THE DETAILED RELATIONSHIP BETWEEN PALEOCURRENTS AND LATERAL VARIATIONS OF DEPOSITIONAL FACIES OF A WAVE-INFLUENCED DELTA WITHIN THE GALLUP SANDSTONE NEAR SHIPROCK, NEW MEXICO

by

Ryan Krueger

Research Supervisor: Dr. Janok P. Bhattacharya

Proposal submitted to the Faculty of the Earth and Atmospheric Sciences Department, University of Houston, in partial fulfillment of the requirements for the degree of:

Masters of Science in Geology

Date: November 24, 2008

Abstract

The Gallup Sandstone has been interpreted as amalgamated shoreface, strand plain, and delta deposits within the Cretaceous Western Interior Seaway of the late Turonian. Reassessment of a Gallup Sandstone exposure near Shiprock, New Mexico shows elements of river- and wave-influenced deposition varying laterally. This calls for a change in the interpretation from marine-dominated processes to mixed marine- and river-depositional processes. An asymmetric delta forms under the influence of oblique wave action to the river input, resulting in muddy river sediments being deposited downdrift, while updrift sediments form a homogenous sandy shoreface lacking river influence. It is important to make the distinction between river- or wave-dominated deltas, shorefaces, and mixed-influence asymmetric deltas. If there is a lack of lateral control or over simplified modeling, an asymmetric delta could either be interpreted as a shoreface or river-dominated delta, resulting in unexpected production behavior in hydrocarbon reservoirs.

I propose a field study of the Gallup Sandstone outcrop near Shiprock, New Mexico to contribute to the development of detailed facies architecture modeling of asymmetric deltas for use in subsurface reservoir characterization. I will collect paleocurrent measurements throughout the study area to determine the association of longshore currents to the lateral variation in depositional facies. I will also collect hand samples from the river- and wave-dominated deposits for analysis using a petrographic microscope, collecting data on grain composition, grain size, and textural maturity. Comparing samples from updrift and downdrift will test the hypothesis that sediments downdrift are younger and less mature compared to the sediments updrift.

Introduction

Thirty percent of the world's hydrocarbon reserves can be found in delta reservoirs (Tyler and Finley, 1991). It is imperative to have specific and comprehensive facies models to help predict fluid flow conduits and barriers to aid production (Willis and White, 2000). Currently, deltas are separated into tide-, wave-, and river-dominated end member facies models (figure 1; Galloway, 1975). Many delta systems can not be confined to a single end member but are a product of combined influence. New assessment of these older facies models is needed because they assume deposition in systems with symmetrical longshore sediment transport. Deltas that form under the influence of wave fronts oblique to shoreline resulting in a dominant direction of longshore sediment transport can form asymmetric deltas. These types of deltas display wave-influence updrift and river-influence downdrift rather than a purely intermediate product of the two processes (figure 2). River-dominated deltas exhibit a muddier facies assemblage than wave-dominated deltas (Tye et al., 1999). This model predicts that areas downdrift of river input in a mixed wave- and river-dominated delta would have more mud than updrift areas (Bhattacharya and Giosan, 2003). In wave-dominated deltas, the lithofacies typically consist mostly of sand, with mud prevalent at the base directly above the sandy top of the previously deposited package (Larue and Legarre, 2004).

To fully understand the lateral variations in heterogeneity, scale of heterogeneity, and the effect of the heterogeneity on fluid flow in these asymmetric deltas, highly detailed outcrop studies are necessary (Willis and White, 2000). There is a lack of documented examples of asymmetric deltas in the rock record (Bhattacharya and Giosan, 2003).

The Gallup Sandstone has previously been interpreted as a strand plain (McCubbin, 1981), regressive beach and offshore bar deposits (Campbell, 1979), and prograding coastal barrier and delta front (Molenaar, 1973). Recent field work during the summer of 2008, suggests that portions of the Gallup are an asymmetric mixed-influenced delta. Gallup outcrops near Shiprock, New Mexico display a sharp lateral contrast between river-dominated delta front deposits to the west and wave-dominated shoreface deposits to the east. Separating the two different depositional facies in outcrop is a distributary channel. Detailed paleocurrent analysis will be needed to determine the direction of longshore drift to conclude if the asymmetric delta interpretation is accurate at the study location. The Gallup Sandstone is ideal for collecting paleocurrents and measuring section because it has continuous exposure along depositional dip, and more importantly, along depositional strike.

Asymmetric Delta Model

An asymmetric delta is a wave-dominated delta that forms under the influence of a dominant direction of longshore sediment transport and year-round river discharge (Bhattacharya and Giosan, 2003). The asymmetric delta model predicts a laterally abrupt change in depositional facies. Heterogeneous river-dominated delta front and prodelta deposits are found downdrift of river input and homogenous wave-dominated shoreface deposits lie updrift (figure 2). Studies of modern systems off the coast of Brazil show that the sediments downdrift are less mature relative to updrift sediments because they have been in transport a shorter amount of time removed from their source (Dominguez, 1996). A dominant direction of longshore sediment transport deflects river sediment downdrift of the river mouth. The downdrift area may form as a sequence of back barrier muds and sandy barrier bar deposits in the river dominated portion of the delta. The river delivers sandy sediments to the delta during storm events that are reworked into shore parallel barrier bars. Behind the barrier bars, mud is delivered by the river during times of normal discharge. The river plume creates a hydraulic groyne that prevents reworked shoreface sand updrift from being transported past the river mouth. The source of the updrift sediments is previously deposited shoreface or delta fronts that have been disaggregated and had their sediments transported downdrift by longshore currents. The updrift deposits are hypothesized to form superior reservoirs compared to downdrift deposits due to the higher number of mudstones downdrift which are potential fluid flow barriers (figure 3). Without lateral control, potential mixed-influenced deltaic reservoirs could be misclassified, resulting in poor estimation of reservoir architecture (Bhattacharya and Giosan, 2003).

Aside from the higher proportion of interbedding in the downdrift compared to updrift, sedimentary structures can help determine lateral variation in depositional facies (Bhattacharya and Giosan, 2003). The main difference is due to the rapid deposition of river sediments downdrift versus updrift. Features typical of high sedimentation rates such as flame structures, ball and pillow structures, growth faults, and climbing ripples would be expected downdrift. Ball and pillow and flame structures are the result of sand being rapidly deposited on less dense, high water content, muddy prodelta sediment causing it to squeeze upward. Rapid deposition of river derived sands on prodelta mud can lead to slumping represented by growth faults. A higher relative abundance of allochthonous plant and coal fragments would also suggest the influence of river deposition, which would be expected downdrift (Bhattacharya and Walker, 1991; Tye et al., 1999; Bhattacharya and Giosan, 2003; Lavoie, 2004; Bhattacharya, 2006; Clifton, 2006). A lateral change in ichnology would be predicted updrift versus downdrift due to river derived stresses. Trace size, abundance, and distribution would be expected to be lower in the downdrift portion of the delta (Gingras et al., 1998; MacEachern et al., 2005). Looking for lateral variations of these criteria within a single parasequence would be an excellent way to test the asymmetric delta model in outcrop.

Gallup Study Area

The Gallup Sandstone crops out on the western and southern edges of the San Juan Basin, primarily in New Mexico (figure 4). The Gallup shoreline prograded northeast into the Western Interior Seaway and trends northwest-southeast, extending 200 miles parallel to the shoreline and 100 miles perpendicular to the shoreline (Campbell,1979). Fossil dating reveals that the Gallup was deposited in the late Cretaceous. The oldest fossil found is an *Inoceramus dimidius* of late Turonian age and the youngest fossil found is *Inoceramus erectus* of early Coniacian age, suggesting that deposition spanned approximately 1.2 million years (Molenaar and Nummedal, 1995).

The Gallup Sandstone was named by Sears in 1925 after describing outcrops near the town of Gallup in northwestern New Mexico (Tillman, 1985). The Gallup has produced 132 million barrels of oil with 20 more million barrels of reserve as of 1979, making it an important producer in the San Juan basin (Campbell, 1979). Recent interest in the Gallup is a result of its easy access, lack of structural deformation, and excellent outcrop exposure perpendicular and parallel to the shoreface.

The Gallup Sandstone shorefaces are regressive, with each younger shoreface package being deposited seaward of the older one. The Gallup has 6 distinct tongues, consisting of parasequences to parasequence sets, within the Mancos Shale as defined by Molenaar (1973). These tongues are designated A through F, A being the youngest and F being the oldest (figure 5). The sandstone tongues range from 15-30 m in thickness. This labeling scheme is used by subsequent workers (Campbell, 1979; Tillman, 1985; Nummedal and Riley, 1991; Molenaar and Nummedal, 1995). Although the Gallup is referred to as a regressive deposit, there were also periods of transgression. The F through D and A tongues are relatively aggradational compared to tongues C and B, which are more progradational. This suggests that there was more accommodation resulting from a relative sea-level rise during the deposition of tongues F, E, D, and A. Tongues C and B were deposited in times of less accommodation during a relative sea-level fall or still stand. Each of these tongues show evidence of small scale relative sea-level changes in multiple parasequences (Molenaar and Nummedal, 1995). There is a large unconformity between tongues D and C (Nummedal and Riley, 1991). This unconformity correlates with the Upper Zuni A2/A3 super sequence boundary and is the result of a eustatic fall of sea-level (Haq et al., 1988). There is another major unconformity at the top of the Gallup which is the result of tectonic uplift. It is a regional erosional surface that is expressed by fluvial by pass and erosion of the Gallup Sandstones by the younger Torrivio Sandstone (Nummedal and Riley, 1991). The Tocito Sandstone overlies the Torrivio, with a sharp erosional base associated with coarse sand and gravel. These are surfaces associated with a regional transgression during the Middle to Late Coniacian (Nummedal and Riley, 1991).

