U. S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

An evaluation of sand and gravel resources in and near the Prescott National Forest in the Verde Valley, Arizona

By Leslie J. Cox[1]

with a section on

Evaluation of sand and gravel resources using selected engineering variables

By James D. Bliss[2] and Robert J. Miller[3]

Open-File Report 99-127

1999

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

---

[1] Formerly with the U.S. Geological Survey, Tucson, Arizona
[2] U.S.Geological Survey, Tucson, Arizona
[3]U.S. Geological Survey, Menlo Park, California

PREFACE

by James D. Bliss

This report was written in two separate parts. The main body of the report was prepared by Leslie J. Cox in 1995 and the part addressing engineering variables by James D. Bliss and Robert J. Miller in 1997-1998. The synthesis provided by Cox links surficial geologic mapping and mineral resource assessment of sand and gravel. The 50 aggregate pits shown on Plate 1 are those listed in Appendix A, which were taken from a materials inventory for Yavapai County done by the Arizona Department of Transportation (Arizona Highway Department, 1972). The six known sites described by Cox are also found on Plate 1. See conclusions (p. 33) for summary of the work by Bliss and Miller which are not addressed in the executive summary by Cox.

CONTENTS

Executive summary **1**
Abstract/ Non-technical summary **1**
Introduction **2**
- Location and physiography **2**
- Purpose of evaluation **2**
- Previous investigations **2**
- Acknowledgments **4**

Evaluation of the potential for sand and gravel resources **4**
- General Geologic History **4**
- Rationale for depiction of tracts **6**
- Description of tracts **6**
  - [TRACT 2] tract of the basin-fill gravel facies of the Verde Formation of upper Miocene and Pliocene age **8**
  - [Tract 3N] tract of high alluvial fans of upper Pliocene to lower Pleistocene age **9**
  - [Tract 3] tract of thick alluvial fans of Pleistocene age **10**
  - [Tract 4] tract of stream terraces of upper Pliocene to Pleistocene age **11**
  - [Tract 5] tract of alluvial fans of upper Pleistocene to lower Holocene age **12**
  - [Tract 6] tract of stream terraces of middle Pleistocene to lower Holocene age **13**
  - [Tract 7N] tract of young stream terraces, alluvial fans, and active-channel deposits of Holocene age **14**

Conclusions **16**

Evaluation of sand and gravel resources using selected engineering variables, by James D. Bliss and Robert J. Miller

Introduction **18**
Source and types of engineering data **19**
Evaluation of data **19**
- Introduction to data evaluation **19**
- Evaluation of pits and geology using sieve data **20**
  - Introduction to evaluation **20**
  - Less than 3 inch but greater than 3/4 inch mesh sieves **21**

3/4 inch mesh sieve **21**
No. 4 mesh sieve **22**
No. 10 mesh sieve **23**
No. 40 mesh sieve **24**
No. 200 mesh sieve **25**
Los Angeles degradation test (LADT) **26**
Plastic index (PI) **27**
Volume change **29**
Evaluation of pit distribution and geology **31**
Conclusions **33**
References cited **34**

APPENDIXES

A. Basic data used in evaluation of selected engineering characteristics (AHD, 1972) **36**
B. Standard size of processed coarse aggregate for road and bridge construction in 19 classes in AASHTO specification M 43-88 (AASHTO, 1993) **39**

PLATE

1. Tracts with identified sand and gravel resources and the locations of historic sand and gravel, gravel, and borrow pits west of the Verde River in the Verde Valley, Yavapai and Coconino Counties, Arizona.

FIGURES

1. Index map showing the location of the Verde Valley, Arizona **3**
2. Index to U.S. Geological Survey 7.5’ topographic maps and geologic maps of the Prescott National Forest in the Verde Valley, Arizona used in this study **5**
3. Boxplots of material passing the 3 inch (75 mm) mesh sieve but not passing the 3/4 inch (19 mm) mesh sieve **21**
4. Boxplots of material passing the 3/4 inch (19 mm) mesh **22**
5. Boxplots of material passing the no. 4 mesh sieve (4.75 mm) **23**
6. Boxplots of material passing the no. 10 mesh sieve (2 mm or less) **24**
7. Boxplots of material passing the no. 40 mesh sieve (0.42 mm) **25**
8. Boxplots of material passing the 200 mesh sieve (0.074 mm) **26**
9. Boxplots of test results of resistance of a coarse aggregate to degradation by abrasion and impact of the Los Angeles degradation test (AHD, 1972) **27**
10. Boxplots of PI values of plastic Index (PI) values for sites in upper and lower Quaternary alluvial materials **28**
11. Scatter plot of log (PI) and minus 200 mesh material **29**
12. Boxplots of swell values for sites in upper and lower Quaternary alluvial materials **30**

TABLES

1. Stratigraphic table showing correlation of rock unit map symbols to the tracts permissive for the occurrence of sand and gravel resources in and near the Prescott National Forest of the Verde Valley, Yavapai and Coconino Counties, Arizona **7**
2. A comparison of the characteristics of sand and gravel tracts in the Verde Valley, Yavapai

and Coconino Counties, Arizona **8**
3. Resource potential of tracts permissive for the occurrence of sand and gravel resources in and near the Prescott National Forest of the Verde Valley, Yavapai and Coconino Counties, Arizona **16**
4. Comparison of numbers of aggregate and borrow pits by surficial geology **31**

An evaluation of sand and gravel resources in and near the Prescott National Forest in the Verde Valley, Arizona

by Leslie J. Cox

EXECUTIVE SUMMARY

An evaluation of sand and gravel resources in and near the Prescott National Forest in the Verde Valley, Arizona

GENERAL

° The Verde Valley is an area with numerous, isolated, small or of otherwise marginal quality, sedimentary and alluvial deposits that could be utilized as sand and gravel resources.

° The identification and evaluation of sand and gravel resources is facilitated by the availability of recent large scale maps of Quaternary geology.

° The areas that have development potential for sand and gravel resources are divided into 7 tracts on the basis of location, thickness, sorting, soil development, and type of vegetation supported.

ABSTRACT/NON-TECHNICAL SUMMARY

This study was based on available published literature. Although no field investigation was conducted in the Prescott National Forest to the west of the Verde River, a field investigation was conducted in the summer of 1994 by this author on the Coconino National Forest, to the east of the Verde River, where units of surficial materials of the same age and similar character are found (Cox, 1995). The intent of this evaluation of sand and gravel resources in the Prescott National Forest and adjacent areas in the Verde Valley, is to provide the land managers of the U.S. Forest Service with a map that delineates sand- and gravel-bearing geologic units. The map distinguishes (1) sand- and gravel-bearing units that are limited to channels from those that are not, (2) sand- and gravel-bearing units that are thin (generally less than 40 feet thick which is one contour interval on the topographic maps) from those that are locally thick (generally 40 feet or more), (3) sand- and gravel-bearing units that are poorly sorted from those that are well-sorted[4], (4) sand- and gravel-bearing units that have little or no soil development from those that have greater degrees of soil development and lithification, (5) and sand- and gravel-bearing units that support riparian vegetation from those that do not. These distinctive characteristics are related to the geologic age or depositional setting of the rock materials and can be distinguished where areas are mapped in detail.

[4] Deposits of sand and gravel are usually more desirable for commercial development if **not** too well sorted (J. Bliss).

INTRODUCTION

Location and Physiography

The Verde Valley is in central Arizona (fig. 1). The valley is one of several northwest-trending basins in the Transition Zone geological province in Arizona (House and Pearthree, 1993, p. 12). An excellent brief history of the human inhabitation of the valley was summarized in Twenter and Metzger (1963, p. 5-11).

The Verde River flows southwest through the Verde Valley. The flow in the Verde River is perennial and is sustained by ground water from numerous springs (Twenter and Metzger, 1962, p. 1). The eastern tributaries to the Verde River, including West Clear, Beaver, Oak, and Sycamore Creeks, drain the Mogollon Rim, a prominent escarpment marking the southern edge of the Colorado Plateau (House and Pearthree, 1993, p. 12) that rises abruptly 1,000 to 2,000 ft above the valley floor (Twenter and Metzger, 1963, p. 5) on the north and east sides of the valley. On the southwest, the Verde Valley is bounded by a northwest-trending range, the Black Hills, which rise 1,000-3,000 ft above the valley floor.

