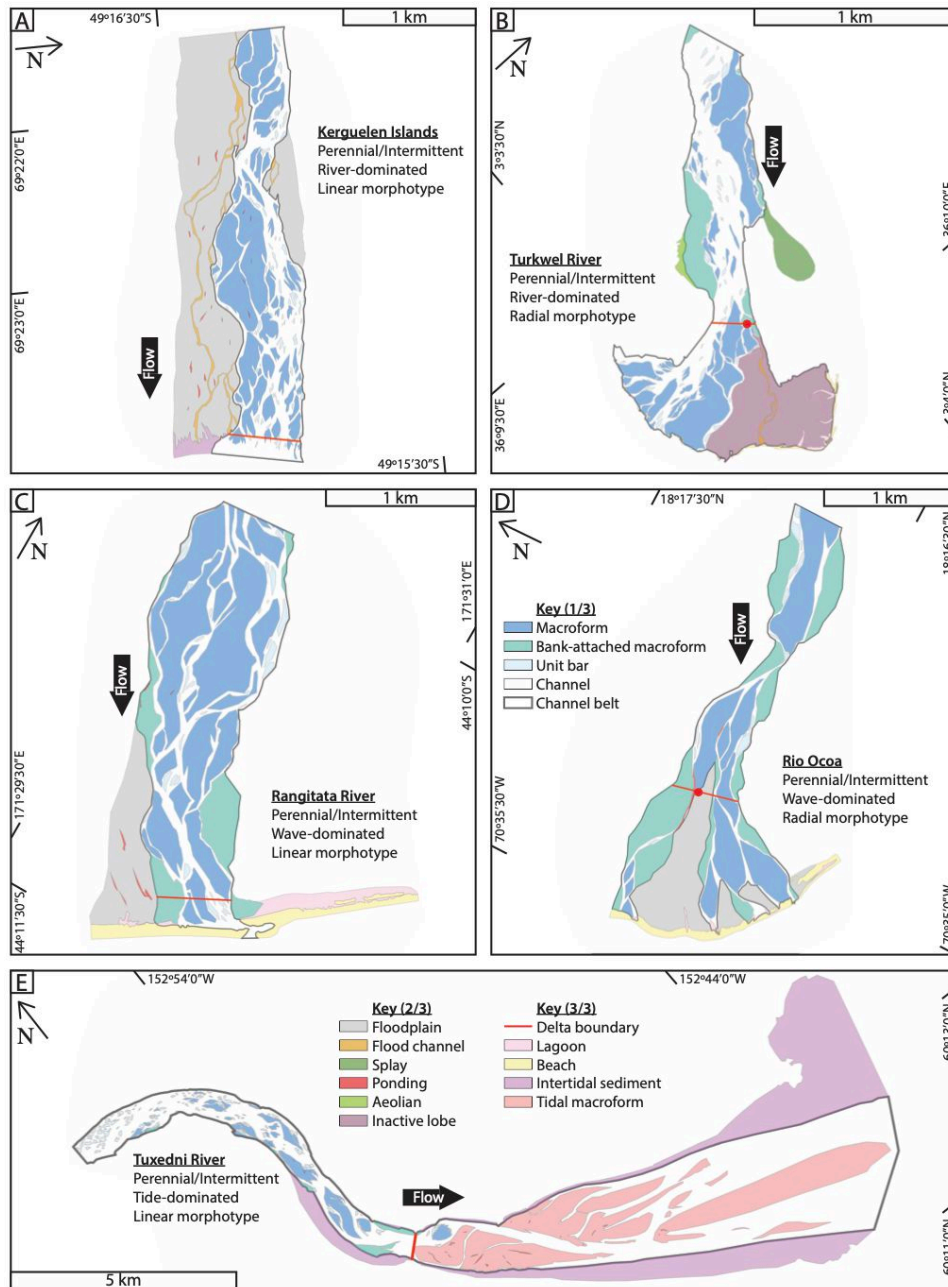


Figure 3.9: Geomorphic maps of perennial/intermittent braid-delta type localities in Esri™ ArcMap. Sites mapped include **A**) a Kerguelen Islands braided system (BD0684), **B**) the Turkwel River delta, Kenya (BD1975), **C**) the Rangitata River delta of New Zealand (BD0403), **D**) the Rio Ocoa delta in the Dominican Republic (BD0849), and **E**) the Alaskan Tuxedni River delta (BD1181). Red points on radial braid-delta maps represent circle-origin parameter O , described in Figure 3.3. Scales are independent and marked for each locality; numerical data are presented in Table 3.2. Additional views and coordinates in Appendix A-4, Table 4.4, Figures 4.2–4.16.

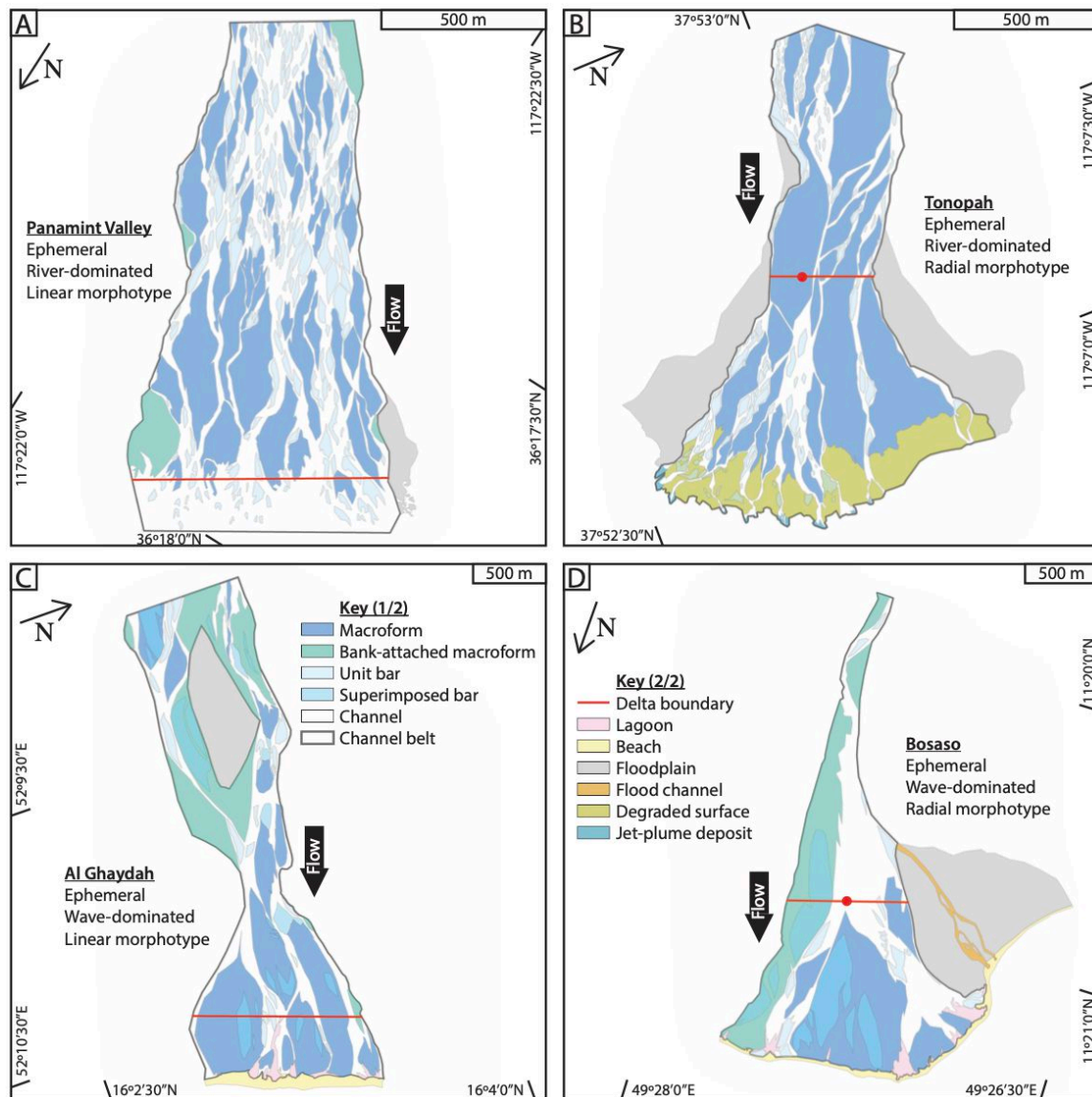


Figure 3.10: Geomorphic maps of ephemeral braid-delta type localities in Esri™ ArcMap. Sites mapped include **A**) a Panamint Valley braided system in California (BD2063), **B**) a braid delta near Tonopah, Nevada (BD2209), **C**) a locality east of Al Ghaydah, Yemen (BD0096), and **D**) a braid delta west of Bosaso, Somalia (BD1579). Red points on radial braid-delta maps represent circle-origin parameter O , described in Figure 3.3. Scales are independent and marked for each locality; numerical data are presented in Table 3.2. Additional views and coordinates in Appendix A-4, Table 4.1, Figures 4.17–4.28.

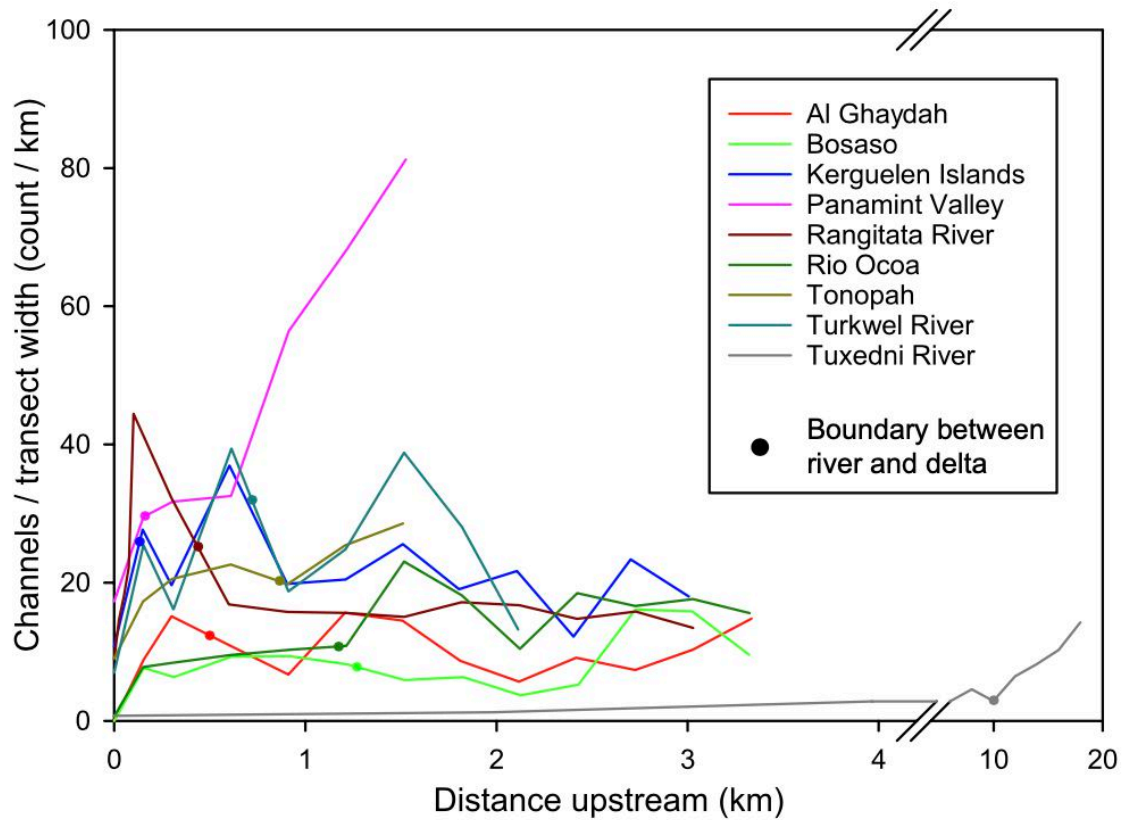


Figure 3.11: Plot of channel-count braid index (Fig. 3.3B) over distance (km) for each type-locality map in Figures 3.9 and 3.10. Channel counts are normalized per kilometer for comparison. Notably, the lowest channel count for each system is closest to base level. Circles placed on each line indicate the boundary between braided-river and braid-delta environments. Data and images of channel-count transects are presented in Appendix A-4, Table 4.6.

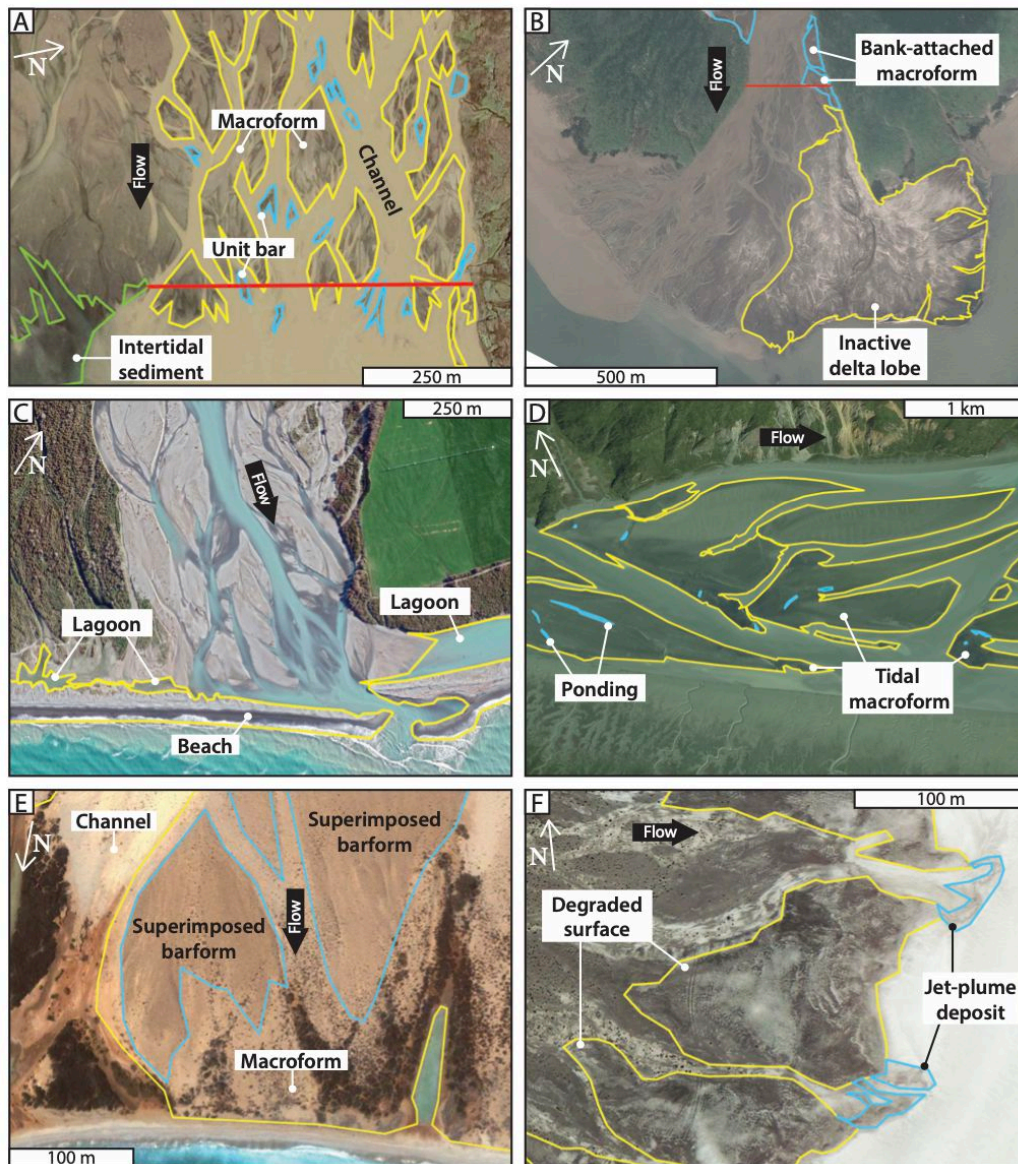


Figure 3.12: Braid-delta facies component examples from type localities. **A)** Fluvial facies components in the Kerguelen Islands channel belt (Fig. 3.9A), including complex macroforms (yellow), simple unit bars (blue), and active channels. Sediment outlined in green is within the tidal range. Boundary between braided-river and braid-delta environments marked in red. **B)** Additional fluvial facies components in the radial Turkwel River delta (Fig. 3.9B). Bank-attached macroforms outlined in blue; inactive delta lobe outlined in yellow. **C)** Traced barrier beaches and lagoons, the common wave-dominated facies components of braid deltas exemplified by the Rangitata River (Fig. 3.9C). **D)** Tidal dominance in the Tuxedni River braid delta (Fig. 3.9E) forms tidal macroforms (yellow) reworking fluvial sediments and low-tide ponding (blue). **E)** Darker superimposed barforms (blue) overriding larger macroforms (yellow) in the ephemeral Bosaso site (Fig. 3.10D). **F)** Braid delta reaching a salt flat at the Tonopah location (Fig. 3.10B), with fluvial sediments degraded by wave or wind reworking (yellow) and jet-plume deposits (Wellner et al., 2005) basinward of channel outflows (blue).

CONCLUSION

Detailed stratigraphic logging, facies analysis, and stratigraphic panels of the middle member Wood Canyon Formation, in the southern Marble Mountains, improve on prior descriptions of depositional environment for the member and hold significance for the classification of other pre-vegetation fluvial and deltaic systems. Structure-from-Motion techniques generate 3D models that, combined with field-based observation and measurement, allow interpretation of architectural elements from bedform to outcrop scale. In fluvial middle member strata, stacked sandstone cosets interpreted as low-relief fluvial bars and channel fills preserve vertical-, downstream-, and lateral-accretion elements as part of a channel belt with unimodal NNW transport. Sedimentary analysis of interbedded units reveals a perennial fluvial system that gradually built large sand bars on a continental-scale braidplain, where overbank sediments were subject to weathering and aeolian transport. A connected braid delta, preserved in a nearby stratigraphic section 8 km to the south of the fluvial deposits, preserves up to 12% mudstone, comprising decimeter-thick beds that show the first evidence for deposition of fluidized muds within the brackish waters of a pre-vegetation braid delta. Abundant symmetrical and interference oscillation ripples indicate submergence of the distal braid delta beneath shallow water, and rare bedforms migrating opposite paleoslope may preserve minor tidal modification. Bedding-plane subparallel ichnofossils discovered in the braid-delta front interval are traces of Terreneuvian organisms that lived in water of oceanic salinity. Unable to survive the brackish and turbid setting of the distal braid delta, metazoans did not migrate into the fluvial system. Progression from more fluvial to more marine settings with increasing stratigraphic height requires that the middle member experienced gradual sea-level rise during deposition, separating the strata from braided environments deposited under regression.

Braid deltas, similar to those that flowed in the early Cambrian, are also plentiful along Holocene coastlines. A survey of 786 systems, fed by braided rivers over 500 meters in width, identified the depositional environment across all latitudes and every continent except Antarctica. A novel classification, utilizing flow characteristics, wave-, river-, or tide-dominance, and radial or linear morphology, predicts twelve morphotypes, nine of which occur under present-day conditions. Importantly, the majority of braid deltas are not distributive systems, contributing to the current deficiency in their geomorphic recognition. The most abundant braid deltas are those with perennial/intermittent fluvial input and those dominated by river or wave energy. Each distinct morphotype produces its own diagnostic facies components, flow patterns, and channel-belt extent, illustrating the need for detailed observation of modern analogues to identify braid deltas in sedimentary strata on Earth, or on Mars. Importantly, common-delta and fan-delta facies models cannot adequately describe braid-delta strata, nor can the facies models for braided rivers. Large Holocene braid deltas, now extensively catalogued, are a target for continued geomorphic study and represent suitable analogues for the pre-vegetation, Quaternary, and planetary sedimentology communities.

Appendix A-4

Additional data for Chapter I

Table 4.1: Fracture-plane measurements.

Unit M1			Unit M2			Unit M3		
Strike	Dip	Dip direction	Strike	Dip	Dip direction	Strike	Dip	Dip direction
160	80	W	230	49	N	181	61	W
95	90	S	193	20	W	181	35	W
162	51	W	206	52	W	205	87	W
260	80	N	294	87	N	282	81	N
135	75	S	111	90	S	275	74	N
159	85	W	150	59	W	285	74	N
146	59	W	238	61	N	172	35	W
240	72	N	130	86	S	168	20	W
151	54	W	185	30	W	272	63	N
241	54	N	146	21	W	262	79	N
238	61	N	140	60	W	165	30	W
148	38	W	174	41	W	276	61	N
164	76	W	310	85	N	159	26	W
159	65	W	176	34	W	122	64	S
248	81	N	181	34	W	186	20	W
168	81	W	164	36	W	145	60	W
255	62	N	155	59	W	168	22	W
176	71	W	84	85	S	130	66	S
155	65	W	154	60	W	188	70	W
260	74	N	260	62	N	256	75	N
260	86	N	86	86	S	181	22	W
200	53	W	160	59	W	190	34	W
185	56	W	159	62	W	202	47	W
249	61	N	248	68	N	191	30	W
28	82	E	240	71	N	211	25	W
101	90	S	242	51	N	249	65	N
195	47	W	155	52	W	174	23	W
240	60	N	231	59	N	228	66	N
146	56	W	280	67	N	191	22	W
104	90	S	151	61	W	235	45	N
170	59	W	206	40	W	215	46	W
229	51	N	283	85	N	236	45	N

Table 4.1: Fracture-plane measurements. Continued.

Unit M1			Unit M2			Unit M3		
Strike	Dip	Dip direction	Strike	Dip	Dip direction	Strike	Dip	Dip direction
140	62	W	241	64	N	114	74	S
166	49	W	140	57	W	115	78	S
220	64	W	249	60	N	146	63	W
154	57	W	155	70	W	111	84	S
236	62	N	239	60	N	249	51	N
126	22	S	178	35	W	151	59	W
254	53	N	113	78	S	158	56	W
301	81	N	149	44	W	93	81	S
151	68	W	180	65	W	160	50	W
209	53	W	278	86	N	146	65	W
155	43	W	185	52	W	265	60	N
254	56	N	162	51	W	286	87	N
245	54	N	163	58	W	141	69	W
169	66	W	162	54	W	167	75	W
150	61	W	290	79	N	114	90	S
250	64	N	236	66	N	164	64	W
173	52	W	111	90	S	265	74	N
140	71	W	219	46	W	264	66	N

Table 4.2: Bedding-plane measurements.

Zabriskie Quartzite dip slope			Upper member Wood Canyon Fm. Bedding		
Strike	Dip	Dip direction	Strike	Dip	Dip direction
11	55	E	5	43	E
20	52	E	6	55	E
16	57	E	0	46	E
14	54	E	6	55	E
14	52	E	9	51	E
18	50	E	4	51	E
15	50	E	10	52	E
15	58	E	11	48	E
19	49	E	10	47	E
14	50	E	10	49	E
16	52	E	14	55	E
4	51	E	9	54	E
11	53	E	11	50	E
11	54	E	6	53	E
15	49	E	10	50	E
15	48	E	7	58	E
16	46	E	7	52	E
19	54	E	5	47	E
6	51	E	9	52	E
19	48	E	5	58	E
14	53	E	9	52	E
14	53	E	7	52	E
10	55	E	10	51	E
10	52	E	7	50	E
11	55	E	6	51	E
8	58	E	9	49	E
12	57	E	11	46	E
17	49	E			

Additional data for Chapter II

Table 4.3: Fracture-plane measurements.

Strike	Dip	Dip Direction
155	56	W
155	59	W
59	72	N
60	68	N
36	56	S
46	53	S
142	42	W
74	58	N
137	42	W
77	63	N
35	90	
31	90	
13	44	W
144	39	W
108	74	S
145	40	W
36	78	S
85	62	N
127	31	W
80	71	N
136	60	W
130	53	W
107	79	S
63	50	N
66	52	N
128	62	E
134	79	E
132	69	W
106	90	
107	90	
43	58	N
115	56	W
43	52	N

Table 4.3: Fracture-plane measurements. Continued.

Strike	Dip	Dip Direction
54	54	N
118	60	N
122	82	E
115	81	W
129	90	
52	57	N
37	90	
130	78	W
29	90	
60	47	N
124	82	W
61	38	N
38	80	N
120	74	S
46	44	N
81	45	N
132	62	W
84	58	N
114	70	S
148	69	W
42	67	N
86	58	N
83	90	
135	37	W
0	54	W
85	65	N
80	65	N
108	76	S
111	82	S
136	39	W
89	64	N
45	54	N
106	70	S
136	62	W
47	77	N

Table 4.3: Fracture-plane measurements. Continued.

Strike	Dip	Dip Direction
154	90	
89	62	N
79	68	N
140	50	W
146	81	W
79	63	N
79	72	N
149	68	W
170	80	W
161	41	W
70	64	N
148	42	W
70	64	N
30	62	S
120	67	W
71	61	N
74	60	N
143	81	S
130	62	S
59	54	N
60	54	N
10	46	W
76	62	N
166	35	W
176	42	W
6	70	W
79	68	N
169	59	W
45	75	N
74	67	N
148	46	W
173	80	W
120	52	W
68	74	N
171	42	W

Table 4.3: Fracture-plane measurements. Continued.

Strike	Dip	Dip Direction
126	54	W
71	50	N
123	62	W
87	64	N
158	48	W
64	66	N
179	57	W
82	68	N
156	75	W
145	70	W
38	90	
85	70	N
127	70	N
130	61	W
4	32	W
140	68	W
85	62	N
131	65	W
117	67	W
69	64	W
131	57	W
87	67	N
117	44	W
37	63	S
113	40	W
150	72	W
79	63	N
75	56	N
136	56	W
142	74	W
89	80	N
80	50	N
75	66	N
150	64	W
78	85	N

Table 4.3: Fracture-plane measurements. Continued.

Strike	Dip	Dip Direction
124	67	W
75	70	N
25	64	W
72	78	S
126	69	W
109	70	S
95	40	N
115	52	S
120	64	W
113	66	S
73	63	N
32	42	N

Table 4.4: Bedding-plane measurements.