Outcrop data of previous Gallup work describes strandplain shoreface association with distinctive foreshore, upper shoreface, lower shoreface, and offshore transition to offshore facies (figure 6; Molenaar, 1973; Campbell, 1979). The offshore section consists of mottled mudstone with very fine-grained wave-rippled sandstone interbeds (Campbell, 1979). Up section the mudstone contains more silt and there are interbeds of hummocky cross-stratified sandstones indicating the transition zone from offshore facies to lower shoreface. The lower shoreface consists of very fine to lower fine sandstone that alternates between highly bioturbated beds and hummocky cross-stratification that turns to parallel bedding up section. Some convolute bedding is present due to rapid progradation (Campbell, 1979; Nummedal and Molenaar, 1995). Wave ripples are found in the lower shoreface with crest orientation to the northwest-southeast (McCubbin, 1981). The upper shoreface is coarser grained than the lower shoreface. The sedimentary structure predominantly found in the uppershore face is some northwest dipping trough cross-stratified beds, but a greater abundance of southeast dipping. These trough cross-stratified beds are interpreted to dip in the direction of longshore current flow (Molenaar,1973; McCubbin, 1981). The foreshore is made up of horizontal to gently seaward dipping bedded lower fine sandstone (Molenaar, 1973; Campbell, 1979).

The proposed research area is an exposure of the Gallup Sandstones Tongues A and B, as defined by Molenaar (1973), located 35 km southwest of Shiprock, New Mexico (figure 7). This area is ideal for application of the asymmetric delta model due to continuous outcrop showing an abrupt lateral change between river-dominated delta front deposits and wave-dominated shoreface deposits (figure 8).

The west side of the study area shows characteristics of rapid, river dominated deposition. A measured section from “Parasequence Point” shows a high amount of heterogeneity, a high abundance of allochthonous plant and coal fragments, climbing ripples, as well as a coarse grained channel (figure 9). Mudstones on the west side of the study area commonly have thin laminations of graded siltstone and lack bioturbation (figure 10). Other evidence of rapid deposition are soft-sediment deformation features such as growth faults, ball and pillow structures, and flame structures (figure 11). Outcrop-scale loading features are found on the far west side of the study area (figure 12).

There is an abrupt transition to homogenous sandy shoreface deposits to the east side of the study area (figure 13). The sandstones are pervasively bioturbated and lack soft sediment deformation features (figure 14). Wave ripples are found throughout the east side of the study area, but are absent on the west side.

There is an incised, coarse-grained unit, with large-scale lateral accretion bedding which is interpreted as a distributary channel (figure 15). The unit displays a sharp increase in grain size relative to the fine-grained deposits below. This feature separates the river-dominated delta deposits to the west from the wave-dominated shoreface deposits to the east, as predicted by the asymmetric delta model. The interpreted distributary channel can be seen exposed at the tops of cliff faces in the middle of the study area.

The observation of rapidly deposited heterolithic facies to the west of the channel and homogenous sandy deposits to the east of the channel suggests long shore sediment transport in the study area was to the northwest according to the asymmetric delta model (figure 16; Bhattacharya and Giosan, 2003).

Proposed Time-line

Preliminary field work, which consisted of scouting, paleocurrent measurements, and hand sample collection, was conducted from June to August, 2008. From August to the present I have been working on my proposal for submission in early November. After acceptance of my proposal I will cut and analyze thin sections and analyze paleocurrent measurements from November, 2008 to May, 2009. During the summer of 2009 I will do any final field work as well as continue to do thin section work and analyze paleocurrent data. During the summer of 2009 I will also compile my finds and begin to write my thesis. I plan to present my thesis for graduation by December, 2009.

Proposed Research

I will be conducting my research in conjunction with another graduate student, Michael LoParco. My focus will be on petrographic work and spatial paleocurrentreconstruction while his will be on measuring vertical sections to work out the stratigraphy and facies architecture of the area.

Paleocurrent measurements were taken over the entire extent of the study area on the mesa tops, which exposes the Gallup upper shoreface. I collected 815 measurements of trough cross-bedding dip directions and 31 measurements of wave ripple crest orientation. Bed thickness was taken where possible to calculate water depth (LeClair and Bridge, 2001). I took GPS measurements at each of the paleocurrent measurements in order to contour spatial trends in paleocurrent direction. The orientation of the wave ripple crests is to the northwest-southeast (figure 17), which is parallel to the Gallup shoreline and corresponds to previous work (McCubbin, 1982). The trough cross-bedding measurements were mostly taken by measuring the opening axis of ribs on floor exposures, although some vertical 3-D exposure measurements were taken as well (DeCelles et al., 1983). These measurements indicate longshore current direction which indicates direction of longshore sediment transport. The foreset dip distribution is extremely bipolar, which maybe a result of tidal influence (Tankard and Barwis, 1982). Orientation of trough cross-bedding is parallel to shoreline, to the northwest and southeast, but with a greater number of measurements to the southeast (figure 18). This is not what would be expected according to the asymmetric delta model. This requires further investigation, including mapping paleocurrent measurements and creating spatial trend analysis relating to the distribution of the depositional facies.

While collecting paleocurrent measurements, I also took GPS locations at channel exposures on the mesa tops to map it throughout the study area. I took 46 paleocurrent measurements within the channel, measuring the axis direction of rib opening on trough cross-beds and the bedding plane intersection with the surface of lateral accretion bars (figure 19). These measurements indicated flow direction perpendicular to shore to the northeast, which is the direction of Gallup progradation (Campbell, 1979; McCubbin, 1982; Molenaar, 1973). In the center of the study area there is a particularly well exposed channel outcrop that I did 3 measured sections on. I measured grain size, sedimentary structures, and grain size from the top of the channel down into the shoreface.

I collected 40 hand samples of sandstones from the uppershore and proximal delta front across the study area to be made into thin sections for petrographic work. I will conduct 100-200 count point counts on the thin sections chosen for analysis to see if there are any differences in the maturity of the samples from the river-dominated and wave-dominated portions of the study area. Dominguez (1996) documented lateral changes in mean grain size of quartz sand in modern asymmetric wave-dominated delta and strand plain deposits off of the east coast of Brazil. Coarser-grained sediments were found downdrift in the river-dominated deposits and finer-grained sediments were found updrift in the wave dominated-deposits. I plan to collect data on grain composition, grain size, amounts and types of clay matrix, roundness and sorting to see if there are variations between updrift and downdrift areas. Due to constant abrasion by wave reworking, updrift sediments are expected to be more mature. Updrift sediments are expected to exhibit smaller grain size, contain less clay matrix, be more rounded, and be better sorted compared to the younger river derived sediments downdrift.

References

Bhattacharya, J.P., 2006, Deltas, *in* Posamentier, H.W. and Walker, R.G., eds., Facies Models Revisited: SEPM, Special Publication 84, p. 241-296.

Bhattacharya, J.P. and Giosan, L., 2003, Wave-influenced deltas: geomorphological implications for facies reconstruction: Sedimentology, v. 50, p. 187-210.

Bhattacharya, J.P. and Walker, R.G., 1991, River- and wave-dominated depositional systems of the Upper Cretaceous Dunvegan Formation, northwestern Alberta: Bulletin of Canadian Petroleum Geology, v. 39, p. 165-191.

Bridge, J.S. and Tye, R.S., 2000, Interpreting the dimensions of ancient fluvial channel bars, channels and channel belts from wireline-logs and cores: AAPG Bulletin 84, p. 1205-1228.

Campbell, C.V., 1979, Model for beach shoreline in Gallup Sandstone (Upper Cretaceous) of northwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 164, p. 1-32.

Clifton, H.E., 2006, A reexamination of facies models for clastic shorelines, *in* Posamentier, H.W. and Walker, R.G., eds., Facies Models Revisited: SEPM, Special Publication 84, p. 241-296.

DeCelles, P.G., Langford, R.P., Schwartz, R.K., 1982, Two methods of paleocurrent determination from trough cross-stratification: Journal of Sedimentary Petrology, v. 53, p. 629-642.

Dominguez, J.M.L., 1996, The São Francisco strandplain: a paradigm for wave-dominated deltas? *in* de Batist, M., and Jacobs, P., eds., Geology of Siliciclastic Shelf Seas: Geological Society of London, Special Publication 117, p. 217-231.

Galloway, W.E., 1975, Process framework for describing the morphologic and stratigraphic evolution of deltaic depositional systems, *in* Broussard, M.L., ed., Deltas, Models for Exploration: Houston, Texas, Houston Geological Society, p. 87–98.