Exposed along the Mogollon Rim are the Kaibab Formation, Toroweap Formation, Coconino Sandstone, and Supai Formation, all of Paleozoic age ranging from Upper Pennsylvanian to Lower Permian. Also exposed along the rim are Tertiary volcanic rocks and the sedimentary rocks of the Verde Formation. Exposed in the Black Hills are Precambrian rocks, Paleozoic rocks ranging in age from Cambrian to Lower Permian, Tertiary volcanic rocks, and the upper Tertiary Verde Formation.

Purpose of Evaluation

The purpose of this evaluation of the Verde Valley and adjacent areas of the Prescott National Forest is to provide geologic information that may be of use to land managers in making decisions regarding present and future sand and gravel resource development. The distribution of surficial and sedimentary deposits have a wide variation in areal extent and quality were investigated to insure reasonable completeness.

This report used the most detailed geologic maps available to demonstrate the relationships between geologic age, depositional setting, expected quality, and distribution of sand- and gravel-bearing units.

Previous Investigations

Pearthree (1993), House and Pearthree (1993), and House (1994) studied the geology and geomorphology of the central Verde River and prepared detailed maps of the surficial alluvial deposits of the Verde River and its tributaries. Their work defined the physical framework in which the riparian environments along the river exist (Pearthree, 1993, p. 3).

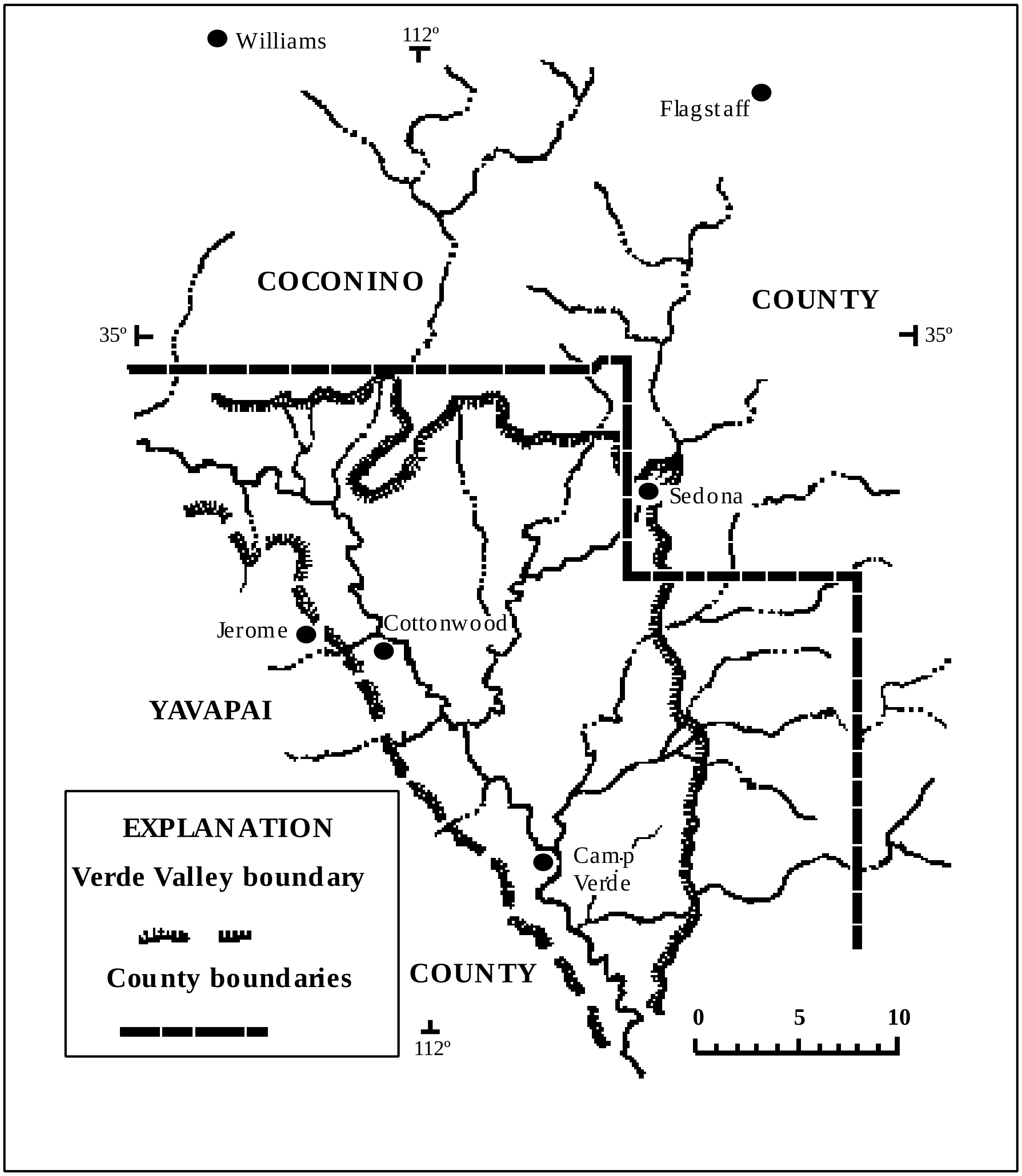

Figure 1. Index map showing location of the Verde Valley, Yavapai and Coconino Counties, Arizona, modified from Twenter and Metzger (1963, p. 6).

On the east side of the Verde River, in the Coconino National Forest, Lane (1992) identified several areas as having moderate development potential for sand and gravel resources. He noted that most of the sand and gravel presently mined is on private land (Lane, 1992, p. 42).

Acknowledgments

Indispensable to this study are the detailed maps of the surficial geology of the northern Verde Valley by P.A. Pearthree and P.K. House of the Arizona Geological Survey (fig. 2). My study utilized the hierarchy of age established in Pearthree (1993) and House and Pearthree (1993) and benefited significantly from my discussions with them about the Quaternary geology of the area. Robert Miller's expertise was invaluable in preparation of the figures.

EVALUATION OF THE POTENTIAL FOR SAND AND GRAVEL RESOURCES

General Geologic History

Sand and gravel resources have been exploited in the Verde Valley from geologic units ranging from lower Miocene to modern. The general geologic history of the area during this time is as follows:

<u>Tertiary Period</u>

lower Miocene and older to upper Miocene (24 Ma to about 8 Ma) Stream, lake, and fan deposits of several generations and different source areas were deposited unconformably on uneven, locally markedly channeled surfaces that truncate Mesozoic and Paleozoic rocks (Weir and others, 1989).

upper Miocene (about 8 Ma to 5 Ma) Stream, lake, and fan deposits, interbedded with lava flows, began to accumulate in a basin whose external drainage was probably blocked at the southern margin by structural subsidence and volcanic activity (*after* Bressler and Butler, 1978, and McKee and Elston, 1980; as cited by House and Pearthree, 1993, p. 12).

Pliocene (5 Ma to 2 Ma) The basin-filling sediments reached their highest level at 2 to 2.5 Ma (House and Pearthree, 1993, p. 4). Basin accumulation ended and basin dissection began when the Verde River breached the southeast end of the Valley (*after* Bressler and Butler, 1978, and Nations and others, 1981, as cited by House and Pearthree, 1993, p. 12).