Strike	Dip	Dip Direction
14	50	E
15	50	E
8	52	E
11	49	E
3	50	E
9	52	E
2	49	E
12	47	E
4	50	E
6	46	E
5	54	E
0	55	E
358	56	E
5	52	E
11	50	E
359	58	E
7	51	E
7	49	E
5	48	E
10	47	E
4	46	E

Additional data for Chapter III

Table 4.4: Holocene braid-delta database.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0001	63.75136113	-17.52410376	0.79	1.58	0.13	0.07	W	W	Increase	Marine	Not visible	Absent	Glacial
BD0002	63.46136955	-18.21811119	4.95	9.9	0.15	0.09	W	W	Increase	Marine	Not visible	Absent	Glacial
BD0003	63.77557101	-20.79380708	1.72	3.44	0.03	0.02	W	W	Increase	Marine	Heavy	Minimal	Glacial
BD0004	65.97848979	-17.59045633	1.58	3.16	0.00	0.00	W	W	Increase	Marine	Heavy	Absent	Glacial
BD0005	64.36261231	-14.80687353	2.63	5.26	0.30	0.17	W	W	Increase	Marine	Visible	Absent	Glacial
BD0006	63.5380066	-50.75181586	2.84	5.68	0.00	0.00	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0007	64.2175504	-50.17811031	2.91	5.82	0.00	0.00	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0008	71.2817632	-24.58030149	4.21	8.42	0.24	0.14	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0009	80.17141362	-88.92895106	1.44	2.88	1.67	0.95	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0010	81.45931691	-76.72517738	2.84	5.68	1.18	0.68	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0011	73.56793589	-124.0575902	3.93	7.86	0.05	0.03	W	R	Decrease	Marine	Visible	Absent	Glacial
BD0012	72.51346015	-125.2021935	4.4	8.8	0.13	0.07	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0013	72.08140175	-125.6755933	2.02	4.04	0.05	0.03	W	M	Decrease	Marine	Heavy	Absent	Glacial
BD0014	73.14792927	-76.59152848	0.67	1.34	0.00	0.00	W	W	Increase	Marine	Visible	Absent	Glacial
BD0015	72.97308051	-76.33029159	2.89	5.78	1.23	0.70	W	W	Neutral	Marine	Not visible	Absent	Glacial
BD0016	73.15477617	-80.14223332	2.14	4.28	0.07	0.04	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD0017	73.48924912	-80.69389619	1.61	3.22	0.31	0.18	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0018	73.35551831	-77.03480435	5.19	10.38	0.50	0.29	W	W	Increase	Marine	Visible	Absent	Glacial
BD0020	66.70676754	-63.40839573	2.49	4.98	1.18	0.68	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0021	66.37088234	-66.57688879	1.3	2.6	0.00	0.00	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0022	73.2407715	-80.17490167	0.52	1.04	0.38	0.22	W	R	Decrease	Marine	Visible	Absent	Glacial
BD0023	69.79596619	174.0027191	2.99	5.98	0.00	0.00	W	M	Decrease	Marine	Heavy	Absent	Uplift

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0024	69.22164072	179.3620079	1.86	3.72	0.03	0.02	W	M	Decrease	Marine	Heavy	Absent	Uplift
BD0026	68.18414965	-177.6273817	7.15	14.3	0.01	0.00	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0027	65.06119665	-175.7561388	0.52	1.04	0.00	0.00	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0028	65.2213501	-175.8297474	1.29	2.58	0.00	0.00	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0029	59.48900732	160.4668004	1.24	2.48	0.24	0.14	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0030	61.78747693	157.7441336	0.81	1.62	0.12	0.07	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0031	61.78863163	157.4733464	1.2	2.4	0.33	0.19	W	R	Decrease	Marine	Heavy	Absent	Uplift
BD0033	61.56776267	156.9448553	1.81	3.62	0.03	0.02	W	M	Neutral	Marine	Heavy	Absent	Uplift
BD0035	60.44699374	155.1968091	1.12	2.24	0.09	0.05	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0036	60.23694288	154.7609486	1.03	2.06	0.29	0.17	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0037	59.65855266	150.1414863	1.19	2.38	0.25	0.14	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0038	59.37536405	144.9102463	2.67	5.34	0.17	0.10	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0039	59.37797873	144.428483	2.13	4.26	0.26	0.15	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0040	59.34073005	143.0650118	0.83	1.66	0.30	0.17	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0041	59.28268281	142.8498205	1.48	2.96	0.14	0.08	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0042	58.85891601	141.864282	2.4	4.8	0.08	0.05	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0045	57.75139011	140.1928648	0.6	1.2	0.67	0.38	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0046	57.37756305	139.531648	0.63	1.26	0.40	0.23	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0047	56.95530876	138.603609	0.66	1.32	0.68	0.39	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0048	55.03138879	135.4432897	1.61	3.22	0.53	0.30	W	R	Decrease	Marine	Heavy	Minimal	Uplift
BD0049	54.72532468	135.2799928	4.16	8.32	0.06	0.03	W	R	Neutral	Marine	Heavy	Minimal	Uplift
BD0053	34.92946662	138.3928991	0.62	1.24	0.40	0.23	W	W	Increase	Marine	Visible	Heavy	Uplift
BD0054	35.11834747	138.6363307	0.72	1.44	0.35	0.20	W	W	Increase	Marine	Visible	Heavy	Uplift
BD0060	34.66230246	137.7909312	0.9	1.8	0.00	0.00	W	W	Increase	Marine	Visible	Heavy	Uplift

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0061	34.76901499	138.2926193	0.82	1.64	0.18	0.10	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD0063	42.44635114	143.4088536	0.5	1	0.50	0.29	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0067	25.42381593	66.01500642	2.68	5.36	0.24	0.14	D	W	Increase	Marine	Not visible	Absent	Arid
BD0072	25.3959734	59.65545549	0.88	1.76	0.34	0.20	D	W	Increase	Marine	Visible	Absent	Arid
BD0073	25.4705373	59.37948489	0.93	1.86	0.00	0.00	D	W	Increase	Marine	Visible	Absent	Arid
BD0077	27.02067595	55.88881817	4.01	8.02	0.06	0.04	D	M	Decrease	Marine	Not visible	Minimal	Arid
BD0079	18.32846676	56.60284258	0.54	1.08	0.19	0.11	D	W	Decrease	Marine	Visible	Minimal	Arid
BD0080	17.88314448	55.60054537	0.71	1.42	0.42	0.24	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0095	16.32106822	52.33281113	0.57	1.14	0.26	0.15	D	W	Increase	Marine	Not visible	Minimal	Arid
BD0096	16.05242317	52.17954879	0.69	1.38	0.07	0.04	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0097	16.00180686	52.15502866	0.81	1.62	0.25	0.14	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0098	15.301725	51.48327841	0.57	1.14	0.09	0.05	D	W	Neutral	Marine	Not visible	Absent	Arid
BD0100	15.17968265	51.13106102	2.59	5.18	0.17	0.10	D	W	Increase	Marine	Visible	Absent	Arid
BD0102	15.11755796	50.90981918	0.82	1.64	0.55	0.31	D	W	Decrease	Marine	Visible	Minimal	Arid
BD0103	15.06212401	50.64172603	0.84	1.68	0.30	0.17	D	W	Neutral	Marine	Visible	Absent	Arid
BD0106	14.84748631	50.08931301	0.63	1.26	0.08	0.05	D	W	Increase	Marine	Visible	Minimal	Arid
BD0107	14.84760517	49.96168554	1.32	2.64	0.87	0.50	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0112	14.57868381	49.22810303	0.52	1.04	0.00	0.00	D	W	Neutral	Marine	Visible	Heavy	Arid
BD0121	13.81945086	47.59262128	1.65	3.3	0.67	0.38	D	W	Decrease	Marine	Visible	Heavy	Arid
BD0122	13.57340905	47.08282487	0.95	1.9	1.47	0.84	D	W	Neutral	Marine	Visible	Absent	Arid
BD0124	13.43165172	46.68354447	2.81	5.62	0.20	0.11	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0133	12.62110082	44.06535632	1.23	2.46	0.53	0.30	D	W	Decrease	Marine	Visible	Minimal	Arid
BD0134	12.74545065	43.60781184	2.72	5.44	1.07	0.61	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0135	17.05570495	42.45798837	1.2	2.4	0.42	0.24	D	R	Decrease	Marine	Not visible	Minimal	Arid

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0136	18.09011272	41.5947365	0.93	1.86	0.00	0.00	D	W	Decrease	Marine	Visible	Minimal	Arid
BD0140	18.88514393	41.16209788	1.63	3.26	0.28	0.16	D	M	Decrease	Marine	Visible	Minimal	Arid
BD0142	19.22729259	41.04703948	1.59	3.18	0.28	0.16	D	W	Decrease	Marine	Visible	Heavy	Arid
BD0146	19.64242135	40.80193802	0.97	1.94	0.10	0.06	D	M	Decrease	Marine	Visible	Heavy	Arid
BD0147	19.79369668	40.72112079	2.05	4.1	0.37	0.21	D	M	Decrease	Marine	Visible	Heavy	Arid
BD0148	22.85157049	38.96669375	2.71	5.42	0.04	0.02	D	R	Neutral	Marine	Not visible	Minimal	Arid
BD0149	24.28711422	37.70581719	0.76	1.52	0.46	0.26	D	W	Decrease	Marine	Visible	Minimal	Arid
BD0152	24.56275953	37.36805429	0.65	1.3	0.15	0.09	D	W	Neutral	Marine	Not visible	Minimal	Arid
BD0154	24.67603209	37.29464297	0.59	1.18	0.51	0.29	D	W	Increase	Marine	Visible	Minimal	Arid
BD0161	25.41658324	37.08192901	2.34	4.68	0.26	0.15	D	W	Decrease	Marine	Not visible	Minimal	Arid
BD0164	25.58891007	36.96657935	0.59	1.18	0.51	0.29	D	W	Decrease	Marine	Not visible	Minimal	Arid
BD0168	25.74042102	36.83370073	0.79	1.58	0.63	0.36	D	W	Decrease	Marine	Not visible	Minimal	Arid
BD0169	25.89382724	36.68278731	1.79	3.58	0.17	0.10	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0171	26.05640581	36.66057436	0.53	1.06	0.38	0.22	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0172	26.1073928	36.51280317	0.64	1.28	0.31	0.18	D	W	Increase	Marine	Visible	Minimal	Arid
BD0183	26.59429379	36.25329775	0.99	1.98	0.76	0.43	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0191	26.66504634	36.18609625	1.03	2.06	0.19	0.11	D	W	Increase	Marine	Visible	Minimal	Arid
BD0200	26.7620767	36.09285518	0.52	1.04	0.77	0.44	D	W	Increase	Marine	Visible	Minimal	Arid
BD0208	27.0017398	35.91501065	0.65	1.3	0.23	0.13	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0218	27.1240534	35.80436349	0.66	1.32	0.53	0.30	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0220	27.17193682	35.79650734	1.53	3.06	0.36	0.21	D	R	Decrease	Marine	Not visible	Minimal	Arid
BD0221	27.2077099	35.80961097	0.62	1.24	0.73	0.42	D	R	Decrease	Marine	Visible	Minimal	Arid
BD0232	27.73721396	35.45367784	0.58	1.16	0.86	0.49	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0239	27.89226818	35.31043918	1.38	2.76	0.80	0.46	D	W	Neutral	Marine	Visible	Minimal	Arid

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0242	28.02314997	35.21211707	1.5	3	0.43	0.25	D	M	Neutral	Marine	Visible	Minimal	Arid
BD0243	28.06490666	35.15131215	0.74	1.48	0.68	0.39	D	M	Decrease	Marine	Visible	Heavy	Arid
BD0246	28.11391466	35.03600495	2.93	5.86	0.26	0.15	D	R	Decrease	Marine	Visible	Minimal	Arid
BD0253	-23.56851797	43.76133279	1.43	2.86	0.10	0.06	W	M	Neutral	Marine	Visible	Absent	Arid
BD0256	-21.44664028	43.4669654	1.18	2.36	0.00	0.00	W	M	Decrease	Marine	Heavy	Absent	Arid
BD0257	-21.05252801	43.86272102	0.68	1.36	0.29	0.17	D	W	Increase	Marine	Visible	Absent	Arid
BD0258	-20.47139143	44.14371112	0.85	1.7	0.18	0.10	D	M	Decrease	Marine	Visible	Absent	Arid
BD0259	-20.33358101	44.25647332	0.82	1.64	0.00	0.00	W	M	Decrease	Marine	Heavy	Absent	Arid
BD0260	-19.71951172	44.5444557	1.21	2.42	0.04	0.02	W	M	Decrease	Marine	Heavy	Absent	Arid
BD0261	-19.25490729	44.33811754	0.51	1.02	0.10	0.06	W	R	Decrease	Marine	Heavy	Absent	Arid
BD0265	-14.14671784	50.15227633	0.59	1.18	0.25	0.15	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0267	-25.17202635	46.43545943	0.57	1.14	0.09	0.05	W	W	Increase	Marine	Visible	Minimal	Arid
BD0268	27.82725793	34.03996531	1.29	2.58	1.86	1.07	D	M	Decrease	Marine	Not visible	Minimal	Arid
BD0269	27.90371596	33.94700141	1.32	2.64	1.74	1.00	D	M	Neutral	Marine	Visible	Minimal	Arid
BD0270	28.536718	32.93627403	0.84	1.68	2.02	1.16	D	W	Decrease	Marine	Not visible	Minimal	Arid
BD0279	-6.743696374	146.9677832	0.9	1.8	0.17	0.10	W	R	Neutral	Marine	Heavy	Absent	Uplift
BD0280	-6.727863405	147.0537071	0.74	1.48	0.54	0.31	W	M	Decrease	Marine	Heavy	Absent	Uplift
BD0283	-6.724966112	147.1798482	0.5	1	2.10	1.20	W	M	Decrease	Marine	Heavy	Absent	Uplift
BD0284	-6.74732349	147.3312965	1.02	2.04	1.76	1.01	W	W	Decrease	Marine	Heavy	Absent	Uplift
BD0288	-5.840711597	146.8326727	1.02	2.04	0.69	0.39	W	W	Decrease	Marine	Heavy	Absent	Uplift
BD0303	-0.361438912	132.569976	0.56	1.12	2.86	1.64	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0304	15.26114345	120.0177238	1.29	2.58	0.19	0.11	W	M	Neutral	Marine	Heavy	Heavy	Uplift
BD0306	15.03566019	120.0585094	0.64	1.28	0.23	0.13	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD0310	18.27328572	120.5714626	0.97	1.94	0.26	0.15	W	W	Increase	Marine	Heavy	Heavy	Uplift

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0311	18.19746393	120.5298053	1.05	2.1	0.05	0.03	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD0312	17.51628266	120.4213327	2.13	4.26	0.12	0.07	W	R	Neutral	Marine	Heavy	Heavy	Uplift
BD0313	16.91124228	120.4162126	1.28	2.56	0.16	0.09	W	W	Decrease	Marine	Heavy	Heavy	Uplift
BD0314	13.13342588	120.6863356	0.58	1.16	0.26	0.15	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0315	12.73623726	120.7905319	0.63	1.26	0.24	0.14	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0317	11.01691546	122.0415153	0.75	1.5	0.13	0.08	W	R	Decrease	Marine	Heavy	Minimal	Uplift
BD0318	10.81154404	121.9485471	0.77	1.54	0.26	0.15	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0319	-3.594849914	126.170078	0.54	1.08	0.65	0.37	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0332	-3.394232286	129.9696184	1.05	2.1	0.14	0.08	W	M	Decrease	Marine	Heavy	Absent	Uplift
BD0340	-9.436670672	123.9014159	1	2	1.00	0.57	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0341	-9.401743325	123.9445448	1.06	2.12	0.80	0.46	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0345	-8.739872037	125.0944848	1.43	2.86	0.21	0.12	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0357	-8.81443995	126.5739564	0.67	1.34	0.75	0.43	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0364	-9.998791912	124.5887866	0.51	1.02	1.37	0.79	W	W	Decrease	Marine	Heavy	Minimal	Uplift
BD0370	-0.997901188	121.4145083	0.73	1.46	0.27	0.16	W	R	Decrease	Marine	Heavy	Minimal	Uplift
BD0389	-37.85463808	177.5888417	0.88	1.76	0.00	0.00	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0392	-42.1734872	173.925118	0.8	1.6	0.81	0.47	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0393	-42.32769687	173.7395871	0.56	1.12	1.61	0.92	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0396	-42.61555688	173.466905	0.52	1.04	0.96	0.55	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0400	-43.27867914	172.7211005	0.77	1.54	0.13	0.07	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD0401	-43.90014857	172.2090919	1.16	2.32	0.39	0.22	W	W	Increase	Marine	Heavy	Minimal	Glacial
BD0403	-44.18876361	171.5036375	0.85	1.7	0.41	0.24	W	W	Increase	Marine	Heavy	Minimal	Glacial
BD0405	-44.94128846	171.1440389	0.89	1.78	0.34	0.19	W	W	Increase	Marine	Heavy	Minimal	Glacial
BD0406	-43.9970605	168.6697999	1.33	2.66	0.00	0.00	W	W	Increase	Marine	Heavy	Minimal	Uplift

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0408	-43.48826332	169.7418265	0.73	1.46	2.33	1.33	W	W	Increase	Marine	Heavy	Absent	Glacial
BD0409	-43.33620795	170.0072079	0.58	1.16	0.69	0.40	W	W	Increase	Marine	Heavy	Absent	Glacial
BD0410	-43.28641599	170.0534214	0.8	1.6	0.50	0.29	W	W	Increase	Marine	Heavy	Minimal	Glacial
BD0412	-43.04992461	170.4066503	0.58	1.16	0.69	0.40	W	W	Increase	Marine	Heavy	Absent	Glacial
BD0414	-44.84696741	168.3636864	1.8	3.6	2.11	1.21	W	R	Neutral	Marine	Heavy	Minimal	Uplift
BD0415	-44.62293141	169.0158135	1.73	3.46	0.95	0.55	W	M	Neutral	Lacustrine	Heavy	Minimal	Uplift
BD0416	-44.31806779	169.1717651	1.39	2.78	1.87	1.07	W	R	Neutral	Lacustrine	Heavy	Minimal	Uplift
BD0417	-44.28270828	169.4540602	1.09	2.18	1.70	0.97	W	R	Neutral	Lacustrine	Heavy	Absent	Uplift
BD0419	-44.18207848	169.8644283	1.14	2.28	1.45	0.83	W	R	Decrease	Lacustrine	Heavy	Minimal	Uplift
BD0420	-44.34361422	170.2087517	1.88	3.76	0.08	0.05	W	R	Neutral	Lacustrine	Heavy	Minimal	Uplift
BD0421	-43.90748156	170.1577851	4.08	8.16	0.67	0.39	W	R	Neutral	Lacustrine	Visible	Minimal	Glacial
BD0423	-42.69839729	172.1627693	0.58	1.16	2.33	1.33	W	R	Decrease	Lacustrine	Heavy	Absent	Uplift
BD0424	-19.67191321	147.5321796	1.47	2.94	0.00	0.00	W	M	Decrease	Marine	Heavy	Minimal	Arid
BD0425	-19.96721167	148.221909	0.7	1.4	0.07	0.04	W	W	Increase	Marine	Heavy	Minimal	Arid
BD0426	-24.87017748	113.6214574	0.91	1.82	0.00	0.00	W	M	Decrease	Marine	Visible	Heavy	Arid
BD0428	-20.70552064	117.7685143	1.12	2.24	0.18	0.10	D	M	Decrease	Marine	Visible	Absent	Arid
BD0429	-20.4192961	118.0972323	0.9	1.8	0.44	0.25	D	W	Decrease	Marine	Visible	Absent	Arid
BD0430	-20.37201192	118.4172432	0.61	1.22	0.25	0.14	D	M	Decrease	Marine	Visible	Minimal	Arid
BD0431	-20.06678609	119.1679525	0.77	1.54	0.00	0.00	D	R	Decrease	Marine	Visible	Absent	Arid
BD0434	-15.50578417	141.566996	1.38	2.76	0.00	0.00	D	M	Decrease	Marine	Heavy	Minimal	Arid
BD0441	-39.64292515	-69.31927584	4.88	9.76	0.11	0.06	W	R	Neutral	Lacustrine	Visible	Minimal	Uplift
BD0442	-40.39451336	-70.70500412	1.09	2.18	0.46	0.26	W	R	Neutral	Lacustrine	Visible	Minimal	Uplift
BD0444	-36.8165078	-73.15661517	1.72	3.44	0.09	0.05	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD0446	65.67109009	-14.2921826	2.59	5.18	0.12	0.07	W	W	Increase	Marine	Heavy	Minimal	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0447	64.24339507	-15.21653841	1.19	2.38	0.00	0.00	W	W	Increase	Marine	Visible	Minimal	Glacial
BD0448	64.23029036	-15.48980644	1.8	3.6	0.50	0.29	W	W	Increase	Marine	Visible	Minimal	Glacial
BD0449	64.19665926	-15.71109801	1.41	2.82	0.43	0.24	W	W	Increase	Marine	Visible	Minimal	Glacial
BD0451	64.14722915	-15.91741734	0.65	1.3	0.77	0.44	W	W	Increase	Marine	Visible	Minimal	Glacial
BD0452	63.78761089	-16.886609	7.25	14.5	0.25	0.14	W	W	Increase	Marine	Not visible	Absent	Glacial
BD0453	63.77808693	-17.05074315	5.71	11.42	0.33	0.19	W	W	Increase	Marine	Not visible	Absent	Glacial
BD0455	63.66080706	-17.79665405	2.27	4.54	0.09	0.05	W	W	Increase	Marine	Visible	Absent	Glacial
BD0459	63.53385127	-20.07283681	1.7	3.4	0.24	0.13	W	W	Increase	Marine	Visible	Minimal	Glacial
BD0460	65.74439007	-19.55755467	0.84	1.68	0.00	0.00	W	W	Increase	Marine	Heavy	Heavy	Glacial
BD0461	65.74367567	-19.41820332	0.83	1.66	0.00	0.00	W	W	Increase	Marine	Visible	Heavy	Glacial
BD0462	73.54806915	-91.01223562	2.35	4.7	0.51	0.29	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0463	74.07041063	-93.79889998	2.76	5.52	0.22	0.12	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0464	72.81994327	-93.40535803	0.89	1.78	0.06	0.03	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0472	70.7172068	-95.82030898	0.54	1.08	0.83	0.48	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0473	70.53527359	-95.76283698	0.91	1.82	0.05	0.03	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0475	67.13754598	-95.28249984	2.76	5.52	0.02	0.01	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD0476	68.36095357	-90.33487729	1.13	2.26	0.04	0.03	W	R	Neutral	Marine	Heavy	Absent	Glacial
BD0482	73.63091724	-79.03456153	2.54	5.08	1.42	0.81	W	W	Increase	Marine	Visible	Absent	Glacial
BD0484	73.03466799	-76.34751119	1.02	2.04	0.98	0.56	W	W	Increase	Marine	Visible	Absent	Glacial
BD0485	70.16114961	-69.84837584	0.75	1.5	1.07	0.61	W	M	Neutral	Marine	Not visible	Absent	Glacial
BD0486	69.65638771	-68.70465838	0.8	1.6	1.88	1.07	W	M	Increase	Marine	Not visible	Absent	Glacial
BD0488	69.25395246	-69.28020029	1.28	2.56	1.25	0.72	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0489	68.86358811	-69.41381764	1.35	2.7	2.48	1.42	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0490	68.7472061	-69.00971507	1.14	2.28	0.26	0.15	W	R	Neutral	Marine	Not visible	Absent	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0491	68.26542921	-67.85963363	1.82	3.64	0.44	0.25	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0494	66.64126512	-62.90121336	1.19	2.38	0.38	0.22	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0495	66.38122568	-65.48982916	1.32	2.64	0.23	0.13	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0496	71.75989274	-76.49488661	0.93	1.86	0.00	0.00	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD0497	73.21207339	-88.86289751	1.19	2.38	0.59	0.34	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0498	73.28101881	-88.5957091	0.88	1.76	0.45	0.26	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0500	73.24908477	-86.1341854	0.53	1.06	1.42	0.81	W	W	Decrease	Marine	Not visible	Absent	Glacial
BD0501	72.84729506	-86.6883734	0.77	1.54	0.71	0.41	W	W	Increase	Marine	Not visible	Absent	Glacial
BD0502	71.50238449	-27.3950688	0.96	1.92	3.13	1.79	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0504	71.59304146	-28.03335628	1.03	2.06	3.06	1.75	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0505	71.55082698	-28.55455881	1.18	2.36	2.20	1.26	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0509	71.62747411	-26.46342761	1.53	3.06	2.42	1.39	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0511	71.6218988	-23.0794274	4.73	9.46	0.71	0.41	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0512	71.82769488	-22.78012263	7.22	14.44	0.50	0.29	W	M	Neutral	Marine	Not visible	Absent	Glacial
BD0513	72.00666841	-23.19688039	2.15	4.3	1.40	0.80	W	M	Neutral	Marine	Not visible	Absent	Glacial
BD0515	72.11774936	-23.85153672	1.65	3.3	2.09	1.20	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0516	72.26579547	-24.03192235	1.4	2.8	2.18	1.25	W	M	Neutral	Marine	Not visible	Absent	Glacial
BD0518	72.44119252	-25.39188424	1.05	2.1	1.62	0.93	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0519	72.22979596	-22.53746364	0.96	1.92	2.97	1.70	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0523	72.43705866	-22.7494483	1.17	2.34	2.26	1.30	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0524	72.73626829	-25.07195223	1.97	3.94	1.80	1.03	W	M	Decrease	Marine	Not visible	Absent	Glacial
BD0525	72.57358482	-26.45870005	2.27	4.54	1.70	0.97	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0526	72.9023426	-25.71311794	1.44	2.88	1.94	1.11	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0528	73.04755245	-24.68325048	0.5	1	2.00	1.15	W	M	Decrease	Marine	Not visible	Absent	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0529	73.80785958	-25.60804948	1.06	2.12	2.69	1.54	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0530	73.61854522	-22.30145727	1.8	3.6	1.33	0.76	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0531	73.64436236	-21.84436315	2.93	5.86	1.02	0.59	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0532	74.42642282	-20.93038476	1.18	2.36	2.54	1.46	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0535	74.52440374	-21.0564222	1.26	2.52	0.83	0.48	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD0537	74.64796581	-20.99959664	1.6	3.2	1.78	1.02	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0538	74.72262144	-20.34023818	1.42	2.84	2.18	1.25	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0540	75.36464084	-21.34628505	1.22	2.44	2.13	1.22	W	M	Decrease	Marine	Not visible	Absent	Glacial
BD0541	81.52061091	-51.20187653	0.7	1.4	2.43	1.39	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0543	80.66199918	-65.62927677	0.76	1.52	0.20	0.11	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0545	72.28859259	-53.82199251	1.8	3.6	2.47	1.42	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0546	72.04146621	-53.37700619	0.99	1.98	3.13	1.79	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0547	71.86436266	-52.84116569	1.24	2.48	2.46	1.41	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0548	69.69460915	-51.98878318	1.63	3.26	1.10	0.63	W	R	Decrease	Marine	Visible	Absent	Glacial
BD0551	70.28485887	-53.90647565	1.89	3.78	1.38	0.79	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0554	69.92393362	-54.26252867	3.05	6.1	1.38	0.79	W	M	Neutral	Marine	Not visible	Absent	Glacial
BD0558	69.61064909	-53.98359675	2.07	4.14	1.96	1.12	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0559	69.5728744	-53.91090352	0.57	1.14	1.32	0.75	W	R	Decrease	Marine	Visible	Absent	Glacial
BD0560	69.58428392	-53.34732964	1.47	2.94	2.69	1.54	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0561	69.44818837	-53.46679551	1.53	3.06	2.16	1.24	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0562	67.60404899	-50.91865445	4.15	8.3	0.00	0.00	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0563	67.32421733	-52.61629256	3.3	6.6	0.02	0.01	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0564	66.95909728	-50.87914873	3.49	6.98	0.00	0.00	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0565	66.83809718	-50.79278844	2.55	5.1	0.00	0.00	W	R	Neutral	Marine	Not visible	Absent	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0567	65.55302579	-51.87863025	1.79	3.58	0.06	0.03	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0569	64.40975129	-49.75448991	1.23	2.46	0.81	0.47	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0571	61.53270189	-48.22513401	1.8	3.6	3.42	1.96	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0572	60.97920913	-47.72167689	0.51	1.02	0.00	0.00	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0573	60.93811142	-47.31304779	0.87	1.74	0.00	0.00	W	R	Decrease	Marine	Visible	Absent	Glacial
BD0575	60.2247702	-44.31927199	0.86	1.72	2.97	1.70	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0576	65.93260725	-36.84530637	0.92	1.84	1.68	0.97	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0577	66.06606323	-37.04316541	1.39	2.78	2.70	1.55	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0586	-4.0576453	-81.01911942	0.57	1.14	0.18	0.10	D	W	Decrease	Marine	Visible	Absent	Uplift
BD0589	-4.517897505	-81.28436749	0.94	1.88	0.43	0.24	D	W	Neutral	Marine	Visible	Heavy	Uplift
BD0593	-5.842974132	-81.10244736	0.53	1.06	1.89	1.08	D	W	Neutral	Marine	Visible	Minimal	Uplift
BD0599	-6.136965136	-80.98658451	0.67	1.34	0.67	0.38	D	R	Decrease	Marine	Visible	Absent	Uplift
BD0604	-8.969979876	-78.64147474	0.6	1.2	0.58	0.33	W	W	Decrease	Marine	Heavy	Minimal	Uplift
BD0608	-10.73505747	-77.79293703	0.52	1.04	1.63	0.94	W	M	Neutral	Marine	Heavy	Minimal	Uplift
BD0614	-13.67839202	-76.21531102	0.5	1	0.50	0.29	D	W	Increase	Marine	Visible	Minimal	Uplift
BD0615	-14.87395229	-75.56193226	0.59	1.18	0.25	0.15	W	W	Increase	Marine	Visible	Absent	Uplift
BD0632	-10.49219022	-36.40365822	2.13	4.26	0.00	0.00	W	R	Neutral	Marine	Heavy	Minimal	Uplift
BD0633	-49.69995815	-73.04038696	1.06	2.12	1.51	0.86	W	R	Neutral	Lacustrine	Visible	Absent	Glacial
BD0634	-48.49774168	-72.58199262	0.77	1.54	0.32	0.19	W	R	Decrease	Lacustrine	Heavy	Absent	Glacial
BD0654	-29.30843483	-71.36048662	1.54	3.08	0.75	0.43	D	W	Neutral	Marine	Visible	Minimal	Uplift
BD0655	-30.11730616	-71.37152677	0.61	1.22	0.16	0.09	D	W	Neutral	Marine	Visible	Heavy	Uplift
BD0659	-36.38785266	-72.85117533	1.71	3.42	0.03	0.02	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0660	-47.09886067	-73.98251471	1.53	3.06	0.03	0.02	W	R	Neutral	Marine	Heavy	Absent	Glacial
BD0662	-50.38904799	-73.10486665	1.44	2.88	0.76	0.44	W	R	Neutral	Lacustrine	Heavy	Absent	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0663	-48.73907706	-74.27326661	1.59	3.18	0.09	0.05	W	R	Neutral	Marine	Heavy	Absent	Glacial
BD0664	-48.6676543	-73.11292237	1.33	2.66	1.02	0.58	W	R	Neutral	Lacustrine	Visible	Absent	Glacial
BD0665	-48.93191116	-72.30014125	0.64	1.28	2.50	1.43	W	M	Decrease	Lacustrine	Heavy	Minimal	Uplift
BD0666	-47.62719113	-73.66823981	0.6	1.2	0.17	0.10	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD0668	-46.71661977	-72.54373193	0.6	1.2	1.17	0.67	W	M	Decrease	Lacustrine	Heavy	Minimal	Uplift
BD0670	-46.00939852	-73.38995037	2.86	5.72	0.26	0.15	W	R	Neutral	Marine	Heavy	Absent	Uplift
BD0671	-45.8595632	-73.52951579	1.91	3.82	0.24	0.13	W	R	Neutral	Marine	Heavy	Absent	Uplift
BD0672	-46.31251768	-71.94225887	0.79	1.58	0.06	0.04	W	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD0673	-42.21948215	-71.67860507	0.61	1.22	0.33	0.19	W	R	Decrease	Lacustrine	Heavy	Absent	Uplift
BD0675	-31.4933789	-68.69470478	4.62	9.24	0.71	0.41	D	R	Decrease	Lacustrine	Visible	Heavy	Uplift
BD0680	-18.52392157	-67.1093333	8.4	16.8	0.03	0.02	W	R	Neutral	Lacustrine	Visible	Absent	Arid
BD0681	-18.82635378	-66.7088421	0.61	1.22	0.41	0.23	W	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD0684	-49.27054127	69.40137081	0.96	1.92	0.21	0.12	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0685	-49.18160528	69.30820316	0.73	1.46	0.07	0.04	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0686	-49.50041125	69.62311015	1.57	3.14	0.45	0.26	W	M	Neutral	Marine	Visible	Absent	Glacial
BD0687	-49.48294855	69.20848436	3.12	6.24	0.40	0.23	W	M	Neutral	Marine	Visible	Absent	Glacial
BD0688	-49.53792897	69.07646069	1.47	2.94	0.41	0.23	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0689	-49.54439062	69.06080762	1.39	2.78	3.31	1.90	W	M	Neutral	Marine	Visible	Absent	Glacial
BD0691	-49.66322141	69.08542017	0.5	1	0.20	0.11	W	W	Increase	Marine	Visible	Absent	Glacial
BD0692	-49.70036074	69.0109497	0.83	1.66	0.48	0.28	W	W	Neutral	Marine	Visible	Absent	Glacial
BD0693	-49.71325246	68.93282914	2.14	4.28	0.37	0.21	W	W	Increase	Marine	Not visible	Absent	Glacial
BD0695	-49.42865642	68.89913213	0.71	1.42	0.85	0.48	W	W	Increase	Marine	Not visible	Absent	Glacial
BD0710	12.61434099	53.76722872	1.34	2.68	0.19	0.11	D	W	Increase	Marine	Visible	Minimal	Arid
BD0711	79.43467991	13.39950567	1.49	2.98	0.54	0.31	W	R	Neutral	Marine	Not visible	Absent	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0712	79.42631572	13.97937465	1.02	2.04	1.37	0.79	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0713	79.48395659	13.88021119	0.72	1.44	1.81	1.03	W	M	Decrease	Marine	Not visible	Absent	Glacial
BD0714	79.60704602	14.18856334	1.03	2.06	0.68	0.39	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0716	79.52231311	15.20328238	1.44	2.88	0.38	0.22	W	W	Increase	Marine	Not visible	Absent	Glacial
BD0719	79.14782331	15.60590964	1.33	2.66	1.92	1.10	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0720	79.09877586	15.6710403	1.73	3.46	0.69	0.40	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0721	79.00677089	16.09806325	0.85	1.7	2.65	1.52	W	W	Decrease	Marine	Not visible	Absent	Glacial
BD0723	78.74719059	14.65190813	3.54	7.08	0.81	0.46	W	T	Neutral	Marine	Not visible	Absent	Glacial
BD0724	78.82841842	15.33996965	3.63	7.26	0.12	0.07	W	M	Neutral	Marine	Not visible	Absent	Glacial
BD0726	78.48593704	15.35244171	0.65	1.3	0.31	0.18	W	W	Increase	Marine	Visible	Absent	Glacial
BD0728	79.54421691	17.62102207	0.77	1.54	2.66	1.53	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0729	78.33944815	16.85752523	0.78	1.56	0.19	0.11	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0730	78.22963772	15.6992199	1.93	3.86	0.13	0.07	W	R	Neutral	Marine	Visible	Minimal	Glacial
BD0735	77.86170077	15.51347777	6.08	12.16	0.02	0.01	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0736	77.79029686	16.33174665	1.75	3.5	0.89	0.51	W	W	Increase	Marine	Not visible	Absent	Glacial
BD0737	77.75375076	15.88352587	1.45	2.9	0.72	0.41	W	W	Decrease	Marine	Not visible	Absent	Glacial
BD0738	78.05043378	18.44756033	0.84	1.68	0.00	0.00	W	W	Increase	Marine	Visible	Absent	Glacial
BD0741	77.9379791	21.5151676	0.54	1.08	1.85	1.06	W	W	Increase	Marine	Visible	Absent	Glacial
BD0743	77.64424761	21.16616511	1.89	3.78	1.24	0.71	W	M	Decrease	Marine	Visible	Absent	Glacial
BD0747	80.91482967	96.910502	2.11	4.22	0.64	0.37	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0748	81.05947395	94.4915153	0.81	1.62	0.25	0.14	W	R	Decrease	Marine	Not visible	Absent	Glacial
BD0751	74.38442621	58.62690911	1.49	2.98	0.07	0.04	W	M	Neutral	Marine	Visible	Absent	Glacial
BD0752	74.18415432	58.29688368	1.37	2.74	1.93	1.11	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0753	74.12397409	58.17978126	1.29	2.58	0.50	0.29	W	M	Decrease	Marine	Visible	Absent	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0755	72.44475545	55.21328152	1.16	2.32	0.04	0.02	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0756	73.24271573	53.66529911	0.54	1.08	0.28	0.16	W	W	Increase	Marine	Visible	Absent	Glacial
BD0757	73.29679527	54.41038395	0.69	1.38	0.00	0.00	W	W	Increase	Marine	Not visible	Absent	Glacial
BD0758	73.42489755	55.91798564	1.04	2.08	0.05	0.03	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0759	73.61069311	54.69904375	0.98	1.96	0.10	0.06	W	W	Increase	Marine	Not visible	Absent	Glacial
BD0760	73.70658141	55.36952283	1.53	3.06	0.07	0.04	W	R	Neutral	Marine	Visible	Absent	Glacial
BD0761	73.71347069	55.11780236	0.87	1.74	0.06	0.03	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD0765	-5.763605431	151.3904621	0.68	1.36	0.88	0.51	W	W	Increase	Marine	Heavy	Absent	Uplift
BD0766	-5.864158462	151.2827472	0.52	1.04	0.48	0.28	W	W	Neutral	Marine	Heavy	Absent	Uplift
BD0772	24.85410402	120.925887	0.77	1.54	0.32	0.19	W	M	Increase	Marine	Visible	Heavy	Uplift
BD0774	24.40450078	120.5981612	1	2	0.80	0.46	W	R	Decrease	Marine	Heavy	Heavy	Uplift
BD0775	24.33309406	120.5535544	0.94	1.88	0.59	0.34	W	M	Neutral	Marine	Heavy	Heavy	Uplift
BD0776	23.84787813	120.2411225	1.68	3.36	0.06	0.03	W	R	Decrease	Marine	Heavy	Heavy	Uplift
BD0777	22.48219823	120.4224262	0.63	1.26	0.00	0.00	W	R	Neutral	Marine	Heavy	Heavy	Uplift
BD0787	22.59141675	121.00797	0.56	1.12	0.98	0.56	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD0790	22.76539244	121.1752713	1.16	2.32	0.60	0.35	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD0793	23.94174109	121.6077954	0.58	1.16	0.09	0.05	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD0794	24.14059126	121.6605	0.87	1.74	0.98	0.56	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD0795	24.3126135	121.7694795	1.42	2.84	0.92	0.52	W	W	Neutral	Marine	Heavy	Heavy	Uplift
BD0798	40.10352789	128.4243189	0.66	1.32	0.00	0.00	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD0800	39.81113258	127.5805827	0.66	1.32	0.00	0.00	W	M	Decrease	Marine	Heavy	Heavy	Uplift
BD0801	19.29746395	108.6555452	1.19	2.38	0.04	0.02	W	M	Decrease	Marine	Heavy	Heavy	Uplift
BD0811	40.43434594	128.9457098	0.52	1.04	0.00	0.00	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD0821	70.86903616	179.5256867	1.09	2.18	0.14	0.08	W	M	Decrease	Marine	Heavy	Absent	Uplift