Gingras, M.K., MacEachern, J.A., and Pemberton, S.G., 1998, A comparative analysis of the ichnology of wave- and river-dominated allomembers of the Upper Cretaceous Dunvegan Formation: Bulletin of Canadian Petroleum Geology, v. 46, p. 51-73.

Haq, B.U., Hardenbol, J., and Vail, P.R., 1988, Mesozoic and Cenozoic chronostratigraphy and cycles in sea level change, *in* Wilgus, C.K., Hastings, B.S., Kendall, C., Posamentier, H.W., Ross, C.A., and Van Wagoner, J.C., eds., Sea-Level Changes: An Integrated Approach: Soc. Econ. Paleon. Mineral, Special Publication 42, p. 71-108.

Larue, D.K. and Legarre, H., 2004, Flow units, connectivity, and reservoir characterization in a wave-dominated deltaic reservoir: Meren reservoir, Nigeria: AAPG Bulletin, v. 88, p. 303-324.

Lavoie, D., 2004, The Lower Devonian Compton Formation in southern Quebec: from delta front to pro-delta sedimentation: Canadian Journal of Earth Science, v. 41, p. 571-585.

LeClair, S.F. and Bridge, J.S., 2001, Quantitative interpretation of sedimentary structures formed by river dunes: Journal of Sedimentary Research, v. 71, p. 713-716.

MacEachern, J., Bhattacharya, J.P., Howell, C.D., and Bann, K., 2005, Ichnology of deltas, *in* Giosan, L., and Bhattacharya, J.P., eds., River Deltas—Concepts, Models, and Examples: SEPM, Special Publication 83, p. 49–85.

McCubbin, D.G., 1969, Cretaceous strike-valley sandstone reservoirs, northwestern New Mexico: AAPG Bulletin, v. 53, p. 2114-2140.

McCubbin, D.G., 1982, Barrier-island and strand-plain facies, *in* Scholle, P.A. and Spearing, eds., Sandstone Depositional Environments: AAPG Memoir 31, p. 247–280.

Molenaar, C. M., 1973, Sedimentary facies and correlation of the Gallup Sandstone and associated formations, northwestern New Mexico; in J. E. Fassett (ed.); Cretaceous and Tertiary Rocks of the Southern Colorado Plateau, Four Corners Geol. Soc. Mem., p. 85-110.

Molenaar, C. M., 1983, Principal reference section and correlation of Gallup Sandstone, northwestern New Mexico, in S.C. Hook (compiler), Contributions to Mid-Cretaceous Paleontology and Stratigraphy of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circ. 185, p. 29-40.

Nummedal, D. and Molenaar, C.M., 1995, Sequence stratigraphy of ramp-setting strand plain successions: The Gallup Sandstone, New Mexico, *in* Van Wagoner, J.C. and Bertram, G.T., eds., Sequence Stratigraphy of Foreland Basin Deposits: AAPG Special Volumes 64, p. 277-310.

Nummedal, D. and Riley, G.W., 1991, Origin of Late Turonian and Coniacian unconformities in the San Juan Basin: AAPG Special Volumes: Sequence Stratigraphy Applications to Shelf Sandstones Reservoirs, v. 25, p. 1-12.

Tankard, A.J. and Barwis, J.H., 1982, Wave-dominated deltaic sedimentation in the

Devonian Bokkeveld Basin of South Africa: Journal of Sedimentary Petrology, v. 52, p. 959-974.

Tillman, R. W., 1985, The Tocito and Gallup sandstones, New Mexico, a comparison, *in* Tillman, R. W., Swift, D. J.P., and Walker, R. G., eds., Shelf Sands and Sandstone Reservoirs: Soc. Econ. Paleontologists Mineralogists Short Course No. 13, p. 403-463.

Tye, R.S., Bhattacharya, J.P., Lorsong, J.A., Sindelar, S.T., Knock, D.G., Puls, D.D., and Levinson, R.A., 1999, Geology and stratigraphy of fluvio-deltaic deposits in the Ivishak Formation: Applications for development of Prudhoe Bay Field, Alaska: AAPG Bulletin, v. 83, p. 1588-1623.

Tyler, N., and Finley, R.J., 1991, Architectural controls on the recovery of hydrocarbons from sandstone reservoirs, *in* Miall, A.D., and Tyler, N., eds., The Three-dimensional Facies Architecture of Terrigenous Clastic Sediments, and Its Implications for Hydrocarbon Discovery and Recovery: SEPM, Concepts and Models in Sedimentology and Paleontology, no. 3, p. 1–5.

Van Wagoner, J.C., Jones, C.R., Taylor, D.R., Nummedal, D., Jennette, D.C., and Riley, G.W., 1991, Road Log, Day 6: San Juan Basin Segment, New Mexico: Sequence Stratigraphy Applications to Shalf Sandstone Reservoirs: AAPG Special Volume 25, p. 1-23.

Willis, B.J. and White, C.D., 2002, Research Articles: Quantitative outcrop data for flow Simulation: Journal of Sedimentary Research, v. 70, p. 788-802.

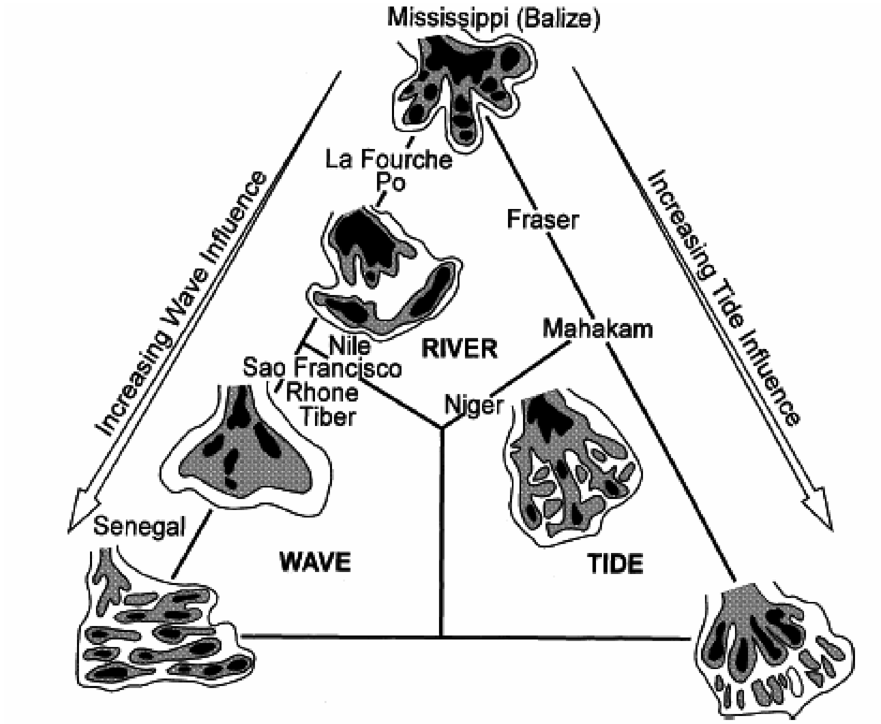


Figure 1. Sand distributions resulting from the three end member depositional processes (from Bhattacharya and Giosan, 2003, after Galloway, 1975)

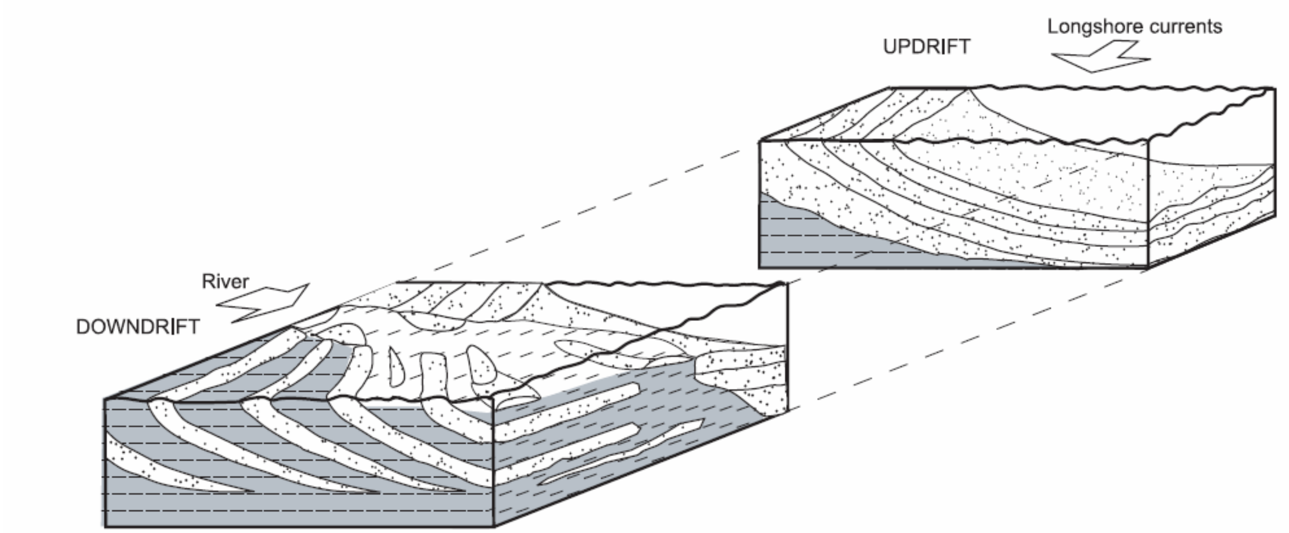


Figure 2. The predicted distribution of sand and mud related to longshore currents in a wave-influenced, asymmetric delta (from Bhattacharya and Giosan, 2003)