<u>Quarternary Period</u>

Pleistocene (2 Ma to 10 ka) Basin dissection and downcutting by streams continued into the Quaternary, possibly in response to regional uplift of the Transition Zone

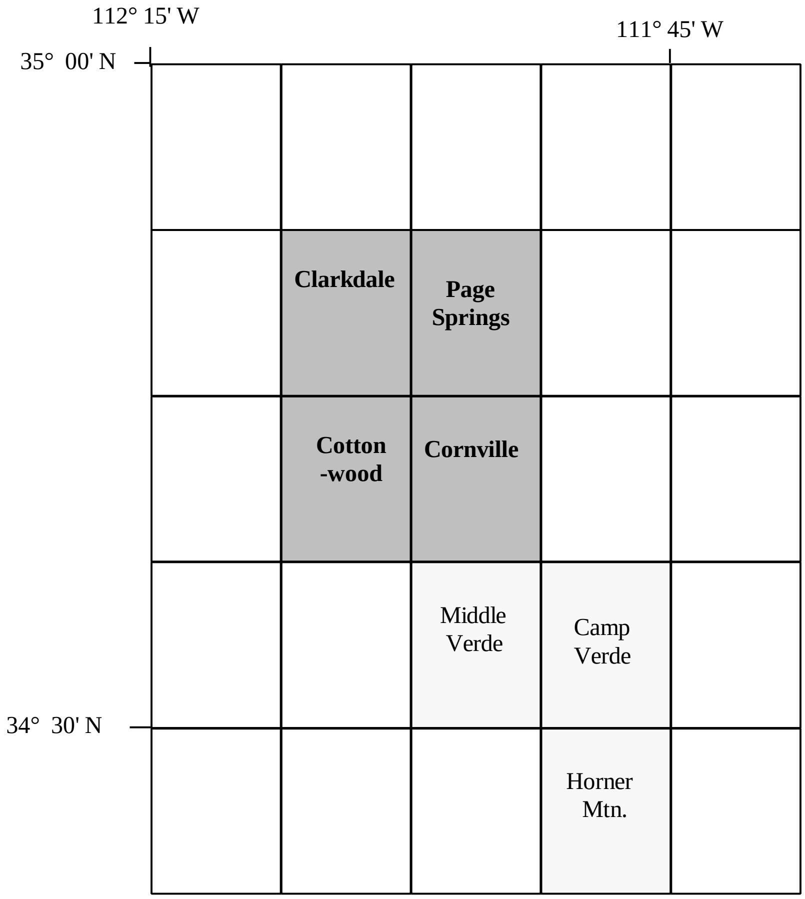

Figure 2. Index to U.S. Geological Survey 7.5' topographic maps and geologic maps of the Prescott National Forest in the Verde Valley, Arizona used in this study. Source of geologic data for Clarkdale, Page Springs, Cottonword and Cornville 7.5' quadrangles (darkly shaded) is House and Pearthree (1993). Source of geologic data for Middle Verde, Camp Verde, and Horner Mtn. 7.5' quadrangles (lightly shaded) is House (1994).

(*after* Péwé 1978, and Menges and Pearthree, 1989, as cited by House and Pearthree, 1993, p. 13). Erosion-resistant coarse gravels were deposited in piedmont alluvial fans and in the terraces of major streams.

Holocene (10 ka to <a few thousand years) Erosion resistant coarse gravels were deposited in young piedmont alluvial fans and low terraces along piedmont and ephemeral drainage courses (House and Pearthree, 1993).

upper Holocene (<a few thousand years) Silt, sand, gravel and cobbles are deposited in the active flood plains and channels of major streams during a time that may represent the deepest level of incision reached in the valley during the Quarternary (House and Pearthree, 1993, p. 17).

In summary, the history of the Verde Valley is one of basin accumulation or aggradation, mostly in the Tertiary period, followed predominately by dissection or degradation in the Quaternary period. Aggradation resulted in broadly distributed, interfingered facies of materials that had been eroded from the surrounding highlands and deposited in the basin as sediments in lakes, alluvial plains, and alluvial fans. Sand and gravel occur in the alluvial-fan facies, which are, in the case of the Verde Formation, generally located at the margins of the basin in which they were deposited. The subsequent, overall, degradation of the Verde basin resulted in geomorphically defined, alluvial-fan and stream deposits that consist of reworked basin-fill sediments as well as new material eroded from the present-day highlands. Sand and gravel occur in alluvial-fan remnants, thin alluvial fans, and stream deposits whose positions relative to (and heights above) the Verde River and its major tributaries are a function of their age (the time of abandonment of the geomorphic surface).

Rationale for Depiction of Tracts

Clast composition, thickness, degree of sorting, the degree of weathering, and the extent and distribution of mappable units are some of the characteristics related to the geologic age (Tertiary, Quaternary) or depositional setting (aggradational, degradational, alluvial fan, stream terrace) of alluvial materials. The differences in these characteristics (i.e. well sorted versus poorly sorted; major soil development versus minor soil development) make it desirable to group sedimentary and alluvial materials with shared characteristics. Such a group is here called a tract. Although each tract consists of several geographically separated islands, the descriptions and evaluations of each tract that follow refer to the sum total of the area covered by the islands.

Description of Tracts

Seven tracts are shown in plate 1. Also given on plate 1 is the correlation of rock unit map symbols corresponding to tracts repeated in Table 1. Some characteristics of the tracts are summarized in Table 2. Resource potential is rated as either high (**hi**) or moderate (**mod**). Tracts characterized by better sorted material, less soil development, and historic exploitation are rated as having higher resource potential than those tracts characterized by poor sorting, greater soil development, and for which exploitation history is unknown or uncertain. Detailed descriptions of the quality, quantity, and distribution are given in the text that follows. Bedrock geology is not shown on plate 1 but can be found in Pearthree (1993) and House and Pearthree (1993).

Table 1. Stratigraphic table showing correlation of rock unit map symbols to the tracts permissive for the occurrence of sand and gravel resources in and near the Prescott National Forest of the Verde Valley, Yavapai and Coconino Counties, Arizona.

[Column head abbreviations are: AF, Alluvial Fan; ST, Stream Terrace; and AC, Active Channel. Beneath the correlative map symbols, the tract labels in square brackets are: **7N**, Youngest Undivided alluvial fans, stream terraces, and active channel deposits; **6**, Young stream terraces; **5**, Young alluvial fans; **4**, Old stream terraces; **3**, Old alluvial fans; **3N**, High and old alluvial fans; and **2**, Basin-fill gravels. Map symbols of House and Pearthree (1993) and House (1994) are: Yp, Young piedmont alluvium; Yr, Active channels of major streams; YT, Young terraces; S, S1, and S2, Sheepshead Group, C, Cla, Clb, and C2, Chuckwalla Group; CT1 and CT2, Chuckwalla Terraces; M, Montezuma alluvial fan complex; MT, Montezuma Terraces; O, O1, O2a, and O2b, Oxbow Group; OT1, OT2, and OT3, Oxbow Terraces; Tvg, gravel facies of Verde Formation]

Geochronologic Uiits		Age estimates of boundaries, in Ka (thousand years) and Ma (million years	Map symbols of House & Pearthree (1993) and House (1994)		
Period	Epoch		AF	ST	AC
QUATERNARY	Holocene		S; S2; Yp **[7N]**	Yp **[7N]**	Yr **[7N]**
QUATERNARY	Holocene	5 Ka	S; S2; Yp **[7N]**	YT **[7N]**	
QUATERNARY	Holocene / Pleistocene	10 Ka	S; S2; C2 **[5]**	CT2 **[6]**	
QUATERNARY	Pleistocene	20 Ka 50 Ka	S; S1; C2 **[5]**; C1a	CT2 **[6]**	
QUATERNARY	Pleistocene	125 Ka	S; S1; C1a, C1b **[5]**	CT2 **[6]**	
QUATERNARY	Pleistocene	250 Ka 500 Ka	M **[3]**	MT **[4]**	
QUATERNARY	Pleistocene	800 Ka	M **[3]**	MT **[4]**	
QUATERNARY	Pleistocene	1.0 Ma	O2b O2a **[3N]**	OT3 OT2 OT1 **[4]**	
TERTIARY	Pliocene	2.0 Ma	O1 **[3N]**		
TERTIARY	Pliocene	2.5 Ma	Tvg **[2]**		
TERTIARY	Miocene	5.0 Ma 8.0 Ma	Tvg **[2]**		

Table 2. A comparison of the characteristics of sand and gravel tracts in the Verde Valley, Yavapai and Coconino Counties, Arizona. [Abbreviations: **mod** for moderate and **hi** for high.]

Tract Characteristics **resource potential**:	Tract 2 **mod**	Tract 3N **mod**	Tract 3 **mod**	Tract 4 **mod**	Tract 5 **mod**	Tract 6 **mod**	Tract 7n **mod**
SUPPORTS RIPARIAN VEGETATION							X
LITTLE or NO SOIL DEVELOPED							X
RESTRICTED TO CHANNEL						X	X
WELL SORTED TERRACE				X		X	X
MODERATE SOIL DEVELOPED					X	X	
LOCALLY > 40 FT THICK	X		X				
THIN (<40 FT THICK)		X		X	X	X	X
POORLY SORTED FAN	X	X	X		X		
NOT RESTRICTED TO CHANNEL	X	X	X	X	X		
SUPPORTS NON-RIPARIAN VEGETATION	X	X	X	X			
MAJOR SOIL OR LITHIFICATION	X	X					

[TRACT 2] TRACT OF THE BASIN-FILL GRAVEL FACIES OF THE VERDE FORMATION OF UPPER MIOCENE AND PLIOCENE AGE

Description This tract contains alluvial fan materials of about 2.5 Ma, but possibly as old as 8.5 Ma. The fans consist of very poorly sorted coarse gravels and cobbles of diverse lithologies (House and Pearthree, 1993). Particle sizes range from silt and sand to boulders, and clasts are typically subangular (House and Pearthree, 1993).

