Stewart Mountain Terrace: A New Salt River Terrace with Implications for Landscape Evolution of the Lower Salt River Valley, Arizona

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ABSTRACT

Stream terraces of the Salt River form the interpretive backbone of Plio-Pleistocene landscape evolution of central Arizona, because they represent the base level of all tributary streams. This paper presents a new addition to T.L. Péwé's Salt River Terrace sequence (in decreasing topographic position and age: Sawik, Mesa, Blue Point, and Lehi) that has been unrefined for the last 30 years. The existence of an older, higher terrace was predicted by research suggesting that the lower Salt River originated by lake overflow from an ancestral Pliocene lake in the Tonto Basin. Field reconnaissance, aerial photo interpretation, and sedimentological analysis revealed this terrace on the north side of the Salt River, named here the Stewart Mountain Terrace (SMT). Where exposed, the fluvial sediments of SMT overlay Tertiary basin fill unconformably. SMT sediments are characterized by ~50 m thick fluvial gravels found more than 70 m above remnants of the Sawik Terrace. Although the gravels are distinctly Salt River in origin, Stewart Mountain gravels differ from the lower and younger Salt River Terraces. The clast sizes are much larger on average and host a significantly different lithology. Because of these differences the SMT has profound implications for the understanding of regional drainage reorganization after basin and range extension. The existence of this terrace and its distinct gravels are consistent with, but do not prove, a lake overflow mechanism for the initiation of through flowing drainage in the Salt River Valley.

Introduction

Fluvial or stream terraces are remnants of ancient floodplains that rest topographically above modern floodplains to create relatively flat bench-like landforms. The former floodplain surface, or terrace tread, represents a period of relative stability within the fluvial system. The abandonment of that surface is represented by incision into the former floodplain. A stream can incise as the result of any combination of several processes: 1) a drop in base level (lowest point in a fluvial system) to which all the drainages respond, 2) an increase in discharge generating an increase capacity for stream erosion, 3) tectonic and/or isostatic uplift in the headwaters that increase stream gradient resulting in incision, and/or 4) a reduction in sediment load into the stream. Because terraces represent a shift from periods of stability and floodplain formation to a period of instability and steam incision, each terrace and incision event records key geomorphic and geochronologic evidence of how the fluvial landscape has changed over time (Leopold and Bull 1979, Pazzaglia et. al 1998, Ritter et. al 2002, Schumm 1973).

Recognizing the significance of stream terraces, Professor Troy L. Péwé and his students at Arizona State University mapped and analyzed Plio-Pleistocene stream terraces along the Salt River of central Arizona in the 1970s (Fig. 1; Kokalis 1971, Pope 1974, Péwé 1978). They documented four former floodplains that were successively abandoned each time the Salt River incised (Fig. 2). The oldest three (Sawik, Mesa, and Blue Point) are strath stream terraces. The term strath connotes that a river incised in its floodplain and into the underlying bedrock, leaving behind only a few meters of alluvial gravel cover. The Lehi Terrace, is a fill terrace, reflecting the Salt River's incision into its own fluvial deposits.

Little data exist as to when the Salt River eroded into its former floodplains leaving behind the sequence of stream terraces. Campbell (1999) analyzed the accumulation of cosmogenic ^{36}Cl in

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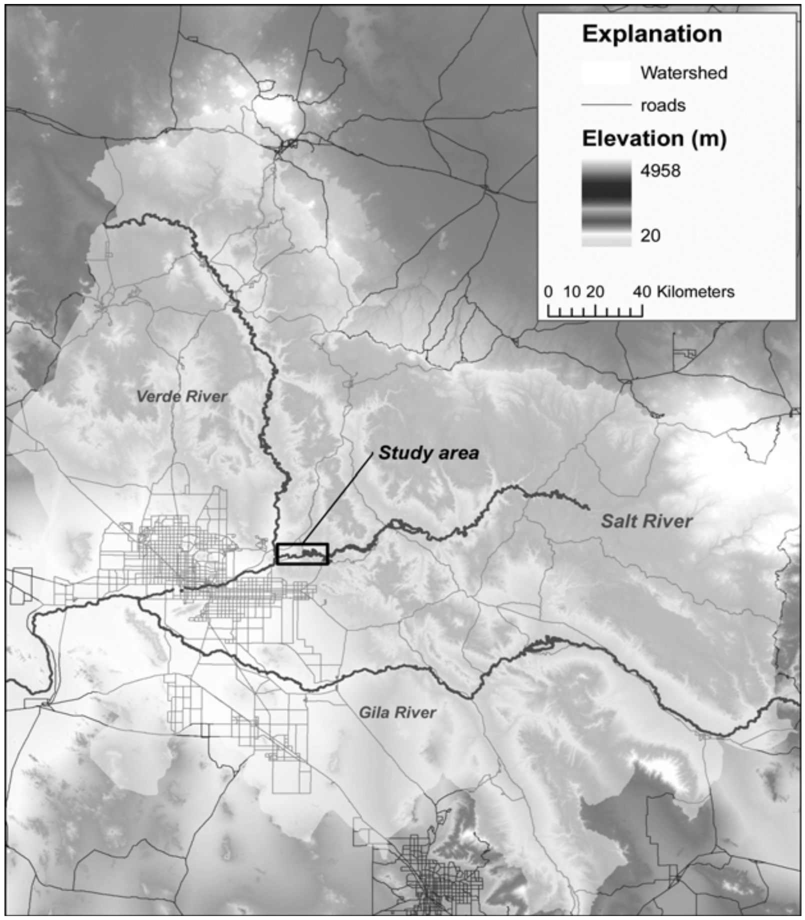

Figure 1. Digital elevation model of Maricopa County, Central Arizona and the location of the Stewart Mountain Terrace study reach within.