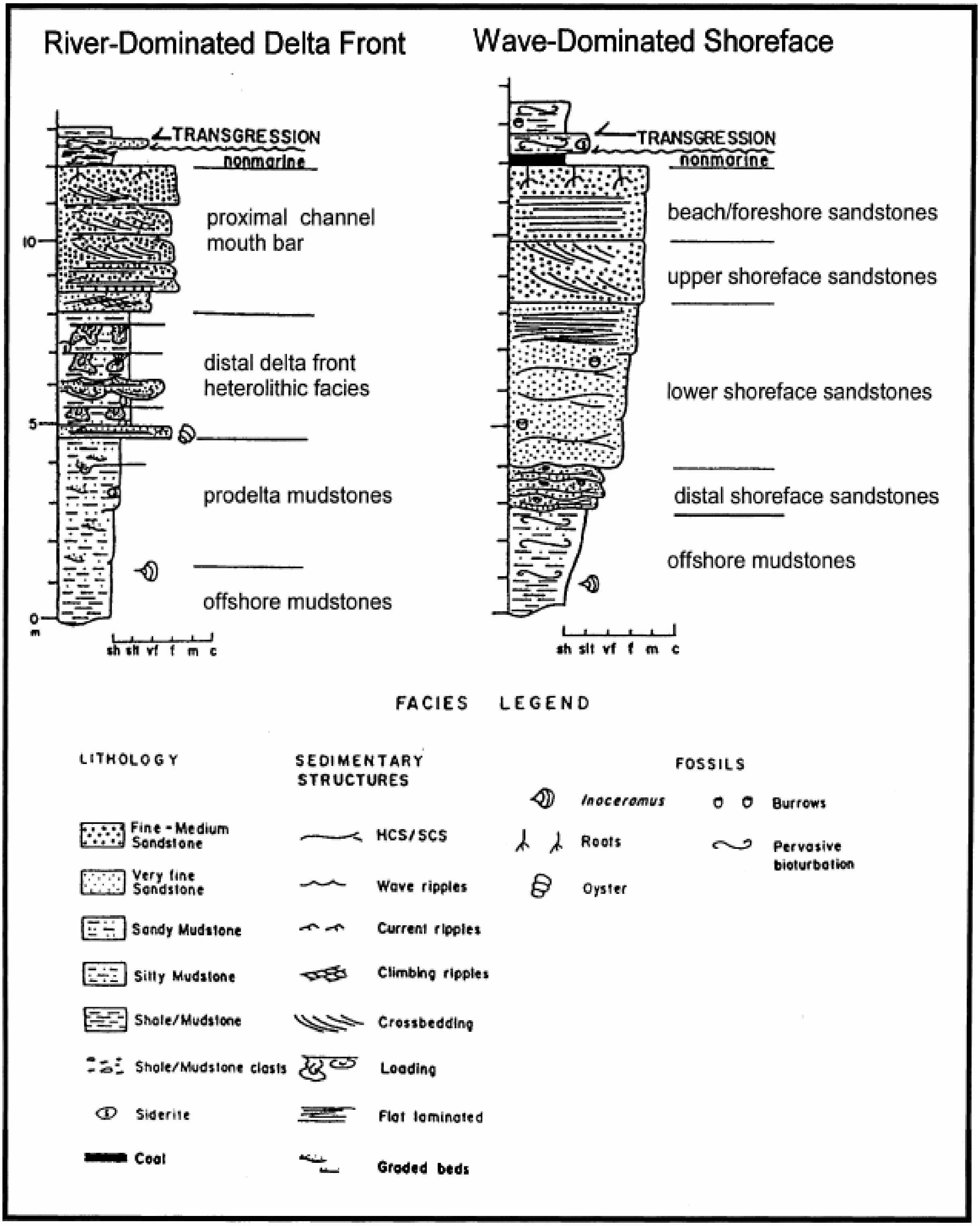


Figure 3. Typical river-dominated and wave-dominated delta sections. The river-dominated delta front would be expected downdrift and the wave-dominated delta front would be expected updrift in an asymmetric delta (from Bhattacharya and Giosan, 2003).

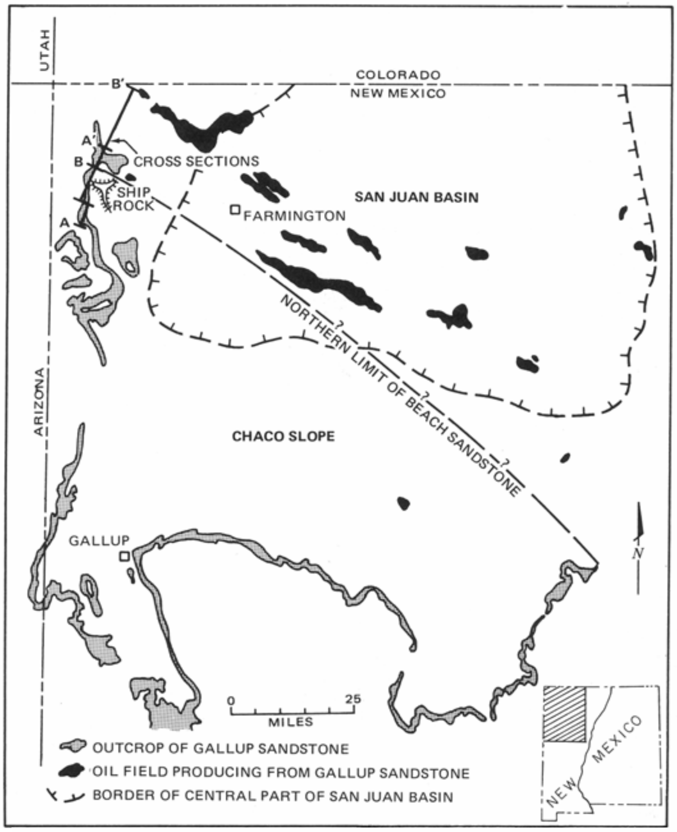


Figure 4. Map of Gallup Sandstone outcrop exposure and northern extend of shoreface (from Campbell, 1979).

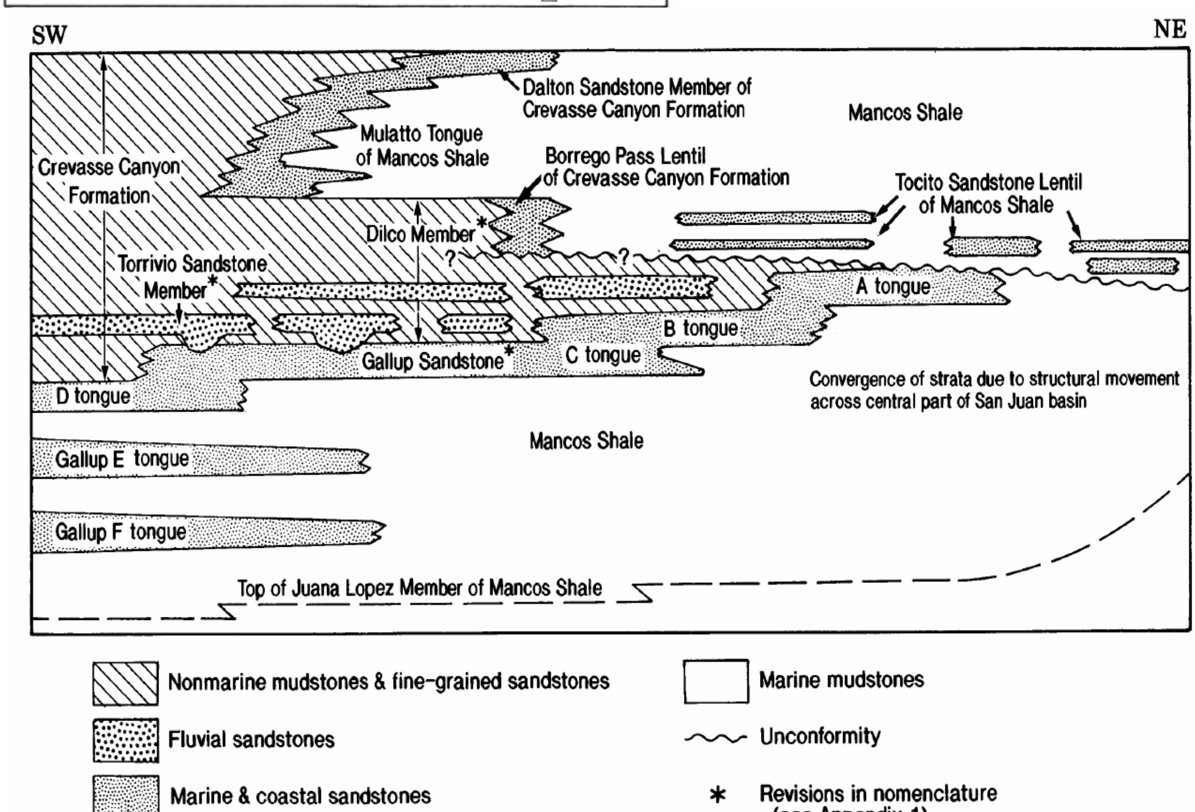


Figure 5. Schematic stratigraphic section of the Gallup Sandstone tongues and associated formations (from Nummedal and Molenaar, 1995).