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0822	70.87660473	178.7842835	1.53	3.06	0.13	0.07	W	M	Neutral	Marine	Heavy	Absent	Uplift
BD0824	71.30958933	179.2546954	0.68	1.36	1.47	0.84	W	W	Neutral	Marine	Heavy	Absent	Uplift
BD0826	71.55602001	-179.4731546	1.23	2.46	0.00	0.00	W	R	Neutral	Marine	Heavy	Absent	Uplift
BD0827	71.56526903	-179.0621118	1.13	2.26	0.00	0.00	W	R	Decrease	Marine	Heavy	Absent	Uplift
BD0833	70.89897098	-179.1346683	0.58	1.16	1.12	0.64	W	M	Decrease	Marine	Heavy	Absent	Uplift
BD0836	29.43421061	-101.2816787	0.92	1.84	0.49	0.28	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD0837	53.34886267	-60.17705039	1.37	2.74	0.00	0.00	W	R	Neutral	Marine	Heavy	Minimal	Uplift
BD0845	18.17804416	-72.75841664	0.63	1.26	0.63	0.36	W	W	Neutral	Marine	Heavy	Minimal	Uplift
BD0849	18.27534247	-70.58998142	0.5	1	0.60	0.34	W	W	Decrease	Marine	Heavy	Minimal	Uplift
BD0860	19.95987567	-76.67581966	0.79	1.58	1.90	1.09	W	W	Neutral	Marine	Heavy	Minimal	Uplift
BD0867	17.40761026	-93.43193183	1.19	2.38	0.29	0.17	W	R	Neutral	Lacustrine	Heavy	Minimal	Uplift
BD0876	16.50313631	-98.72929552	0.62	1.24	0.00	0.00	W	M	Increase	Marine	Heavy	Minimal	Uplift
BD0881	16.68559095	-99.60487803	0.99	1.98	0.00	0.00	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD0910	29.07275307	-112.1711423	0.82	1.64	2.38	1.36	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0911	29.12274691	-112.1697752	1.18	2.36	2.33	1.34	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0920	29.88585101	-112.6609011	1.08	2.16	0.79	0.45	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0941	30.4943635	-114.6333216	0.81	1.62	0.80	0.46	D	W	Decrease	Marine	Visible	Minimal	Arid
BD0946	29.45625143	-113.8389663	0.63	1.26	1.19	0.68	D	W	Decrease	Marine	Visible	Absent	Arid
BD0947	29.23317581	-113.6437529	1.1	2.2	1.68	0.96	D	W	Neutral	Marine	Visible	Absent	Arid
BD0953	27.83406541	-112.7430093	0.89	1.78	0.45	0.26	D	W	Neutral	Marine	Visible	Absent	Arid
BD0955	27.70020393	-112.6380194	0.95	1.9	0.47	0.27	D	W	Neutral	Marine	Visible	Absent	Arid
BD0956	27.66799518	-112.6040263	0.7	1.4	0.57	0.33	D	W	Neutral	Marine	Visible	Absent	Arid
BD0957	27.59065354	-112.4204663	0.58	1.16	2.07	1.19	D	W	Neutral	Marine	Visible	Absent	Arid
BD0958	27.40408609	-112.3003342	0.74	1.48	0.74	0.43	D	W	Neutral	Marine	Visible	Minimal	Arid

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD0960	27.20048953	-112.2010014	1.17	2.34	1.88	1.08	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0961	27.18858659	-112.186912	0.98	1.96	2.35	1.34	D	W	Neutral	Marine	Visible	Minimal	Arid
BD0991	23.69408028	-109.6995904	0.74	1.48	0.88	0.50	D	W	Decrease	Marine	Visible	Minimal	Arid
BD0992	23.61721217	-109.6064277	3.1	6.2	0.60	0.34	D	W	Decrease	Marine	Visible	Minimal	Arid
BD0995	23.05136342	-109.6839872	1.1	2.2	0.50	0.29	D	W	Increase	Marine	Visible	Heavy	Arid
BD0998	23.36886837	-110.2046925	0.69	1.38	1.45	0.83	D	W	Neutral	Marine	Visible	Heavy	Arid
BD0999	23.51260339	-110.2852593	1.86	3.72	1.61	0.92	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1004	24.24390801	-111.2729764	0.88	1.76	0.11	0.07	D	W	Increase	Marine	Visible	Minimal	Arid
BD1008	28.49250428	-114.0678458	0.7	1.4	0.29	0.16	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1019	30.71617082	-116.0426318	0.55	1.1	0.45	0.26	D	W	Neutral	Marine	Visible	Heavy	Arid
BD1020	31.26275749	-116.3772997	0.93	1.86	0.59	0.34	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1021	34.96856974	-120.6480612	0.71	1.42	0.35	0.20	D	W	Neutral	Marine	Visible	Heavy	Uplift
BD1025	40.62897443	-124.3001206	1.39	2.78	0.04	0.02	W	M	Increase	Marine	Heavy	Minimal	Uplift
BD1029	47.49355608	-123.8463552	0.5	1	0.40	0.23	W	R	Neutral	Lacustrine	Heavy	Minimal	Uplift
BD1032	49.87403122	-125.7390516	0.55	1.1	0.36	0.21	W	R	Neutral	Lacustrine	Heavy	Minimal	Uplift
BD1036	50.8269269	-123.1139883	0.6	1.2	0.00	0.00	W	R	Neutral	Lacustrine	Heavy	Absent	Glacial
BD1038	51.65533257	-126.7000033	0.69	1.38	0.22	0.12	W	R	Neutral	Marine	Heavy	Minimal	Glacial
BD1044	51.80687163	-117.3667171	0.94	1.88	0.27	0.15	W	R	Neutral	Lacustrine	Heavy	Minimal	Uplift
BD1054	56.52235543	-132.39688	2.94	5.88	0.00	0.00	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1055	56.68990833	-132.5359678	1.14	2.28	0.00	0.00	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1057	57.78129893	-132.4148685	0.72	1.44	1.18	0.68	W	R	Neutral	Lacustrine	Heavy	Absent	Glacial
BD1058	57.09339936	-132.8233032	1.55	3.1	0.74	0.43	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1061	57.9927509	-133.702519	1.03	2.06	0.00	0.00	W	R	Neutral	Marine	Heavy	Absent	Glacial
BD1063	58.49108886	-133.9588559	2.29	4.58	0.02	0.01	W	R	Neutral	Marine	Heavy	Absent	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD1065	58.79853828	-134.9866976	1.39	2.78	0.00	0.00	W	R	Neutral	Marine	Heavy	Absent	Glacial
BD1067	59.16098088	-133.8706394	1.04	2.08	0.48	0.28	W	R	Decrease	Lacustrine	Heavy	Absent	Glacial
BD1071	59.40981671	-134.4507668	1.28	2.56	0.27	0.16	W	R	Neutral	Lacustrine	Heavy	Absent	Glacial
BD1072	59.63154568	-134.5929283	0.89	1.78	0.00	0.00	W	R	Neutral	Lacustrine	Heavy	Absent	Glacial
BD1076	58.78014575	-135.2451413	0.51	1.02	0.59	0.34	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1078	59.19066299	-135.300915	0.72	1.44	0.00	0.00	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1080	59.21995401	-135.4937537	3.46	6.92	0.00	0.00	W	R	Neutral	Marine	Heavy	Minimal	Glacial
BD1083	58.89010068	-135.8071097	1.44	2.88	0.76	0.44	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1086	58.88378953	-135.9296998	0.71	1.42	0.42	0.24	W	R	Neutral	Marine	Heavy	Absent	Glacial
BD1087	59.06597707	-136.1841483	0.79	1.58	0.13	0.07	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1088	59.09034428	-136.3759268	0.82	1.64	1.65	0.94	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1090	58.98741889	-136.4158871	0.76	1.52	0.46	0.26	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1094	59.05991925	-137.0358723	0.57	1.14	1.67	0.95	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1096	58.76564479	-136.6100298	0.78	1.56	1.03	0.59	W	R	Neutral	Marine	Heavy	Absent	Glacial
BD1099	58.32547804	-136.5796833	3.01	6.02	0.66	0.38	W	R	Neutral	Marine	Heavy	Absent	Glacial
BD1102	59.13485863	-138.5949798	3.04	6.08	0.00	0.00	W	W	Increase	Marine	Heavy	Absent	Glacial
BD1104	59.34608409	-139.3050923	1.09	2.18	0.00	0.00	W	W	Increase	Marine	Visible	Absent	Glacial
BD1107	59.78457974	-139.2774931	0.63	1.26	1.03	0.59	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1115	59.81547342	-139.8370336	5.98	11.96	1.09	0.62	W	W	Increase	Marine	Heavy	Absent	Glacial
BD1117	61.00762442	-138.495305	0.6	1.2	0.75	0.43	W	R	Decrease	Lacustrine	Visible	Minimal	Glacial
BD1121	60.08312544	-142.5187976	0.79	1.58	0.19	0.11	W	W	Increase	Marine	Heavy	Minimal	Glacial
BD1122	60.42675978	-143.7839803	1.76	3.52	3.24	1.85	W	R	Neutral	Lacustrine	Heavy	Absent	Glacial
BD1125	60.27128234	-145.1065751	21.73	43.46	0.09	0.05	W	M	Decrease	Marine	Heavy	Absent	Glacial
BD1126	60.66524832	-145.6246197	0.87	1.74	0.46	0.26	W	T	Neutral	Marine	Heavy	Absent	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD1127	60.67934627	-145.8731512	0.81	1.62	0.19	0.11	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1128	60.86592833	-146.2079098	1.07	2.14	0.89	0.51	W	T	Neutral	Marine	Heavy	Absent	Glacial
BD1130	61.10282682	-146.2628473	2.51	5.02	0.24	0.14	W	R	Neutral	Marine	Heavy	Heavy	Glacial
BD1133	61.01788765	-147.6586081	0.75	1.5	0.60	0.34	W	M	Neutral	Marine	Heavy	Absent	Glacial
BD1139	61.94746897	-146.4320857	0.76	1.52	0.79	0.45	W	R	Decrease	Lacustrine	Heavy	Absent	Glacial
BD1140	61.33431863	-149.0057393	0.72	1.44	0.97	0.56	W	R	Neutral	Lacustrine	Heavy	Absent	Glacial
BD1141	61.45738771	-149.44647	2.2	4.4	0.07	0.04	W	T	Neutral	Marine	Heavy	Minimal	Glacial
BD1147	60.12430708	-149.4080864	1.66	3.32	0.39	0.22	W	R	Decrease	Marine	Visible	Heavy	Glacial
BD1149	60.39991546	-150.1252668	1.7	3.4	0.44	0.25	W	R	Neutral	Lacustrine	Visible	Absent	Glacial
BD1150	60.06119314	-150.6573509	1.13	2.26	0.75	0.43	W	R	Neutral	Lacustrine	Heavy	Absent	Glacial
BD1159	59.58183519	-150.4086521	0.9	1.8	0.83	0.48	W	T	Neutral	Marine	Heavy	Absent	Glacial
BD1162	59.54699724	-150.640336	0.55	1.1	0.55	0.31	W	M	Decrease	Marine	Heavy	Absent	Glacial
BD1165	59.54820928	-151.3787083	0.51	1.02	2.06	1.18	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1166	59.65147012	-151.175468	0.52	1.04	0.96	0.55	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1168	59.78212949	-150.970757	0.9	1.8	0.00	0.00	W	T	Neutral	Marine	Heavy	Minimal	Glacial
BD1169	61.28370379	-150.645218	7.33	14.66	0.05	0.03	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1170	60.57203908	-152.1669718	1.55	3.1	0.42	0.24	W	R	Decrease	Marine	Heavy	Minimal	Glacial
BD1172	61.16249361	-152.8953907	1.78	3.56	0.17	0.10	W	R	Decrease	Lacustrine	Visible	Absent	Glacial
BD1174	60.94844213	-153.7482172	1.37	2.74	1.24	0.71	W	R	Neutral	Lacustrine	Heavy	Absent	Glacial
BD1175	60.78188959	-153.8744428	1.16	2.32	1.38	0.79	W	R	Neutral	Lacustrine	Visible	Absent	Glacial
BD1180	58.53384698	-155.3604352	2.43	4.86	0.58	0.33	W	R	Neutral	Lacustrine	Heavy	Absent	Glacial
BD1181	60.22430239	-152.8288613	2.91	5.82	0.00	0.00	W	T	Neutral	Marine	Heavy	Absent	Glacial
BD1184	58.99739542	-153.5976724	0.53	1.06	0.09	0.05	W	W	Increase	Marine	Heavy	Absent	Glacial
BD1189	58.40690131	-154.0491702	0.67	1.34	0.67	0.38	W	W	Increase	Marine	Heavy	Absent	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD1192	58.26727267	-154.323838	1.51	3.02	0.20	0.11	W	R	Neutral	Marine	Heavy	Absent	Glacial
BD1196	58.00632668	-154.9458513	3.87	7.74	0.14	0.08	W	W	Increase	Marine	Heavy	Absent	Glacial
BD1202	56.90298417	-157.0116434	0.51	1.02	0.88	0.51	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD1205	55.96628848	-158.8901981	0.99	1.98	0.20	0.12	W	W	Increase	Marine	Heavy	Absent	Uplift
BD1215	55.04138197	-163.7252154	0.51	1.02	0.49	0.28	W	W	Increase	Marine	Heavy	Absent	Uplift
BD1218	54.65933134	-164.712432	1.38	2.76	0.47	0.27	W	W	Increase	Marine	Heavy	Absent	Uplift
BD1220	54.41572652	-164.4850253	0.75	1.5	2.20	1.26	W	W	Increase	Marine	Heavy	Absent	Uplift
BD1228	53.08653313	-168.4421167	0.82	1.64	2.07	1.19	W	W	Neutral	Marine	Visible	Absent	Uplift
BD1230	53.26344017	-168.1851469	0.57	1.14	1.49	0.85	W	W	Increase	Marine	Heavy	Absent	Uplift
BD1232	53.52681206	-167.9310318	0.89	1.78	0.90	0.52	W	W	Neutral	Marine	Heavy	Absent	Uplift
BD1236	53.87084213	-167.1087554	0.69	1.38	1.38	0.79	W	W	Neutral	Marine	Heavy	Absent	Uplift
BD1242	70.27782074	-148.1866174	3.32	6.64	0.27	0.16	W	R	Decrease	Marine	Heavy	Minimal	Uplift
BD1243	70.17548114	-147.3074944	1.7	3.4	0.12	0.07	W	R	Decrease	Marine	Heavy	Absent	Uplift
BD1244	70.1268463	-145.9107731	0.75	1.5	0.47	0.27	W	M	Decrease	Marine	Heavy	Absent	Uplift
BD1247	69.97782055	-144.7942992	0.55	1.1	0.91	0.52	W	W	Increase	Marine	Heavy	Absent	Uplift
BD1248	69.28582842	-145.0351803	0.61	1.22	2.54	1.46	W	R	Neutral	Lacustrine	Visible	Absent	Glacial
BD1249	70.02031715	-144.4345202	0.62	1.24	0.32	0.18	W	R	Decrease	Marine	Heavy	Absent	Uplift
BD1250	70.05451296	-144.0840195	1.74	3.48	0.14	0.08	W	M	Decrease	Marine	Heavy	Absent	Uplift
BD1251	70.12185489	-143.3112566	1.14	2.28	0.18	0.10	W	R	Decrease	Marine	Heavy	Absent	Uplift
BD1252	69.82083501	-142.0397732	1	2	0.15	0.09	W	R	Decrease	Marine	Heavy	Absent	Uplift
BD1254	69.77179671	-141.7156035	1.23	2.46	0.65	0.37	W	M	Decrease	Marine	Heavy	Absent	Uplift
BD1257	69.58999822	-139.7771046	0.53	1.06	2.36	1.35	W	M	Decrease	Marine	Heavy	Absent	Uplift
BD1258	69.54673348	-139.4872618	1.13	2.26	0.00	0.00	W	M	Decrease	Marine	Heavy	Absent	Uplift
BD1259	69.46308768	-123.4108599	1.05	2.1	0.05	0.03	W	W	Decrease	Marine	Heavy	Absent	Uplift

