Geoarcheology Studies
Fieldwork Report
June 1994

by
Kate Thompson

Activities

Approximately two weeks were spent in the field mapping debris flows and gathering surficial weathering data in various study areas along the Colorado River from 24.5 mile to 220 mile. Kelly Burke, myself, and a GCES volunteer spent the majority of time identifying the geomorphic relationships between debris flow levels, mapping the levels on 1:4800 scale aerial photos, measuring weathering characteristics of debris flow clasts, and finding datable materials to calibrate the weathering technique. The purpose and scope of project work are discussed in the study plan submitted after the river trip request to GCES dated March 9, 1994. Debris flow mapping and data collection in the eastern Grand Canyon areas are now completed and ready for analysis. Our findings will address the age of large magnitude fan-forming debris flows, their correlation throughout the river corridor, and their relationship to the pools and rapids of the Colorado River. Presently, Hereford and others are writing a publication for Open-File Report status entitled "Segmented Debris-Flow Fans and the Age of the Pools-and-Rapids of the Colorado River, Eastern Grand Canyon, Arizona".

These tasks were carried out during the April 28 - May 13 trip:

1. Mapping on air photos, description of map units, and collection of weathering data on debris fans at 12 tributaries, beginning with 24.5 mile and ending with 220 mile. Sites were selected based on well-defined and multiple fan-forming debris flow levels.

2. Identification of datable materials that are closely associated with prehistoric debris fans. Organic materials to be collected for radiocarbon dating include charcoal, driftwood, and mesquite piths; other materials such as prehistoric cultural artifacts are important to identify for our study if they are closely associated with a debris flow deposit. We hope to collect any relevant charcoal and wood samples in the future in conjunction with an NPS archeologist.

3. Description of debris flow units and collection of weathering data at unplanned sites where we found cross-datable materials.

4. Identification of source of debris flow deposits up tributaries.

5. Repeat weathering measurements on several different previously measured traverses. This will aid in fine-tuning our techniques for consistency and establishing the repeatability of our study.