Description of known workings One Gravel Pit is shown as being located on private land in the NE 1/4 sec. 14, T. 15 N., R. 3 E. of the Cornville quadrangle (Pit No. CX01, pl. 1). The geologic map of House and Pearthree (1993, sheet 4 of 4) shows the gravel pit as being located in undifferentiated Verde Formation very close to its contact with the Montezuma alluvial fan complex. Recommendation: Visit the site, describe the characteristics of the material, and determine whether the material was extracted from a gravel facies of the Verde Formation, from the Montezuma alluvial fan, from both, or from another unit.

Three Borrow Pits are located on private land near the Cottonwood Airport southwest of Cottonwood: two of these Borrow Pits (Pit No. CX03, CX04) are located in the W half of sec. 3, T. 15 N., R. 3 E. and one of these Borrow Pits (Pit. No. CX02) is located in the E half of sec. 4, T. 15 N., R. 3 E. of the Cottonwood quadrangle. The easternmost pit (CX04) is shown on the contact of the units mapped by House and Pearthree (1993, sheet 3 of 4) as the lacustrine facies of the Verde Formation (Tvl) and the thin alluvial fans mapped as C2 (see tract 5). The other two borrow pits are shown as being in Tvl. Recommendation: Visit the sites, describe the characteristics of the material, and determine whether the material was extracted from a gravel facies of the Verde Formation, from the Chuckwalla alluvial fan, from both, or from another unit.

Rationale for tract type
(1) Distribution In many places these gravels occur as rounded, high-standing hillocks (House and Pearthree, 1993, p. 11) between, rather than within stream channels at the margin of the Verde Valley.

(2) Sorting and thickness These gravels are very poorly sorted but are generally greater than 40 ft thick.

(3) Soil development Soil is strongly developed and there are various degrees of lithification.

Method of tract delineation This tract contains the gravel facies of the Verde Formation as mapped by House & Pearthree (1993, unit Tvg).

Recommendations for future work see the Recommendations given in the *"Description of known workings"* section.

In general, map the gravel (Tvg) and lacustrine (Tvl) facies of the Verde Formation as separate map units where they are undifferentiated (Tvu).

The approximate volume of material in this tract should be calculated.

Resource potential This tract has moderate potential for sand and gravel resources in alluvial fan materials. Negative attributes include strong soil development in, and lithification of, poorly sorted material. A positive attribute is local thickness in excess of 40 ft.

[Tract 3N] TRACT OF HIGH ALLUVIAL FANS OF UPPER PLIOCENE TO LOWER PLEISTOCENE AGE

Description This tract contains the alluvial fans that are about 0.8 to 2.5 Ma (House and Pearthree, 1993, p. 4). The highest and oldest fans generally rest on surfaces eroded into either the Verde Formation or Paleozoic units and locally grade gradually downward into the coarse fan facies of the Verde formation (Pearthree, 1993, p. 10). These alluvial fans are typically found 260 to 490 ft above modern drainages and are generally less than 40 ft thick (House and Pearthree, 1993, p. 3). These fans consist of particles ranging from silt to boulder in size but are typically very poorly sorted gravels (House and Pearthree, 1993, p. 3).

Rationale for tract type

(1) Sorting and thickness Alluvial fans are typically thicker and less well sorted than correlative stream terraces. The oldest high alluvial fans are typically very poorly sorted and relatively thin (<33 ft thick) (House and Pearthree, 1993) in comparison with the younger mid-level alluvial fans described in Tract 3 below.

(2) Distribution These alluvial fans were abandoned at levels higher above the modern channels than the younger alluvial fans and are generally not restricted to the interiors of narrow canyon reaches.

(3) Soil development There is extremely strong soil development on the surface of these fans. Calcic horizons range from substantially to moderately well developed (House and Pearthree, 1993, p. 5, and Pearthree, 1993, p. 10).

(4) Vegetation Although these alluvial-fan deposits have reasonable water-holding capacities, they typically are high above stream channels and, therefore, do not hold much water nor typically support riparian vegetation (Pearthree, 1993, p. 9-10).

Method of tract delineation This tract contains high, or piedmont, alluvial fans of upper Pliocene to lower Pleistocene age as mapped by House and Pearthree (1993) and by House (1994) (units O, O1, O2, O2a, O2b; "O" for "Oxbow").

Recommendations for future work The approximate volume of material in this tract should be calculated.

Resource potential This tract has moderate potential for sand and gravel resources in alluvial fan materials. The material is generally poorly sorted, thin, and has strong soil development.

[Tract 3] TRACT OF THICK ALLUVIAL FANS OF PLEISTOCENE AGE

Description This tract contains the alluvial fans that are about 0.8 to 0.25 Ma (House and Pearthree, 1993). These alluvial fans typically are found 80 to 100 ft above modern drainages and comprise the thickest Quaternary deposits in the northern Verde Valley, however the local variation in thickness is considerable (House and Pearthree, 1993, p. 5). These fans typically consist of poorly sorted silt to gravel (Pearthree, 1993, p. 9-10).

Description of known workings One Gravel Pit (CX01, pl. 1) is shown as being located in the NE sec. 14, T. 15 N., R. 3 E. of the Cornville quadrangle (see Tract 1). The geologic map of House and Pearthree (1993, sheet 4 of 4) shows the gravel pit as being located in undifferentiated Verde Formation very close to its contact with the Montezuma alluvial fan complex. Recommendation: Visit the site, describe the characteristics of the material, and determine whether the material was extracted from a gravel facies of the Verde Formation, from the Montezuma alluvial fan, from both, or from another unit.

Rationale for tract type
(1) Sorting and thickness The alluvial fans are typically thicker and less well sorted than correlative stream terraces. The fans that sit below the oldest and highest alluvial fans yet above the modern drainages can be quite thick. In the vicinity of Black Canyon in the Cornville and Cottonwood 7.5' quadrangles, alluvial-fan deposits are locally at least 80 ft thick (House and Pearthree, 1995, p. 5). The local variations in thickness indicate that the alluvium may have filled irregular paleotopography carved into the Verde Formation (House, 1994, p. 6). Great thickness seems to be more common on the west side of the Verde River in the Prescott National Forest than on the east side of the Verde River in the Coconino National Forest.

(2) Distribution These alluvial fans were abandoned at levels higher above the modern channels than the younger alluvial fans (tract described below) and are generally not restricted to the interiors of narrow canyon reaches.

(3) Soil development Clay horizons in the soils associated with the surfaces of these alluvial fans are strongly developed. Well developed calcic horizons are found at depths that range from 0 to 3 ft depending upon the amount of soil that has been removed (House and Pearthree, 1993, p. 5).

(4) Vegetation Although these alluvial-fan deposits have reasonable water-holding capacities, they typically are high above stream channels and, therefore, do not hold much water nor typically support riparian vegetation (Pearthree, 1993, p. 9-10).

Method of tract delineation This tract contains alluvial fans of middle Pleistocene age as mapped by House and Pearthree (1993) and by House (1994) (map unit "M" for "Montezuma").

Recommendations for future work see the Recommendation given in the *"Description of known workings"* section.

The approximate volume of material in this tract should be calculated.

Resource potential This tract has moderate potential for sand and gravel resources in alluvial fan materials. Even though the material is generally poorly sorted, local thickness may exceed 40 ft.

[TRACT 4] TRACT OF STREAM TERRACES OF UPPER PLIOCENE TO PLEISTOCENE AGE

Description This tract contains high- to mid-level stream terraces of the ages 2 Ma to about 0.25 Ma that were abandoned at fairly high levels above the modern stream channels and, therefore, are not restricted to the interiors of narrow canyon reaches. The terrace surfaces are typically 80 to 200 ft above the active channel but may be as high as 350 ft (House and Pearthree, p. 9). The oldest and highest stream deposits commonly consist of very coarse, well rounded cobbles and boulders, whereas the mid-level terraces are composed of the coarse gravels. Both are probably facies of channels and bars (Pearthree, 1993, p. 9-10). These terraces are usually less than 33 ft thick (Pearthree, 1993, p. 9-10).