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD1267	63.68260837	-85.63824667	1.44	2.88	0.10	0.06	W	R	Neutral	Marine	Visible	Absent	Uplift
BD1274	55.28351398	-85.08837961	1.91	3.82	0.00	0.00	W	T	Neutral	Marine	Heavy	Minimal	Uplift
BD1275	62.52415402	-77.39892135	0.64	1.28	0.63	0.36	W	W	Increase	Marine	Visible	Absent	Uplift
BD1276	61.43701801	-71.87021906	1.34	2.68	0.00	0.00	W	R	Decrease	Marine	Visible	Absent	Uplift
BD1277	61.06310001	-70.93578559	0.61	1.22	0.00	0.00	W	R	Neutral	Marine	Visible	Absent	Uplift
BD1278	58.78813694	-70.18011136	1.49	2.98	0.00	0.00	W	R	Neutral	Marine	Visible	Absent	Uplift
BD1280	59.24436069	-63.80710871	1.44	2.88	0.00	0.00	W	R	Neutral	Marine	Visible	Absent	Uplift
BD1282	58.9558622	-63.87520655	0.75	1.5	0.27	0.15	W	R	Neutral	Marine	Visible	Absent	Uplift
BD1285	57.97246035	-63.37799631	1.58	3.16	0.09	0.05	W	R	Neutral	Marine	Visible	Absent	Uplift
BD1286	56.01613622	-61.40030155	1.29	2.58	0.00	0.00	W	R	Neutral	Marine	Heavy	Absent	Uplift
BD1287	70.51658939	28.38385956	2	4	0.00	0.00	W	M	Decrease	Marine	Heavy	Minimal	Uplift
BD1288	41.68221581	-8.838054893	0.87	1.74	0.00	0.00	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD1347	39.84409886	16.5185378	0.84	1.68	2.74	1.57	D	W	Neutral	Marine	Heavy	Heavy	Uplift
BD1355	40.13126555	16.32406495	0.61	1.22	0.00	0.00	W	R	Neutral	Lacustrine	Heavy	Heavy	Uplift
BD1462	-13.10169851	12.87899322	0.52	1.04	0.87	0.50	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1467	-14.27671005	12.36537055	0.63	1.26	0.40	0.23	D	W	Increase	Marine	Visible	Minimal	Arid
BD1481	-15.72412971	11.91241962	0.95	1.9	0.21	0.12	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1482	-17.25053044	11.7520234	0.65	1.3	0.00	0.00	W	M	Increase	Marine	Visible	Absent	Arid
BD1483	-19.07322252	12.5575193	1	2	0.50	0.29	D	W	Neutral	Marine	Visible	Absent	Arid
BD1487	-20.49182802	13.26767929	1.23	2.46	1.18	0.68	D	W	Neutral	Marine	Not visible	Absent	Arid
BD1488	-20.91765011	13.45709331	2.15	4.3	0.16	0.09	D	W	Neutral	Marine	Visible	Absent	Arid
BD1489	-21.18797436	13.62940849	0.61	1.22	0.33	0.19	D	W	Increase	Marine	Visible	Absent	Arid
BD1491	-21.66202656	13.93959915	0.51	1.02	0.98	0.56	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1495	-28.62951241	16.45490566	2.37	4.74	0.06	0.04	W	W	Increase	Marine	Visible	Minimal	Arid

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD1501	-20.90600475	35.06855547	0.61	1.22	0.00	0.00	W	M	Decrease	Marine	Heavy	Minimal	Uplift
BD1502	-16.89507091	39.13909508	0.53	1.06	0.00	0.00	W	M	Increase	Marine	Heavy	Absent	Uplift
BD1506	-14.17119431	40.52671053	0.63	1.26	0.00	0.00	W	M	Increase	Marine	Visible	Minimal	Uplift
BD1509	-13.51329814	40.52511181	1.27	2.54	0.24	0.14	W	M	Increase	Marine	Heavy	Minimal	Uplift
BD1511	-10.47613753	40.43512132	1.77	3.54	0.00	0.00	W	R	Neutral	Marine	Heavy	Absent	Uplift
BD1525	8.133742081	50.05349813	0.56	1.12	0.63	0.36	W	W	Neutral	Marine	Not visible	Absent	Arid
BD1536	10.42682237	51.02259498	0.89	1.78	0.34	0.19	D	M	Decrease	Marine	Visible	Absent	Arid
BD1537	10.66077008	51.14186706	1.25	2.5	0.24	0.14	D	W	Neutral	Marine	Visible	Absent	Arid
BD1538	10.99887482	51.12124263	1.6	3.2	0.53	0.30	D	W	Decrease	Marine	Visible	Absent	Arid
BD1541	11.28089694	51.07810409	0.5	1	0.60	0.34	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1545	27.20821887	-13.37629645	1.3	2.6	0.04	0.02	D	W	Increase	Marine	Visible	Minimal	Arid
BD1554	35.22068385	-3.5590165	0.57	1.14	0.96	0.55	D	W	Neutral	Marine	Visible	Heavy	Arid
BD1578	11.45762917	49.6104022	0.63	1.26	2.22	1.27	D	W	Decrease	Marine	Visible	Absent	Arid
BD1579	11.35614006	49.45383612	0.77	1.54	0.97	0.56	D	W	Decrease	Marine	Visible	Minimal	Arid
BD1581	11.3346959	49.30068029	0.5	1	1.00	0.57	D	W	Neutral	Marine	Visible	Absent	Arid
BD1585	11.30739862	48.5799302	0.53	1.06	0.38	0.22	D	W	Increase	Marine	Visible	Absent	Arid
BD1588	11.19162924	48.22870599	0.52	1.04	0.48	0.28	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1589	11.16544768	48.19860426	0.63	1.26	0.87	0.50	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1595	11.12501277	47.91758953	0.68	1.36	2.28	1.31	D	W	Decrease	Marine	Visible	Absent	Arid
BD1597	11.11955874	47.79670501	0.86	1.72	1.22	0.70	D	W	Decrease	Marine	Visible	Minimal	Arid
BD1598	11.10541047	47.74576591	0.79	1.58	1.33	0.76	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1603	11.12608716	47.28952454	1.04	2.08	0.91	0.52	D	W	Decrease	Marine	Visible	Absent	Arid
BD1613	3.551382659	9.651635666	1.5	3	0.03	0.02	W	M	Decrease	Marine	Heavy	Absent	Uplift
BD1614	10.89320313	46.89934971	0.69	1.38	1.01	0.58	D	W	Neutral	Marine	Visible	Absent	Arid

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD1630	10.78045341	46.2045235	0.91	1.82	0.22	0.13	D	W	Neutral	Marine	Visible	Absent	Arid
BD1636	10.50549218	45.08788393	0.56	1.12	0.45	0.26	D	W	Decrease	Marine	Visible	Absent	Arid
BD1639	10.38578527	44.49892128	8.76	17.52	1.47	0.84	W	W	Decrease	Marine	Visible	Absent	Arid
BD1640	10.50173551	44.20270266	0.53	1.06	0.38	0.22	D	W	Decrease	Marine	Visible	Absent	Arid
BD1642	10.68613939	43.93895261	1.23	2.46	0.61	0.35	D	W	Decrease	Marine	Visible	Absent	Arid
BD1643	11.06540292	43.60946977	1.02	2.04	0.34	0.20	D	W	Increase	Marine	Visible	Absent	Arid
BD1644	11.26779151	43.48939514	1.95	3.9	0.08	0.04	D	W	Increase	Marine	Visible	Absent	Arid
BD1645	11.35718585	43.44525013	0.78	1.56	0.32	0.18	D	M	Decrease	Marine	Visible	Absent	Arid
BD1646	11.46473696	43.2881684	0.99	1.98	0.10	0.06	D	R	Decrease	Marine	Visible	Absent	Arid
BD1647	11.9539681	43.19906202	0.64	1.28	0.55	0.31	D	M	Decrease	Marine	Visible	Minimal	Arid
BD1651	12.51650352	43.25389322	0.61	1.22	0.82	0.47	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1652	12.58828018	43.19918536	1.88	3.76	0.64	0.37	D	W	Increase	Marine	Visible	Minimal	Arid
BD1654	12.84167334	42.84518033	0.72	1.44	0.35	0.20	D	M	Decrease	Marine	Visible	Minimal	Arid
BD1655	12.86132683	42.76465411	1.31	2.62	0.19	0.11	D	W	Decrease	Marine	Visible	Heavy	Arid
BD1658	13.16852204	42.57282034	1.42	2.84	0.35	0.20	D	W	Increase	Marine	Visible	Heavy	Arid
BD1661	13.64691855	42.09586704	0.63	1.26	0.87	0.50	D	M	Decrease	Marine	Visible	Minimal	Arid
BD1662	13.9124563	41.73435401	0.61	1.22	0.41	0.23	D	W	Decrease	Marine	Visible	Minimal	Arid
BD1667	14.94765555	40.39987365	1.72	3.44	0.64	0.37	D	M	Neutral	Marine	Not visible	Minimal	Arid
BD1668	14.91665548	40.33698071	0.65	1.3	0.62	0.35	D	R	Decrease	Marine	Visible	Minimal	Arid
BD1674	15.88813136	39.3258383	0.7	1.4	0.36	0.20	D	W	Decrease	Marine	Visible	Minimal	Arid
BD1675	16.20877267	39.21371263	0.74	1.48	1.28	0.74	D	W	Decrease	Marine	Visible	Absent	Arid
BD1676	16.27282573	39.20447616	0.64	1.28	0.63	0.36	D	W	Decrease	Marine	Visible	Minimal	Arid
BD1677	16.93830605	39.04877168	1.14	2.28	0.53	0.30	D	W	Increase	Marine	Visible	Absent	Arid
BD1681	19.19779592	37.33105273	0.54	1.08	0.46	0.27	D	M	Increase	Marine	Visible	Minimal	Arid

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD1688	21.34252116	37.00697004	0.67	1.34	0.22	0.13	D	M	Neutral	Marine	Visible	Minimal	Arid
BD1701	23.87370315	35.47791503	0.73	1.46	1.30	0.75	D	W	Decrease	Marine	Visible	Minimal	Arid
BD1709	24.75407659	35.06422619	0.52	1.04	1.15	0.66	D	W	Increase	Marine	Visible	Minimal	Arid
BD1715	25.32211661	34.74290763	0.74	1.48	0.54	0.31	D	W	Neutral	Marine	Visible	Heavy	Arid
BD1726	26.63262547	33.99137057	0.72	1.44	0.97	0.56	D	W	Decrease	Marine	Visible	Minimal	Arid
BD1731	64.5563488	-14.57545775	0.65	1.3	0.31	0.18	W	R	Decrease	Marine	Visible	Minimal	Glacial
BD1732	66.14622077	-16.71275693	0.88	1.76	0.06	0.03	W	W	Increase	Marine	Heavy	Absent	Glacial
BD1734	63.88016376	-21.2134869	1.17	2.34	0.00	0.00	W	W	Increase	Marine	Heavy	Minimal	Glacial
BD1736	72.93253977	-124.4324678	2.54	5.08	0.10	0.06	W	R	Neutral	Marine	Heavy	Absent	Glacial
BD1737	73.389758	-124.3652295	2.01	4.02	0.20	0.11	W	M	Neutral	Marine	Heavy	Absent	Glacial
BD1738	72.27741854	-125.4718734	1.96	3.92	0.26	0.15	W	M	Decrease	Marine	Heavy	Absent	Glacial
BD1739	71.53326952	-123.7971312	1.26	2.52	0.12	0.07	W	W	Increase	Marine	Heavy	Absent	Glacial
BD1741	76.74115155	-120.7106921	1.41	2.82	0.14	0.08	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1742	76.04897048	-121.9101765	0.97	1.94	0.26	0.15	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1743	76.18583618	-120.8163192	0.54	1.08	0.19	0.11	W	R	Decrease	Marine	Heavy	Absent	Glacial
BD1744	76.56178569	-116.9897107	0.6	1.2	0.25	0.14	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1746	77.15992688	-116.2250743	0.59	1.18	0.25	0.15	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1749	77.30176671	-119.2147367	1.24	2.48	0.12	0.07	W	M	Decrease	Marine	Visible	Absent	Glacial
BD1750	77.10398633	-119.7282999	0.72	1.44	0.14	0.08	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1751	77.00237652	-120.0471113	0.62	1.24	0.24	0.14	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1756	71.69023405	-120.4041223	0.84	1.68	0.77	0.44	W	W	Increase	Marine	Visible	Absent	Glacial
BD1757	71.95945625	-120.4281531	1.46	2.92	0.99	0.57	W	W	Increase	Marine	Visible	Absent	Glacial
BD1758	72.27567394	-120.1731327	0.69	1.38	0.07	0.04	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1759	73.88480182	-116.3317983	0.62	1.24	0.56	0.32	W	W	Decrease	Marine	Visible	Absent	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD1760	73.97861038	-116.5813356	0.53	1.06	0.19	0.11	W	W	Increase	Marine	Visible	Absent	Glacial
BD1762	74.24546618	-118.4316992	1.37	2.74	0.33	0.19	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1763	74.160433	-118.8300007	0.72	1.44	1.11	0.64	W	M	Decrease	Marine	Visible	Absent	Glacial
BD1764	74.12424141	-119.7241119	2.65	5.3	0.00	0.00	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1765	74.27191204	-119.9577231	0.82	1.64	0.12	0.07	W	M	Decrease	Marine	Visible	Absent	Glacial
BD1766	74.31747946	-120.3116237	2.24	4.48	0.22	0.13	W	M	Decrease	Marine	Visible	Absent	Glacial
BD1767	74.38269724	-120.6670099	1.24	2.48	0.04	0.02	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1768	74.44293772	-123.2205354	1.73	3.46	0.32	0.18	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1769	74.15628224	-124.3876939	0.97	1.94	0.21	0.12	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1770	74.08465417	-124.3896087	1.78	3.56	0.37	0.21	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1771	74.01972553	-124.318101	1.53	3.06	0.07	0.04	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1772	73.6933526	-123.9173572	1.01	2.02	0.25	0.14	W	M	Decrease	Marine	Visible	Absent	Glacial
BD1773	71.44100122	-121.8164406	0.82	1.64	0.30	0.17	W	W	Increase	Marine	Visible	Absent	Glacial
BD1774	79.58378799	-81.64458427	0.62	1.24	0.73	0.42	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1776	78.84164953	-81.72770568	1.2	2.4	0.54	0.31	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1777	78.72323271	-82.19175596	1.97	3.94	1.95	1.12	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1780	79.22921192	-90.42819784	1	2	1.10	0.63	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1781	79.25283545	-90.40178823	1.64	3.28	0.85	0.49	W	R	Neutral	Marine	Not visible	Absent	Glacial
BD1783	78.7460323	-93.00456169	1.25	2.5	1.36	0.78	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1784	78.59256572	-92.5169411	1.45	2.9	0.38	0.22	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1785	78.33330653	-90.69063264	1.94	3.88	0.67	0.38	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1786	78.61218235	-88.6377241	0.75	1.5	1.80	1.03	W	R	Decrease	Marine	Visible	Absent	Glacial
BD1788	79.10075933	-87.72834368	0.87	1.74	2.18	1.25	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1790	78.91611152	-82.13031936	0.53	1.06	1.04	0.59	W	W	Decrease	Marine	Visible	Absent	Glacial

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD1795	80.74254987	-83.69393407	1.1	2.2	1.45	0.83	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1796	81.23199916	-85.76813272	0.78	1.56	0.58	0.33	W	W	Decrease	Marine	Visible	Absent	Glacial
BD1798	65.92763124	-63.50257329	1.4	2.8	0.25	0.14	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1800	70.52456646	-70.99979521	1.01	2.02	1.19	0.68	W	R	Neutral	Marine	Visible	Absent	Glacial
BD1801	73.27640031	-81.21445863	0.6	1.2	0.83	0.48	W	M	Decrease	Marine	Visible	Absent	Glacial
BD1803	76.68088904	109.9185444	0.94	1.88	0.05	0.03	W	W	Increase	Marine	Heavy	Absent	Uplift
BD1804	76.36596917	112.046771	0.8	1.6	0.00	0.00	W	R	Neutral	Marine	Heavy	Absent	Uplift
BD1807	74.8810285	112.1847966	0.98	1.96	0.00	0.00	W	M	Increase	Marine	Heavy	Absent	Uplift
BD1808	74.49261898	110.4020464	1.46	2.92	0.07	0.04	W	R	Decrease	Marine	Heavy	Absent	Uplift
BD1811	65.84322692	-170.5660087	1.25	2.5	0.56	0.32	W	M	Neutral	Marine	Heavy	Absent	Uplift
BD1812	64.92814416	-172.5103694	0.6	1.2	0.42	0.24	W	M	Increase	Marine	Heavy	Absent	Uplift
BD1815	13.08503235	109.3218251	1.25	2.5	0.08	0.05	W	M	Increase	Marine	Heavy	Heavy	Uplift
BD1821	66.23944128	-170.6048203	0.6	1.2	0.00	0.00	W	R	Decrease	Marine	Heavy	Absent	Uplift
BD1822	64.64538467	-173.0769326	0.76	1.52	0.66	0.38	W	W	Increase	Marine	Heavy	Absent	Uplift
BD1831	66.24881222	-178.473145	0.59	1.18	0.00	0.00	W	R	Decrease	Marine	Heavy	Absent	Uplift
BD1833	66.38742856	-178.5337133	0.78	1.56	0.13	0.07	W	R	Decrease	Marine	Heavy	Absent	Uplift
BD1842	61.73056679	173.5222128	2.69	5.38	0.04	0.02	W	W	Increase	Marine	Heavy	Absent	Uplift
BD1843	56.21669214	162.4946707	1.05	2.1	0.00	0.00	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD1846	62.5570134	163.4118278	1.12	2.24	0.13	0.08	W	R	Neutral	Marine	Heavy	Absent	Uplift
BD1856	12.46621647	80.14918934	1.34	2.68	0.11	0.06	D	W	Increase	Marine	Heavy	Minimal	Arid
BD1865	21.9991851	59.65549082	0.82	1.64	0.12	0.07	D	W	Increase	Marine	Visible	Minimal	Arid
BD1866	21.65393083	59.45118569	1.13	2.26	0.00	0.00	D	W	Increase	Marine	Visible	Minimal	Arid
BD1867	20.18304278	57.81780926	1.07	2.14	1.64	0.94	D	W	Neutral	Marine	Visible	Minimal	Arid
BD1870	18.6897149	56.73997285	0.52	1.04	0.10	0.06	D	W	Decrease	Marine	Visible	Minimal	Arid

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD1871	18.63608479	56.69198686	0.74	1.48	0.34	0.19	D	W	Decrease	Marine	Visible	Minimal	Arid
BD1879	15.61046168	52.17918083	1.36	2.72	0.11	0.06	D	W	Decrease	Marine	Visible	Minimal	Arid
BD1890	15.8389886	42.81123889	0.62	1.24	0.40	0.23	D	M	Decrease	Marine	Visible	Heavy	Arid
BD1900	42.81832357	41.13182192	0.73	1.46	0.55	0.31	W	W	Increase	Marine	Heavy	Minimal	Uplift
BD1902	41.602879	41.57276736	0.55	1.1	0.00	0.00	W	W	Increase	Marine	Heavy	Heavy	Uplift
BD1932	2.887143858	36.62425858	0.69	1.38	0.80	0.46	D	W	Decrease	Lacustrine	Visible	Absent	Arid
BD1961	4.280422151	35.92219785	0.63	1.26	0.87	0.50	D	R	Decrease	Lacustrine	Visible	Absent	Arid
BD1966	4.16853095	35.92264433	0.51	1.02	0.69	0.39	D	R	Neutral	Lacustrine	Visible	Absent	Arid
BD1967	4.13965727	35.92802753	0.74	1.48	0.61	0.35	D	R	Decrease	Lacustrine	Visible	Absent	Arid
BD1970	4.020698416	35.87285204	0.79	1.58	0.76	0.44	D	W	Decrease	Lacustrine	Visible	Minimal	Arid
BD1975	3.059069191	36.16398104	0.5	1	0.20	0.11	W	R	Decrease	Lacustrine	Heavy	Absent	Arid
BD1983	7.637968625	38.62300892	0.71	1.42	0.00	0.00	W	R	Neutral	Lacustrine	Not visible	Absent	Arid
BD1988	11.15193104	41.81024604	6.6	13.2	0.11	0.07	D	W	Neutral	Lacustrine	Not visible	Absent	Arid
BD1989	14.0496201	40.3741903	0.52	1.04	0.38	0.22	D	R	Decrease	Lacustrine	Visible	Absent	Arid
BD1991	-42.57565295	-72.52360967	0.76	1.52	0.33	0.19	W	R	Decrease	Marine	Heavy	Minimal	Uplift
BD1992	-41.97567751	-72.43990492	0.57	1.14	0.88	0.50	W	R	Neutral	Marine	Heavy	Minimal	Uplift
BD1993	-31.35121675	136.7613312	0.5	1	0.30	0.17	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD1994	75.95549849	139.8745727	0.72	1.44	0.28	0.16	W	M	Increase	Marine	Heavy	Absent	Glacial
BD1996	30.33283957	-105.6662417	0.55	1.1	1.09	0.63	D	R	Decrease	Lacustrine	Visible	Absent	Arid
BD2000	32.3435754	-115.5533539	0.52	1.04	1.83	1.05	D	R	Decrease	Lacustrine	Visible	Absent	Arid
BD2004	25.40892382	-102.630055	3.82	7.64	1.91	1.09	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2006	25.32289202	-102.7839074	1.32	2.64	1.21	0.69	D	R	Decrease	Lacustrine	Visible	Heavy	Arid
BD2010	26.33777815	-102.7770625	0.97	1.94	2.58	1.48	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2016	28.17848371	-103.2615957	0.57	1.14	0.09	0.05	D	R	Decrease	Lacustrine	Visible	Minimal	Arid

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD2030	33.3526773	-115.695619	0.65	1.3	0.15	0.09	D	M	Decrease	Lacustrine	Visible	Minimal	Arid
BD2034	34.22855578	-115.3614454	1.36	2.72	0.48	0.27	D	R	Neutral	Lacustrine	Visible	Absent	Arid
BD2037	34.15128826	-115.7126904	1.07	2.14	2.48	1.42	D	R	Neutral	Lacustrine	Visible	Heavy	Arid
BD2040	34.84123369	-116.1767703	4.12	8.24	2.57	1.47	D	R	Neutral	Lacustrine	Visible	Absent	Arid
BD2044	35.6065281	-115.4075816	1.6	3.2	2.88	1.65	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2046	35.5334007	-116.1651751	3.68	7.36	1.85	1.06	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2047	35.512371	-116.1640105	1.3	2.6	0.38	0.22	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2048	35.31575525	-116.0862112	4.03	8.06	2.36	1.35	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2057	35.06979963	-116.783634	1.17	2.34	1.79	1.03	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2059	35.08424631	-116.7413041	1.31	2.62	1.87	1.07	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2063	36.29813801	-117.3745963	0.88	1.76	0.28	0.16	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2064	36.36635014	-117.4086581	0.63	1.26	1.03	0.59	D	R	Decrease	Lacustrine	Visible	Absent	Arid
BD2065	36.41198133	-117.4176412	1.5	3	1.87	1.07	D	R	Neutral	Lacustrine	Visible	Absent	Arid
BD2066	36.70042553	-117.5657057	1.17	2.34	1.37	0.78	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2067	36.66375925	-117.5649829	0.53	1.06	1.42	0.81	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2071	36.95554585	-116.0080201	0.59	1.18	0.76	0.44	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2072	36.8269605	-115.6287872	1.8	3.6	0.53	0.30	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2074	36.6273128	-115.4982721	1.47	2.94	0.44	0.25	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2079	36.93524933	-115.2106263	3.4	6.8	2.68	1.53	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2084	39.56110908	-113.4576699	1.94	3.88	0.95	0.55	D	R	Neutral	Lacustrine	Visible	Absent	Arid
BD2085	39.88423467	-115.9836263	6.27	12.54	0.18	0.10	D	R	Neutral	Lacustrine	Visible	Heavy	Arid
BD2086	40.1230349	-118.0542597	2.61	5.22	0.17	0.10	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2087	40.32198472	-117.9551087	1.15	2.3	1.70	0.97	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2092	-20.15320586	-67.13146672	0.6	1.2	0.25	0.14	D	R	Decrease	Lacustrine	Visible	Absent	Uplift

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD2093	-24.3436031	-66.9973096	6.4	12.8	3.43	1.96	D	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2094	-32.18005559	-69.26457915	1.65	3.3	1.15	0.66	D	R	Neutral	Lacustrine	Visible	Minimal	Uplift
BD2095	-32.17588779	-69.31076023	0.66	1.32	2.20	1.26	D	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2096	-30.86677446	-68.85046212	1.19	2.38	3.03	1.73	D	R	Neutral	Lacustrine	Visible	Minimal	Uplift
BD2099	-30.98815368	139.8169643	2.62	5.24	0.00	0.00	D	R	Decrease	Lacustrine	Visible	Absent	Arid
BD2101	-29.05716397	142.3449322	1.24	2.48	0.16	0.09	D	R	Decrease	Lacustrine	Visible	Absent	Arid
BD2102	-28.77982177	142.2081203	0.72	1.44	0.07	0.04	D	R	Decrease	Lacustrine	Visible	Absent	Arid
BD2103	-29.27251707	142.6077873	2.42	4.84	0.06	0.04	D	R	Decrease	Lacustrine	Visible	Absent	Arid
BD2105	-26.34469851	141.3120239	0.74	1.48	0.07	0.04	D	R	Decrease	Lacustrine	Visible	Absent	Arid
BD2107	35.4433535	4.581854397	10.73	21.46	0.07	0.04	D	R	Neutral	Lacustrine	Not visible	Absent	Arid
BD2108	34.08836091	0.548752268	1.05	2.1	0.14	0.08	D	R	Neutral	Lacustrine	Visible	Absent	Arid
BD2110	21.55434437	56.1776089	3.78	7.56	0.09	0.05	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2113	33.00222623	43.57175141	0.52	1.04	0.00	0.00	W	R	Decrease	Lacustrine	Visible	Absent	Arid
BD2120	31.06884119	84.06579967	0.87	1.74	0.34	0.20	W	R	Decrease	Lacustrine	Not visible	Absent	Glacial
BD2124	31.57506264	61.16892411	0.68	1.36	1.40	0.80	D	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2125	31.27845249	83.38377743	0.53	1.06	0.19	0.11	W	R	Decrease	Lacustrine	Not visible	Absent	Glacial
BD2131	32.03453869	88.22153711	0.85	1.7	1.29	0.74	W	R	Decrease	Lacustrine	Visible	Absent	Uplift
BD2134	32.01242367	88.29097965	0.56	1.12	0.71	0.41	W	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2137	32.4499056	88.07054326	1.08	2.16	3.43	1.96	D	M	Decrease	Lacustrine	Visible	Absent	Uplift
BD2139	32.17076265	86.17377998	1.33	2.66	1.77	1.01	D	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2143	32.30222661	82.16754267	0.73	1.46	0.21	0.12	W	M	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2151	32.53973584	80.29480737	2.42	4.84	0.19	0.11	W	R	Neutral	Lacustrine	Visible	Absent	Uplift
BD2152	33.51428367	80.29296335	2.06	4.12	1.14	0.65	D	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2154	33.25612518	81.66940591	1	2	1.00	0.57	W	R	Decrease	Lacustrine	Not visible	Absent	Uplift

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD2155	34.07216598	81.70961734	2.99	5.98	1.71	0.98	W	M	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2156	34.12070167	81.55625638	4.25	8.5	1.74	1.00	D	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2157	34.1224588	81.50687803	3.23	6.46	2.03	1.16	D	M	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2159	32.99917989	82.51406063	2.9	5.8	1.62	0.93	D	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2161	33.52961018	84.64189579	0.59	1.18	0.59	0.34	W	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2163	44.38715122	97.93525521	12.91	25.82	1.42	0.81	D	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2166	40.98447134	-122.6506918	0.68	1.36	0.00	0.00	W	R	Neutral	Lacustrine	Heavy	Minimal	Uplift
BD2168	46.87819898	94.47518748	5.77	11.54	1.07	0.62	D	R	Neutral	Lacustrine	Visible	Minimal	Uplift
BD2169	45.62298103	99.24348924	0.98	1.96	0.26	0.15	W	M	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2171	48.87773981	93.40789468	1	2	0.10	0.06	W	R	Decrease	Lacustrine	Visible	Absent	Uplift
BD2172	49.1918285	93.73505733	0.51	1.02	2.25	1.29	D	W	Decrease	Lacustrine	Visible	Absent	Uplift
BD2173	47.63684945	93.38392536	3.03	6.06	0.89	0.51	D	W	Neutral	Lacustrine	Visible	Minimal	Uplift
BD2174	48.21241761	93.17025541	0.53	1.06	1.79	1.03	D	W	Decrease	Lacustrine	Visible	Absent	Uplift
BD2175	47.70702009	84.27920824	1.5	3	1.50	0.86	D	W	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2176	49.58519954	90.674481	6.37	12.74	1.58	0.90	D	R	Neutral	Lacustrine	Visible	Minimal	Uplift
BD2177	50.54935017	92.63989536	1.01	2.02	1.58	0.91	W	R	Decrease	Lacustrine	Heavy	Minimal	Uplift
BD2179	50.30317746	93.40852661	5.82	11.64	0.17	0.10	W	R	Neutral	Lacustrine	Visible	Absent	Uplift
BD2180	50.08999183	91.10642384	1.13	2.26	2.08	1.19	D	M	Decrease	Lacustrine	Not visible	Minimal	Glacial
BD2181	50.18016784	90.91837965	0.5	1	1.20	0.69	W	R	Decrease	Lacustrine	Visible	Absent	Uplift
BD2186	33.02196084	86.7516262	4.62	9.24	0.25	0.14	W	R	Neutral	Lacustrine	Visible	Absent	Glacial
BD2199	37.83717697	-115.2866956	1.72	3.44	0.61	0.35	D	R	Neutral	Lacustrine	Not visible	Absent	Arid
BD2202	37.96741414	-116.0261316	4.5	9	0.78	0.45	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2209	37.87879467	-117.1141347	0.52	1.04	1.06	0.61	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2210	37.83314072	-117.0654166	1.54	3.08	1.88	1.08	D	R	Decrease	Lacustrine	Visible	Absent	Arid