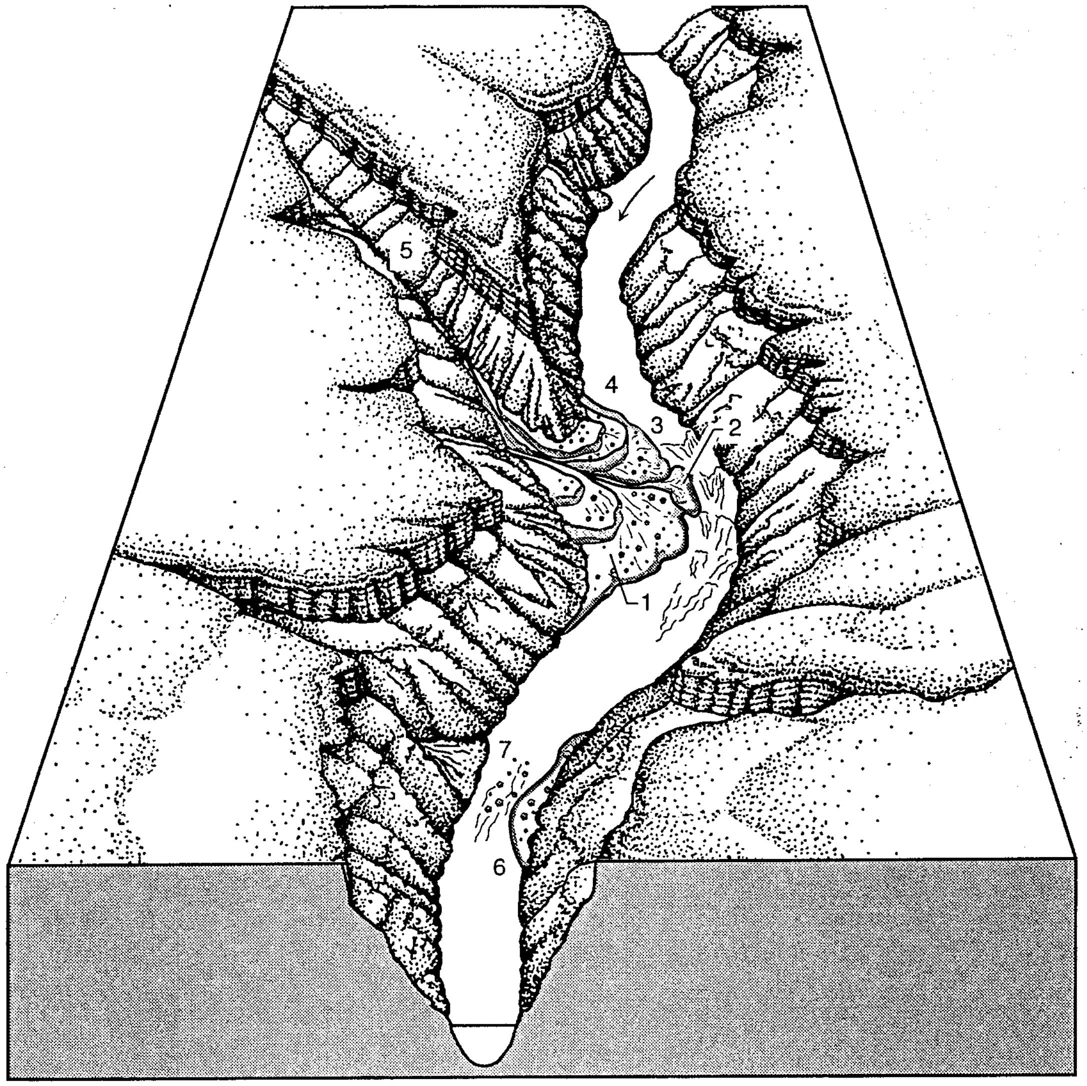
Notable Findings

Previous research in eastern Grand Canyon shows that most of the large magnitude, fan-forming debris flow deposits are segmented and typically express three distinct surfaces and time periods: older, intermediate, and younger age (see Hereford, 1993, and Hereford et al, 1993). Many of these fans have been truncated at their distal end by high floods of the Colorado River, which in prehistoric time exceeded 300,000 cfs. Figure 1 shows a generalized scheme of the three debris flow levels and their truncation by Colorado River floods. The course of the river and location of the pool and rapid were initially established by the formation of these debris fans. Subsequent debris flows modify the rapid until a large enough flood is able to blow out the constriction.

The three levels point to three separate periods of high debris flow activity and are separated by periods of erosion where the river has removed and translocated the debris-flow sediment. Kieffer (1985) estimates that flow rates of 300,000 to 400,000 cfs are necessary to erode these fans as extensively as we have seen in the field. Our findings in eastern Grand Canyon show that these fans were formed and subsequently eroded by large floods during the past 3000 years. After analyzing our present data, we hope to see how our expanded study areas correlate to these findings.

We found debris fans that appeared to be of similar age and morphology throughout Grand Canyon, with the exception of a few tributary areas between 195 mile and 220 mile. In all cases the fans had been truncated by large Colorado River floods; moreover, the tributaries each presently contained a recent, channelized debris flow deposit that reached the river and has remained fairly intact because of the present day Colorado River flow regime (as discussed by Webb et al, 1989, and Melis and Webb, 199??).

In western Grand Canyon, we found several areas where intermediate-aged fans were missing. This gap in time could represent a different debris flow frequency for some (and perhaps a majority of) tributaries in western Grand Canyon. Perhaps, many debris flows occurred during this time, but may have never reached the river. This example was demonstrated two miles up 205 mile canyon where debris flows had aggraded at the confluence of two tributaries, but were missing further down 205 mile canyon. This confluence area along the Granite Park fault provided an accommodation space for debris to collect. At the mouth of 205 mile canyon, it appears that a younger debris fan was instrumental in forming the rapid.



EXPLANATION

1 Segmented debris-flow fan
2 Debris-flow channel
3 Rapid
4 Pool
5 Tributary canyon
6 Gravel bar
7 "Rock garden" and riffle

Figure 1. Block diagram showing the relationship of a segmented debris-flow fan to the Colorado River in eastern Grand Canyon, Arizona.

