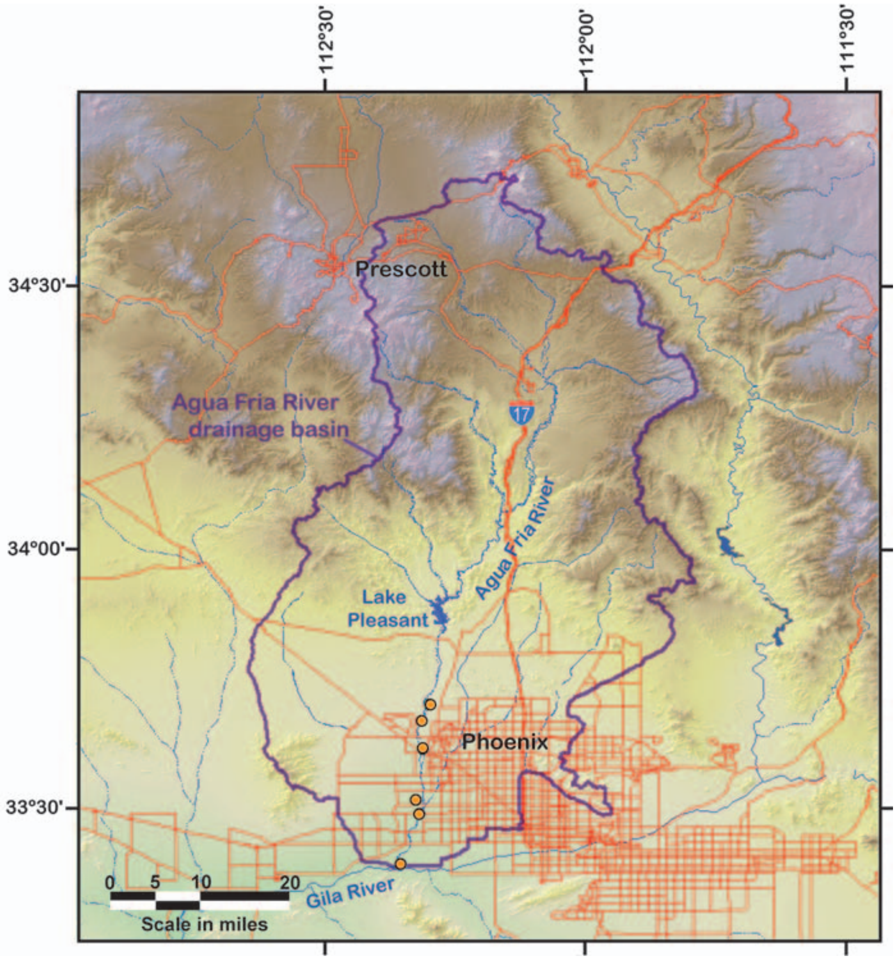
Geologic study of gravels of the Agua Fria River, Phoenix, AZ

The annual consumption of sand and gravel aggregate in 2006 in the Phoenix, AZ metropolitan area was about 76 Mt (84 million st) (USGS, 2009), or about 18 t (20 st) per capita. Quaternary alluvial deposits in the modern stream channel of the Agua Fria River west of Phoenix are mined and processed to provide some of this aggregate to the greater Phoenix area. The Agua Fria drainage basin (Fig. 1) is characterized by rugged mountains with high elevations and steep stream gradients in the north, and by broad alluvial filled basins separated by elongated fault-block mountain ranges in the south. The Agua Fria River, the basin's main drainage, flows south from Prescott, AZ and west of Phoenix to the Gila River. The Waddel Dam impounds Lake Pleasant and greatly limits the flow of the Agua Fria River south of the lake. The southern portion of the watershed, south of Lake Pleasant, opens out into a broad valley where the river flows through urban and agricultural lands to its confluence with the Gila River, a tributary of the Colorado River.

