Sedimentology, geomorphology, and pedology of an alluvial fan adjacent to the Mazatzal Range, Central Arizona

Katherine Werner
Department of Geology, Carleton College, 300 N. College St., Northfield, MN 55057
Faculty sponsor: Clint A. Cowan, Carleton College

INTRODUCTION

I document the sedimentological and pedological facies in order to reconstruct the architectural element distribution of an alluvial fan in a tributary of Tonto Basin, Central Arizona. Tonto Basin is a Cenozoic extensional basin that began subsiding in the Oligocene coincident with the uplift of the Mazatzal Range (Anderson et al., 1987). The alluvial fan connects Barnhardt Canyon to Rye Creek, a tributary of Tonto Creek. Previous studies of the Cenozoic formations in Tonto Basin focus on the region surrounding Tonto Creek, and do not encompass the Rye Creek tributary area. Therefore, this study of the alluvial fan associated with Rye Creek and Barnhardt Canyon fills a gap in our understanding of the Tonto Basin region.

METHODS

My methods consist of traversing the proximal, medial, and distal alluvial fan surfaces and drainages to collect data in the form of stratigraphic columns, drawings, notes, photographs and rock samples. Some of the data are correlated to aerial photographs and topographic maps in order to determine the architectural element distribution and fan morphology.

FACIES ANALYSIS AND ARCHITECTURAL ELEMENTS

A "facies" is a unit of rock distinguished in the field by a specific combination of lithological, physical, biological structures that differentiate it from other rock units above, below, or adjacent to it (Walker, 1992). The facies of the alluvial fan are designated with a letter code adapted from Miall (1985) and further organized into architectural elements, morphological subdivisions of the depositional system. The main elements are channel bar and fill, clast-supported massive, and stratified sheet elements which represent braided fluvial, mass flow, and sheetflood surficial processes, respectively.

Channel bar and fill. The channel bar and fill element is represented by various gravel and sand facies that represent bar formation, channel-floor dune migration, low-water accretion, and overbank deposition. Three bar types are represented: longitudinal, tranverse to linguoid, and point or side bars (Rust, 1978). The abundance of gravel and sand facies characteristic of a braided system throughout proximal, medial, and distal regions suggests that braided streams were a prominent surficial process on the fan. Relying on studies of modern braided systems (Miall, 1977), the presence of these elements indicates a fluvial system of high bed load, high flood peaks, and strongly fluctuating discharges indicative of arid to semi-arid climates.

Stratified sheet. The stratified sheet element is composed of laterally continuous sheets of subrounded gravel and sand deposited during sheetflood events. Sheetfloods are associated with abundant sediment availability and a flashy discharge regime. The stratified sheet element is identified in all regions of the fan.

Clast-supported massive Element. A clast-supported deposit of massive or crudely bedded, imbricated gravel, composes the clast-supported massive element. I interpret this element to be deposited by a hyperconcentrated flood flow. There is only one clast-supported massive deposit in the fanglomerate and it is recorded in the lowest stratigraphic position in the distal region.

Terrace gravels. Terrace gravels comprise a fourth element that resulted from erosional events occurring after the fanglomerate was deposited. Therefore, they are not a component of fan architecture. However, the terrace gravel element is useful in determining the age of the fanglomerate because it records activity in the region since the time when constructional fan episodes ceased. Its extremely coarse nature contrasts with the fanglomerate elements indicating a change in depositional processes. Barsch and Royse (1972) propose that terrace gravels and surfaces formed in Tonto Basin during the shift to glacial climate starting in the late Pliocene to Pleistocene as major erosion took place in the drainage areas and induced downcutting throughout the source area and the alluvial fans. Further study of the asymmetrical terracing associated with the terrace gravels may have implications for the neotectonics of the region.