Calibration of our weathering studies has been a challenge. We needed to calibrate our measurements by collecting organic materials for radiometric dating. However, these materials are scarce on intermediate and older debris fans. If archeologic structures or artifacts appear on or lie in close association with these fans, we can use these materials as age-constraining tools. Luckily, we identified and located several archeologic features with charcoal, the ages of which would benefit our study immensely. We hope to return to these sites with an NPS archeologist and collect charcoal for radiometric dating. Recently, I have sent a list of these sites to Helen Fairley, NPS archeologist, in case she can provide information on ages.

Presently, Richard Hereford, Kelly Burke, and I are finishing a paper presenting our findings of debris flow frequency in eastern Grand Canyon for peer review in July. Meanwhile, we will be analyzing weathering data and writing up results for yet another publication, hopefully as a USGS Bulletin article. This will address the specifics of weathering rates on debris fans at 21 tributaries and will develop correlative time periods of debris flow activity throughout Grand Canyon.

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United States Department of the Interior

U.S. GEOLOGICAL SURVEY

Branch of Western Regional Geology
2255 North Gemini Drive
Flagstaff, Arizona 86001
(602) 556-7159
(602) 556-7169 Telefax

November 15, 1994

Memorandum

To: Dave Wegner

From: Richard Hereford Richard

Subject: Trip Report
Geomorphology/Cultural Research Trip, October 31-November 13

Personnel on this trip were myself, Kelly Burke, and Kate Thompson. The logistics of the trip went well and we were treated handsomely by the crew. The objective of this trip was to map the late Quaternary surficial geology of the Nankoweap Rapids area. We spent 10-full working days and finished the mapping. The next step is to compile the mapping on the topographic base (Open-File Report 94-564) and field check the results later this winter or early spring.

We were fortunate to have a rowing trip, which I understand is not usually allowed by GCES because of the additional expense. I thought it was best to complete this field work as soon as possible; I'm grateful for the opportunity to do the field work this fall and I realize that it was an additional expense for GCES.

The mapped area extends from just above Little Nankoweap Creek to just downstream of the campsite farthest downstream. It includes the Little Nankoweap and Nankoweap Creek debris fans and the small debris fan of an unnamed tributary near the southern boundary of the map. A number of archeologic sites are present on the debris fans, terraces, and the high ridge of rubble material on the south side of Nankoweap Creek. We mapped the ridge because of the archeologic sites, because the ridge is within the area of the

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topographic map, and to clear-up any lingering confusion that others may have about the geology and origin of the rubble deposits on the ridge.

Alluvial Deposits

Most of the recent deposits are similar to those we have mapped in eastern Grand Canyon (Hereford, 1993; Hereford and others, 1993). A sequence of sandy terrace-forming deposits records the fluvial activity of the river during the past 2,000-3,000 years. The primary terrace is similar in age and archeologic content to the alluvium of Pueblo-II age that we defined in eastern Grand Canyon. Organic material for dating is almost completely absent at Nankoweap Rapids area, but the archeologic sites show that the alluvium is similar in age and origin to the alluvium of Pueblo-II age in eastern Grand Canyon. A still older and topographically higher terrace-forming alluvium is present at Nankoweap, which we believe is equivalent to the striped alluvium of eastern Grand Canyon. This terrace could contain Basketmaker or Archaic-period archeologic material, although none is exposed on the surface in the Nankoweap area.

The period from abandonment of Grand Canyon by the Anasazi (about 1150-1200 A.D.) to the present is represented by seven terraces or terrace-like features. This terrace sequence resembles the sequence we mapped in eastern Grand Canyon. In the Nankoweap area, however, we have been unable to date the pre-dam terraces because organic material of known stratigraphic context is lacking. Charcoal is abundant in the deposits, but it resulted from numerous historic-age burnings that carbonized roots in the shallow subsurface.