FIGURE 1

Index map of the Agua Fria River drainage basin showing locations of six major sand and gravel operations (yellow dots) along the lower part of the Agua Fria River.



General stratigraphy of the Agua Fria River gravel deposits

The sand and gravel aggregate exploited from the Aqua Fria River channel consist of three stratigraphic layers or potential resource zones referred to in this article as the upper, middle and lower alluvial deposits. Some of the middle and lower alluvial deposits contain weathered clasts of volcanic rocks, which are commonly removed during aggregate processing. An understanding of the occurrence of these weathered clasts can help producers estimate production costs and the value of their reserves.

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The upper alluvial deposit consists of an even mix of sand and gravel with varying amounts of silt and clay. An overburden layer consisting of fine grained silty sand to sandy silt with trace amounts of fine gravel overlies most of the upper alluvial deposit.

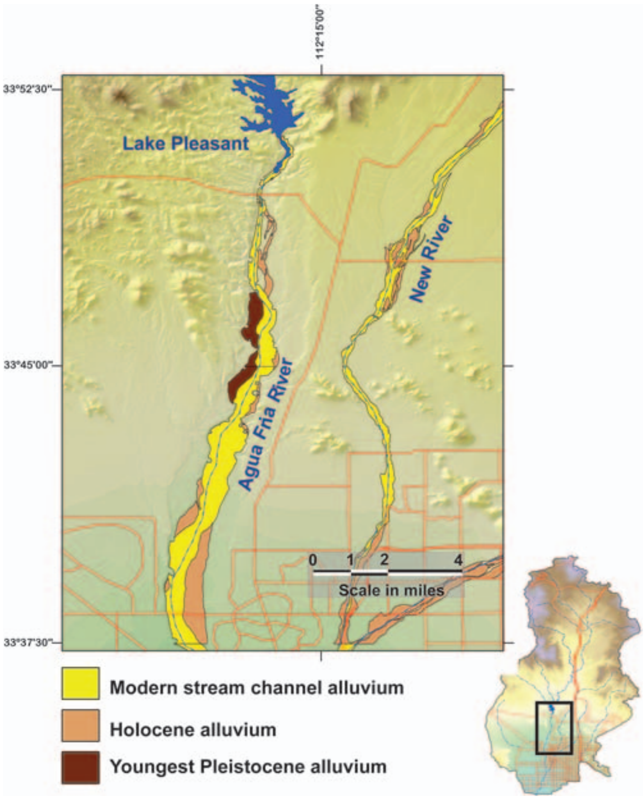
The middle alluvial deposit underlies the upper alluvial deposit. It is slightly coarser with larger sized gravel than the upper alluvial deposit, and has slightly more clay, silt and coarse sand.

The lower alluvial deposit is the lowest unit that could theoretically be extracted without extensive interburden removal. It has significantly more fines than the upper and middle alluvial deposits and lies on a fairly pervasive clay unit below.

Huckleberry (1995) defined one Holocene and six Pleistocene terraces formed along the modern channel of the Agua Fria River. The upper alluvial deposit correlates with Huckleberry's unit Y2 – the modern stream channel of the Agua Fria River (Fig. 2). The middle alluvial deposit is tentatively correlated to deposits associated

FIGURE 2

Quaternary deposits described in this report, located in the southern part of the Agua Fria River basin. Compiled from Huckleberry, 1995.



with Huckleberry's unit Y1 – Holocene alluvium located outside the modern stream channel of the Agua Fria River (less than10,000 years old). The lower alluvial deposit is tentatively correlated to the deposits associated with Huckleberry's unit M2d – the lowest and youngest Pleistocene stream terrace along the Agua Fria River (10,000 to 200,000 years old).