PEDOGENIC ELEMENT

Paleosols in this area range from clay-rich samples formed in a humid environment to well-developed calcretes indicative of semi-arid conditions. Soils represent periods of non-deposition and weathering on the fan surface. Three out of the four paleosol samples contain calcareous soil structures. Well-developed calcretes (stage IV) are characterized by thick (> 1 cm) calcareous laminae, carbonate coatings on clasts, a calcareously indurated matrix, or some combination of these features (Figure 1). Paleosols with minimal carbonate accumulation (stage I) have scarce carbonate structures or a slight carbonate matrix component. I formulate an age range for the calcic paleosols based on their morphological characteristics and the climatic history of the region in accordance with Machette's quantitative index (1985).

Today, calcification is occurring in Tonto Basin. Likely sources of calcareous material include the dry lakes of the Great Basin and high Ca^{++} in rainfall throughout the southwest (Bull, 1991). The fan environment receives a moderate amount of precipitation, 45 cm annually, and has an average temperature of 18°C. I can assess the age of the pedogenic calcretes by comparing them to other regions of similar climate that have dated calcic horizons (Machette, 1985). The region around Tonto Basin is similar in climate to Roswell-Carlsbad, New Mexico, which develops calcic soils at a rapid rate. I expect that the alluvial fan does not calcify at such a high rate because the Roswell-Carlsbad area contains limestone parent materials that would accelerate the calcification process. I estimate that stage IV paleosols took 200,000 to 500,000 years to form and stage I paleosols took less than 7,000 years to form. These estimates are useful in dating the fan deposits.

ARCHITECTURAL ELEMENT DISTRIBUTION

Overall, gravel- and sand-dominant braided and sheetflood elements alternate vertically and laterally throughout the fanglomerate until eventually, sheetflood and sand-dominant braided elements dominate in the extremely distal part of the fan. The hyperconcentrated flood flow (located at the base of the stratigraphic section in the distal region) is an exception to this trend. There is a non-conformable vertical change from hyperconcentrated flood flow elements to channel-fill and bar elements accompanied by an upward reduction in grain size (Figure 2). Within the channel-fill and bar element, there is an upward transition from facies Gt and Gp to Gm representing a drop in stream competence in the distal region over time. Higher up in the stratigraphic section, the change from braided stream deposits to sheetflood deposits is another vertical change in elements accompanied by a decrease in grain size.

To explain the vertical change accompanied by a fining upwards sequence from mass flow and pedogenic elements to braided stream and sheetflood elements, I propose the abnormal fanhead incision model (Figure 3). The abnormal fanhead incision model calls upon the processes of channel entrenchment and fan segmentation to deliver a hyperconcentrated flood flow to the distal region (Hooke, 1966; Bull, 1964). The processes incise the older fan segments to such an extent that overbank deposition is impossible therefore facilitating the development of a stage IV pedogenic calcrete. Eventually, backfilling raises the streambed to the original level of the fan and braided stream and sheetflood deposits cover the calcrete. The process of abnormal fanhead incision is a response to an extrinsic disruption of the fan-source system. An extrinsic disruption related to tectonics or climate is most likely responsible for the abnormal incision and segmentation.

ALLUVIAL FAN DATING

I estimate a minimum age for the fan deposits by adding the time necessary for the formation of the sediments and paleosols comprising the vertical transition in architectural elements (Figure 2). The base of the stratigraphic section contains a hyperconcentrated flood flow element and a stage IV pedogenic calcrete that took 200,000 to 500,000 years to form. The stage IV calcrete is buried by 20 meters of braided fluvial and sheetflood elements that contain a stage I pedogenic element thereby adding a minimum of 7,000 years to the section. Terrace gravels that are dated to 1.6 Ma by Barsch and Royse (1972) cap these elements. I sum these lengths of time to conclude the stage IV pedogenic calcrete and hyperconcentrated flood-flow are 1.8-2.0 million years old.