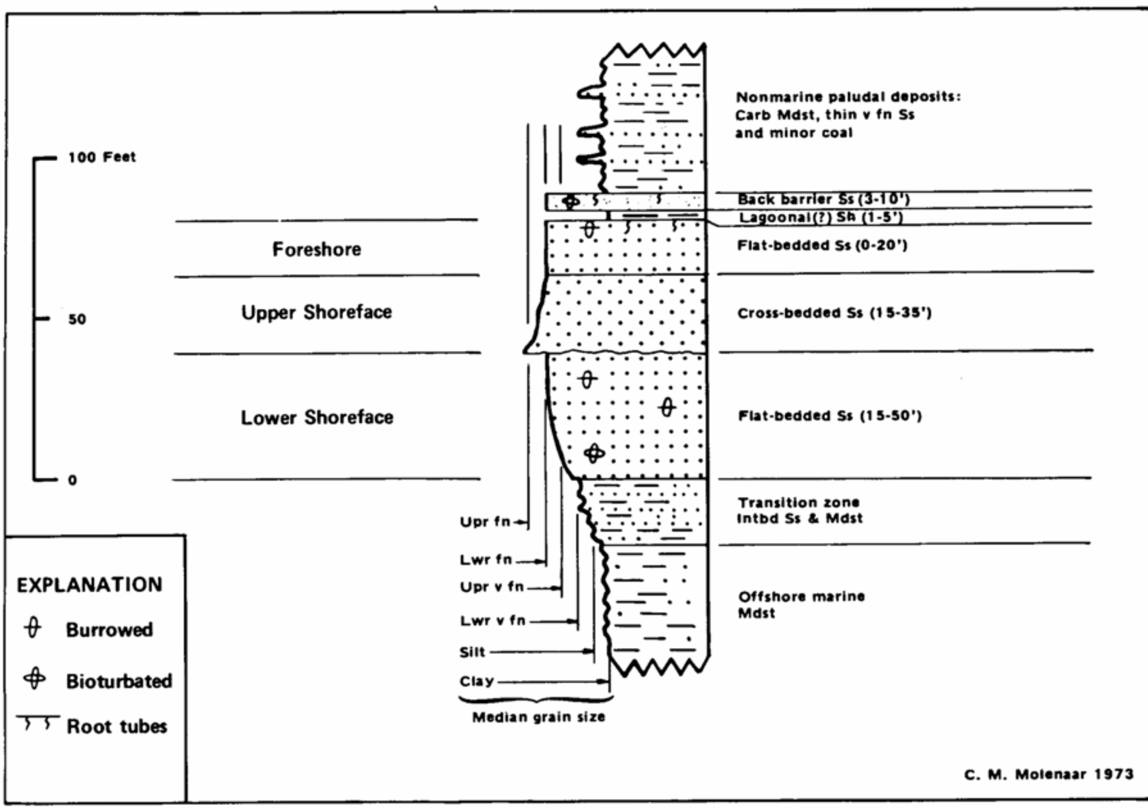
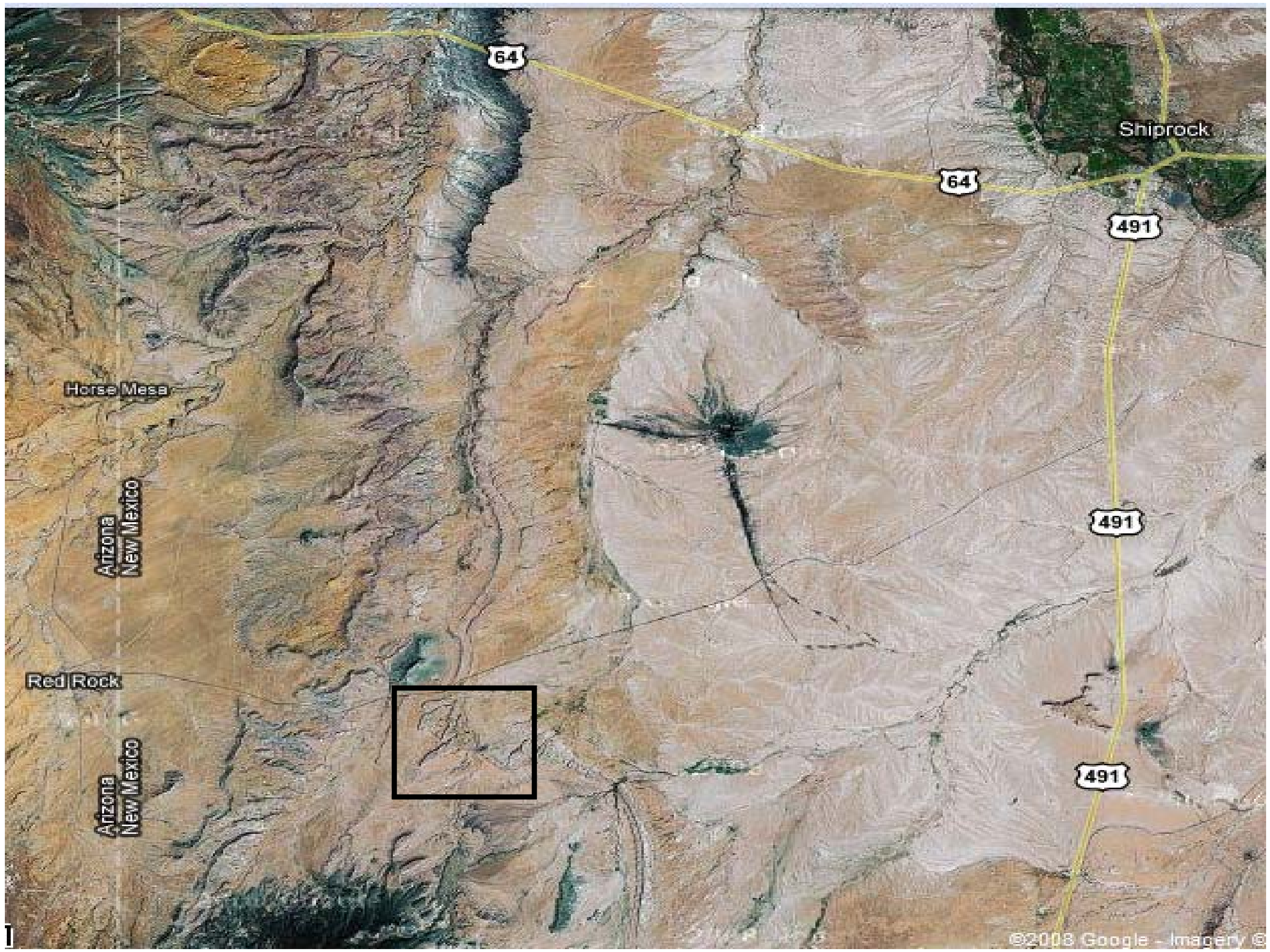


Figure 6. Schematic vertical section of the Gallup shoreface (from Molenaar, 1973).



5 km

Figure 7. Location of Rock Ridge study area, south of Shiprock, New Mexico.