Rationale for tract type

(1) Thickness and Sorting Stream terraces are typically thinner but predictably better sorted than correlative alluvial-fan deposits.

(2) Distribution These terraces were abandoned at levels higher above the modern channels than the younger terraces (tract described below) and therefore are not restricted to the interiors of narrow canyon reaches.

(3) Soil development Soil development with clay and calcium carbonate (caliche) accumulation ranges from strong to fairly strong with decreasing age (House and Pearthree, 1993, p. 9).

(4) Vegetation These steam terraces typically do not hold much water nor do they support riparian vegetation (Pearthree, 1993, p. 9-10).

Method of tract delineation This tract contains stream terraces that are upper Pliocene to middle Pleistocene in age as mapped by Pearthree (1993, units Qto and Qtmo), House & Pearthree (1993, units OT1, OT2, OT3, and MT), and House (1994, units OT1, OT2, OT3, and MT).

Recommendations for future work The approximate volume of material in this tract should be calculated.

Resource potential This tract has moderate potential for sand and gravel resources in stream terrace materials. Although the material is well sorted, it is generally very thin and soil development ranges from strong to fairly strong.

[Tract 5] TRACT OF ALLUVIAL FANS OF UPPER PLEISTOCENE TO LOWER HOLOCENE AGE

Description This tract contains thin alluvial fans that are generally between 250,000 and 10,000 years old, however some fans are as young as 5,000 (House and Pearthree, 1993, p. 6, and Pearthree, 1993, p. 9). The fans typically consist of a poorly sorted mix of silt, sand, and gravel (Pearthree, 1993, p. 8). This tract also includes some terrace deposits, some of which were locally mapped separately by House and Pearthree (1993, p. 6) and House (1994). Much of the development in the city of Cottonwood has been on 5,000-20,000 year old fans (House and Pearthree, 1993, p. 6-7).

Description of known workings Three Borrow Pits are located on private land near the Cottonwood Airport southwest of Cottonwood: two of these Borrow Pits (Pit No. CX03, CX04, pl 1) are located in the W half of sec. 3, T. 15 N., R. 3 E. and one of these Borrow Pits (Pit. No. CX02) is located in the E half of sec. 4, T. 15 N., R. 3 E. of the Cottonwood quadrangle. The easternmost pit (CX04) is shown on the contact of the units mapped by House and Pearthree (1993, sheet 3 of 4) as the lacustrine facies of the Verde Formation (Tvl) and the thin alluvial fans mapped as C2 (see tract 2). The other two borrow pits are shown as being in Tvl. <u>Recommendation</u>: Visit the sites, describe the characteristics of the material, and determine whether the material was extracted from a gravel facies of the Verde Formation, from the Chuckwalla alluvial fan, from both, or from another unit.

One Gravel Pit (Pit. No. CX05, pl. 1) is shown as being located on Forest land in the SE 1/4 sec. 28, T. 13 N., R. 5 E. of the Horner Mountain quadrangle. The Gravel Pit is shown as being in map unit C2 that is part of the Chuckwalla group which is composed of thin alluvial fans and narrow stream terraces (House, 1994, p. 6-7). House (1994, p. 6-7) describes map unit C2 as being composed primarily of coarse sediments ranging from sand to large cobbles and small boulders with a surface that is often characterized by a dense thorn scrub thicket including catclaw, mesquite, and Freemont holly.

Rationale for tract type
(1) <u>Thickness and Sorting</u> This tract consists mostly of alluvial fans that are less well sorted than correlative stream terraces and thinner than the older alluvial fans (House and Pearthree, 1993, p. 6), however his tract also includes some terrace deposits.

(2) Distribution Alluvial fans are generally not restricted to the interiors of narrow canyon reaches.

(3) Soil development Soil is moderately developed with some clay accumulation (Pearthree, 1993, p. 9).

(4) Vegetation Mid level alluvial fans typically do not hold much water nor support riparian vegetation, however those fans that are younger than 10,000 years old support some riparian vegetation (Pearthree, 1993, p. 8).

Method of tract delineation This tract contains the piedmont alluvial fans of middle Pleistocene and Holocene age as mapped by House & Pearthree (1993, units C1, C1a, C1b, and C2 where not confined to the channel of a perennial or ephemeral stream), and House (1994, units C1, C1a, C1b, and C2 where not confined to the channel of a perennial or ephemeral stream).

Recommendations for future work see the Recommendation given in the *"Description of known workings"* section.

Conduct a field investigation of areas mapped as C2 and by House and Pearthree (1993) and House (1994) to determine, on the basis of distribution, vegetation supported, quality, and soil development, the most appropriate tract classification of map unit C2: either this tract or tract 7N.

The approximate volume of material in this tract should be calculated.

Resource potential This tract has moderate to high potential for sand and gravel resources in alluvial-fan materials. The material is generally thin, poorly sorted, and has moderate soil development but contains some well sorted material that seems to have been exploited in the past.

[Tract 6] TRACT OF STREAM TERRACES OF MIDDLE PLEISTOCENE TO LOWER HOLOCENE AGE

Description This tract contains the mid-level stream terraces that are generally between 250,000 and 10,000 years old; some are as young as 5,000 years old. These terraces are restricted to the channels of modern major streams and consist of abandoned channels and bars of coarse sand and of sand that was deposited in low velocity, slack-water areas during large floods (House and Pearthree, 1993, p. 10).

The terraces are commonly much less than 16 ft thick, are 15 to 100 ft above the active channel, and are spatially separate from (located above) perennial streams and stream channels--therefore water drains out of them quite readily (Pearthree, 1993, p. 9). These mid-level terraces typically consist of the coarse gravel, are quite permeable, are fairly resistant to stream erosion, and are not inundated during large floods (Pearthree, 1993, p. 9, and House and Pearthree, 1993, p. 10).

Descriptions of known workings.

On private land, less than a mile east of the Prescott National Forest on the west side of the Verde River, is an active sand and gravel operation (Superior Sand and Gravel) in the center of sec. 14, T. 14 N., R. 4 E., in the Middle Verde quadrangle (Pit No. CX06, pl. 1). The location of the mining operation seems to correspond to the location of the units mapped by House (1994) as the young and mid-level terraces of the Verde River as well as possibly parts of older alluvial fan material that is middle Pleistocene in age.

Rationale for tract type(1) Distribution The mid-level terraces are restricted to the interior of narrow canyon reaches (House and Pearthree, 1993, p. 9).

(2) Vegetation The mid-level terraces support upland desert vegetation including shrubs, cactus, and small trees but typically do not support riparian vegetation (Pearthree, 1993, p. 9).

(3) Thickness and Sorting Relict channels and bars of the major stream terraces are better sorted, although thinner (<16 ft thick) than correlative alluvial-fan deposits.

(4) Soil development There is moderate soil development and some clay accumulation (Pearthree, 1993, p. 9).

Method of tract delineation This tract contains the stream terraces of middle Pleistocene to Holocene age as mapped separately from their correlative alluvial fans by House & Pearthree (1993, units CT1 and CT2) and House (1994, units CT1 and CT2).

Recommendations for future work Conduct a field investigation of areas mapped as CT2 and by House and Pearthree (1993) and House (1994) to determine, on the basis of distribution, vegetation supported, quality, and soil development, the most appropriate tract classification: either this tract or tract 7N.

The approximate volume of material in this tract should be calculated.

Resource potential This tract has high potential for sand and gravel resources in stream terrace materials. Even though the material is generally thin, it is well sorted and the soil development is weak to moderate.

[Tract 7N] TRACT OF YOUNG STREAM TERRACES, ALLUVIAL FANS, AND ACTIVE-CHANNEL DEPOSITS OF HOLOCENE AGE

Description The young stream terraces of upper Holocene age (<5 ka) are found less than 3m (10 ft) above the lowest parts of the river's channel and are directly adjacent to the river bed (House, 1994, p. 11). The terraces are restricted to the channels of modern major streams and consist of abandoned channels and bars of coarse sand and of sand that was deposited in low velocity, slack-water areas during large floods (House and Pearthree, 1993, p. 10). The young stream terraces are relatively thin, are less than about 20 ft above the lowest parts of the channels, and are almost always found adjacent to the active channels (House and Pearthree, 1993, p. 10, and House, 1994, p. 11). YT2 terrace deposits are composed of a coarse channel and bar facies composed of pebbles, cobbles, and boulders and an overbank facies composed of sand and silt deposited in low velocity, slack-water areas during large floods (House, 1994, p. 11).