Coincidental with the 2 Ma date of the hyperconcentrated flood flow deposit and the associated stage IV paleosol is evidence for the tilting of Tonto Basin reflected in streamflow indicators. Nations and Brumbaugh (1992) surveyed imbricated basin-fill gravels in Tonto and Payson Basins. They concluded that major channels in the region changed from a north-south flow direction to south-north reflecting a change in base level and tilting approximately 2 Ma. This tilting may have been the extrinsic disruption responsible for abnormal incision and segmentation. Therefore, the architecture of the fan is possibly a result of the tilting of Tonto Basin and the surrounding region at 2 Ma.

REFERENCES CITED

Anderson, L.W., Piety, L.A., and LaForge, T.C., 1987, Seismotectonic Investigation, Theodore Roosevelt Dam, Salt River Project, Arizona: Unpublished report, U.S. Bureau of Reclamation, Engineering and Research Center, Seismotectonic Report No. 87-5, Denver, Colorado.

Barsch, B.D. and Royse, C.F., 1972, A model for development of Quaternary terraces and pediment- terraces in the southwestern United States of America: Zeitschrift fur Geomorphologie, v. 16, p. 54-75.

Bull, W.B., 1964, Geomorphology of segmented alluvial fans in Western Fresno County, California: U.S. Geological Survey Professional Paper 352-E, p. 79-129.

Bull, W.B., 1991, Geomorphic Responses to Climatic Change: New York, Oxford New York, 326p.

Hooke, R.L., 1966, Processes on arid-region alluvial fans: Journal of Sedimentary Geology, v. 75, p. 438-460.

Machette, M.N., 1985, Calcic soils of the southwestern United States *in* Weide, D.L. ed., Soils and Quaternary Geology of the Southwestern United States, GSA Special Paper 203: Boulder, Colorado, Geological Society of America, p. 1-21.

Miall, A.D., 1977, A review of the braided-river depositional environment: Earth Science Reviews, v.13, p. 1-62.

Miall, A.D., 1985, Architectural-Element analysis: A new method of facies analysis applied to fluvial deposits: Earth-Science Reviews, v.22, p. 261-308.

Nations, J.D. and Brumbaugh, D.S., 1992, Evidence for pre-27.2 subsidence of Tonto Basin, Central Arizona: Geological Society of America—Abstracts with Programs, v.24, no. 6, p. 54.

Rust, B.R., 1978, Depositional models for braided alluvium, *in* Miall, A.D., ed., Fluvial Sedimentology, Memoir 5: Calgary, Canadian Society of Petroleum Geologists, p. 605-625.

Walker, R.G., 1992, Facies, facies models and modern stratigraphic concepts *in* Walker, R.G. and James, N.P., eds., Facies Models: Response to Sea Level Change: St. John's, Newfoundland, Geological Association of Canada, p.1-14.