Discussion

Fourteen samples ranging in size from 34 to 57 kg (75 to 125 lbs) were collected from Agua Fria River alluvium for geologic examination: three samples from the upper alluvial deposit, seven from the middle alluvial deposit and four from the lower alluvial deposit. Samples were sieved and weighed in the field to determine gradation. Clasts larger than 76 mm (3 in.) were separated from the sample by hand. Sieve sizes, from top to bottom, were: 38 mm (1.5 in.), 19 mm (0.75 in.), 9.53 mm (0.375 in.) and 4.75 mm (0.2 in.).

All sieved samples were discarded in the field except for the -38 mm (-1.5 in.) + 19 mm (+0.75 in.) gravel clasts, that were reserved for further geologic analyses and engineering tests. These clasts were classified into eight groups based on the lithology of the clasts and were traced back to their bedrock source in the upstream portion of the Agua Fria drainage basin.

The eight lithologic groups were combined into three larger groups; Precambrian and Cretaceous plutonic rocks, Precambrian metamorphic rocks, and Tertiary volcanic and sedimentary rocks. Samples from these three groups were analyzed for specific gravity, porosity and loss from abrasion. Weathering was measured at 13 of the sample localities using in situ measurements of individual clasts. Selected weathered samples were also examined with a scanning electron microscope equipped with an energy dispersive X-ray spectrometer to determine characteristics of weathered gravel.

Grain size distribution (gradation)

The grain size distribution curves of the upper alluvial deposit and middle alluvial deposit overlap and are essentially the same (Fig. 3). The lower alluvial deposit has about 10 percent more fines than the upper and middle alluvial deposits. Many clasts from the lower alluvial deposit broke apart during sieving and collected on the 4.75 mm (0.2 in.) sieve. These clast fragments probably would have broken down even more with more vigorous, mechanical screening and probably would have passed through to the pan, thus increasing the percentage of fines in the lower alluvial deposit even more.

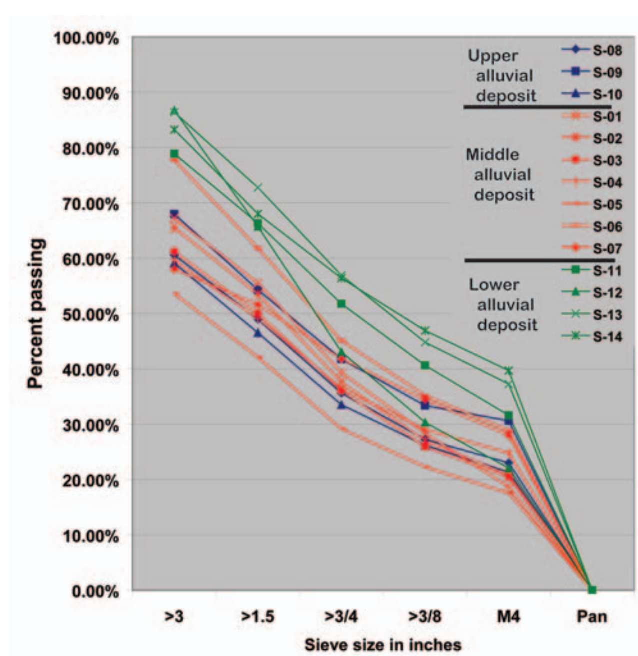
Gravel clast lithology

Each of the -38 mm (-1.5 in.) +19 mm (+0.75 in.) gravel clasts were visually classified into one of the eight following lithologic groups (Table 1): Crazy Basin granite, Crazy Basin pegmatite, gabbro, New River aplite, New River rhyolite, other metamorphic rocks, Tertiary basalt and Tertiary felsic volcanic and sedimentary rocks. Many of these clasts can be traced back to their bedrock source areas in the northern part of the Agua Fria basin (Fig. 4). Most of the clasts have been transported 40 km (25 miles) or more, but potential source areas for Tertiary volcanic and sedimentary rocks are within 16 km (10 miles) of some of the Agua Fria River gravel operations.