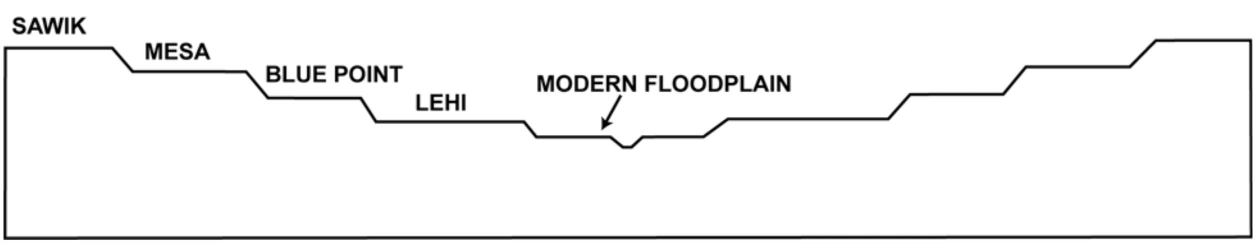

Figure 2. Diagrammatic profile view of terraces of the lower Salt River Valley, after Péwé (1978). This depicts the previously known sequence of four paired terraces within the Salt River Valley.

multiple cobbles from one Sawik Terrace location near the TRW plant in Mesa (N 33.49030 W 111.70840). Campbell (1999) found that cobbles from the Sawik Terrace are close to or at secular equilibrium. Thus, the sampled strath Sawik Terrace exposure was eroded into bedrock and then abandoned more than 1.2 million years ago. Péwé (pers. comm.) thought the Sawik was as old as 2.2 Ma because of its apparent correlation with a terrace surface on the Gila River that is overlain by a 2.2 Ma basalt flow. More dating is needed to determine the precise age of the Sawik Terrace. The Sawik-age course of the Salt River did not mirror its modern day course, but instead flowed on the southern side of the South Mountains, Phoenix, AZ (Hoyos-Patino 1985, Arrowsmith 2001, Block 2007).

The Mesa River Terrace is the most extensive of all four known terraces. It forms a continuous surface from west of the Arizona State University's campus in Tempe, AZ, eastward into the city of Mesa, with more sporadic remnants continuing up the Salt River Valley (Péwé 1978; Fig. 3). The Mesa River Terrace represents a period of base level stability in the Salt River system after incision into the Sawik Terrace. As such, numerous pediments and local tributary streams were graded to this surface (Péwé 1978). Campbell (1999) analyzed ^{36}Cl in multiple cobbles from a road cut along the Bush