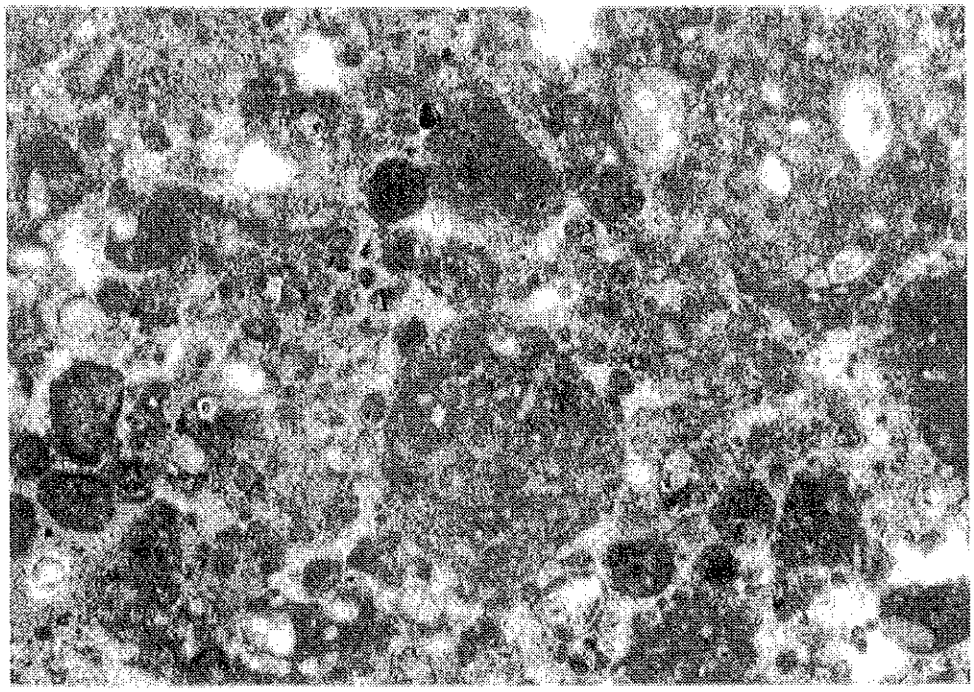


Figure 1. Thin section of stage IV pedogenic calcrete showing carbonate pellets and clotted texture common to calcic soils. Length of photo equals 2.8 mm.

Figure 2. Stratigraphic column of distal fan sediments demonstrating the vertical change from hyperconcentrated flood flow elements to braided stream and sheetflood elements. The fan deposits are capped by terrace gravels.

Facies code		Sedimentary structures	Interpretation
Gms	massive, matrix supported gravel	none or grading	debris flow deposits
Gh	gravel, stratified	horizontal bedding	sheetflood deposits, longitudinal bars
Gm	massive or crudely bedded gravel, clast supported	none or horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits, mass flow deposits
Gt	gravel, stratified	trough cross beds	minor channel fills
St	sand, medium to very coarse,	solitary or grouped trough cross beds	dunes (lower flow regime)
Sp	sand, medium to very coarse,	solitary or grouped planar cross beds	linguoid, transverse bars (lower flow regime)
Sr	sand, very fine to coarse	ripple cross-lamination	ripples (lower flow regime)
Sl	sand, very fine to very coarse,	low angle (<10°) cross beds	scour fills, washed-out dunes
Sh	sand, very fine to very coarse,	horizontal lamination	planar bed flow, sheetflood (l. and u. flow regime)
Ss	sand, fine to very coarse,	broad, shallow scours	scour fills
Fl	sand, silt, mud deposits	fine lamination, very small ripples	waning flood, or overbank deposits