There is very little difference in the distribution of rock types among the three alluvial deposits (Table 1), especially when grouping Crazy Basin granitic and Crazy Basin pegmatites into a single class, and when considering all Tertiary rocks as one class (Table 1). This leads to the conclusion

FIGURE 3

Grain-size distribution by sample site and by alluvial deposit. Total weight of samples 637 kg (1,404 lbs).



that the gravel clasts of all three deposits share the same general source areas. This observation also holds true when combining the clasts into three groups: Precambrian and Cretaceous plutonic rocks, Precambrian metamorphic rocks, and Tertiary volcanic and sedimentary rocks.

Engineering properties of rock types

After the -38 mm (-1.5 in.) +19 mm (+0.75 in.) clasts were classified for lithology, the individual clast types were physically combined by alluvial deposit into three classes: Precambrian and Cretaceous plutonic rocks, Precambrian metamorphic rocks and Tertiary volcanic and sedimentary rocks. Each class of rocks was tested to determine specific gravity, absorption and resistance to abrasion (Table 2).

The results of the engineering tests provide insights into the state of weathering of the gravels in the three alluvial deposits. The specific gravity of all rock types decreased with increasing depth (and age) of alluvial deposit. Conversely, absorption increased with increasing depth (and age) of alluvial deposit. One exception is plutonic rocks of the lower alluvial deposit, which appears to have an anomalously low absorption, especially when compared to specific gravity or the equivalent metamorphic rocks. Loss due to abrasion (Micro-Deval) increased with increasing depth (and age) of the alluvial deposits. Decreasing specific gravity, increasing absorption and increasing loss due to abrasion with increasing depth and age of the alluvial deposits are all indications that weathering of the deposits increases with depth and age. The anomalous absorption result for plutonic rocks may be because the strongly weathered pegmatites that commonly have a high absorption value broke apart during sieving and may have preferentially been removed from the samples.

Gravel clast weathering

The state of weathering was measured in situ at 13 of the 14 localities. Weathering was not measured at one locality for safety considerations. A reference line was established approximately horizontally along the pit face. Weathering was measured for clasts 25.4-mm (1-in.) in diameter or greater in a zone extending 101.6 mm (4 in.) above and

FIGURE 4

Generalized distribution of rocks in the Agua Fria River basin. Compiled from DeWitt et al., 2008; Korroch et al., 1997; Richard et al., 2007 and unpublished mapping by DeWitt (U.S. Geological Survey).