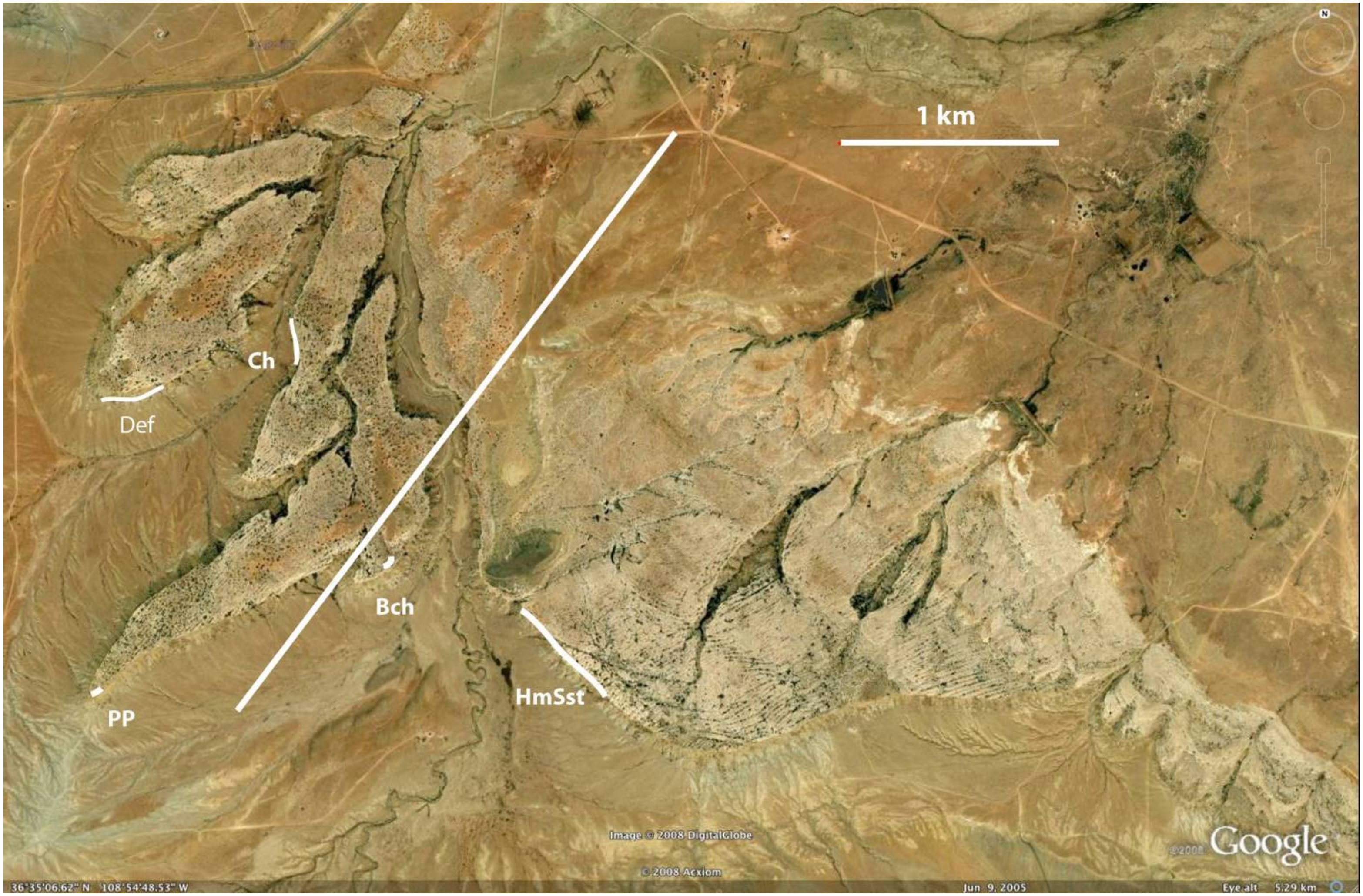


Figure 8. Rock Ridge Study area. Heterolithic deposits on the west side, homogenous sandy deposits on the east side.
PP = Parasequence Point
Ch = Possible distributary channel
Bch = Homogenous shoreface section with beach deposits
HmSst = Homogenous sandy shoreface outcrop
Def = Large-scale soft sediment deformation

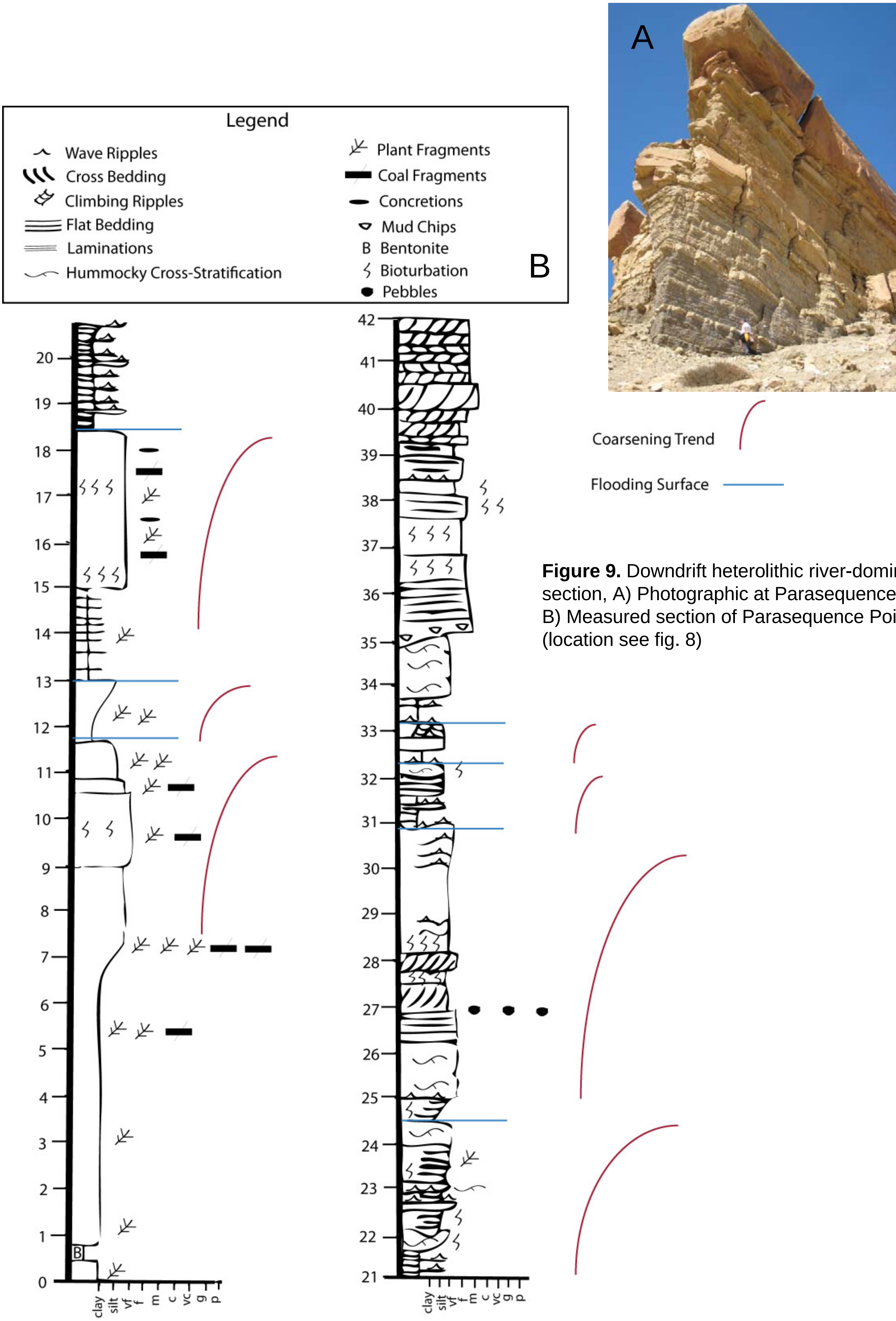


Figure 9. Downdrift heterolithic river-dominated section, A) Photographic at Parasequence Point. B) Measured section of Parasequence Point. (location see fig. 8)

Figure 10. Silt laminated mudstone, low BI, from west side of study area.

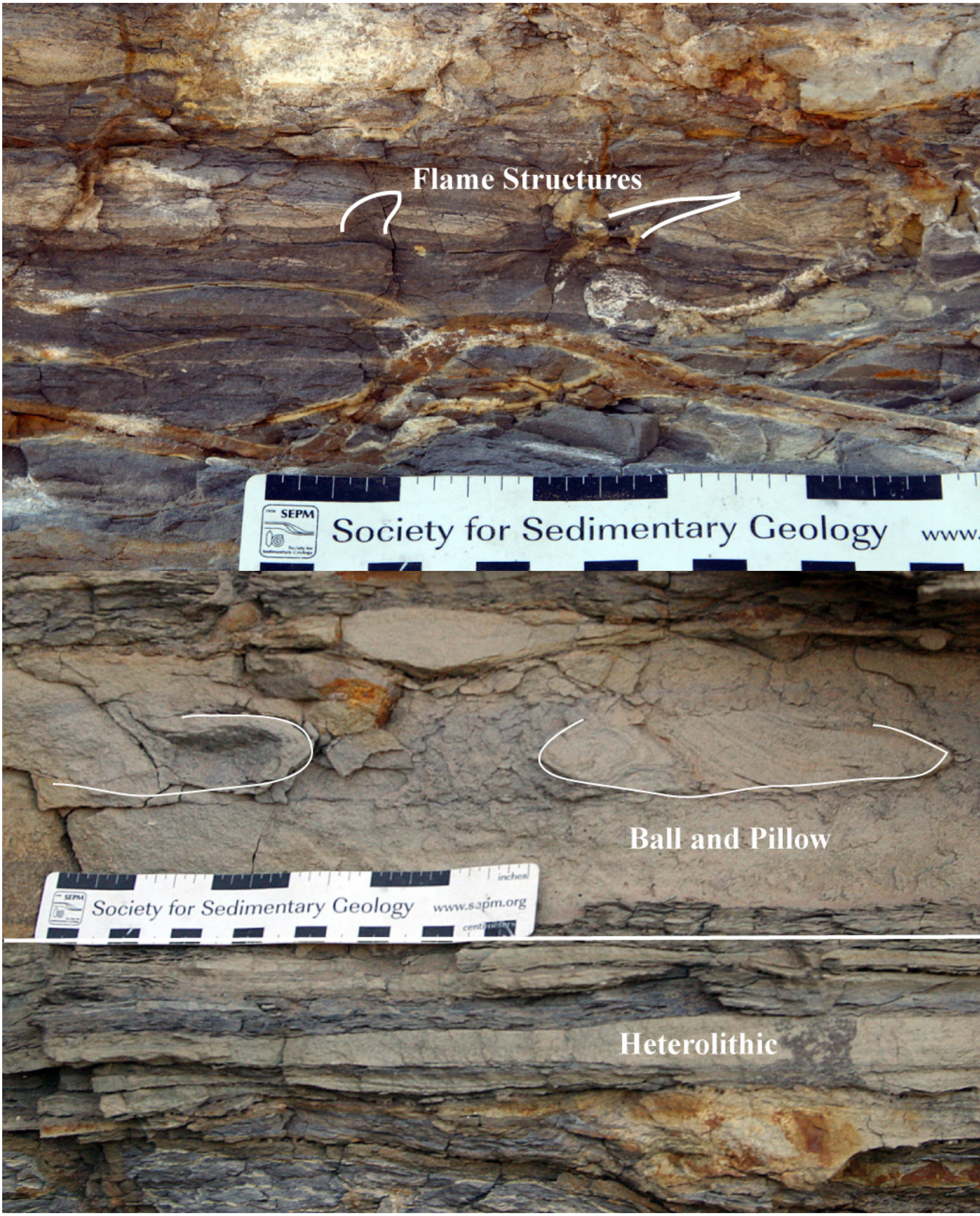


Figure 11. Evidence of rapid depostion on west side of study area.
A) low BI, heterlolithic, flame structure
B) low BI, heterolithic, ball and pillow