The young alluvial fans are less well sorted than correlative stream terraces and typically consist of a poorly sorted mix of silt, sand, and gravel (Pearthree, 1993, p. 8).

The active stream beds and flood channels of the Verde River and its tributaries contain poorly sorted, relatively coarse deposits of sand, pebbles, cobbles, and boulders that are probably less than a few feet thick in all areas (Pearthree, 1993, p. 8). Flood channels include areas that convey floodwaters frequently enough to limit the development of mature riparian plant communities (House and Pearthree, 1993, p. 10). Bedrock is exposed in many of the streams.

The largest active channel, the Verde River, lies between the Prescott and Coconino National Forests, mostly on private land. The perennial and ephemeral streams that are lined with terraces less than 500,000 years old also contain active channel deposits. These include, but are not limited to: Bitter, Blowout, and Cherry Creeks and Hayfield Draw.

Descriptions of known workings The privately owned Superior Sand and Gravel is located in sec. 14, T. 14 N., R. 4 E. of the Middle Verde quadrangle (see Tract 6). The deposit (CX06, pl. 1) appears to be located in the unit mapped by House (1994) as YT, however a field investigation is recommended to determine whether the deposit is in YT, Yp, Yr, CT1, M, C2, and/or MT.

Rationale for tract type
(1) <u>Distribution</u> The youngest alluvial fans, stream terraces, active stream beds, and flood channels are restricted to the Verde River and its perennial and ephemeral tributaries.

(2) <u>Vegetation</u> The alluvial fans support some riparian vegetation; the low terraces support riparian vegetation; and the active channel deposits support riparian vegetation that recovers during the periods between large floods (Pearthree, 1993, p. 8, and House, 1994, p. 11).

(3) <u>Thickness and Sorting</u> Young alluvial fans and active river deposits are generally thin and poorly sorted, however, the stream terraces are better sorted.

(4) <u>Soil development</u> There is minimal to no soil development, minimal to no sediment cohesion, and no cementation (Pearthree, 1993, p. 8).

Method of tract delineation This tract contains the piedmont alluvial fans and stream terraces of Holocene age as mapped by Pearthree (1993, units Qfy and Qty), alluvial fan and stream terrace deposits younger than 5,000 years old as mapped by House and Pearthree (1993) and House (1994) (units Yp, Yt, and where mostly confined to the channel of a perennial or ephemeral stream, unit C2), and active channel deposits mapped as the units Qc by Pearthree (1993) and Yr by House and Pearthree (1993) and House (1994).

Recommendations for future work Conduct a field investigation of areas mapped as C2 and by House and Pearthree (1993) and House (1994) to determine, on the basis of distribution, vegetation supported, quality, and soil development, the most appropriate classification: either this tract or tract 5. Conduct a field investigation of areas mapped as CT2 and by House and Pearthree (1993) and House (1994) to determine, on the basis of distribution, vegetation supported, quality, and soil development, the most appropriate classification: either this tract or tract 6.

The approximate volume of material in this tract should be calculated.

Resource potential This tract has high potential for sand and gravel resources in the active channels and in areas that convey floodwaters. Even though the material is generally thin and poorly sorted, poor sorting can be a positive attribute where soil development is absent.

CONCLUSIONS

Areas containing sand and gravel occurrences are outlined on plate 1. Analysis of recent, large scale geologic maps allowed the delineation of seven tracts containing sand and gravel occurrences that share characteristics related to their geologic age and their depositional setting (Tract 2, Tract 3N, Tract 3, Tract 4, Tract 5, Tract 6, and Tract 7N). The detailed geologic maps revealed that in addition to the youngest active-channels, alluvial-fan and terrace deposits, some of which are older than 250,000 years in age, have been exploited in the past for sand and gravel.

The tracts which are summarized in Table 3 have either moderate or high potential for sand and gravel resources in alluvial fans and stream terrace deposits of Tertiary and Quaternary ages.

Table 3. Resource potential of tracts permissive for the occurrence of sand and gravel resources in and near the Prescott National Forest of the Verde Valley, Yavapai and Coconino Counties, Arizona.

[Map unit symbols in parentheses are from House and Pearthree (1993) and House (1994)]

Resource Potential	Unit Descriptions	
High	[7N]	Youngest Undivided alluvial fans, stream terraces and active channel deposits (Yp, Young piedmont alluvium; Yr, Active channels of major streams; YT, Young terraces)
	[6]	Young stream terraces (CT1 and CT2, Chuckwalla terraces)
	[5]	Young alluvial fans (C, C1a, C1b, C2, and CT2, Chuckwalla Group)
Moderate	[4]	Old stream terraces (MT, Montezuma Terraces; OT1, OT2, OT3, Oxbow Terraces)
	[3]	Old alluvial fans (M, Montezuma alluvial fan complex)
	[3N]	High and old alluvial fans (O, O1, O2a, O2b, Oxbox Group)
	[2]	Basin-fill gravels (Tvg, gravel facies of the Verde Formation)

The following can be concluded about sand and gravel resources from the descriptions of the geology of the area by Pearthree (1993), House and Pearthree (1994), and House (1994):
--Older surficial deposits of all kinds are generally either more lithified or have greater soil development than younger surficial deposits.
--Alluvial-fan deposits are typically relatively more poorly sorted and thicker than major stream-terrace deposits.
--Young terrace deposits are generally thinner, and finer grained than older terrace deposits.
--Young terrace deposits are confined to stream channels whereas older surficial deposits of all kinds are not.
--River and low terrace and low alluvial-fan deposits support riparian vegetation whereas higher terrace and alluvial-fan deposits support upland vegetation.

When decisions about land-use are being made, this map of tracts may be used to optimize solutions.

Evaluation of sand and gravel resources using selected engineering variables

by James D. Bliss and Robert J. Miller

Introduction

Aggregate, like most other industrial minerals must meet certain chemical and physical requirements for use. Explicit standards for aggregate used in infrastructure reflect the public concern that roads and structures be safe and durable. Some examples of geotechnical characteristics requiring compliance with standards are sorting, impurities, durability, and weathering susceptibility.

Two general requirements are applicable to sand and gravel in particular. The first is that deposits must contain a range of grain sizes (poorly sorted, not well sorted) to insure stable grain packing in mix design of asphalt and Portland concrete. The second requirement is that the amount of fines (material passing 200 mesh (0.075 mm) sieve) must be small. Mix designs commonly allow no more than 5 percent of fines. Operators working sand and gravel deposits with too much fine material can become overwhelmed with a waste material no one wants. Most operations in the US appear to be working deposits with no more than 15 percent fines (Drake, 1995).

The American Association of State Highway and Transportation Officials (AASHTO) (1993) and the American Society for Testing & Materials (ASTM) (1996) have developed and published standards for aggregate. Local and state government agencies may specify an aggregate must meet AASHTO or ASTM standards, stipulate modifications to one of the existing standards, or customize standards of their own. Most specifications set forth by the Arizona Department of Transportation (ADOT) (1990) for aggregate either follow the AASHTO standard or have been customized. Other economic criteria a potential aggregate site must meet are sufficient volume of material to justify the investment necessary to develop it, nearness to market and transport, accessibility (spatially and legally), and minability.

Source and types of engineering data

Data used to evaluate sand and gravel resources in the study area are derived from Cox (1995; this volume) and from a materials inventory for Yavapai County by the Arizona Department of Transportation (ADOT) then named the Arizona Highway Department (AHD) (1972). This is one of a series of materials inventories prepared by AHD as a part of a statewide inventory of aggregate material sources started in 1959. These inventories were conducted by county. Information from the Yavapai county report used in this study are pit number, pit class, plastic index (PI), Los Angeles durability test (LADT), swell (24 hour), and sieve analysis (Appendix A).