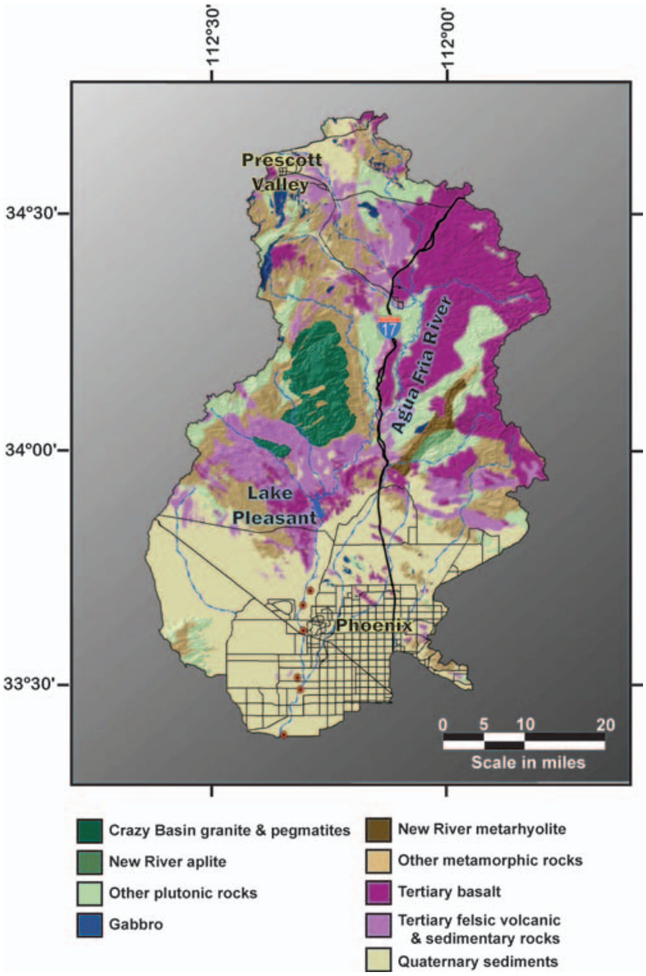


Table 1

Distribution of clast lithology in each alluvial deposit. Total number of clasts – 2,356. Values do not always add to 100 percent due to rounding.

Lithologic unit	Upper alluvial deposit	Middle alluvial deposit	Lower alluvial deposit
Precambrian and Cretaceous plutonic rocks			
Crazy Basin granite and pegmatites (combined)	25%	25%	27%
New River Aplite	3%	4%	7%
Gabbro	4%	5%	3%
Total Precambrian and Cretaceous plutonic rocks	32%	34%	37%
Precambrian metamorphic rocks			
New River metarhyolite	9%	9%	10%
Other metamorphic rocks	24%	22%	23%
Total Precambrian metamorphic rocks	33%	31%	33%
Tertiary volcanic and sedimentary rocks			
Basalt	2%	3%	6%
Tertiary felsic volcanic and sedimentary rocks	31%	33%	24%
Total Tertiary volcanic and sedimentary rocks	33%	36%	30%
Total all lithologic units	98%	101%	100%

Table 2

Specific gravity, absorption and Micro-Deval abrasion values for -38 mm (-1.5 in.) +19 mm (+0.75 in.) clasts of three major rock classifications. Approximate oven-dry weight of sample submitted – 45 kg (99.2 lbs).

Sample location	Specific gravity (ASTM C 127)	Absorption (ASTM C 127)	Micro-Deval abrasion grading B (ASTM D 6928)
Precambrian and Cretaceous plutonic rocks			
Upper alluvial deposit	2.67	0.8%	12%
Middle alluvial deposit	2.62	1.4%	13%
Lower alluvial deposit	2.61	1.0%	16%
Precambrian metamorphic rocks			
Upper alluvial deposit	2.81	0.5%	12%
Middle alluvial deposit	2.79	1.0%	12%
Lower alluvial deposit	2.70	1.2%	16%
Tertiary volcanic and sedimentary rocks			
Upper alluvial deposit	2.62	2.5%	24%
Middle alluvial deposit	2.59	3.9%	30%
Lower alluvial deposit	2.51	4.00%	35%

below the reference line. Each clast was scratched with a sharp-pointed steel awl. Clasts were classified as unweathered, slightly weathered, weathered or decomposed. Unweathered clasts showed no affect from scratching. The surface was slightly scratched on slightly weathered clasts. Weathered clasts were deeply scratched but remained intact. Decomposed clasts broke apart upon being scratched.

In all three alluvial deposits, more than 99 percent of the plutonic rock clasts and the metamorphic rock clasts were unweathered, reflecting the resistant nature of the minerals in those rocks to weathering. In contrast, the Tertiary volcanic clasts demonstrated significant weathering (Table 3). The upper alluvial deposit contained the least amount of decomposed Tertiary volcanic clasts; less than one percent. In the middle alluvial deposit, seven percent of the Tertiary volcanic clasts were decomposed. Weathering was most severe in the lower alluvial deposit, which contained 14 percent decomposed Tertiary volcanic clasts.

The amount of weathered clasts in each alluvial deposit roughly correlates with observations of manganese dioxide staining in the three alluvial deposits, with the upper alluvial deposit having practically no manganese staining, and the lower alluvial deposit having the most staining. Weathered clasts tend to be concentrated around zones of manganese staining.

Weathering also correlates with the age of the deposits. The oldest, lower alluvial deposit has significantly more weathered and decomposed clasts than the younger, upper and middle alluvial deposits.