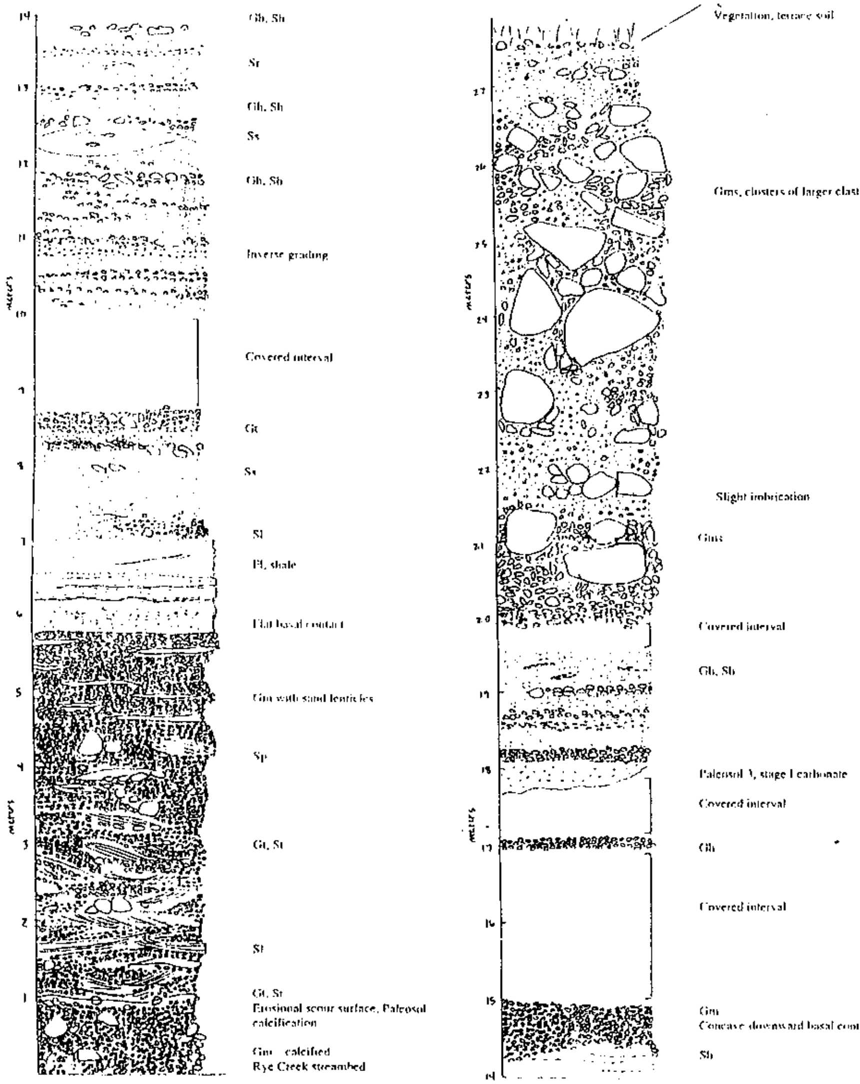
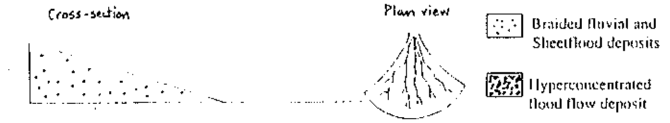
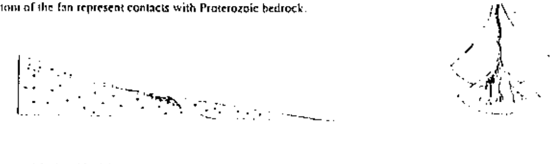


Figure 3. The abnormal fanhead incision model attributed the architectural element distribution to channel entrenchment, fan segmentation, and channel back-filling. Bull (1964) discusses these processes in the context of an alluvial fan in San Joaquin Valley. The cartoons below are the adaptation of his model to the fan in this study.

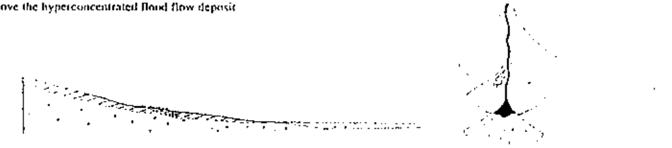


In the first stage, an alluvial fan composed of braided fluvial and sheetflood elements is deposited. The lines bounding the side and bottom of the fan represent contacts with Proterozoic bedrock.

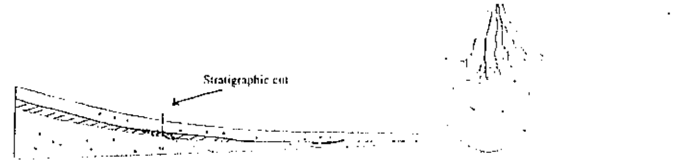


Abnormal fanhead incision and channel entrenchment lead to the deposition of a new fan, including a hyperconcentrated flood flow deposit, on the distal region of the old fan.

Further downcutting of the channel induces the deposition of a newer fan segment above the second. This abnormal incision makes overbank deposition on the older fan surfaces impossible therefore allowing for the development of a stage IV pedogenic calcrete above the hyperconcentrated flood flow deposit



Eventually, downcutting entrenches the channel to such an extent that its gradient is less than that of the adjacent fan segment. As a result, backfilling occurs raising the level of the streambed to the older fan surface so that surficial processes on the old fan surface resume



Finally, braided fluvial and sheetflood elements are deposited over original fan surfaces. A stratigraphic cut at Rye Creek reveals a vertical change in elements accompanied by an upward decrease in grain size