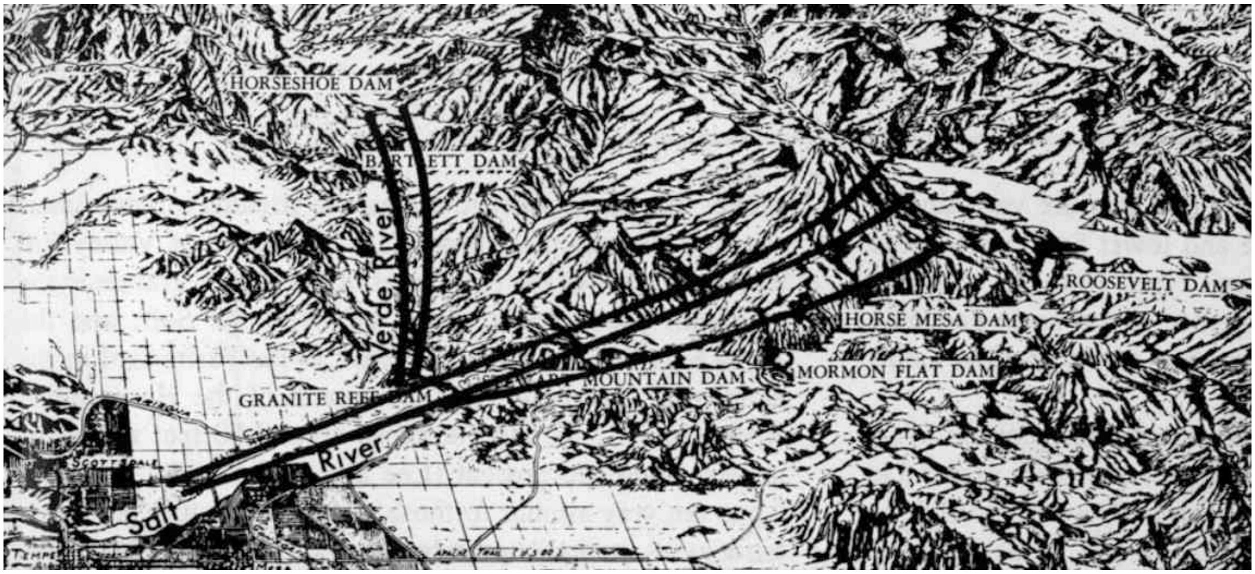

Figure 3. A physiographic diagram produced by the Salt River Project, on which Péwé (1978) indicated the three strath terraces of Sawik, Mesa, and Blue Point along the Salt River. Two terraces were drawn for the Verde River. Note that Péwé pinches out the Blue Point terrace in east Mesa, Arizona. Péwé also used this figure to indicate his assumption of regional correlation of the terraces in each of the tributary watersheds of the Salt-Gila system, central Arizona.

Highway (Marked A on Fig. 4) and calculated a minimum exposure age of 439,000±63,000 years for the Mesa Terrace gravels. This half-million year estimate is roughly consistent with the Stage III-IV soil carbonate development observed at multiple locations in Mesa Terrace soils (Péwé 1978).

Radiocarbon dating of pedogenic carbonate is notoriously difficult and fraught with uncertainties (Callen et al. 1983, Stadelman 1994, Wang et al. 1994), but a radiocarbon age on the innermost carbonate rind around Blue Point terrace cobbles yielded a calendar age of 33,100±380 years (^{14}C age

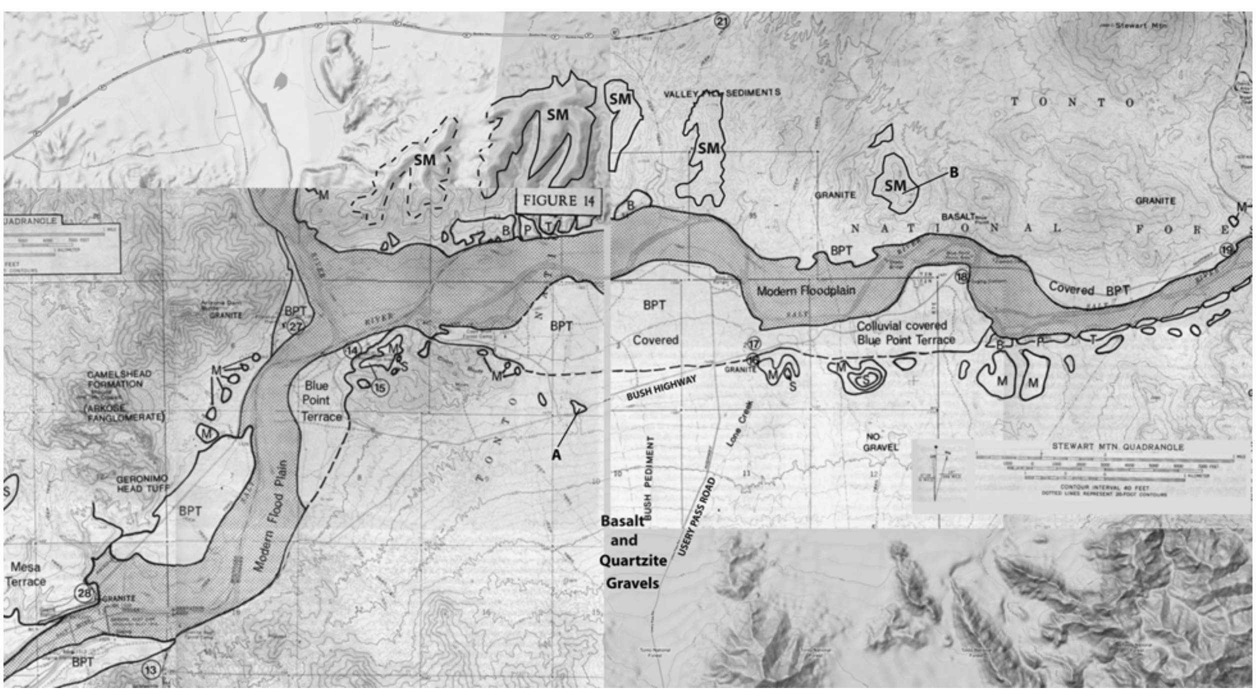

Figure 4. Map of the locations of Stewart Mountain terrace remnants (SM) on the north side of the Salt River, and of rounded quartzite and basalt gravels on the south side of the Salt River - all previously unrecognized. The dashed line indicates the likely boundary of the Stewart Mountain terrace on the Fort McDowell Indian Reservation, as inferred by topography, examination of aerial photographs and binocular examination. Location A marks a ^{36}Cl date on the Mesa Terrace. Location B marks the location of Fig. 5. The base map consists mostly of figures modified from Péwé (1978) showing the locations of Sawik (S), Mesa (M) and Blue Point Terrace (BPT) remnants.

of 30,980±290) (Beta 51401). This age is roughly consistent with the Stage I soil carbonate development seen in Blue Point soils (Péwé 1978). The presence of radiocarbon dated charcoal (Lundin and Royse 1973) and early Holocene turtle shell, reported by Péwé (1978) and Archer (1989) suggests the Lehi Terrace sediment was undergoing active deposition between 5,000-11,2000 years ago. Unlike the other terraces, the Lehi was not eroded into bedrock and consists of alluvium deposited by the Salt River floods. The presence of an early Holocene turtle shell, reported by Péwé (1978) and Archer (1989) suggests the Lehi Terrace is approximately 5,000-10,000 years old. Lehi Terrace fill represents a long sequence of Holocene flooding deposits confined by the higher Blue Point Terrace remnants.