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD2211	37.84096804	-117.4017744	1.56	3.12	1.25	0.72	D	R	Neutral	Lacustrine	Visible	Absent	Arid
BD2216	37.22637656	-117.0443256	0.72	1.44	1.04	0.60	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2217	37.20908867	-117.0292937	0.6	1.2	1.50	0.86	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2219	38.95293767	-118.2663174	0.76	1.52	3.42	1.96	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2222	39.02912772	-117.0495228	0.86	1.72	2.15	1.23	D	R	Decrease	Lacustrine	Visible	Minimal	Arid
BD2226	36.9478957	-115.4544943	1.69	3.38	1.15	0.66	D	R	Neutral	Lacustrine	Visible	Absent	Arid
BD2229	38.35358114	-117.7926572	3.77	7.54	1.21	0.69	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2230	37.14518841	-117.1925391	0.76	1.52	0.46	0.26	D	R	Neutral	Lacustrine	Visible	Minimal	Arid
BD2234	-23.56087229	-68.09837642	1.16	2.32	3.36	1.93	D	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2235	-24.722151	-68.99319138	2.6	5.2	1.33	0.76	D	R	Neutral	Lacustrine	Not visible	Minimal	Uplift
BD2239	-31.88057633	-69.43793681	0.93	1.86	0.65	0.37	D	R	Neutral	Lacustrine	Visible	Minimal	Uplift
BD2240	29.12092856	-1.131127645	1.7	3.4	0.03	0.02	D	R	Neutral	Lacustrine	Visible	Absent	Arid
BD2241	37.57495034	93.69259988	1.21	2.42	0.12	0.07	W	R	Decrease	Lacustrine	Not visible	Minimal	Uplift
BD2243	35.74029614	95.41394988	2.29	4.58	0.07	0.04	W	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2244	35.75826799	95.35974857	0.54	1.08	2.50	1.43	D	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2245	35.57442569	97.1599291	4.84	9.68	1.30	0.75	D	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2250	26.85975119	63.5126577	2.8	5.6	0.59	0.34	D	R	Neutral	Lacustrine	Visible	Minimal	Uplift
BD2251	33.31157321	84.82183083	3.27	6.54	3.24	1.86	D	R	Neutral	Lacustrine	Visible	Absent	Uplift
BD2254	32.69585571	87.58982745	3.06	6.12	1.81	1.04	D	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2255	32.7063581	87.61113077	0.58	1.16	0.78	0.44	W	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2257	32.74505685	87.77699534	1.21	2.42	1.78	1.02	W	R	Decrease	Lacustrine	Visible	Absent	Glacial
BD2264	32.28592909	88.68043868	1.67	3.34	1.08	0.62	D	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2268	37.50670371	89.26377592	1.5	3	0.23	0.13	W	R	Decrease	Lacustrine	Visible	Absent	Uplift
BD2271	40.16219894	78.28278874	1.3	2.6	0.19	0.11	D	R	Decrease	Lacustrine	Visible	Absent	Uplift

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD2272	27.61451609	59.00605824	3.07	6.14	0.72	0.41	D	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2273	29.05405413	54.87844745	3.61	7.22	1.12	0.64	D	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2275	30.84880112	53.69271045	5.6	11.2	1.16	0.67	D	R	Neutral	Lacustrine	Visible	Heavy	Uplift
BD2277	32.84298168	57.42947169	3.91	7.82	2.52	1.44	D	R	Neutral	Lacustrine	Not visible	Minimal	Uplift
BD2278	32.75622396	53.74190586	0.82	1.64	0.24	0.14	D	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2279	32.60645364	54.15908972	4.23	8.46	0.90	0.51	D	R	Neutral	Lacustrine	Not visible	Minimal	Uplift
BD2280	33.60762368	52.81977572	3.17	6.34	1.31	0.75	D	R	Decrease	Lacustrine	Not visible	Minimal	Uplift
BD2281	34.77046019	51.8318978	5.97	11.94	0.03	0.02	W	R	Neutral	Lacustrine	Visible	Absent	Uplift
BD2282	37.12326736	88.20048516	7.39	14.78	0.29	0.17	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2283	37.08324021	88.58046259	5.8	11.6	0.54	0.31	D	M	Neutral	Lacustrine	Visible	Absent	Uplift
BD2284	37.14834641	88.26038214	0.78	1.56	2.24	1.29	D	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2285	37.05194604	88.25481808	1.62	3.24	1.14	0.65	D	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2286	32.43422851	89.20702776	0.52	1.04	0.48	0.28	W	R	Decrease	Lacustrine	Visible	Absent	Uplift
BD2290	32.40151245	89.9879855	1.12	2.24	0.85	0.49	D	R	Decrease	Lacustrine	Visible	Absent	Uplift
BD2291	32.42212547	89.86948845	0.69	1.38	0.80	0.46	W	R	Decrease	Lacustrine	Visible	Minimal	Uplift
BD2292	32.49713127	90.06049858	0.58	1.16	1.29	0.74	W	R	Decrease	Lacustrine	Not visible	Minimal	Uplift
BD2293	45.12550445	95.52538466	4.32	8.64	1.90	1.09	D	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2294	45.45174514	95.60896053	1.43	2.86	0.66	0.38	D	R	Neutral	Lacustrine	Not visible	Minimal	Uplift
BD2302	33.90204866	78.57320278	1.61	3.22	2.24	1.28	W	W	Neutral	Lacustrine	Not visible	Minimal	Glacial
BD2307	30.17080808	86.4288563	0.59	1.18	0.51	0.29	W	M	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2308	30.79285936	86.50927435	0.88	1.76	0.28	0.16	W	R	Decrease	Lacustrine	Not visible	Absent	Glacial
BD2310	30.93206948	87.09866967	0.91	1.82	0.11	0.06	W	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2311	31.8846962	87.37081131	0.71	1.42	0.21	0.12	W	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2313	31.64386111	87.88321885	1.86	3.72	0.32	0.18	W	R	Decrease	Lacustrine	Visible	Absent	Uplift

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD2316	31.5170785	88.76299701	0.52	1.04	0.48	0.28	W	R	Decrease	Lacustrine	Visible	Absent	Uplift
BD2318	32.11676575	91.50858493	1.71	3.42	0.12	0.07	W	R	Neutral	Lacustrine	Not visible	Minimal	Uplift
BD2323	30.53200052	90.32941914	0.97	1.94	0.15	0.09	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2324	31.03804064	85.39756318	0.6	1.2	0.25	0.14	W	R	Decrease	Lacustrine	Not visible	Absent	Glacial
BD2326	35.24234212	79.91987105	0.64	1.28	1.72	0.98	W	M	Decrease	Lacustrine	Visible	Absent	Glacial
BD2327	34.06643773	79.76915048	2.65	5.3	3.11	1.78	W	M	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2329	34.18169246	79.72356866	0.78	1.56	1.79	1.03	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2332	34.59402944	80.20878135	0.77	1.54	0.06	0.04	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2333	33.99972316	80.83888389	0.57	1.14	0.00	0.00	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2336	35.05764315	81.21513957	0.91	1.82	0.11	0.06	W	W	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2337	34.87504197	81.51374758	1.61	3.22	0.47	0.27	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2338	34.87989914	81.99212514	0.56	1.12	0.36	0.20	W	W	Increase	Lacustrine	Not visible	Absent	Glacial
BD2345	35.38670127	84.46097373	0.6	1.2	0.17	0.10	W	R	Neutral	Lacustrine	Visible	Absent	Uplift
BD2347	34.46766902	85.77706327	0.56	1.12	0.63	0.36	W	W	Increase	Lacustrine	Not visible	Absent	Glacial
BD2348	33.69481339	85.77956571	4.28	8.56	0.56	0.32	W	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2350	33.89643668	87.085826	0.77	1.54	0.00	0.00	W	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2351	34.51193384	87.01259064	0.69	1.38	0.07	0.04	W	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2352	35.94693298	86.90423068	0.5	1	1.00	0.57	W	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2353	35.94374092	87.00159301	0.79	1.58	0.13	0.07	D	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2354	35.09373005	86.61424283	0.62	1.24	0.24	0.14	W	R	Decrease	Lacustrine	Not visible	Absent	Glacial
BD2355	35.98822413	87.50083974	0.89	1.78	0.34	0.19	D	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2357	35.70154182	92.84902341	1.12	2.24	0.40	0.23	W	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2359	38.40596012	97.55634999	0.69	1.38	1.30	0.75	W	M	Decrease	Lacustrine	Not visible	Absent	Glacial
BD2362	35.71156793	91.25312406	0.62	1.24	0.32	0.18	D	R	Neutral	Lacustrine	Not visible	Absent	Uplift

Table 4.4: Holocene braid-delta database. Continued.

Code	Latitude	Longitude	w (km)	2w (km)	Slope %	Slope °	Wet/dry	W/R/T/M	Confinement	Marine/lac.	Veg.	Anthro.	Control
BD2363	35.63653889	90.90510724	0.52	1.04	0.87	0.50	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2364	35.6285716	90.90725282	0.85	1.7	0.35	0.20	W	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2365	35.63491512	90.73316584	2.54	5.08	0.73	0.42	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2368	35.74792394	90.33686819	0.85	1.7	0.65	0.37	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2369	35.77001808	90.0194285	2.13	4.26	0.52	0.30	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2371	35.81872221	89.55859432	1.12	2.24	0.36	0.20	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2373	35.97273133	88.45719277	2.09	4.18	0.26	0.15	W	R	Neutral	Lacustrine	Visible	Absent	Uplift
BD2375	36.30187221	88.2341258	1.1	2.2	0.59	0.34	W	R	Neutral	Lacustrine	Not visible	Absent	Uplift
BD2376	35.40936277	89.29793991	0.73	1.46	0.75	0.43	W	R	Decrease	Lacustrine	Not visible	Absent	Glacial
BD2377	35.21572209	89.91723721	0.83	1.66	0.42	0.24	W	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2378	35.26652881	90.16059288	0.79	1.58	0.32	0.18	W	R	Decrease	Lacustrine	Not visible	Absent	Glacial
BD2379	35.22714752	90.47595222	0.67	1.34	0.07	0.04	W	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2380	35.06005043	90.68134911	0.77	1.54	0.19	0.11	W	R	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2382	34.48623195	88.93412928	2.35	4.7	0.26	0.15	W	R	Decrease	Lacustrine	Not visible	Absent	Glacial
BD2387	33.37721564	90.45264453	0.63	1.26	0.56	0.32	W	R	Decrease	Lacustrine	Not visible	Absent	Glacial
BD2388	33.36017142	90.43348965	3.65	7.3	0.32	0.18	W	R	Neutral	Lacustrine	Not visible	Absent	Glacial
BD2390	33.66547353	89.7839507	0.55	1.1	0.36	0.21	W	R	Decrease	Lacustrine	Not visible	Absent	Glacial
BD2391	33.75649211	90.0253923	0.88	1.76	0.17	0.10	W	M	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2392	34.04911834	89.9620211	1.11	2.22	0.41	0.23	W	M	Decrease	Lacustrine	Not visible	Absent	Uplift
BD2393	33.89177042	89.91321053	1.19	2.38	0.13	0.07	W	R	Neutral	Lacustrine	Not visible	Absent	Uplift

Abbreviations: w – width of feeder system; wet/dry – perennial/intermittent or ephemeral; W/R/T/M – wave, river, tide, or mixed; Lac. – lacustrine; Veg. – vegetation; Anthro. – anthropogenic influence; Control – formational control.

Table 4.5: Channel count transect placement testing, Rangitata River. ^a

Trial #	Distance (km)	Channel Count	Transect Length (km)	Normalized channel count (#/km)	Statistics	
1	0	1	0.112	8.929	Average count	12
	0.047	1	0.065	15.385	Standard dev.	1
	0.078	1	0.025	40.000	Total channels	42
	0.193	1	0.076	13.158		
	0.461	8	0.515	15.534		
	0.669	6	0.532	11.278		
	1.023	7	0.637	10.989		
	1.87	8	0.663	12.066		
	2.42	13	0.89	14.607		
	2.92	8	0.689	11.611		
	3.183	10	0.52	19.231		
2	0	1	0.112	8.929	Average count	14
	0.047	1	0.065	15.385	Standard dev.	2
	0.078	1	0.025	40.000	Total channels	46
	0.193	1	0.076	13.158		
	0.461	8	0.515	15.534		
	0.561	8	0.497	16.097		
	1.162	6	0.586	10.239		
	1.716	9	0.692	13.006		
	2.275	13	0.884	14.706		
	3.02	10	0.687	14.556		
	3.188	10	0.52	19.231		
3	0	1	0.112	8.929	Average count	14
	0.047	1	0.065	15.385	Standard dev.	3
	0.078	1	0.025	40.000	Total channels	43
	0.193	1	0.076	13.158		
	0.461	8	0.515	15.534		
	0.51	9	0.495	18.182		
	0.949	7	0.625	11.200		
	1.537	7	0.586	11.945		
	2.135	10	0.8	12.500		
	2.842	10	0.73	13.699		
	3.173	10	0.52	19.231		

Table 4.5: Channel count transect placement testing, Rangitata River. Continued.

Trial #	Distance (km)	Channel Count	Transect Length (km)	Normalized channel count (#/km)	Statistics	
4	0	1	0.112	8.929	Average count	12
	0.047	1	0.065	15.385	Standard dev.	2
	0.078	1	0.025	40.000	Total channels	40
	0.193	1	0.076	13.158		
	0.461	8	0.515	15.534		
	0.778	7	0.522	13.410		
	1.26	8	0.584	13.699		
	1.809	7	0.676	10.355		
	2.351	10	0.904	11.062		
	3.114	8	0.593	13.491		
	3.182	10	0.52	19.231		
5	0	1	0.112	8.929	Average count	13
	0.047	1	0.065	15.385	Standard dev.	2
	0.078	1	0.025	40.000	Total channels	45
	0.193	1	0.076	13.158		
	0.461	8	0.515	15.534		
	0.722	7	0.536	13.060		
	1.395	8	0.512	15.625		
	1.961	8	0.714	11.204		
	2.481	13	0.884	14.706		
	2.757	9	0.755	11.921		
	3.166	10	0.52	19.231		

Each trial represents a random placement of transects at the positions marked with bold text. Statistics reveal similarity between all trials. Transects illustrated in Figure 5.1.

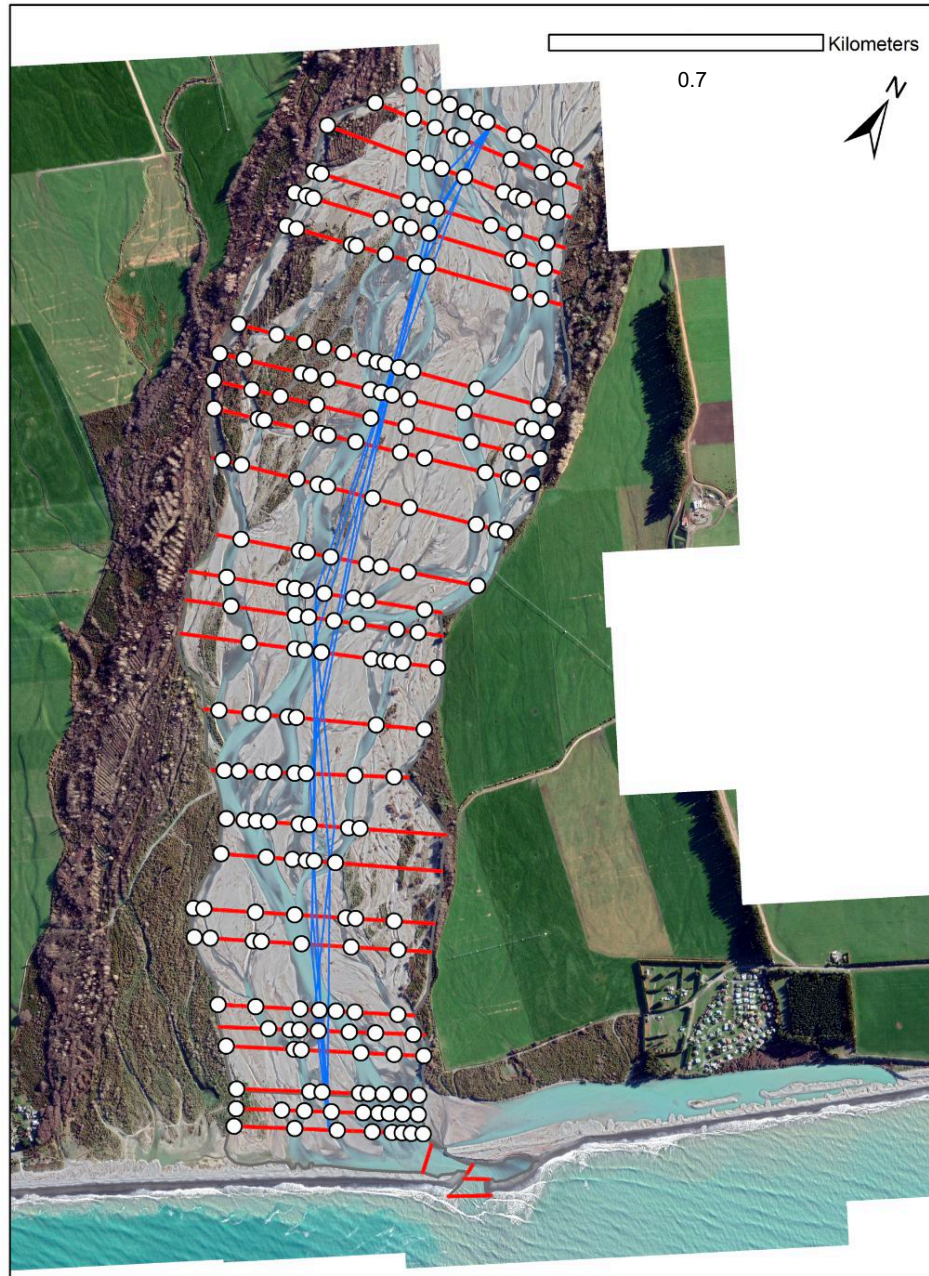


Figure 4.1: Locations of data collected to test transect placement and channel counting (Table 4.5) at the Rangitata River, New Zealand site. Transects are in red, channel belt midlines are blue, and each white circle indicates a counted channel.



Figure 4.2: Image of the Kerguelen Islands braid delta, unannotated. Photographed January 10, 2012 (-49.27054127, 69.40137081).

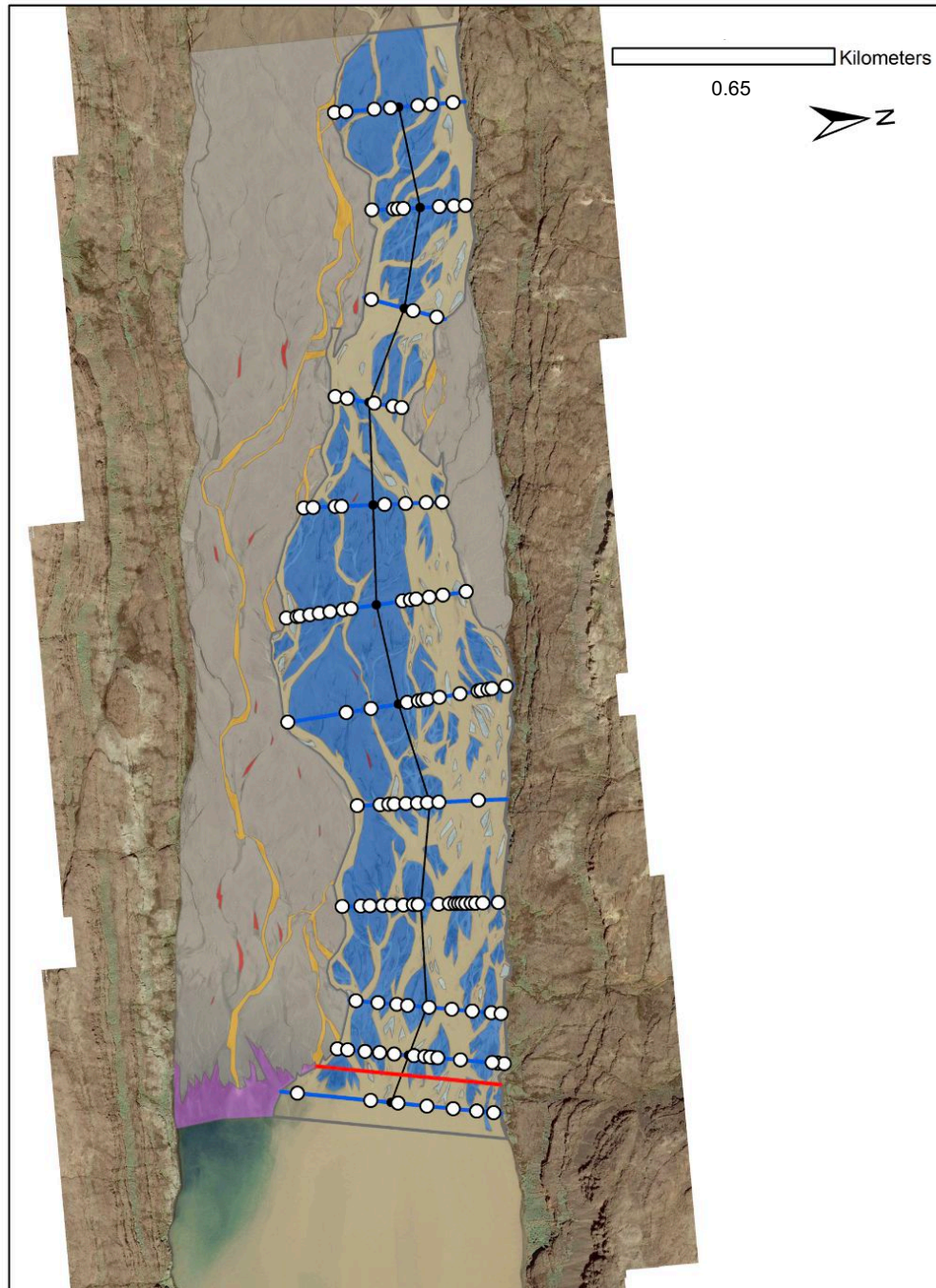


Figure 4.3: Detailed feature mapping of the Kerguelen Islands braid delta, with transparency. Key located in Figure 3.9. Channel counting transects are in blue, white circles are counted channel locations, channel-belt midline is black.

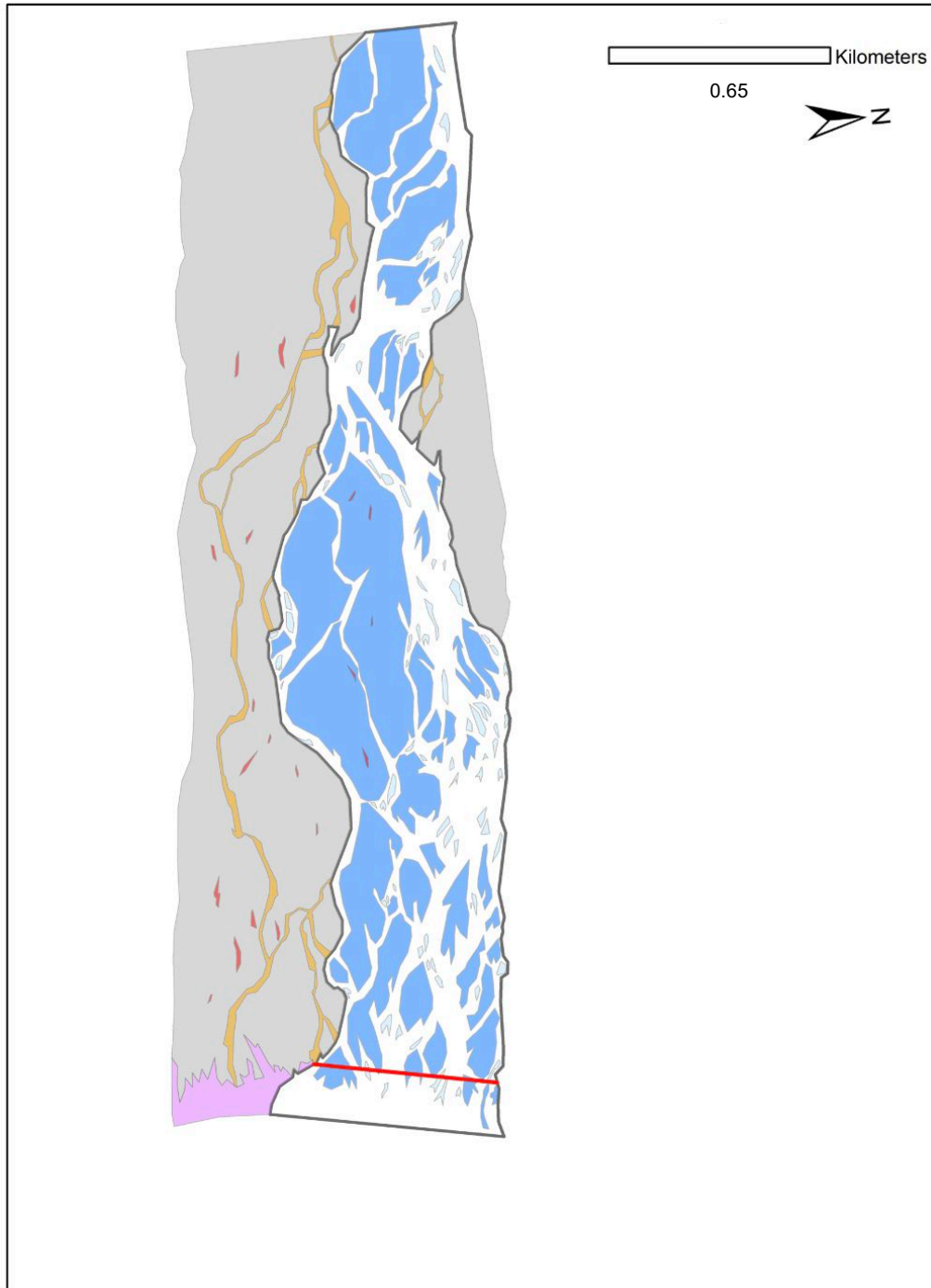


Figure 4.4: Enlarged map of the Kerguelen Islands braid delta. Key located in Figure 3.9.