A number of qualifications are in order. Uncertainty in the location of AHD sites on publication maps is plus or minus an eighth of a mile (0.2 km). Many sites no longer exist due to land development for housing and other uses. Additional location uncertainty is added during digitizing. Some points overlap more than one geologic unit (Plate 1) and have been assigned (Appendix A) using material descriptions, likelihood of accessibility and topography. Uncertainty of an unknown magnitude was also introduced during preparation and digitizing the location of geologic boundaries used in the study by Cox (this volume).

Variability of the material within a given site is unknown, although AHD (1972) noted that tests were made on representative material from each pit. Some of the screen sizes now used in current standards are not the same ones reported in the AHD (1972) inventory. Standards are also usually applied to processed materials, not to raw aggregate. Therefore departures from standard specifications are expected. Sorting, the degree to which particle sizes are distributed among different sieves, is important as most specifications require a range of sizes. Some tests are noted in the current ADOT (1990) standard for which data are not available in the AHD (1972) inventory. For fine grained aggregates, this includes the sand equivalent test (AASHTO T 176); and those tests (AASHTO T 71) used for determining mortar-making characteristics (ADOT, 1990). Material sampling and testing procedures have changed with time and comparing older test results to standards based on newer sampling and testing procedures is somewhat questionable.

Evaluation of data

Introduction to data evaluation

Most of the 50 aggregate and borrow pits (Appendix A) used in this study have been assigned to various ages and types of surficial deposits using Plate 1 (Cox, this volume). Geologic unit assignment of some sites (Pit Nos. 1542, 1884, 1885, 1885A, 2426, 2790, 6422, and 7728) has been made using the results of a similar study (Cox, 1995) northeast side of the Verde River Valley. These sites are found in Plate 1 but without surficial geology. That study was part of an assessment of sand and gravel resources of the Coconino National Forest (Cox, 1995). Twenty-two of the 50 aggregate and borrow pits of this study are in youngest alluvial features (fans, terraces, and active channel deposits undivided (Unit 7N, Plate 1). Although other young units host far fewer sites, including six pits in the young stream terraces or Chuckwalla terraces (Unit 6), and three pits in the young alluvial fans or Chuckwalla group (Unit 5), analyses of data related to pits found in Units 5, 6, and 7N are treated as a single group designated as the "upper Quaternary sites." This group contains material probably deposited after 250 Ka. This group was classified by Cox (this volume) as having a high resource potential for sand and gravel.

Ten aggregate and borrow pits are found in the old alluvial fans or Montezuma alluvial fan complex (Unit 3, Plate 1). Other older surficial units (older than 250 Ka have few sites: three in the old stream terraces or Montezuma terraces (Unit 4), and none at all in the high and old alluvial fans or Oxbow Group (Unit 3N), which is widespread and appears to be relatively accessible by road (Plate 3). Pits found in Units 3 and 4 are treated together as a second group for data evaluation and designated hereafter as the "lower Quaternary sites." These sites occur in material probably deposited between 2 Ma and 250 Ka (Plate 1). This group is classified by Cox (this volume) as having a moderate resource potential for sand and gravel.

One site in the study area apparently is located in the basin fill gravel facies of the upper Tertiary Verde Formation (Pit No. 7455, Unit 2) which tends to crops out along the upper slopes of the basin and has difficult access (Plate 1). One other site (Pit No. 6412) is located in a facies of the Verde Formation undefined by House and Pearthree (1993) but is located in tract 5 in plate 1. Four other pits in Appendix A are probably located in other parts of the Verde Formation (Pit Nos. 7472, 7534, 7729, and 7728) and one pit is located outside the mapped area (Pit No. 7532). Data about sites in the Verde Formation are noted in the text as appropriate during data evaluation, and the site outside the mapped area was not considered.

Each pit was catalogued by AHD (1972) into one of eight aggregate classes based on standards using sieves and plastic index (PI) values. Mineral aggregate (MA) and aggregate for cover material and slurry seal (CM) require that 60 percent or less pass the no. 4 sieve, 8 percent or less pass the no. 200 sieve and the PI be 3 or less. Aggregate base (AB) require that 60 percent or less pass the no. 4 sieve, 10 percent or less pass the no. 200 sieve and the PI be 5 or less. Select material (SM), and subgrade seal (SS) require that 70 percent or less pass the 1/4 inch sieve, 15 percent or less pass the no. 200 sieve and the PI be 8 or less. These requirements are found to be met for a composite sample collected in an interval representing 50 percent or more of the total depth observed in the pit (AHD, 1972). Nearly a third of the 50 sites have material meeting one of these class requirements (Appendix A). No specifications are given for borrow pits that supply the lowest quality material used in highway construction. Those pits only supply material suitable for augmenting construction fill. In fact, AHD pits can be divided into borrow pits and nonborrow pits that have material suitable for some type of aggregate use. Remember that this classification is an expression of the standards used within the time frame of the AHD report (i.e., the early 1970s) and not those used now. Eleven sites had an unknown end use classification, predominately found in the youngest alluvial features (Appendix A).

How similar are pit materials from lower Quaternary sites to those from upper Quaternary sites? Comparisons are made for each sieve mesh size and other geotechnical data available using boxplots, which are explained in some detail in the first figure in which they are used. Final examination is made to see if there are any unusually large numbers of borrow pits in one of the two groups and which units seem to have been avoided as a source of material.

Evaluation of pits and geology using sieve data

Introduction to evaluation

Standards used for comparison purposes are the ADOT (1990) requirements for aggregate subbases and bases as found in section 303, fine aggregates as found in section 1006, part 2.03B, and coarse aggregate as specified in part 2.03C. The later specification in turn uses gradients stipulated in AASHTO M 43-88 (ASTM D448) which are given as 19 classes of coarse aggregate (Appendix B).

Less than 3 inch but greater than 3/4 inch mesh sieves

Material in this group has grain sizes which pass the 3 in (76.2 mm) mesh sieve and are retained on the 3/ 4 in (19 mm) mesh sieve. Presentation of sieve analysis in figure 4 is unlike other figures in this evaluation since the results are reported using **two** sieves and not one as done for all other sieves sizes. The amount of material which did NOT pass the 3 inch mesh sieve is not reported.

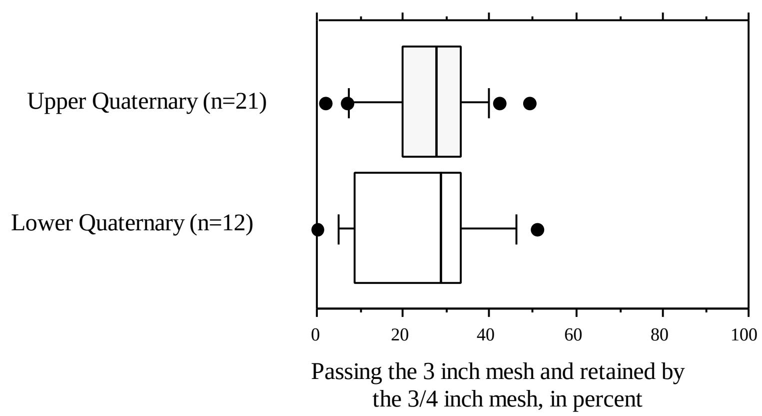

Figure 3. Boxplots of material passing the 3 inch (75 mm) mesh sieve but not passing the ¾ inch (19 mm) mesh sieve. The sieve analyses were adjusted by AHD to reflect 100 percent passing the 3 inch (19 mm) sieve which means material retained by the 3 inch sieve is not reported.

Figure 3 includes two boxplots for the two groupings used. Each of these boxes has 5 vertical lines giving the 10, 25, 50, 75, and 90th percentiles. The 25 and 75 percentiles bound the two narrow ends of the box. The 50th percentile line lies within the box. Values less than the 10th percentile and greater than the 90th percentile show as open points. Overall, the boxplots for the two groups are comparable. The medians are virtually identical (28 percent). Data from lower Quaternary sites are skewed to lesser amounts of coarse material (fig. 3) which makes it a less desirable source of aggregate. One reason is that coarse material can be crushed to specific clast sizes, which are needed to meet user requirements. Crushing also creates grains with broken faces which is another common requirement. For example, ADOT (1990) specifications for some highway subbases and bases require that at least 30 percent of grains retained on sieve no. 8 have at least one rough and angular face.

The one pit found in Verde Formation gravels had 15 percent of the material passing the 3 inch mesh and retained by the ¾ inch mesh screen.   The other four sites in the Verde Formation had material with values between 4 and 34 percent and a median of 12 percent.