METHODS: A DEDUCTIVE APPROACH

Transverse drainages are streams that cut across mountain ranges or significant topographic barriers to flow. A transverse drainage represents a dramatic change in the fluvial system that can be attributed to only four possible processes: antecedence, superimposition, piracy, and overflow (Douglass et al. 2009a). Antecedent streams drain across and erode a channel into a bedrock structure that uplifts beneath the stream, thus the stream is older than the uplifted structure. Superimposed streams originate flowing atop a covermass of easily erodible material. As the stream incises into the covermass it is essentially locked in place by the underlying bedrock structure. Pirated streams are captured by another drainage that has a steeper stream gradient. Streams that result from lake overflow are originally ponded in endoheic, or interior-drained, basins that eventually overspill at the sill, or lowest point of the basin rim, eroding a canyon across the bedrock structure downstream of overflow apex.

The Salt River flows across several mountain ranges and topographic barriers, hence it contains many transverse sections. The most dramatic transverse section starts at the location of today's Roosevelt Dam, where the Salt River tranverses the Mazatzal Mountains (Fig. 3). Recent research developed a new methodology to analyze the origin of transverse drainages. This research suggests the Salt River's presence downstream of today's Roosevelt Dam is likely due to overflow of an ancestral Lake Roosevelt that existed in the Tonto Basin (see Fig. 3; Douglass et al. 2009a, 2009b:49-51). This conclusion was based on matching geological and geomorphological evidence against objective criteria developed through physical modeling.

As suggested in Douglass et al. (2009b: 49-51), a lake overflow event would have distributed Salt River gravel downstream of the overflow apex into basins that formerly lacked deposits from this major river. Concomitantly, Reynolds and Bartlett's (2002) examination of subsurface sediment near Sky Harbor Airport, Phoenix, AZ, records the sudden arrival of "Salt River Gravels" which suggests the possibility of an overflow origin to the through flowing Salt River (cf. Reynolds and Bartlett 2002; their Fig. 19).

However, a key piece of evidence for a lake-overflow origin of the lower Salt River was missing. A lake-overflow event should have produced large gravel deposits on top of an ancestral landscape that would have lacked a major through-flowing drainage prior to this overflow event. This would be analogous to events that occurred during the birth of the lower Colorado River (House et al. 2005). The ancestral landscape of the area now occupied by the Salt River Valley consisted mostly of fanglomerate deposits derived from the Mazatzal and other local mountain ranges. These fanglomerates were previously mapped as "Valley Fill Sediments" (Pope 1974, Péwé 1978) just north of the Salt River (Fig. 3). These were similarly mapped as "younger sedimentary basin-fill deposits" of late Tertiary age by Scarborough et al. (1981), Skotnicki and Leighty (1997), and Skotnicki et al. (2003). Mazatzal Mountains-derived valley-fill fanglomerate sediments can be seen in cliffs along the north side of the Salt River.

We used deduction in carrying out our research. The first step involved field reconnaissance investigating sites for the predicted overflow gravels. Once the predicted gravels were identified, comprehensive mapping of all locations of previously unidentified Salt River gravels was conducted. Also, particle sizes were measured and compared between the predicted gravels and the gravels of the younger Salt River terraces along randomly located line transects. These data were then placed in the context of prior research to begin to reinterpret the drainage evolution of the Salt River.

RESULTS

The largest deposit of previously unmapped Salt River gravels occurs at the topographically highest exposures of previously mapped "valley fill sediment." The highest gravels are found at 1870' on the north side of the Salt River (Fig. 4). Clasts consist of gravel, cobbles and boulders with the largest boulders exceeding 2 m in the intermediate axis – significantly larger than those on the lower Salt River Terraces. Rock types include granite, quartzite, Proterozoic meta-conglomerate, basalt(s), schist, and other lithologies found in the Salt River basin. These gravels occur approximately 60 m above the Sawik Terrace on the south side of the Salt River (Fig. 5).

This deposit, herein called the Stewart Mountain Terrace (SMT), is named after the nearby prom-

Figure 5. Southwest-looking photograph taken from approximately 1860'on the north side of the Salt River (Marked as B on Fig. 4), looking down at remnants of the Sawik and Mesa terraces on the south side of the River. The newly recognized terrace is identifiable by the rounded gravels seen here. Rounded gravels reflect fluvial transport and subsequent deposition of alluvium, preserved as the oldest and highest stream terrace of the Salt River.

inent bedrock mountain that may have played a role in preservation of the terrace remnants. The same gravel deposit exists on top of the valley fill on preserved terraces for about 6 km along the north side of the Salt River (Fig. 4).