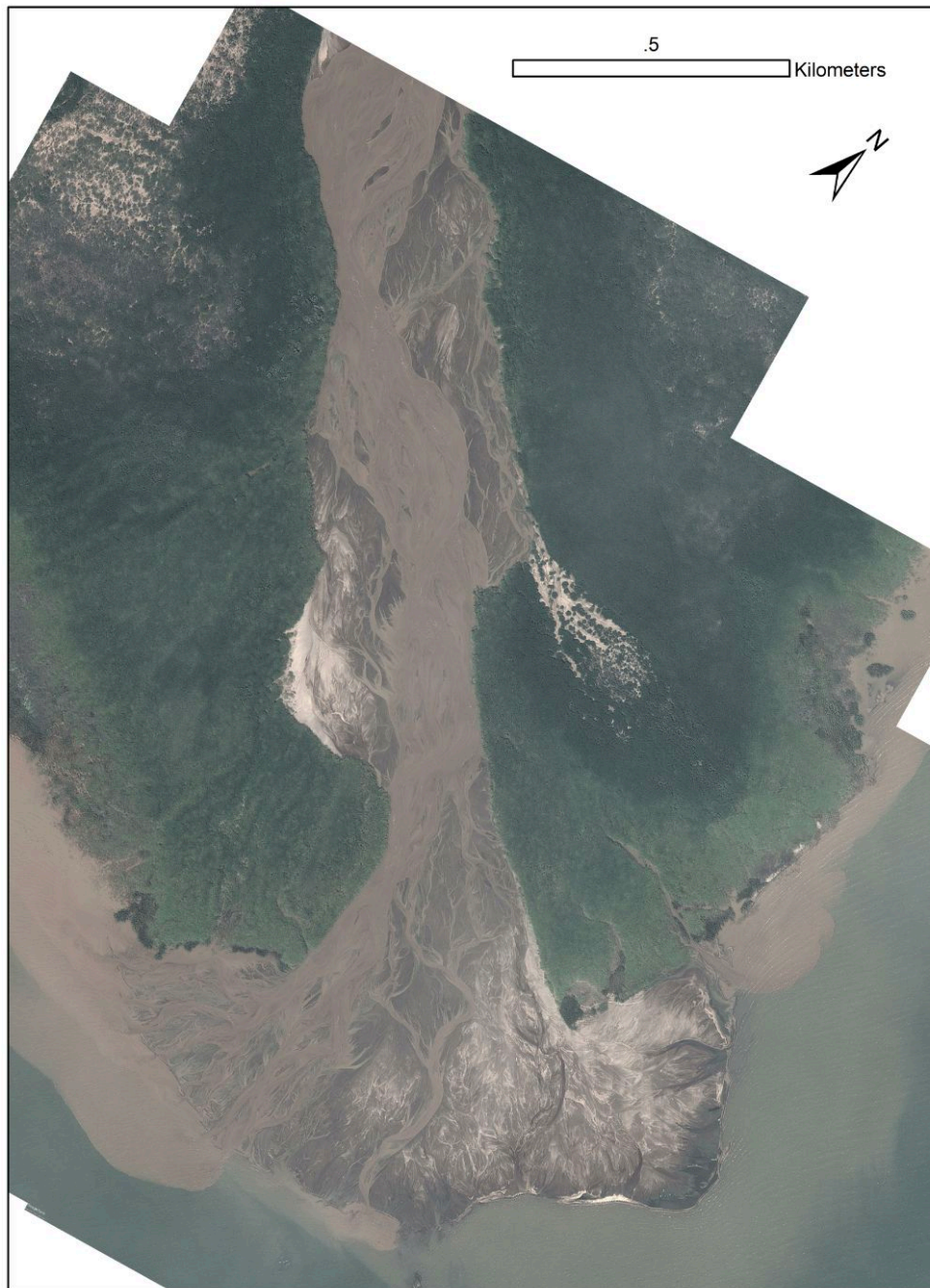


Figure 4.5: Image of the Turkwel River braid delta, unannotated. Photographed January 27, 2012 (3.059069191, 36.16398104).

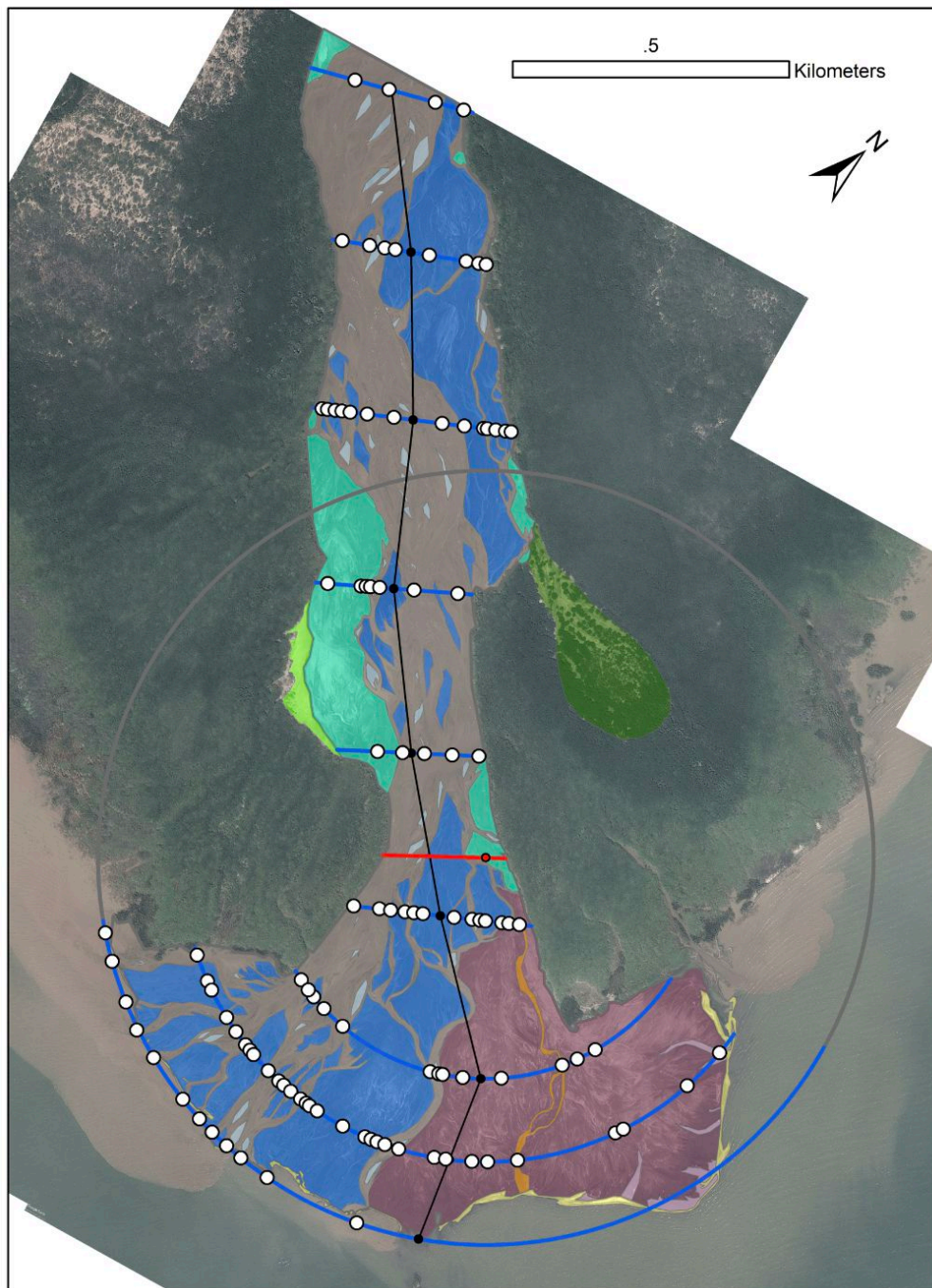


Figure 4.6: Detailed feature mapping of the Turkwel River braid delta, with transparency. Key located in Figure 3.9. Channel counting transects are in blue, white circles are counted channel locations, channel-belt midline is black.

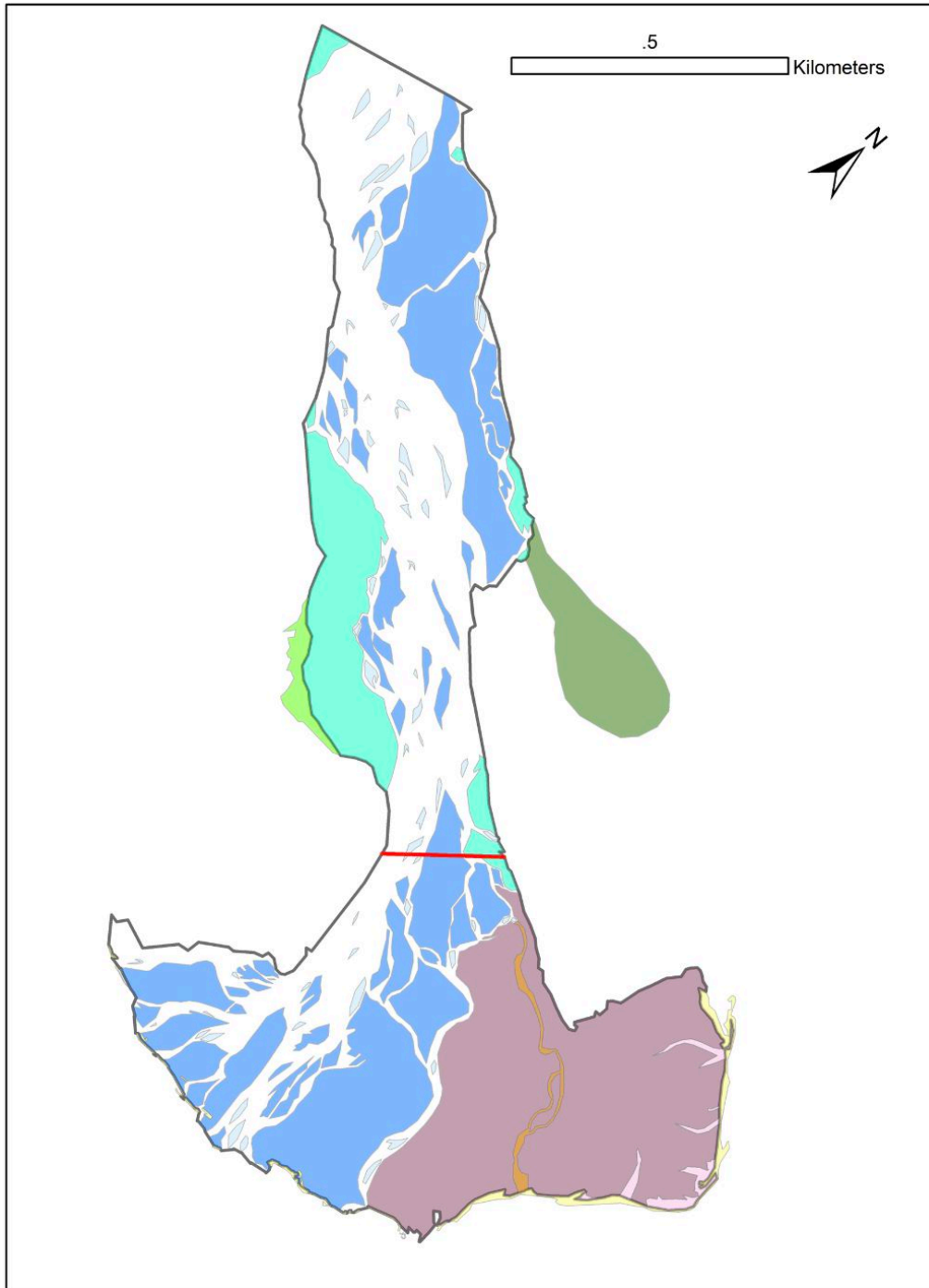


Figure 4.7: Enlarged map of the Turkwel River braid delta. Key located in Figure 3.9.



Figure 4.8: Image of the Rangitata River braid delta, unannotated. Photographed June 5, 2019 (-44.18876361, 171.5036375).

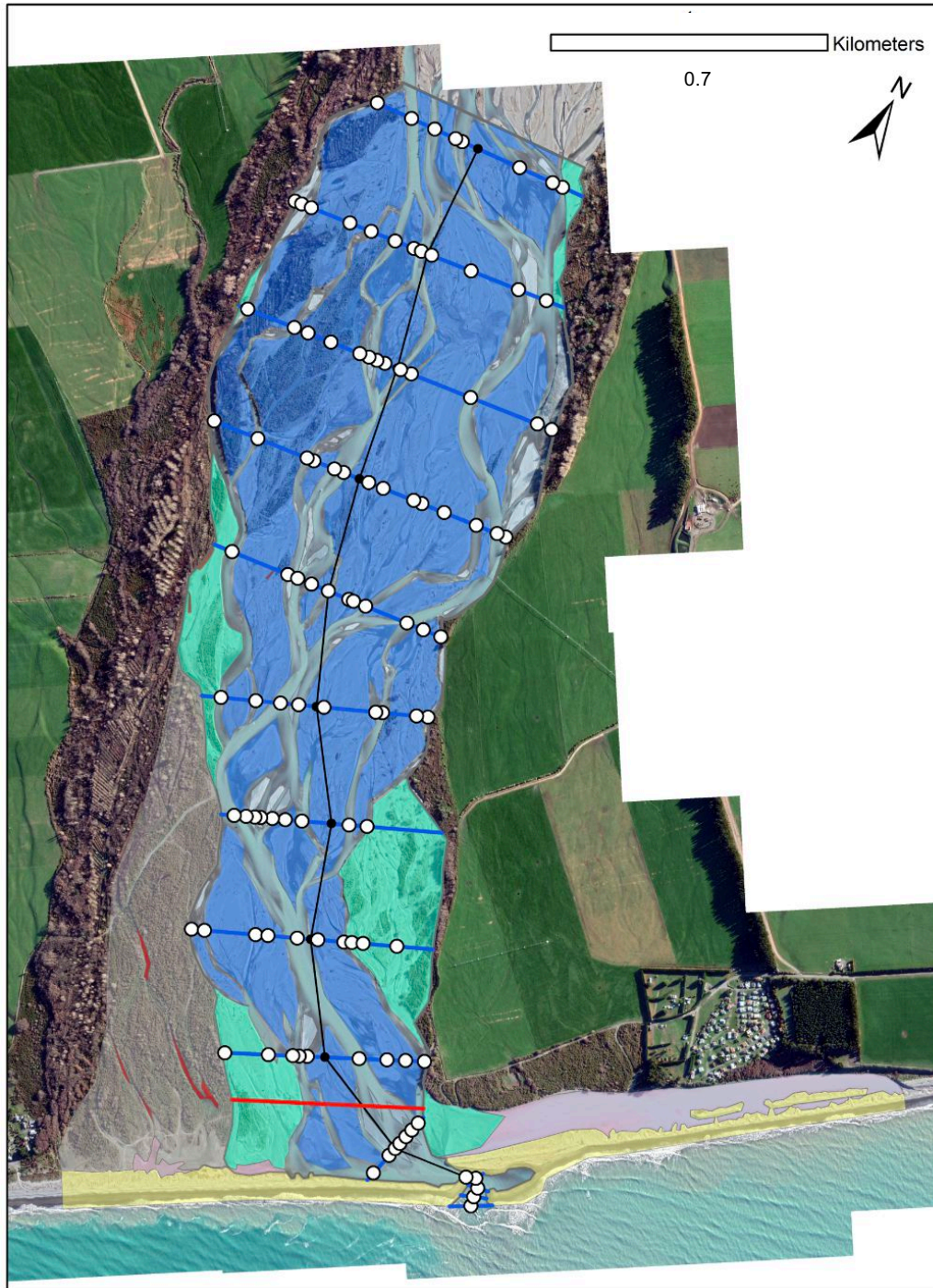


Figure 4.9: Detailed feature mapping of the Rangitata River braid delta, with transparency. Key located in Figure 3.9. Channel counting transects are in blue, white circles are counted channel locations, channel-belt midline is black.

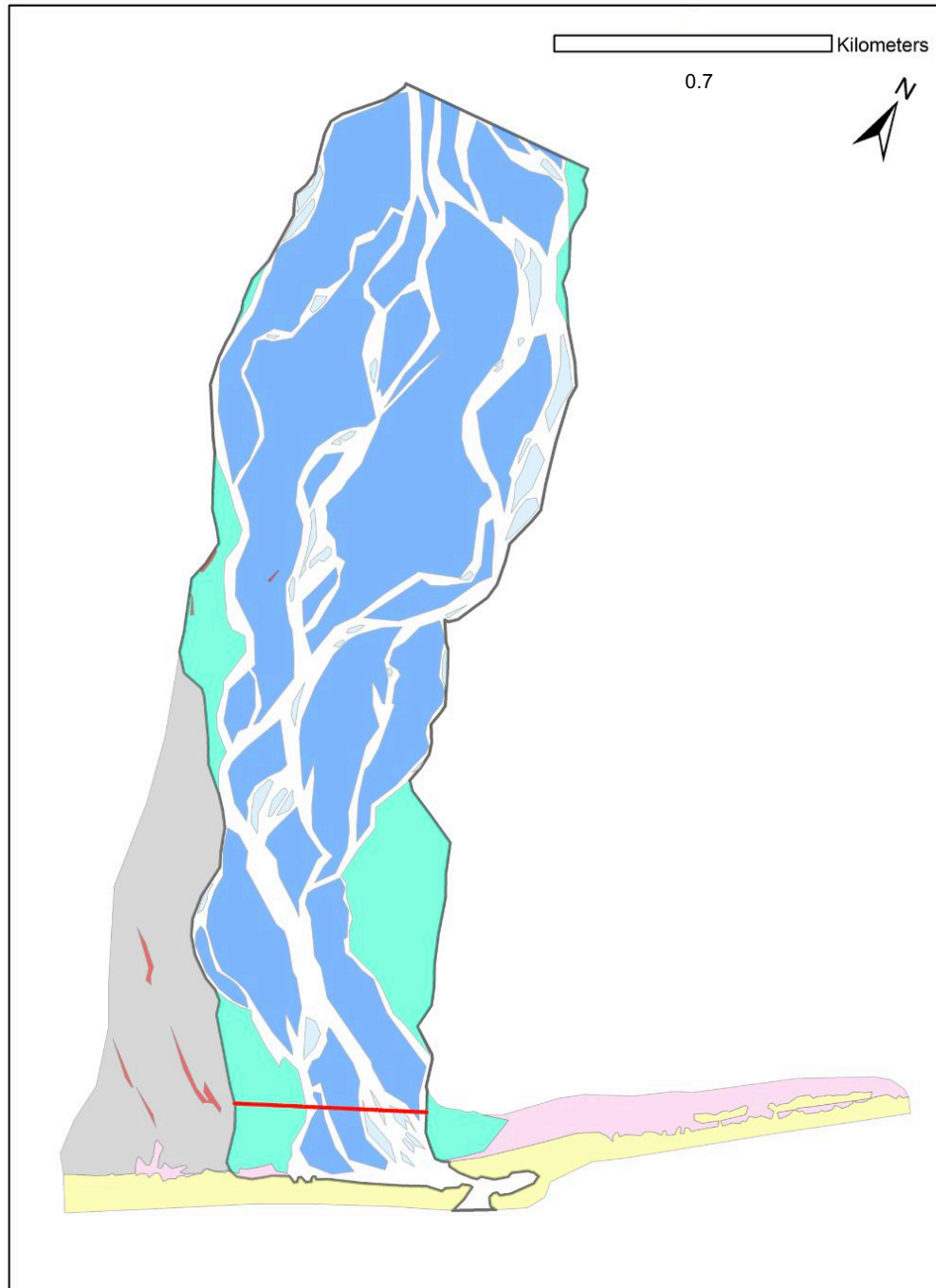


Figure 4.10: Enlarged map of the Rangitata River braid delta. Key located in Figure 3.9.



Figure 4.11: Image of the Rio Ocoa braid delta, unannotated. Photographed October 19, 2018 (18.27534247, -70.58998142).

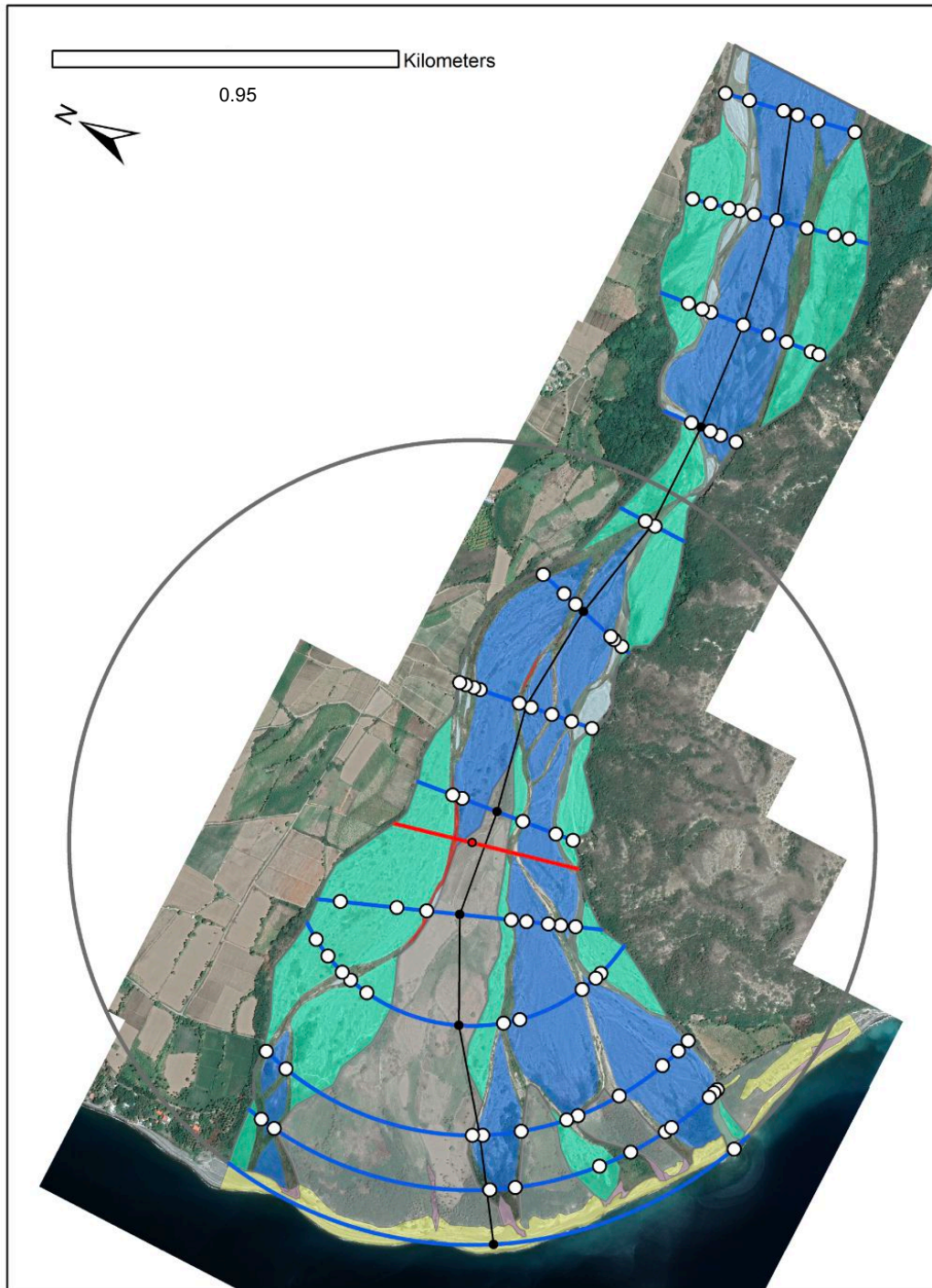


Figure 4.12: Detailed feature mapping of the Rio Ocoa braid delta, with transparency. Key located in Figure 3.9. Channel counting transects are in blue, white circles are counted channel locations, channel-belt midline is black.

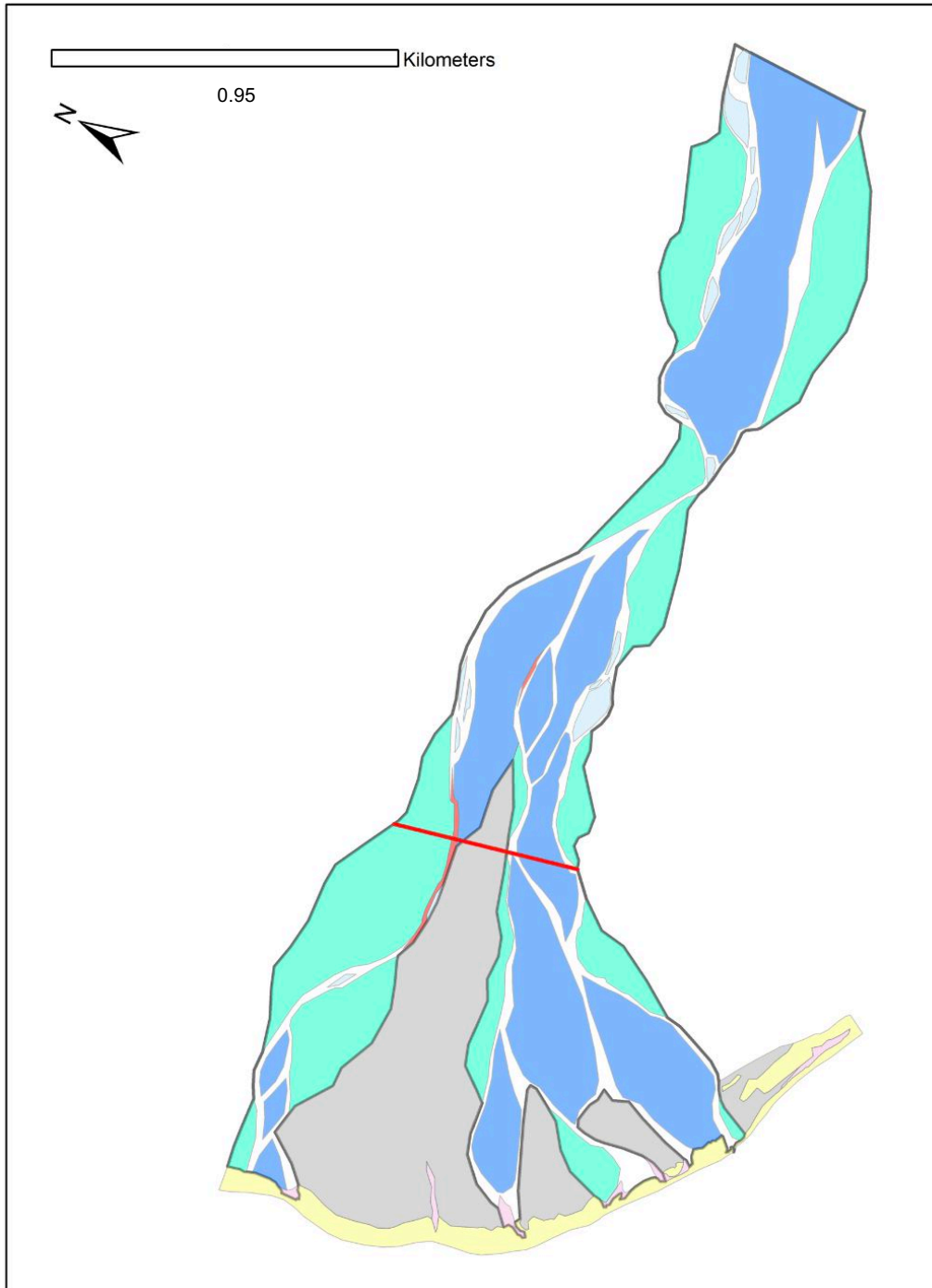


Figure 4.13: Enlarged map of the Rio Ocoa braid delta. Key located in Figure 3.9.



Figure 4.14: Image of the Tuxedni River braid delta, unannotated. Photographed July 11, 2006 (60.22430239, -152.8288613).