Potential Erosion of Archeologic Sites

Erosion of archeologic sites is possible in a number of places based on our observations and the topographic map, although erosion does not appear to be as large a problem as in eastern Grand Canyon. The pattern and style of erosion are identical to the situation in eastern Grand Canyon, and the model of terrace erosion we developed there (Hereford and others, 1993, p. 16-41; Hereford, 1993) applies to the Nankoweap area. These terraces are drained by short, ephemeral-tributary streams that occupy gullies cut into the terraces. Both river- and terrace-based streams are present, just as we defined them in eastern Grand Canyon. The river-based streams are actively eroding the terraces in several places. The terrace-based streams are less of a problem, although headcuts are present locally.

The potential for erosion of the two archeologic terraces is greatest from upstream of Little Nankoweap Creek to just north of Nankoweap Creek, and from the main campsite to the southern boundary of the mapped area. In these areas, river-based gullies have headcuts in the terrace alluvium and terrace-based gullies end close to the river, these could eventually extend downslope to the river. In contrast, erosion of sites is unlikely between the south end of the rubble ridge to the main campsite. Streams in this area are terrace based; they end on the broad terrace of Pueblo-II alluvium. This terrace is separated from the river by a linear sand dune that is 360 m long and 4-5 m high. The dune blocks these streams from extending downslope to the river, thereby preventing them from reaching a lower baselevel.

Debris Fans

Much of our time was spent mapping the three debris fans (Little Nankoweap, Nankoweap, and the unnamed fan south of the main campground) and analyzing surface weathering. Perhaps the most interesting fan is Nankoweap Creek. The fan is comprised of four prehistoric age and three historic-age surfaces. Three of the prehistoric surfaces predate or are closely associated in time with Pueblo-II archeologic sites. The youngest prehistoric fan is probably somewhat younger than Pueblo-II occupation of the area.

The three historic-age fans were deposited in the past 100 years. The most extensive debris-flow activity appears to have been December 1966 and the early 1980s; these dates are tentative pending further analysis of tree-ring samples and aerial photographs. The 1966 event was quite large, effecting the channel extensively and depositing a debris fan at the river. The younger debris flow was smaller, although the deposits are readily shown on the 1:2,000 scale map.

Dating of Debris Fans

We are dating the prehistoric surfaces through a combination of radiocarbon methods and surface weathering of limestone clasts. Driftwood derived from Nankoweap and Little Nankoweap Creek basins is on some of the younger prehistoric fan surfaces. Radiocarbon dating of this wood may provide absolute dates for the debris flows, although a number of factors make the dates difficult to interpret.

In eastern Grand Canyon, we developed a quantitative method of dating the exposure time of prehistoric debris-fan surfaces based on the depth of dissolution pits on limestone clasts on the fan surface. Early on we noticed that the depth of dissolution pits as measured with a depth micrometer was related to the age of the surfaces (Hereford and others, 1993, p. 14-15). We are applying this method to the Nankoweap debris fans.

As limestone clasts on the surface of a fan weather, the surface of the clast roughens through development of small pits. Wetting of limestone clasts by rainfall induces metabolic activity in cyanobacteria (blue-green algae) living on the clast, producing carbonic acid that slowly dissolves the calcium carbonate (Danin, 1983). Dissolution pits on limestone walls of ancient archeologic sites in the Middle East are used to determine the rate of pit development. Maximum pit depth is about 5 mm after 1,000 years in the climate of the Middle East. Although the idea that pit depth increases with time is well grounded, application of this weathering rate to debris-fan surfaces in Grand Canyon is not possible. Clast composition is variable (Redwall Limestone compared with Kaibab Limestone, for example), clasts are spherical compared with flat surfaces of building stone, and the climate is substantially warmer and drier.

The problem, therefore, is to relate pit depth to time; for example how much time is necessary for a limestone clast to develop dissolution pits that average 2 mm deep? To solve this problem requires us to calibrate pit depth with time using independently dated debris-fan surfaces. We have established this calibration using four dated control points. Two of these are radiocarbon dated fan surfaces and one is from an archeologic site of known age that was constructed with limestone clasts. The fourth point is the beginning time when clasts are unpitted. Four control points doesn't seem like many, but it is extremely difficult to date these surfaces. The work that Kate and Kelly have been doing throughout Grand Canyon, which you expressed concern about, was done to expand and test the pit-depth calibration.