Currently, the age of SMT is unknown. Its topographic prominence in relation to the other terraces (Figs. 6 and 7) indicates that it is the oldest in the Salt River terrace sequence. One gully exposure reveals a Stage IV+ calcrete underneath the terrace gravels, but the presence of a calcrete duricrust is not diagnostic of any particular age beyond a half-million years. Resolving its age will require cosmogenic nuclide analyses.

The thickness of the SMT gravels is difficult to determine because of the lack of a clean exposure at the base of the deposit. The best insight comes from the easternmost terrace remnant, because gravels are found directly on top of granite bedrock and on top of >3 m diameter granite core stones that could potentially have been moved by flooding. This contact appears to be about 50 m underneath the top of the gravels.

Péwé (1978) and Kokalis (1971) concluded that the basic rock types and size distributions of the Sawik, Mesa and Blue Point terrace gravels were virtually indistinguishable. In contrast, the SMT gravels – while clearly Salt River in provenance –

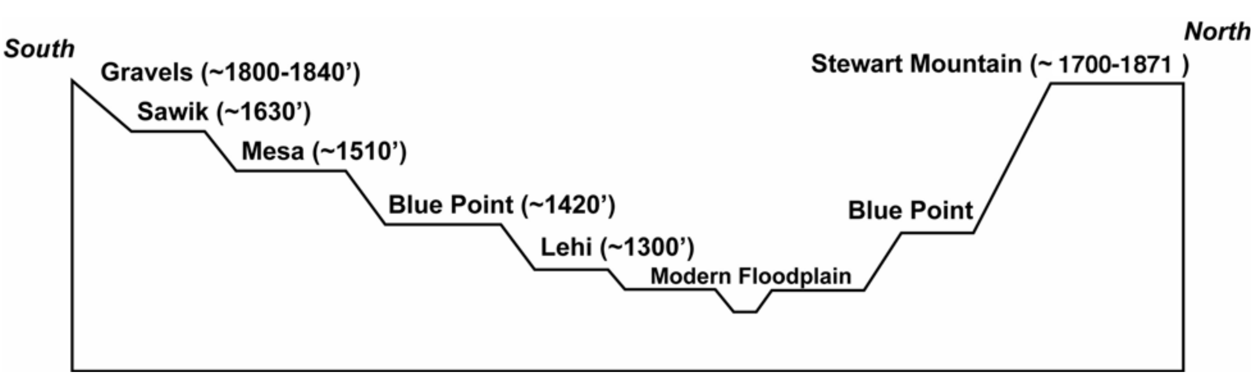

Figure 6. Generalized profile of the revised Salt River terrace sequence, from south to north, approximately where Usery Pass Rd meets the Bush Highway. The lower boundary of the Stewart Mountain Terrace is a rough estimate. The Lehi Terrace does not exist this far east, so the indicated elevation is where Péwé (1978) mapped this inset fill terrace a few kilometers to the west.