Figure 12. Large-scale soft sediment deformation (location see fig. 8)

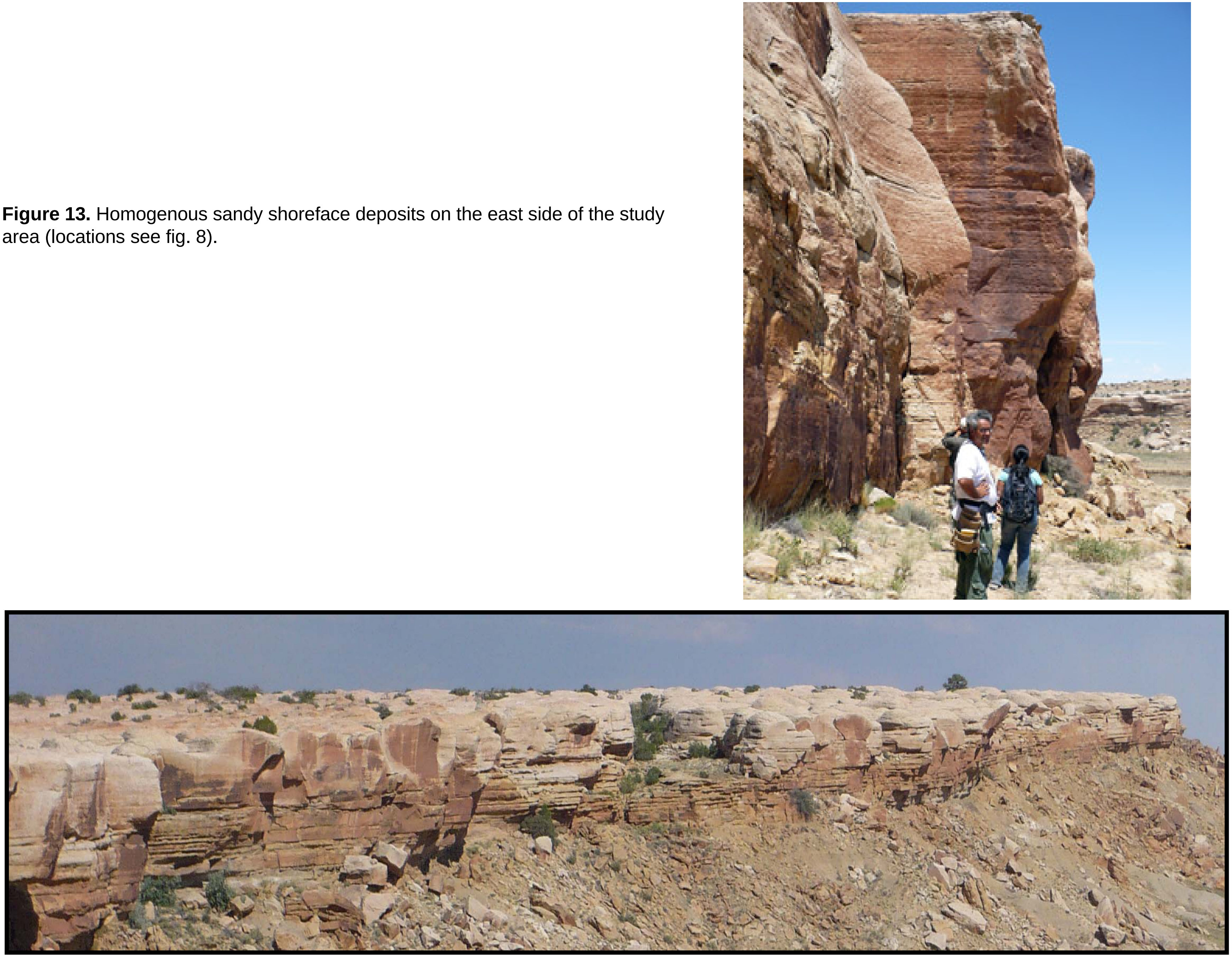
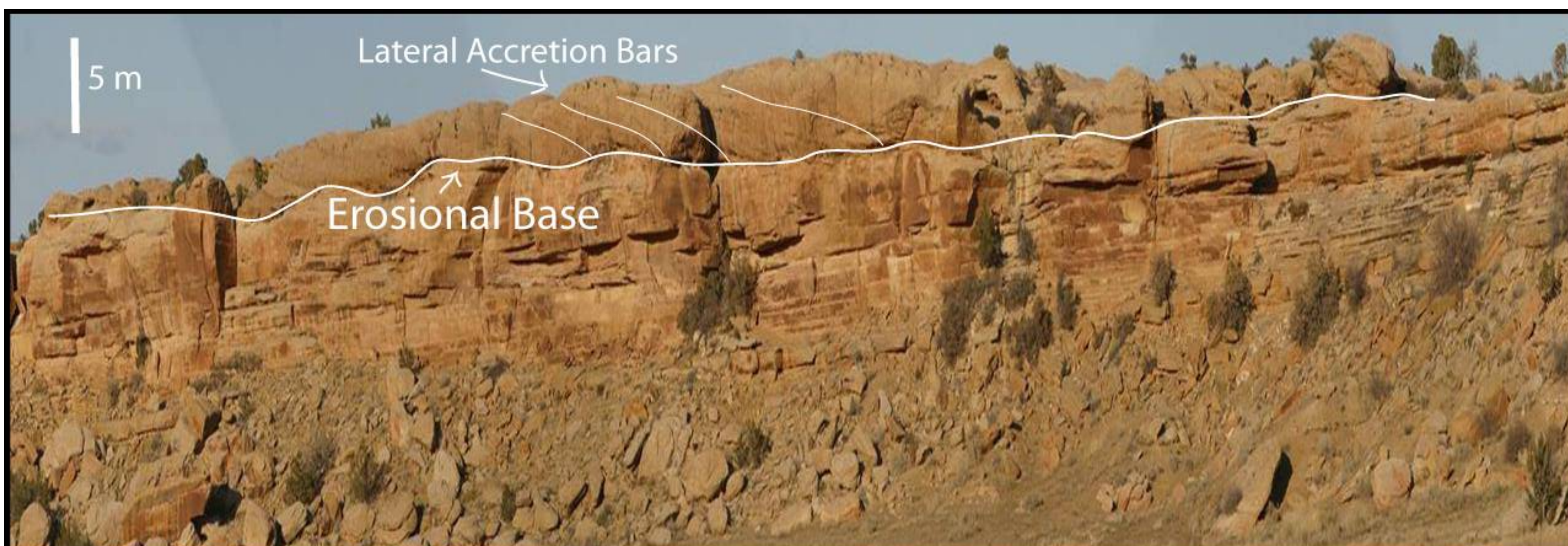


Figure 13. Homogenous sandy shoreface deposits on the east side of the study area (locations see fig. 8).

Figure 14. Pervasively bioturbated sandstone on the east side of the study area.

Figure 15. Distributary channel (vertically exaggerated) and location (location see fig. 8).