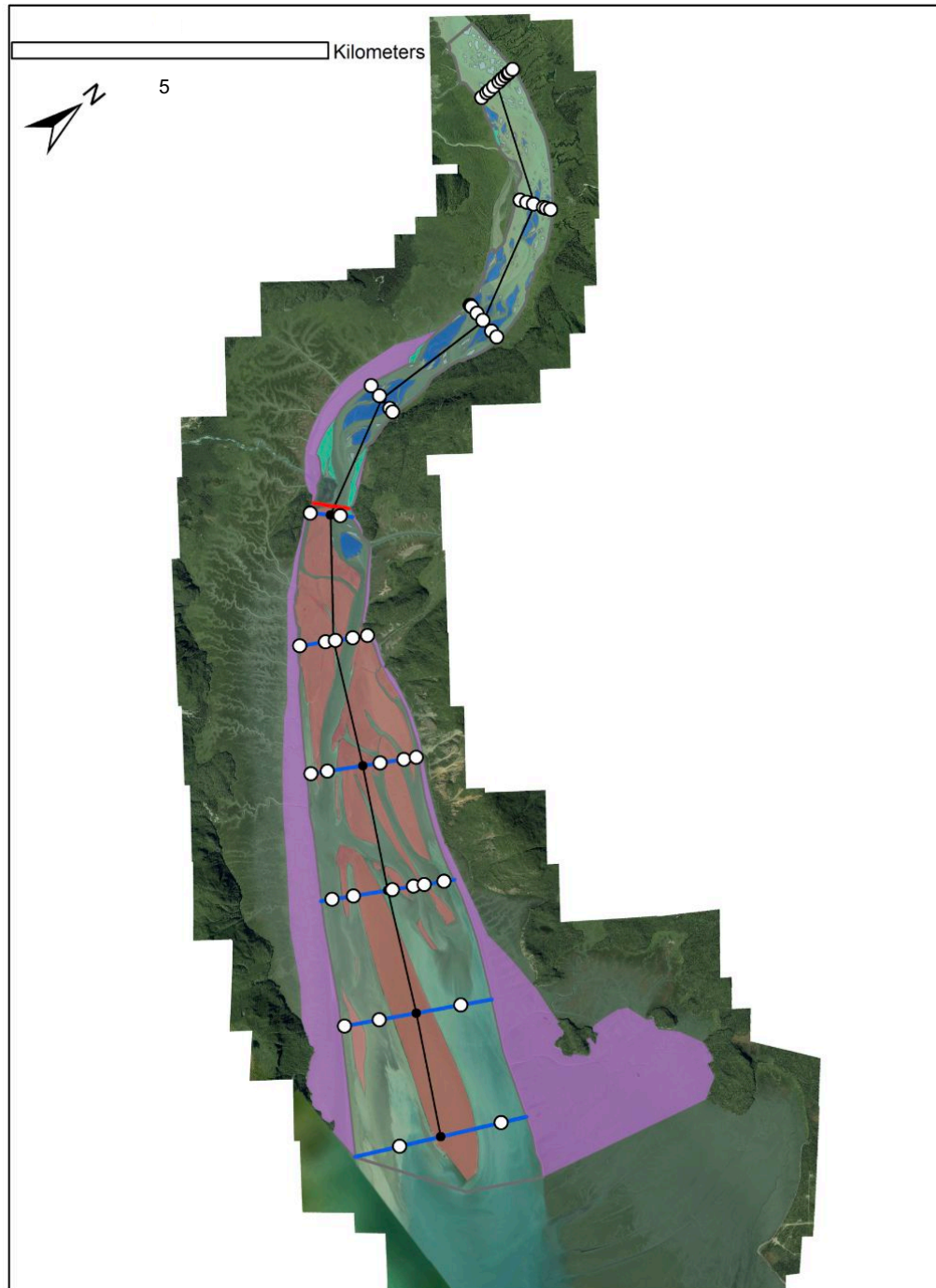


Figure 4.15: Detailed feature mapping of the Tuxedni River braid delta, with transparency. Key located in Figure 3.9. Channel counting transects are in blue, white circles are counted channel locations, channel-belt midline is black.

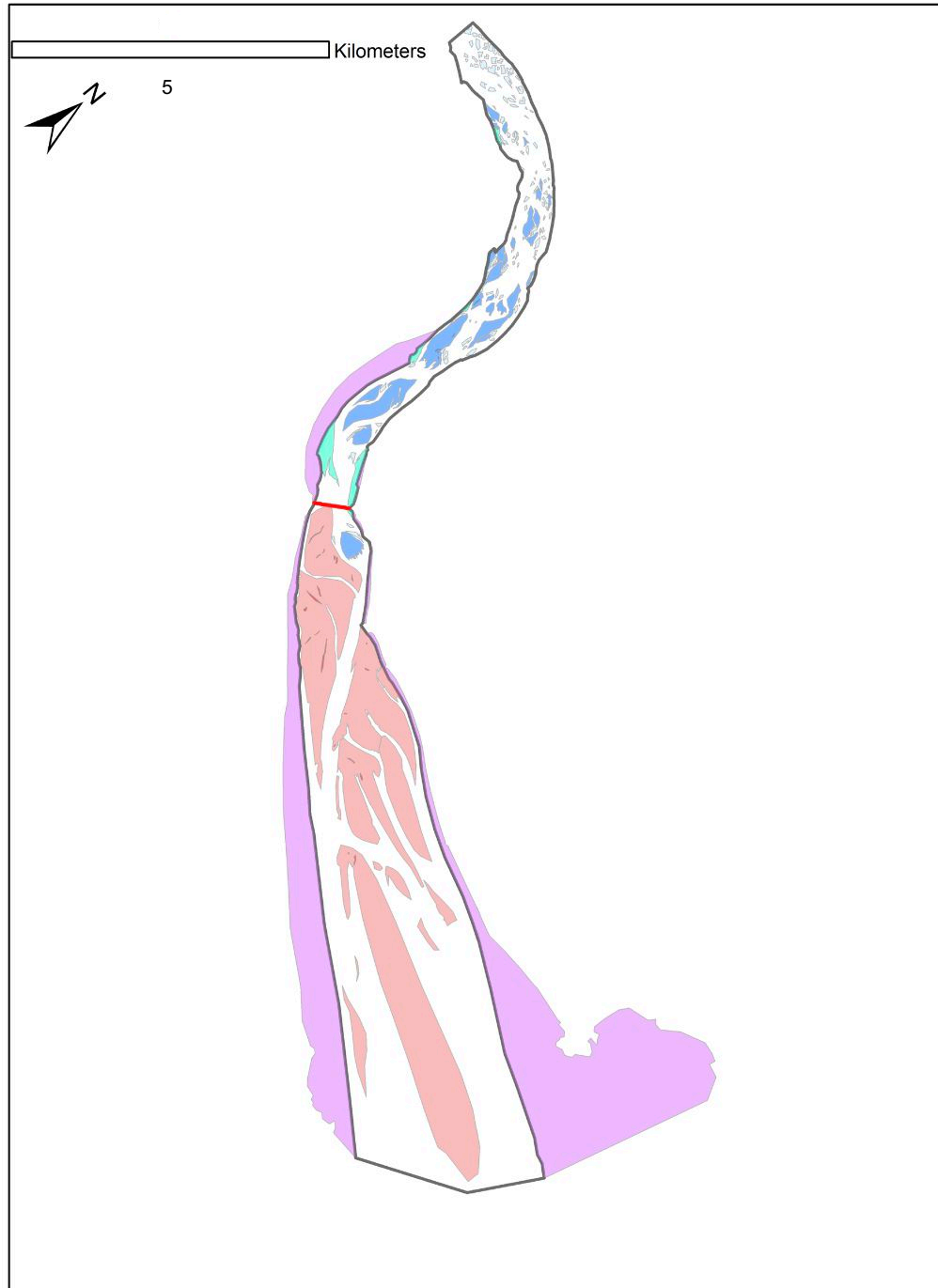


Figure 4.16: Enlarged map of the Tuxedni River braid delta. Key located in Figure 3.9.

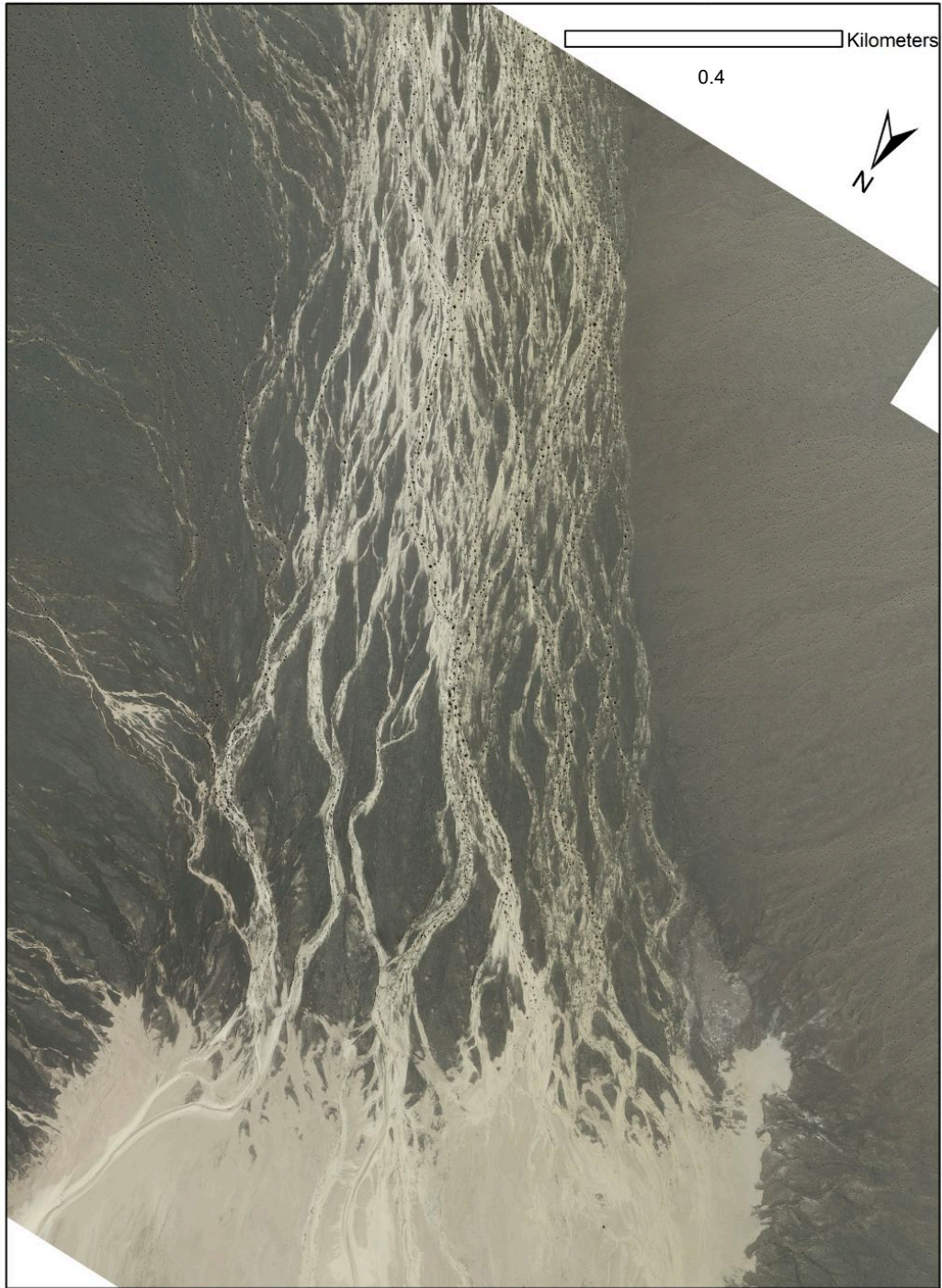


Figure 4.17: Image of the Panamint Valley braid delta, unannotated. Photographed May 2013 (36.29813801, -117.3745963).

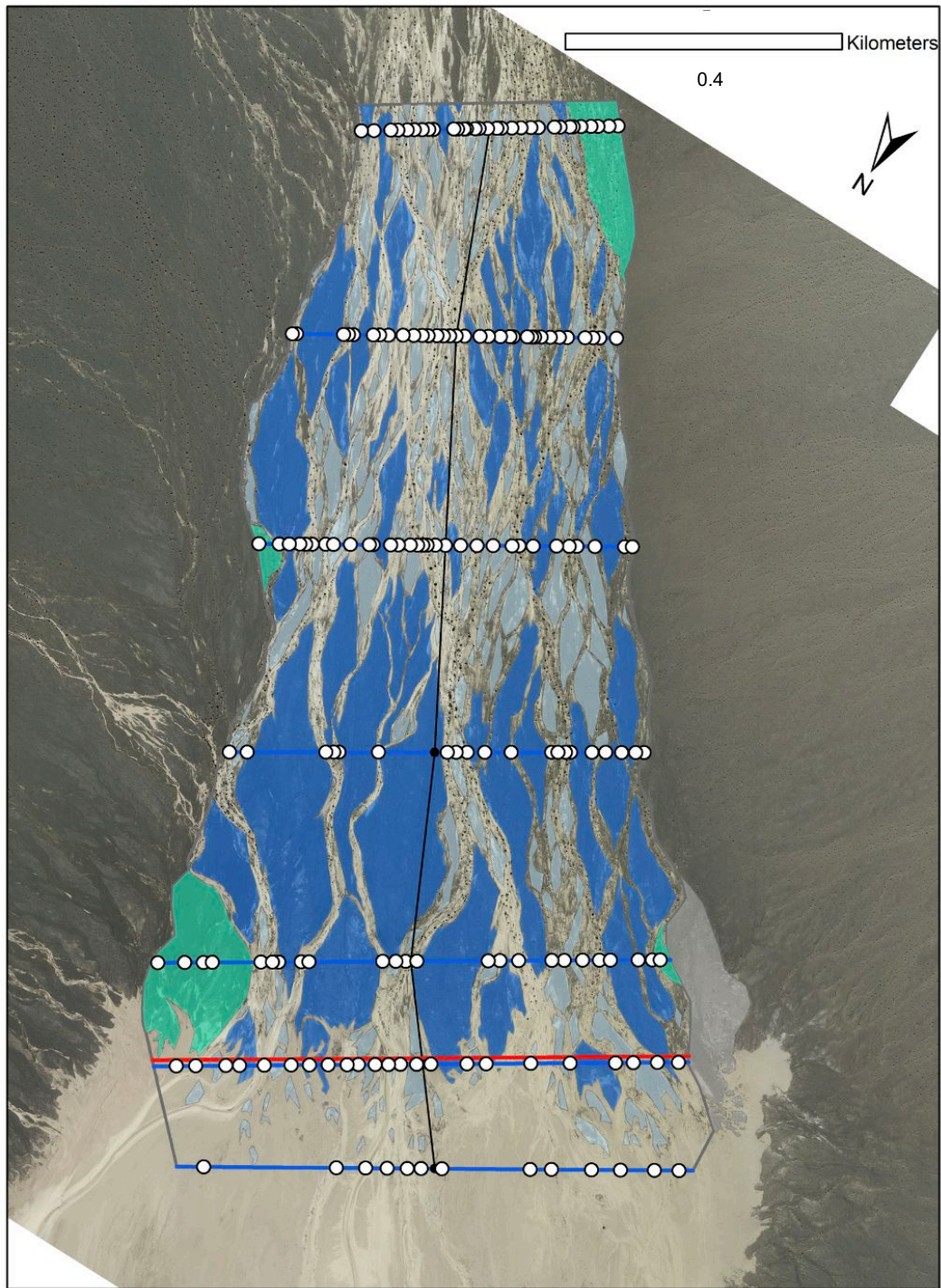


Figure 4.18: Detailed feature mapping of the Panamint Valley braid delta, with transparency. Key located in Figure 3.9. Channel counting transects are in blue, white circles are counted channel locations, channel-belt midline is black.

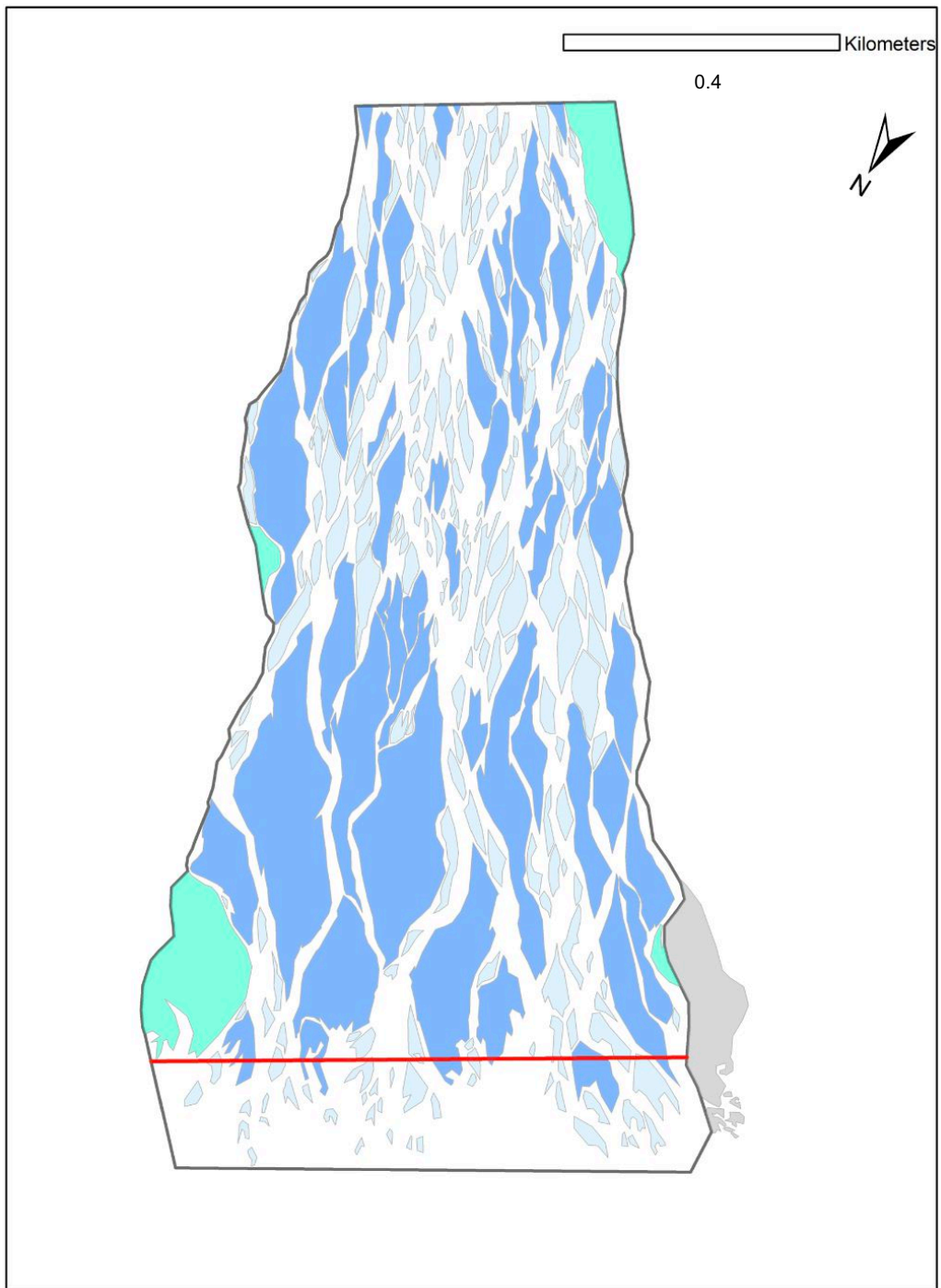


Figure 4.19: Enlarged map of the Panamint Valley braid delta. Key located in Figure 3.9.

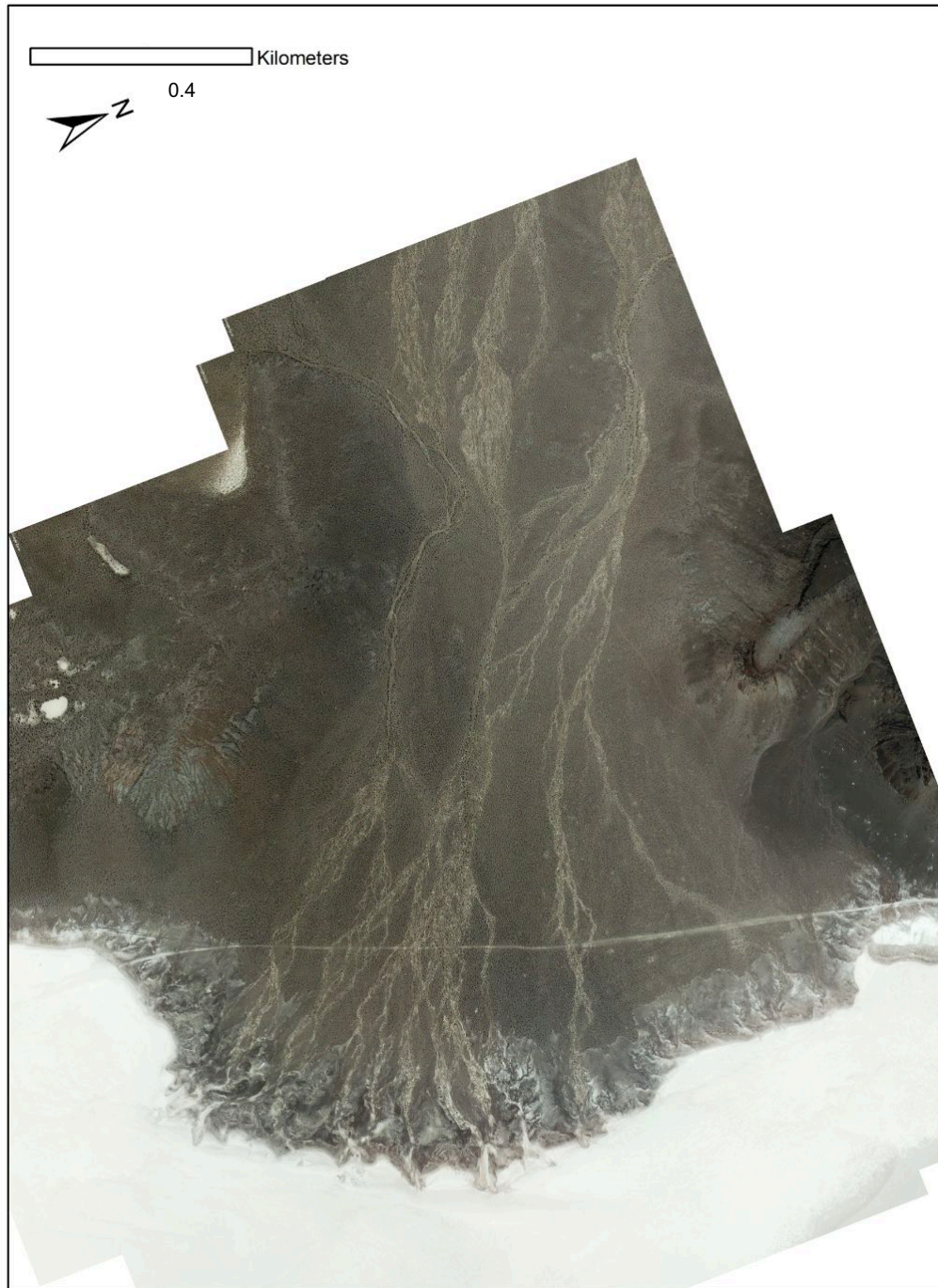


Figure 4.20: Image of the Tonopah braid delta, unannotated. Photographed August 9, 2013 (37.87879467, -117.1141347).

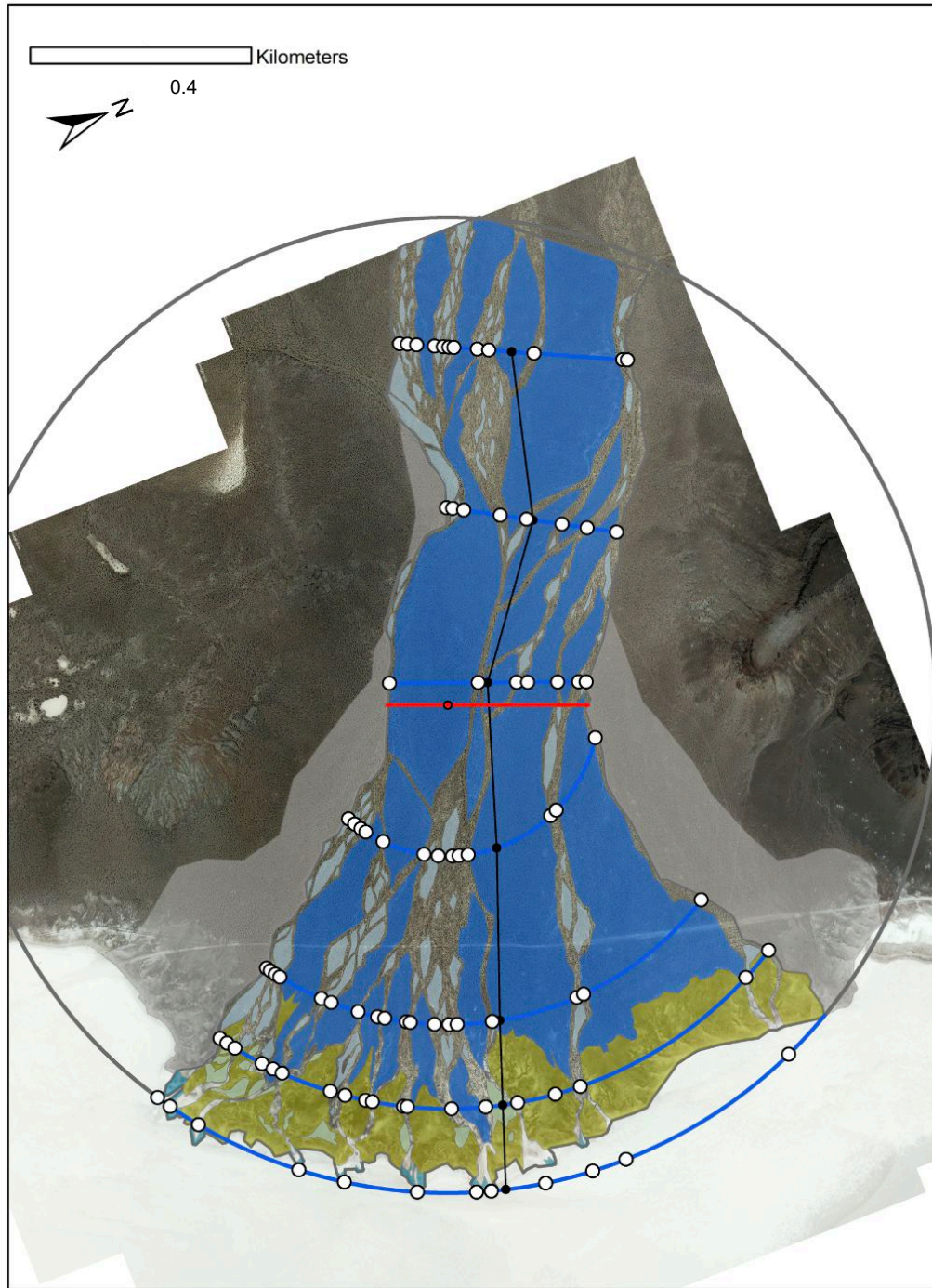


Figure 4.21: Detailed feature mapping of the Tonopah braid delta, with transparency. Key located in Figure 3.9. Channel counting transects are in blue, white circles are counted channel locations, channel-belt midline is black.