Briefly stated, time in years (t) is a power function of average pit depth (d) in millimeters as follows:

$$t = 14 + 683(d^{0.5})$$

Although it will be refined, this relation seems to work in most places, and independent checks indicate that the results are consistent with dates from archeologic sites, relative stratigraphic position, and degree of surface weathering such as patination or rock varnish.

Application of this method to the prehistoric debris fans of the Nankoweap rapids area shows that the three prehistoric fans are roughly similar in age to those in eastern Grand Canyon (Hereford and others, 1993; 1994) as well as those in western Grand Canyon in the Granite Park area. Thus, we can begin to define periods of prehistoric debris-flow activity in Grand Canyon and Marble Canyon that might correlate with climate fluctuations of the late Holocene. In addition, this method provides a means of dating any near channel debris fan in Grand Canyon. Archeologic sites constructed with limestone clasts can also be dated under appropriate conditions using the pit-depth calibration.

The Rockfall (or Rubble) Ridge

For most people, the most interesting geologic feature of the Nankoweap area is the high ridge of rubbly material on the south side of Nankoweap Creek. The ridge is about 50 m high and is conspicuous because of the numerous angular, large blocks of Kaibab Limestone on the top and sides of the ridge. Most rafters notice these deposits, and their age and origin is interesting to both the specialist and layman.

Studies have shown that the rubbly material fell nearly 1 km from the steep east wall of Marble Canyon in a large, catastrophic rockfall that is dated at sometime shortly before 210,000 years ago (Hereford, 1978; 1984; Elston, 1989; Machette and Rosholt, 1989, 1991). Much confusion, however, has recently been generated among the river-running community about these deposits by observations and written comments made during and after a research trip earlier this year (see Lucchitta Trip Report, April 7, 1994). The following paragraphs will clarify what is known about the rockfall ridge from previous and ongoing work.

The alternative to the rockfall hypothesis is that the rubbly material was transported down Nankoweap Creek by an ancient debris flow or debris flows. This hypothesis is not supported by geologic relations and is only a very weak alternative to the rockfall hypothesis. The problem of rockfall versus debris flow origin has a rather simple solution. If the rubble originated from the east side, then it should contain clasts of all the formations above and including the Bright Angel Shale, that is Bright Angel through Kaibab Limestone--the formations exposed in the east wall of Marble Canyon. However, if the material originated from the west it should contain a wide variety of clasts ranging from Precambrian Supergroup through Kaibab Limestone--the formations exposed in Nankoweap Creek basin. In short, a deposit derived from the west would differ from a deposit derived from the east by the addition of several types of "indicator stones," which are clasts of Supergroup through Tapeats Sandstone. We have found almost conclusive evidence for the rockfall origin of the rubbly debris, based on the composition of the clasts in the rockfall and in the debris fans of Nankoweap and Little Nankoweap Creeks.

A thorough and comprehensive examination of the rubble reveals that it is composed of about 90 percent Kaibab Limestone with the remaining 10 percent evenly distributed among Redwall Limestone, Supai Group sandstone, and Coconino Sandstone. There are no indicator stones from the west side in the body of the rubble deposit. It is claimed that the rubble contains west-side indicator stones. This could result from confusion of indicator clasts with Kaibab Limestone and from the local presence of Tapeats Sandstone near the eroded margin of the rubble. The rubble has a long erosional history involving removal of most of the deposit and incision of several terrace levels by the Colorado River and Nankoweap Creek (Hereford, 1984; Machette and Rosholt, 1989, 1991). This resulted in local deposition of rounded clasts derived from Nankoweap Creek around the eroded margin of the rubble. But again, without exception, west-side stones are not present in the body of the rubble.