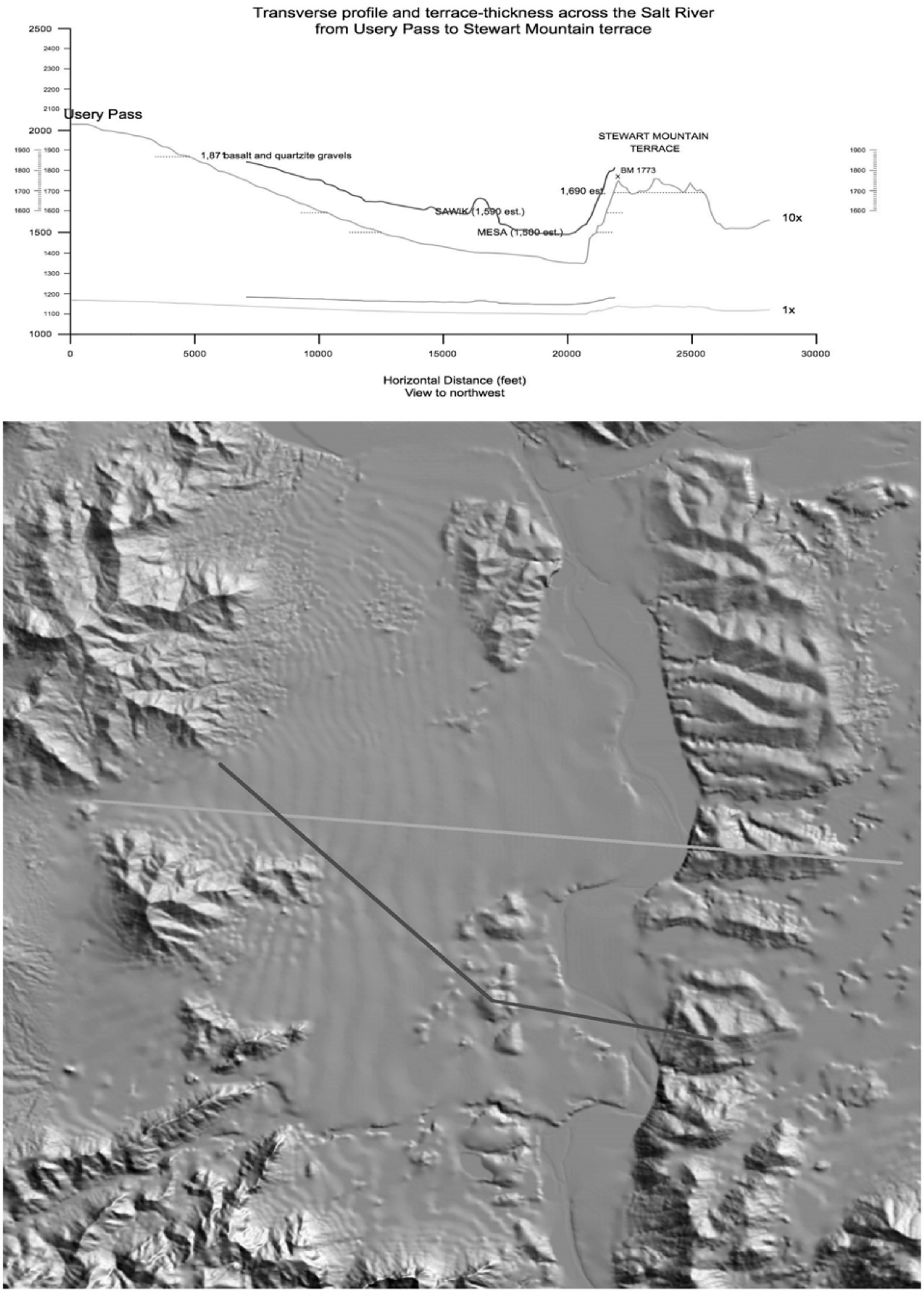

Figure 7. Two topographic profiles across the new terrace sequence. The profiles have been exaggerated 10x and were created in ArcMap using high-resolution DEM elevation.

Table 1. Particle sizes and percent lithology of randomly sampled clasts on different Salt River Terrace. Particle sizes were measured as a part of this study, but the lithology data derives from Kokalis (1971).

Particle sizes	Lehi	Blue Point	Mesa	Sawik	Stewart Mountain
Number of clasts		314	354	360	160
Average (cm)		3.5	3.7	4.9	77.1
Median (cm)		3	3	3	66.5
Largest (cm)		22	21	34	258
Rock Type	**Lehi**	**Blue Point**	**Mesa**	**Sawik**	**Stewart Mountain**
Andesite	5	1	4	1	4
Arkose sandstone	3	4	3	15	3
Basalt	9	8	3	0	3
Dacite	3	3	2	6	1
Diabase, vein quartz and others	13	12	8	1	2
Granite	9	12	10	0	2
Meta-basalt	3	2	1	0	3
Meta-sedimentary	13	14	13	3	6
Orthoquartzite	14	18	24	43	21
Quartz monzonite	5	3	4	1	9
Rhyolite	6	8	8	10	40
Siltstone and shale	10	7	10	13	3
Subarkose sandstone	8	6	10	7	3

are much larger (Table 1). In addition, the lithologies of the SMT gravels are substantially different from the younger terrace gravels. Kokalis (1971) undertook an extensive study of clast lithology on the different terraces of the Salt River in the area of Figure 4, where Kokalis examined hundreds of clasts. A video of the collection process has been archived <http://www.azgs.az.gov/VISUALIZE/VIDEO/Pewe%20Collection/pewe2.mp4>. In addition, Kokalis also examined the composition of clasts in a location he identified as valley fill – but we identify as a remnant of SMT. We are perplexed why Kokalis did not correctly identify this geomorphic feature as belonging to the Salt River Terrace sequence. Still, it is significant that the composition and size of the Sawik and Stewart Mountain Terrace gravels are distinct and significantly different from the younger surfaces (Table 1 and Fig. 8).

Because river terraces can have pairs on the other side of a valley, we investigated the reach between 1600' and 1900' parallelling SMT on the south side of the Salt River and found only one location that contains anomalous quartzite and basalt cobbles. This location lies between 1600' and 1820' just west of the Usery Pass Road (labeled basalt and quartzite gravels; Fig. 4 and Fig. 7). These clasts do not form a river terrace, but represent the base of an anomalous old gravel deposit resting on granodiorite bedrock.

Figure 8. The Stewart Mountain terrace hosts an abundance of boulders with intermediate axes larger than 2 m in diameter. In contrast, it is difficult to find boulders with the axis more than a 0.5 m in diameter on the lower Salt River terraces.