The clasts in the Agua Fria River gravels that are most susceptible to weathering are the tuffaceous clasts where the high porosity and permeability of the rock allows for oxygen and water diffusion from an exposed surface (Oyama and Chigira, 1999). Oxygen and water diffusion into the rock, combined with the rock chemistry, lead to the breakdown of glass and metastable minerals of the original ash into softer minerals such as clays and zeolites (Steindlberger, 2004). These soft alteration products themselves can lead to mechanical weathering, particularly when shrink/swell clay minerals such as smectite are present.

Weathered tuffaceous rock clasts can easily be cut by excavating equipment, with part of the clast remaining in the pit face. The effort required to pluck rock from the pit

FIGURE 5

X-ray map of weathered tuffaceous rock. Much of the material in this field of view is clay (green) with very little original glass remaining (red).

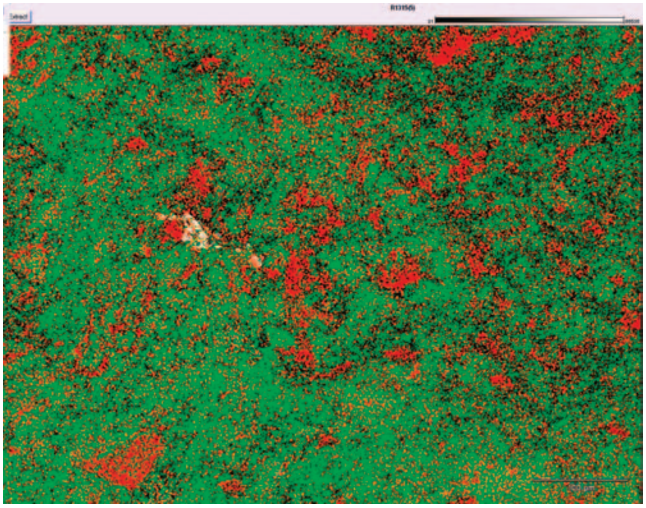


FIGURE 6

X-ray map of weathered basaltic rock. Original minerals such as plagioclase, pyroxene, amphiboles and ferromagnesium minerals (red) occupy most of this field of view. Areas where plagioclase or other minerals have been altered to clay (green) are restricted to a few zones.

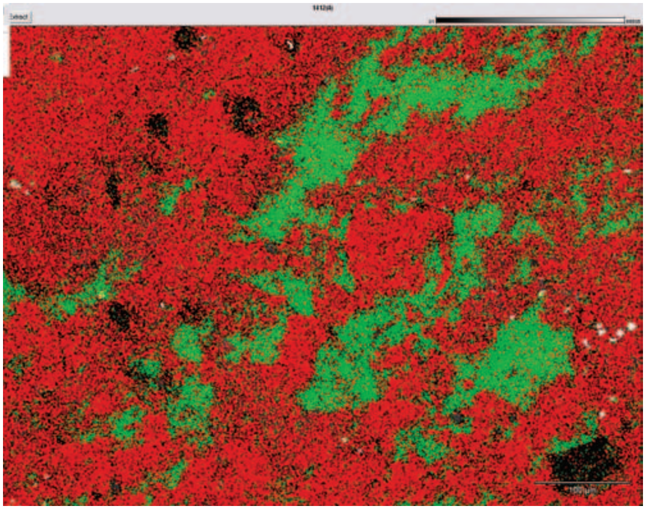


Table 3

Percentage of weathered Tertiary volcanic clasts in each alluvial deposit by degree of weathering. Total number of clasts – 1,120. Values may not add to 100 percent due to rounding.

	Weathering of Tertiary volcanic and sedimentary rocks				
	Unweathered	Slightly weathered	Weathered	Decomposed	Total
Upper alluvial deposit	75%	23%	2%	<1%	100+%
Middle alluvial deposit	37%	45%	12%	7%	101%
Lower alluvial deposit	26%	42%	18%	14%	100%

face is greater than the effort to cut it into pieces, indicating a significant degree of weathering occurs even before the rocks are directly exposed to the atmosphere.