Additional information about the composition of recent (late Holocene) debris flows in Nankoweap and Little Nankoweap Creek shows clearly that the rubble was not derived from the west. The debris fan of Nankoweap Creek does not contain clasts of Kaibab Limestone, although the Little Nankoweap Creek fan contains some Kaibab clasts, but they are typically less than 1 percent. Redwall Limestone is the dominant lithology in both cases, and Tapeats Sandstone is abundant in the Nankoweap Creek fan. A gravel deposit that underlies the rubble also lacks Kaibab clasts, indicating, not surprisingly, that composition of sediment from Nankoweap basin has not changed over time.

Another important difference between the rubble and west-side debris-flow deposits is the degree of rounding. Clasts in the rubble deposit are universally angular in all sizes ranging from about 5 millimeters to 7 meters, except for the very small percentage of rounded clasts derived from the Colorado River. Indeed, the rubble should be properly classified as a sedimentary breccia, which we intend to do after microscopic examination of the sand-sized matrix. In contrast, the recent debris flows and the ancient Nankoweap-derived gravel underlying the rubble have subangular to subrounded clasts, the result of abrasion during transport from the headwaters and canyon of Nankoweap Creek.

Further evidence demonstrating the difference between west-side debris flows and the rubble is the size of clasts. Clasts in the recent debris flows and ancient gravel are significantly smaller than those in the rubble. Average maximum clast size in the rubble is 1-7 meters, whereas in the recent debris flows and ancient gravel maximum size is only about 1 m at most. Extremely large clasts are not carried to Nankoweap delta by debris flow, either in recent or ancient times.

It is also claimed that the rubble resembles a typical debris flow. However, it is difficult to distinguish the two types of deposit under the best of circumstances. A recent publication lists the criteria necessary to distinguish debris flow from rock avalanche (Yarnold and Lombard, 1989, Table 1). The geomorphology and sedimentology of the rubble fits the generally accepted criteria of a rockfall as recognized by these authors.

Finally, elementary calculations are used to claim that debris falling from the present east wall of Marble Canyon could not reach the Nankoweap ridge, which would make the rockfall emplacement mechanism unlikely. Moreover, these calculations are justified by assuming that the rockfall did not spread as a fluid-like substance once at the base of the cliff.

It is argued that if fluidization was important, the debris should be spread up and down the canyon and even part way up the west wall. Large rockfalls typically create fast moving streams of debris called "sturzstroms" (the classic reference is Hsu, 1973). This cohesionless flow causes rockfall debris to be spread far up and down a valley and even surge up the sides by the power of its momentum. Evidence for widespread distribution of the debris is not readily apparent at Nankoweap, which, to some provides evidence that a sturzstrom could not have occurred. However, the rubble is poorly preserved, having been extensively eroded by the Colorado River in the past several hundred thousand years, so its original extent is unknown But, the rockfall debris is preserved on the north side of Nankoweap Creek far-up the base of the west wall. Thus, there is no reason to dismiss sturzstrom emplacement based on the present distribution of the deposit.

The calculations used to show that the debris could not reach the Nankoweap ridge are deemed appropriate on the assumption that it was not a sturzstrom-type event. As shown above, there is no evidence to suggest that it wasn't such a rockfall. The calculations, therefore, are an oversimplification of a complex emplacement mechanism. But this doesn't really matter, because the present configuration of the east wall was used to define the required horizontal movement of the debris. It is clear that the present configuration is quite different than it was 200,000 years ago at the time of the rockfall. Indeed, reconstruction of the wall shows that it was probably 300-400 meters west of its present location.

This is probably more than you ever wanted to know about the rubble ridge at Nankoweap rapids. It is sufficient to say that a number of publications support the rockfall hypothesis, and a date of 210,000 years before present has been determined for the event using the uranium-trend disequilibrium method. Indeed, more information is available than I can recite here, all of which supports the rockfall hypothesis, we will include all of our data regarding this problem in the discussion of the surficial geology accompanying the published map.

What Next?

Work continues on Nankoweap. We're going to assemble low-altitude aerial photographs to date and interpret erosion by the short tributary streams and to date recent debris-flow activity. The pit-depth measurements will be analyzed statistically for comparison with the other Grand Canyon data. Compilation of the surficial geologic map should be completed early this winter, and we'll schedule a research trip to field check the results.

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cc: J.Balsom
T.Hanks
J. Hillhouse