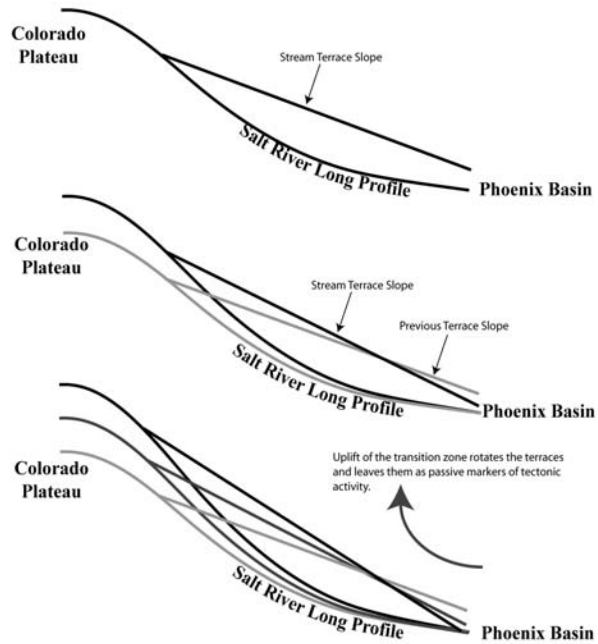

Figure 9. Model of neotectonic uplift resulting in present terrace slope and morphology along the Salt River, based on ideas presented by Péwé (1978, pers. comm.). This model would produce similar rock types for each terrace, since the source areas would be similar. This model also reflects the characteristic change in slope that can be observed in Salt River terraces. As suggested, uplift of the transition zone and subsequent subsidence of the Phoenix Basin may have allowed for the terraces to passively rotate establishing their present change in slopes. This diagram is modified from Block (2007).

DISCUSSION

The general model (e.g., Péwé 1978 and pers. comm.) for the past 30 years has been that the lithology, and hence source areas, of the Salt River terrace gravels has remained relatively similar. This model also suggested that the slope of the terraces, which decreases from Sawik to Lehi, reflects epeirogenic uplift of the transition zone in Arizona and possibly subsidence of the Phoenix Basin, resulting in the passive rotation of the terrace surfaces over time (Fig. 9).

Following Péwé (1978, pers. comm.), available data are consistent with similar source areas for the Lehi, Blue Point, and Mesa terrace gravels. However, the Sawik and SMT gravels appear to have somewhat different lithologies, a finding that indicates a shift in the provenance of Salt River gravels (Table 1). A full understanding of the potential source areas of these gravels is a project beyond the scope of this research; however, at this point, the substantial change in observed gravel rock types justifies reinvestigating the Salt River terraces (Fig. 9).

The observed change in terrace slope over time (Péwé, 1978, pers. comm.; Fig. 3) and the change of rock types would be consistent with an alternative explanation for the older terraces having progressively steeper longitudinal profiles. Enlarging the drainage area of the Salt River would alter its longitudinal profile (Fig. 10). At any given location along the Salt River, the gradient would be lowered every time the Salt River's drainage area increased. Headward extension of the Salt River could be relatively rapid, through the initiation of through-flowing drainage by lake overflow (e.g. Douglass et al. 2009a, 2009b). Alternatively, headward extension of the drainage up into the Mogollon Rim could also be gradual. Either process of headward extension could produce the observed change in lithology and progressively increasing slopes of older terraces.

The model, tentatively favored here, for initiation/localization of through flowing drainage of the Salt River and the occurrence of the SMT is the overflow hypothesis of Douglass et al. (2009a, 2009b). Further support for this model comes from previous research suggesting lacustrine sediments from a large Pliocene lake existed in the Tonto Basin upstream from the SMT (Peirce 1984). Using the analog of the inception of the Lower Colorado River (House et al. 2005), lake overflow first results

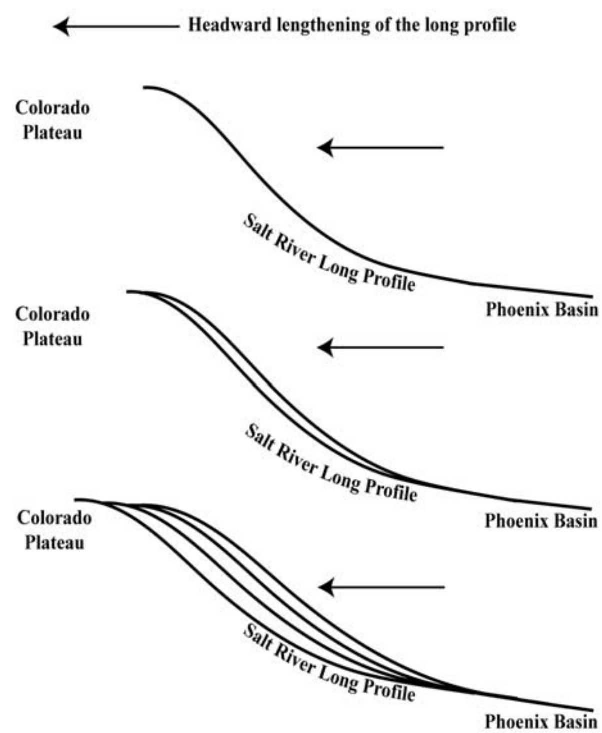

Figure 10. Enlargement of the Salt River's drainage area generates increasingly steep slopes of older Salt River Terraces through headward extension of the Salt River's long profile. Extension of the long profile would result in a decrease in local slope at any given location. In this conceptual model, the initiation of through-flowing drainage would lengthen the long profile of the Salt River over time.

in extensive erosion of the preexisting fanglomerate fill, followed by river aggradation (possibly the SMT gravels) and finally punctuated by dramatic incision until a new base level is reached. The meter-plus diameter gravels of the SMT and underlying calcrete have formed an effective caprock that has preserved the underlying valley-fill sediments. The presence of these large erosion resistant gravels and calcrete could potentially explain the prominent topographic ridge that extends westward from the granite bedrock of Stewart Mountain that separates the lower Salt and lower Verde River valleys (Fig. 11).