Basaltic rock clasts are also susceptible to chemical weathering, although they are less porous and less permeable than tuff. Therefore, it is much more difficult for solutions to infiltrate basaltic rocks, thus limiting the opportunity for alteration solutions to react with the rock, which increases the weathering time.

Weathered basaltic rock cobbles were observed on the pit floors near the pit faces of the middle and lower alluvial deposits. These cobbles obviously were dislodged from the pit face and remained intact after tumbling or falling to the pit floor. It is hypothesized that the cobbles were fractured during the fall, creating pathways for fluid transport and subsequent mechanical weathering through multiple wetting/drying and freezing/thawing cycles. The weathered cobbles were observed in areas where the pit had not been worked for five years, giving a maximum time for weathering.

Samples from weathered tuffaceous and basaltic rock clasts were examined with a JEOL-5800LV scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectrometer (EDS). The EDS is capable of creating X-ray maps of the surface of the samples viewed by the SEM. Figures 5 and 6 are X-ray maps of the weathered tuffaceous material and weathered basaltic material, respectively.

These two figures illustrate the contrasting weathering patterns between tuffaceous and basaltic rocks. In general, the high porosity and permeability, and high glass content of tuffaceous rocks allow uniform weathering through the clasts. The interlocking crystals and lack of glass in basaltic rock restricts water flow to preferential zones, making them more resistant to weathering. This weathering pattern that occurs at the micro scale can also be observed in hand-sized specimen.

Summary

Quaternary alluvial deposits in the modern stream channel of the Agua Fria River, west of Phoenix, AZ, are mined and processed to provide aggregate to the Phoenix metropolitan area. Alluvial sand and gravel exploited for construction grade aggregate on the Aqua Fria River generally consist of three deposits referred to as upper, middle and lower alluvial deposits. These three units tentatively correlate to three units of Huckleberry (1995): the modern stream channel of the Agua Fria River; Holocene alluvium located outside the modern stream channel of the Agua Fria River (less than 10,000 years old); and the lowest and youngest Pleistocene stream terrace along the Agua Fria River (10,000 to 200,000 years old).

A fine-grained overburden layer commonly overlies the upper alluvial deposit. The middle alluvial deposit has slightly more clay and coarser gravel-sized clasts than the upper alluvial deposit. The lower alluvial deposit is more weathered and has more clay than the middle alluvial deposit and overlies a fairly pervasive clay unit, which makes it the lowest gravel unit that could theoretically be extracted without extensive interburden removal.

Sampled gravel clasts were classified into eight groups of rock types based on bedrock outcrops occurring in the northern part of the Agua Fria River drainage basin. Most of the Precambrian and Cretaceous plutonic rock clasts as well as the Precambrian metamorphic rock clasts have been transported 40 to 80 km (25 to 50 miles) or greater. Potential source areas for Tertiary volcanic rock clasts occur within 40 km (10 miles) of some of the Agua Fria River gravel operations. The specific gravity of clasts in all three groups of rock types decrease with increasing depth and age of the alluvial deposits. Conversely, absorption and loss due to abrasion generally increase with increasing depth, age and weathering of the alluvial deposits.

Weathered clasts in the Agua Fria River alluvial gravels commonly are removed from salable products during aggregate processing. The clasts that are most susceptible to weathering are the highly porous and permeable tuffaceous clasts of the Tertiary volcanic and sedimentary rocks. They can easily be infiltrated by oxygen and water, are composed largely of reactive glass, and are highly porous and permeable, all which decrease the time needed to form the alteration products. Tuffaceous rock clasts can weather in situ before being exposed by excavation. Basaltic rock clasts are also susceptible to weathering but are less porous and less permeable than the tuff and begin to weather after being exposed to the atmosphere. ■

References

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