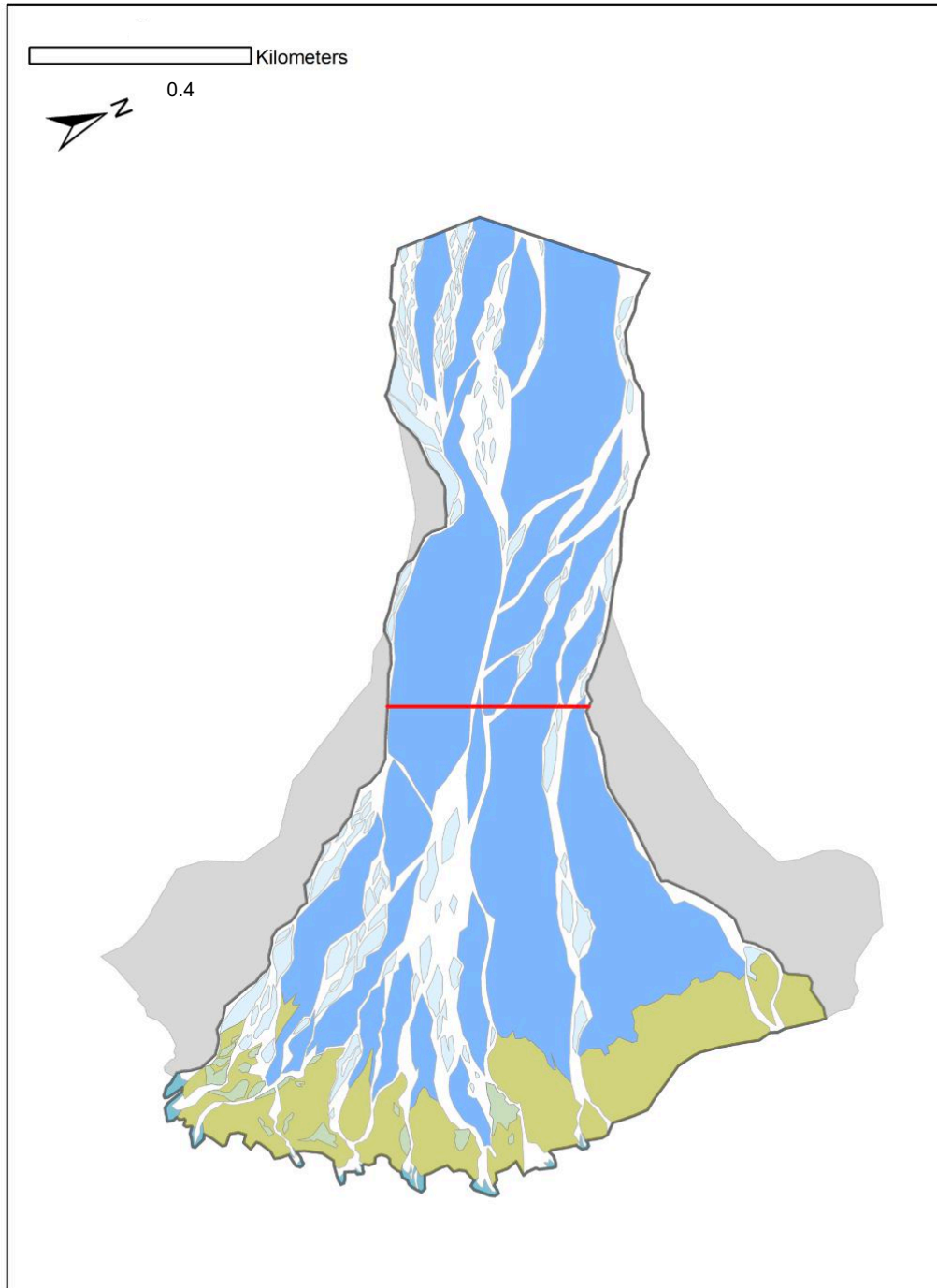


Figure 4.22: Enlarged map of the Tonopah braid delta. Key located in Figure 3.9.



Figure 4.23: Image of the Al Ghaydah braid delta, unannotated. Photographed January 15, 2015 (16.05242317, 52.17954879).

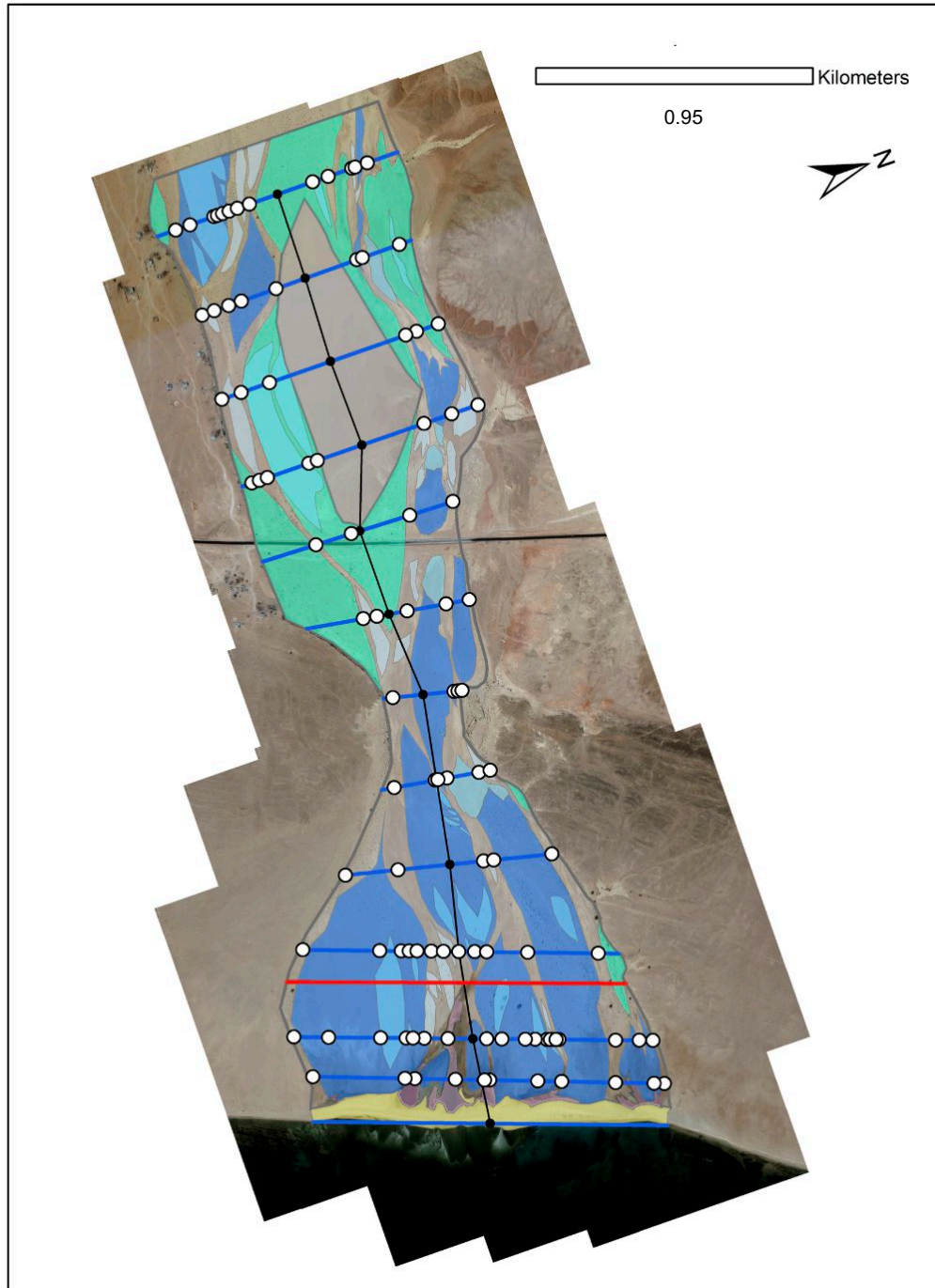


Figure 4.24: Detailed feature mapping of the Al Ghaydah braid delta, with transparency. Key located in Figure 3.9. Channel counting transects are in blue, white circles are counted channel locations, channel-belt midline is black.

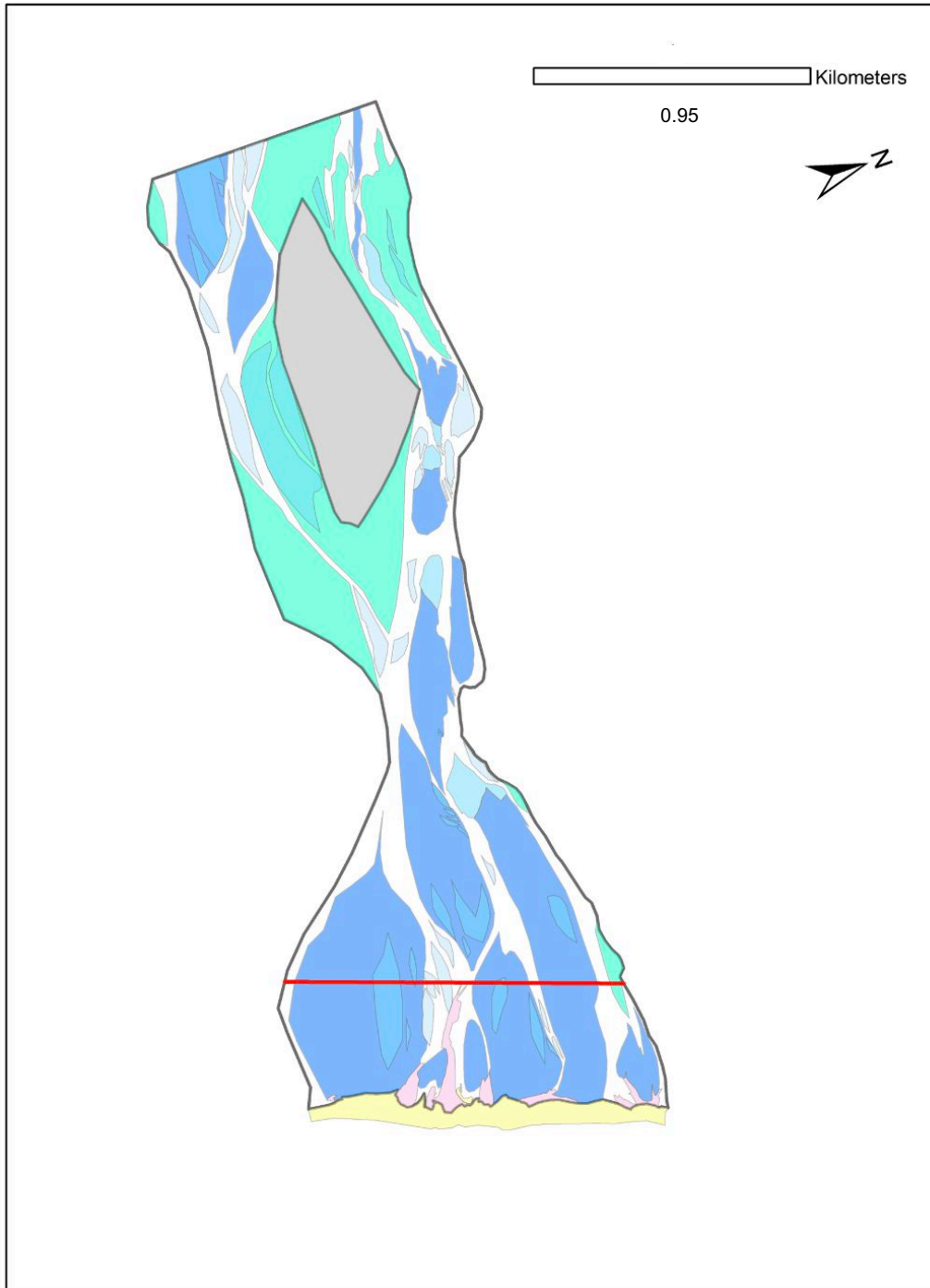


Figure 4.25: Enlarged map of the Al Ghaydah braid delta. Key located in Figure 3.9.

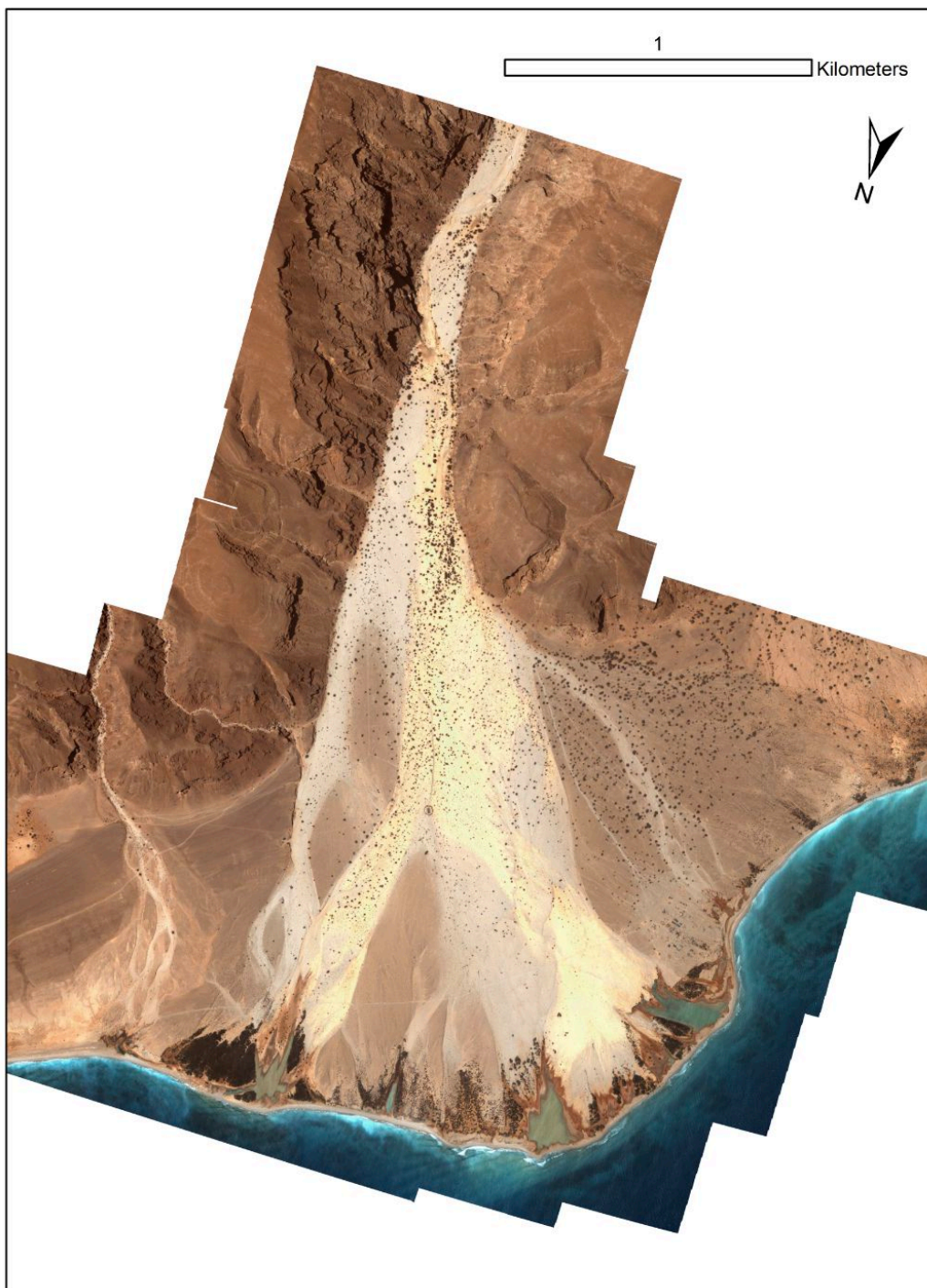


Figure 4.26: Image of the Bosaso braid delta, unannotated. Photographed July 15, 2004 (11.35614006, 49.45383612).

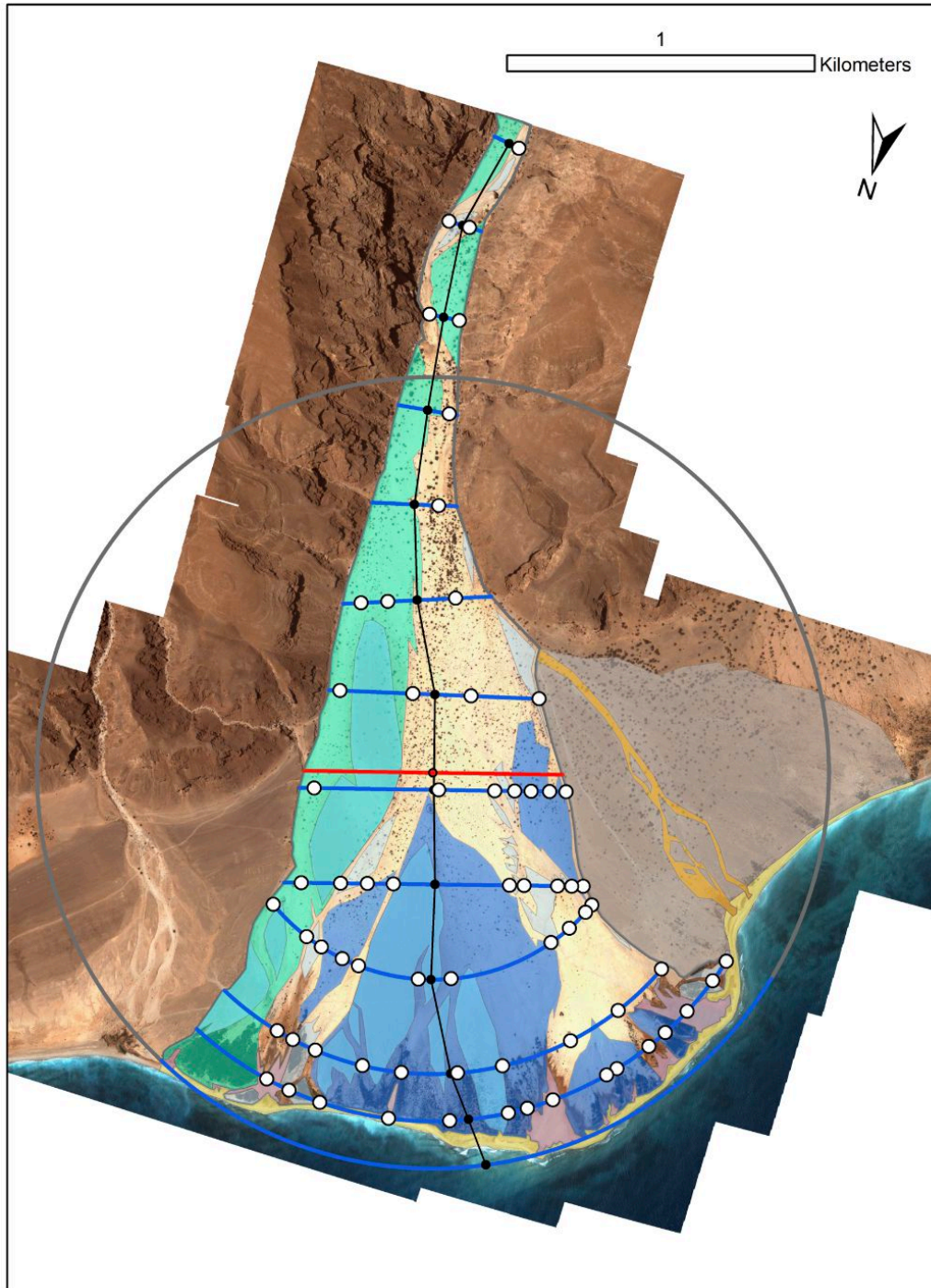


Figure 4.27: Detailed feature mapping of the Bosaso braid delta, with transparency. Key located in Figure 3.9. Channel counting transects are in blue, white circles are counted channel locations, channel-belt midline is black.

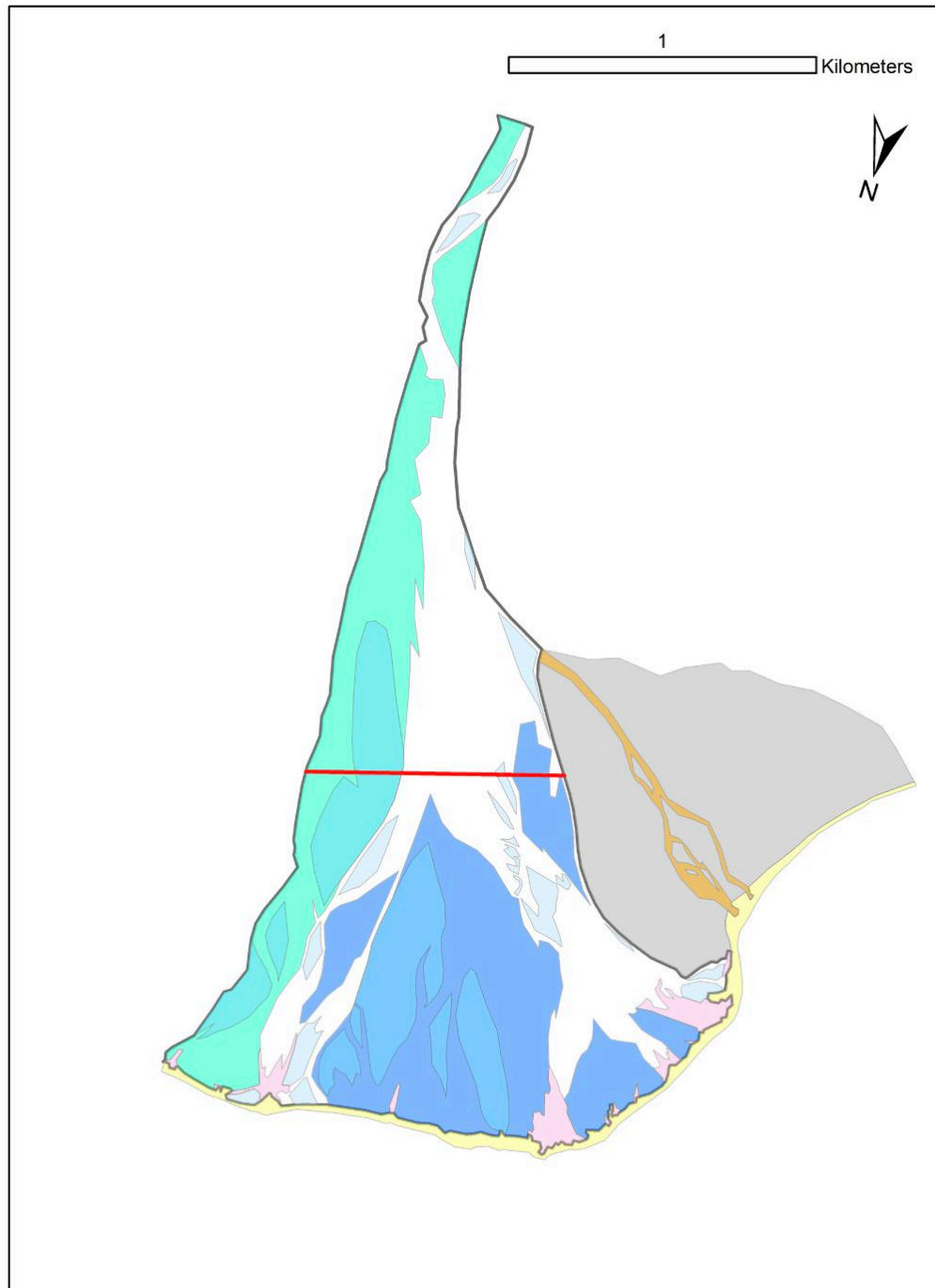


Figure 4.28: Enlarged map of the Bosaso braid delta. Key located in Figure 3.9.

Table 4.6: Channel-count braid index data.

Location	Distance (km)	Transect length (km)	Channel Count	Normalized Channel Count (#/km)
Al Ghaydah	0	1.222	0	0.00
	0.154	1.244	11	8.85
	0.3	1.255	19	15.14
	0.607	1.104	12	10.87
	0.911	0.747	5	6.70
	1.208	0.383	6	15.65
	1.508	0.276	4	14.50
	1.811	0.577	5	8.67
	2.117	0.704	4	5.68
	2.416	0.876	8	9.14
	2.726	0.814	6	7.37
	3.028	0.777	8	10.29
	3.335	0.879	13	14.79
Bosaso	0	2.239	0	0.00
	0.155	1.954	15	7.68
	0.311	1.576	10	6.34
	0.615	1.183	11	9.30
	0.917	0.961	9	9.36
	1.216	0.854	7	8.20
	1.519	0.677	4	5.91
	1.824	0.474	3	6.33
	2.127	0.270	1	3.70
	2.428	0.191	1	5.23
	2.727	0.124	2	16.11
	3.024	0.126	2	15.85
	3.322	0.105	1	9.56
Kerguelen Islands	0	0.650	7	10.76
	0.148	0.506	14	27.67
	0.3	0.459	9	19.62
	0.603	0.488	18	36.92
	0.905	0.454	9	19.81
	1.21	0.685	14	20.44
	1.51	0.548	14	25.56

Table 4.6: Channel-count braid index data. Continued.

Location	Distance (km)	Transect length (km)	Channel Count	Normalized Channel Count (#/km)
	1.804	0.420	8	19.05
	2.107	0.231	5	21.66
	2.403	0.246	3	12.18
	2.703	0.300	7	23.35
	3.007	0.389	7	18.00
Panamint Valley	0	0.753	13	17.27
	0.153	0.780	23	29.49
	0.305	0.757	24	31.69
	0.611	0.615	20	32.53
	0.913	0.549	31	56.42
	1.219	0.483	33	68.37
	1.525	0.381	31	81.27
Rangitata River	0	0.112	1	8.90
	0.024	0.069	1	14.59
	0.05	0.056	1	17.98
	0.076	0.045	1	22.24
	0.101	0.023	1	44.43
	0.299	0.217	7	32.22
	0.599	0.535	9	16.83
	0.906	0.635	10	15.75
	1.211	0.576	9	15.62
	1.517	0.598	9	15.05
	1.817	0.642	11	17.15
	2.119	0.837	14	16.74
	2.421	0.881	13	14.75
	2.728	0.758	12	15.82
	3.03	0.595	8	13.44
Rio Ocoa	0	1.544	1	0.65
	0.151	1.411	11	7.80
	0.302	1.310	11	8.40
	0.609	1.050	10	9.52
	0.913	0.778	8	10.28
	1.214	0.461	5	10.84

Table 4.6: Channel-count braid index data. Continued.

Location	Distance (km)	Transect length (km)	Channel Count	Normalized Channel Count (#/km)
	1.516	0.391	9	23.03
	1.818	0.331	6	18.15
	2.122	0.192	2	10.41
	2.422	0.217	4	18.46
	2.726	0.482	8	16.61
	3.028	0.511	9	17.61
	3.325	0.385	6	15.58
Tonopah	0	1.330	12	9.02
	0.151	1.101	19	17.26
	0.303	0.876	18	20.54
	0.61	0.575	13	22.62
	0.907	0.354	7	19.78
	1.208	0.315	8	25.38
	1.511	0.420	12	28.57
Turkwel River	0	1.722	12	6.97
	0.153	1.219	31	25.42
	0.31	0.807	13	16.12
	0.613	0.330	13	39.38
	0.911	0.267	5	18.72
	1.21	0.282	7	24.81
	1.516	0.361	14	38.79
	1.819	0.285	8	28.04
	2.113	0.303	4	13.21
Tuxedni River	0	2.771	2	0.72
	1.985	2.416	3	1.24
	3.966	2.130	6	2.82
	5.969	1.801	5	2.78
	7.989	1.095	5	4.57
	9.967	0.696	2	2.88
	11.962	0.621	4	6.44
	13.967	0.730	6	8.22
	15.963	0.586	6	10.24
	17.952	0.702	10	14.23

VITA

Jason G. Muhlbauer was born May 28th, 1990 in Sellersville, Pennsylvania. He spent his youth exploring the fields and forests near Hilltown, PA in the heart of a failed Triassic rift. In summer, he clambered over boulders of granular Pocono Formation sandstone or dug tiny rivers through sand-castle towns to watch how they would meander. After attending Pennridge High School, he rediscovered an interest in geology after a chance enrollment in Evolution of the Earth at Bucknell University, between smoothed ridges of the Tuscarora and Bald Eagle Formations. On completion of his Bachelor of Science degree, he joined Chris Fedo at the University of Tennessee to test methods of detrital-zircon analysis in the Wood Canyon Formation and Stirling Quartzite of the Basin and Range Province. In the shadow of the Southern Appalachians, he completed his Master of Science degree and accepted an offer to continue working with Chris on projects that developed into this dissertation. He graduated amid the uncertainty of the COVID-19 pandemic and seeks a career in academia that will allow him to continue research and teaching in the geosciences.