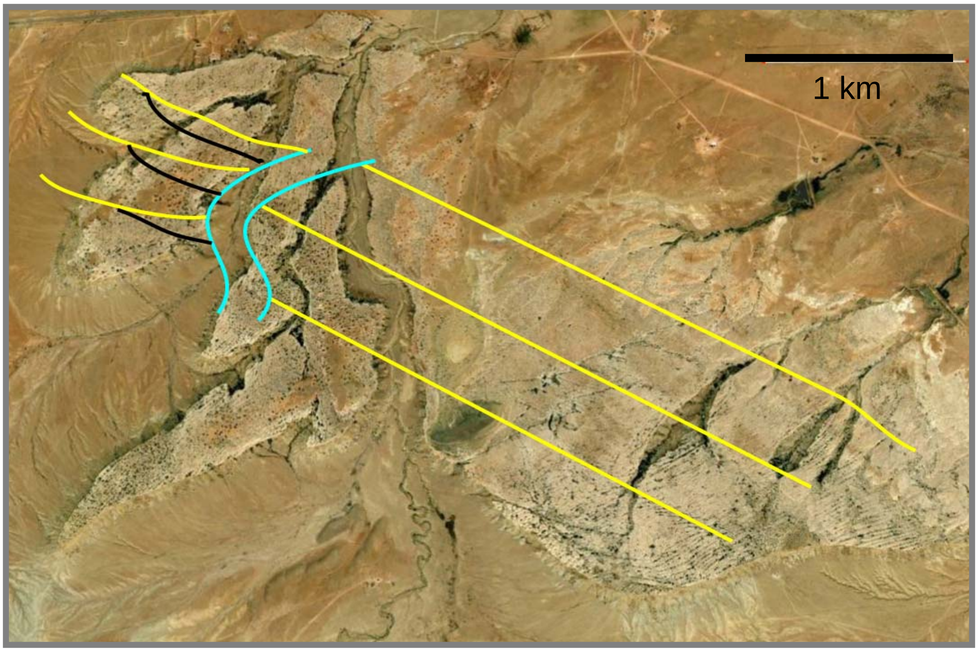


Figure 16. Predicted paleogeography

N=31 Wave ripple crest orientation

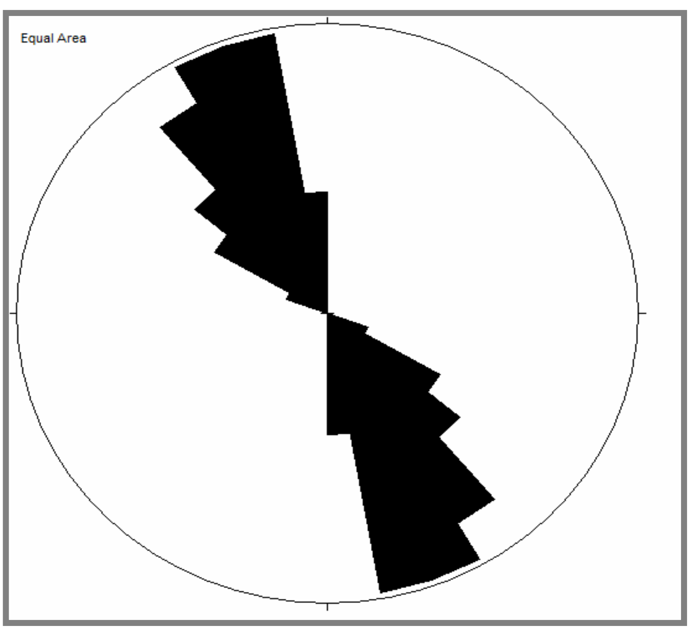
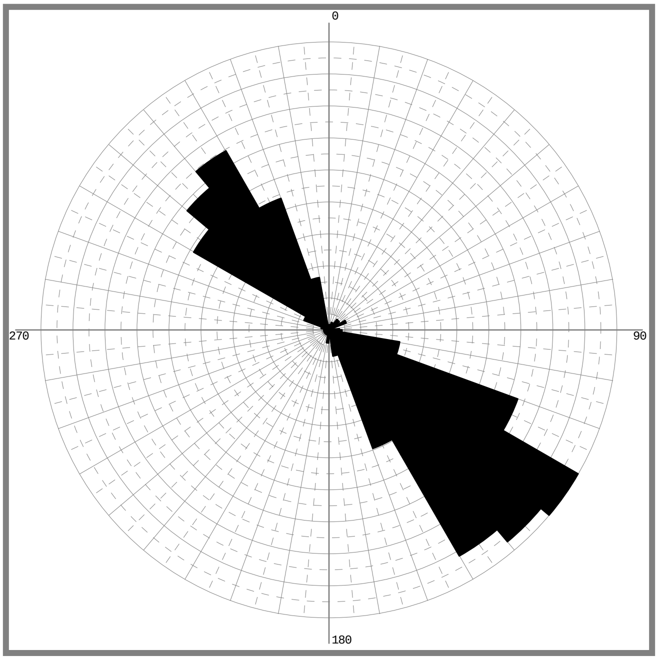


Figure 17. Wave ripple crest orientation, parrallel to shoreline.



N=815

Trough cross-bedding dip direction

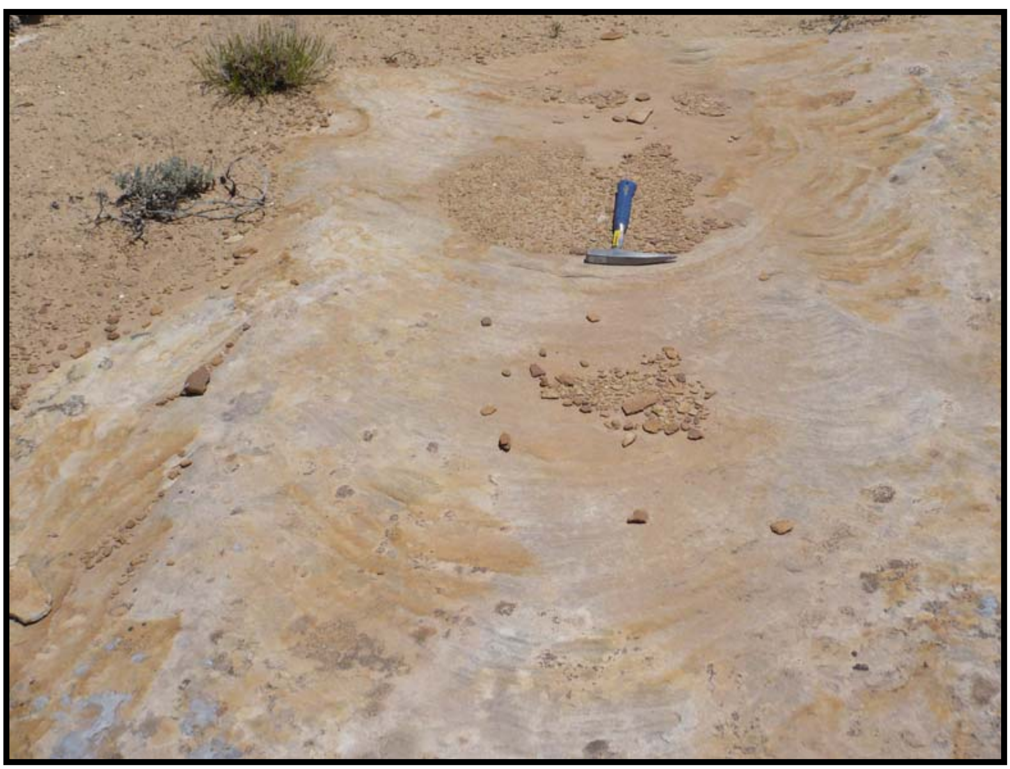


Figure 18. Longshore current direction determined by trough cross-bedding in upper shoreface. Majority of measurements taken by axis of rib opening direction.

Axis opening of trough cross-bedding and plane intersection with the surface of lateral accreting bars

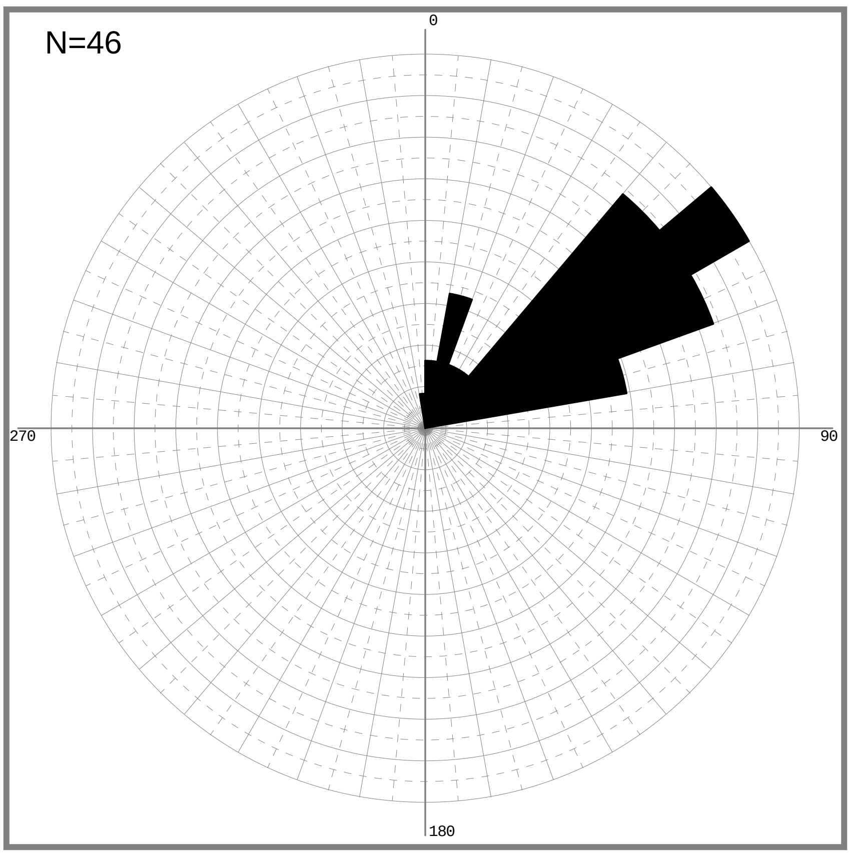


Figure 19. Flow direction of distributary channel to the northeast.