Because the SMT gravels represent the highest known position of the Salt River, a corollary question is how much fanglomerate eroded from the basin before the SMT gravels were deposited. The highest recorded position of basin-fill deposits come from Skotnicki and Leighty (1997, p. 11) who write:

> *Projection of the basin-fill deposits on the north side of the [Salt] river southward suggests that the piedmont south of the river was also once buried by basin-fill deposits. South of the map area in the Apache Junction quadrangle, a high remnant of these deposits rests on the northeast side of Pass Mountain about 2400 feet (T2N, R7E, S25). This means that at least 1000 feet of basin-fill sediments were removed prior to deposition of the Sawik terrace – prior to about the latest Pliocene.*

We have not yet been able to confirm this observation, but there is only about 161 m between the highest SMT position and this remnant. Thus, the overflow event would have had to remove about 161 m of prior valley fill before the onset of aggradation and gravel deposition. Such initial incision is an expectation of the lake overflow process (e.g., House et al. 2005).

Lake area and height of retreating knickpoints determine the severity of the initial overflow event. Initially the overflow water only transports sediment sourced downstream from the lake, as upstream sediment is trapped in an endorheic basin. If an overflow event occurred it would start out by eroding a channel in the pre-existing rocks, because the pre-existing lake would have to be drained completely before a through-flowing stream could transport up-basin gravels. We speculate that erosion of these pre-existing rocks could possibly explain the substantially different lithology of SMT gravels. Floodwaters rapidly incising into pre-existing bedrock and channels would accelerate removal of valley-fill sediment.

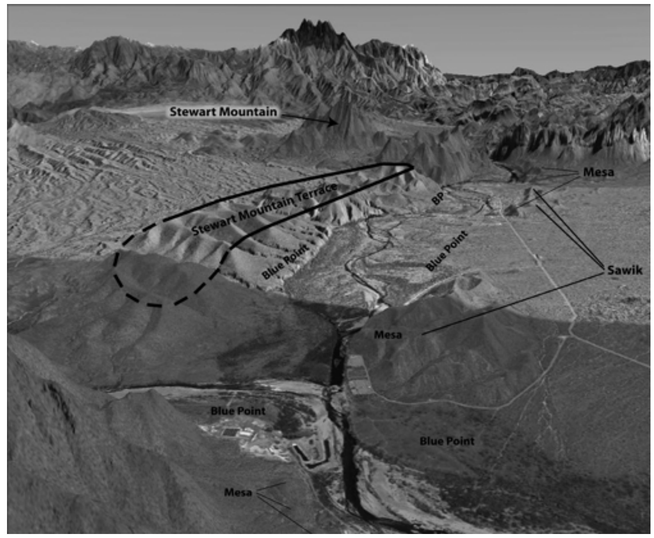

Figure 11. East-looking Google Earth view of the Salt River Terraces mapped in Figure 4. The Stewart Mountain gravels rest on top of a prominent ridge. The image is used following permission guidelines for Google Earth. [http://www.google.com/permissions/geoguidelines.html]

Following the hypothesized overflow event, accumulated sediment stored in the previously closed Tonto Basin would mobilize along the newly lengthened Salt River. The high sediment discharge forces the river to rapidly aggrade in order to steepen the channel and increase the river's slope. The Stewart Mountain gravels could represent this aggradational event. The steeper slope supplies the shear stress or stream power necessary to move the large influx of sediment (Bagnold 1973, 1977; Ritter 2002). As the amount of stored sediment supplied to the Salt River wanes, the river no longer requires the steeper slope and will then more gradually establish a shallower gradient approaching a graded state through periodic incision (Schumm and Lichty 1965, Schumm 1977).

We speculate that the Mesa Terrace may represent this return toward equilibrium, and we speculate that the Sawik gravels could represent the Salt River's slow adjustment towards this equilibrium. It is also possible that SMT gravels did not herald the breaching of the Tonto Basin and that the Stewart Mountain Terrace similarly represents the Salt River's adjustment towards equilibrium; however, the existence of the SMT is strongly consistent with the overflow hypothesis, but neither is proof of the other.

CONCLUSION

Stream terrace sequences provide vital evidence in studies of the evolution of drainage basins. The newly discovered Stewart Mountain Terrace, introduced here, represents a significant addition to scholarship on the Salt River's drainage. The unique position, lithology, and particle sizes of Stewart Mountain gravels suggest that the previous neotectonic uplift model proposed by Péwé (1978) and modified by Block (2007) may require revision. The existence of the Stewart Mountain terrace reveals a need to reinterpret the Plio-Pleistocene evolution of Salt River fluvial system in central Arizona. Although chronometric studies will be needed to analyze the newly discovered sequence of events in the landscape evolution of the Salt River Valley, we note that the lake overflow model proposed by Douglass et al. (2009a, 2009b) predicted the occurrence of a feature such as the Stewart Mountain Terrace. While available data are consistent with lake overflow as the process responsible for initiating the through-flowing Salt River fluvial system, many questions surrounding a lake-overflow mechanism remain to be answered.

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