¾ inch mesh sieve

Material passing the ¾ inch mesh sieve has clast sizes of 19 mm or less (fig. 4).

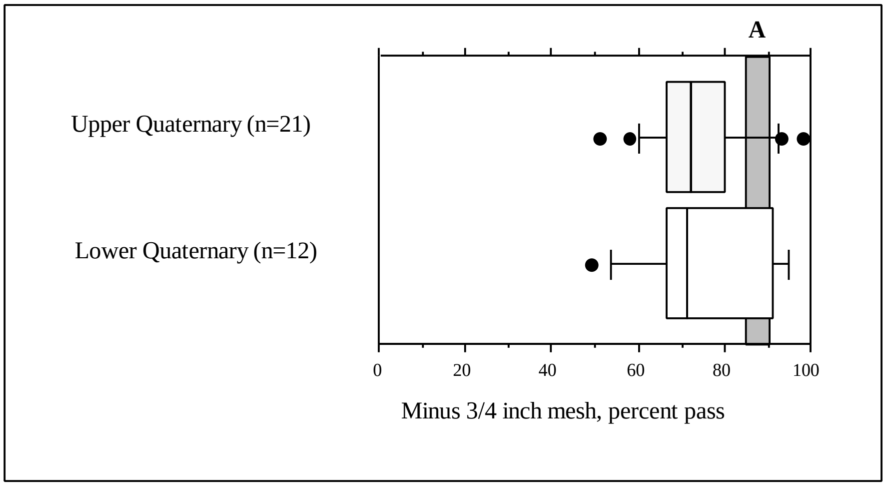

Figure 4. Boxplots of material passing the ¾ inch (19 mm) mesh sieve. Material which did not meet one of the 19 coarse aggregate class requirements for this sieve size is percent range noted by A above.

Note this figure is nearly a mirror image of the figure 3. Only six of the 19 classes listed in AASHTO M 43 specification (Appendix B) overlap with observed size ranges in figure 4. This includes classes nos. 467, 5, 56, 6, 67, and 68. Only a small interval at A in fig 4 for percentages of 85 to 90 percent passing is not included in one or the other of the various of these coarse aggregate class specifications. Note the lower Quaternary sites overlap the most with the not-to-specification zone.

The one pit found in Verde Formation gravels had 74 percent of the material passing the ¾ inch mesh screen. The other four sites in the Verde Formation had material with values between 66 and 96 percent and a median of 88 percent, which would be in the not-to-specification range of fig. 4.

No. 4 mesh sieve

Material passing the no. 4 mesh sieve have clast sizes of 4.75 mm or less.
Of the 19 types of coarse aggregates described in AASHTO M 43 (Appendix B) all contain stipulation about this clast size except classes 1-2, 24, 3, 357, 4, and 5. Sites with material that did not meet one of the 14 remaining coarse aggregate classes (Appendix B) required for this sieve size is percent range A (55 percent) to B (85 percent). Half of the lower Quaternary sites does not meet specifications. This is comparable to a fourth of the upper Quaternary sites (fig. 5) not meeting specifications. All the sites contain substantial coarser material such that none in an unprocessed state will meet the requirement of fine aggregate. The no. 4 mesh sieve is not used in specifications set by ADOT (1990) for aggregate subbases and bases.

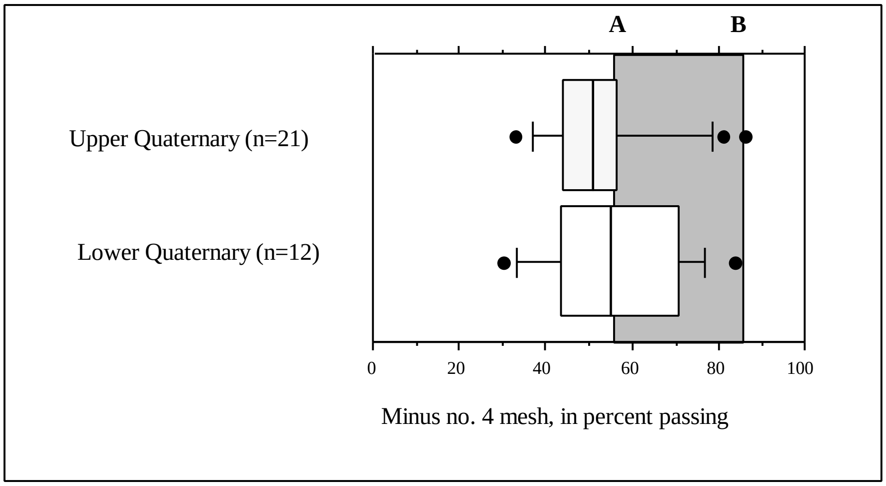

Figure 5. Boxplots of material passing the no. 4 mesh sieve (4.75 mm). Material, which did not meet one of the 19 coarse aggregate class (Appendix B) requirements for this sieve size, is percent range A (55 percent) to B (85 percent).

The one pit found in Verde Formation gravels had 50 percent of the material passing the no. 4 mesh sieve. The other four sites in the Verde Formation had material with values between 52 and 86 percent and a median of 73.5 percent, which would be in the not-to-specification range in fig. 5.

No. 10 mesh sieve

Material passing the no. 10 mesh sieve has clast sizes of 2.0 mm or less. One complication in evaluating data from this sieve size is that standard sizes of aggregates for road and bridge construction provided by AASHTO M 43-88 (Appendix B) for coarse aggregates do not make use of the no. 10 mesh sieve. Most of the classes do not tolerate material this fine grained. Only classes 89 and 9 use screens adjacent to where the no. 10 would be if given in AASHTO specification M 43-88. The boundaries for those two classes are estimated (fig. 6). Class no. 10 does bracket the size range but does not give specifications for grain sizes between the no. 8 and no. 50 sieves (Appendix B) and would not be applicable to size no. 10 mesh sieve if used.

The one pit found in Verde Formation gravels had 39 percent of the material passing the no. 10 mesh sieve. This site, like most of the rest fails to meet any coarse aggregate specifications. The other three sites in the Verde Formation with data had material with values between 56 and 68 percent and a median of 64 percent which meets the specifications for fine aggregate for the mesh sieve (fig. 6).

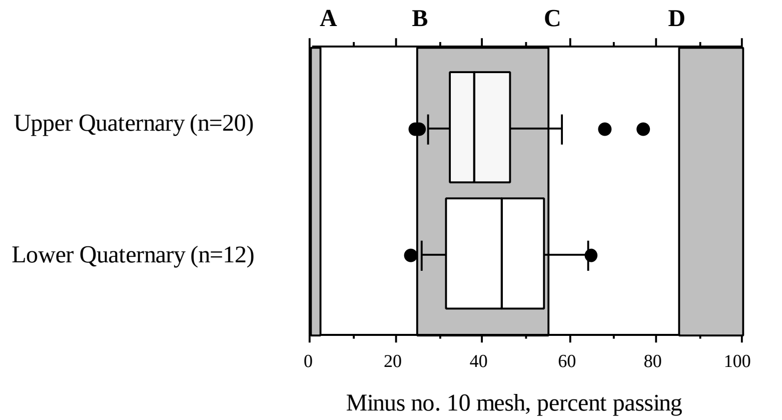

Figure 6. Boxplots of material passing the no. 10 mesh sieve (2 mm). Material which meets either the maxium or minimum of coarse aggregate class 89 or 9 falls between A (3.3 percent) and B (25 percent) and those for fine grain aggregate between C (56.5 percent) and D (85.5 percent).

No. 40 mesh sieve

Material passing the no. 40 mesh sieve has clast sizes of 0.42 mm or less. This is a mesh size not used in current specifications and upper and lower limits of possible application for use as fine aggregate have been estimated. Of the classes in AASHTO M 43-88, only no. 10 brackets this sieve size but no specification for sieve nos. 8, 16, or 50 are given and none would likely have been given for the no. 40 mesh sieve if it had be identified in the standard. Most sites met the specification for fine aggregate in the estimated allowable range (fig. 7) which is from 14 and 34 percent (about A to B). Other sieve sizes used by ADOT (1990) for fine aggregate specifications include the no 50 and 100.

The one pit found in Verde Formation gravels had 21 percent of the material passing the no. 40 mesh sieve and was within the allowable range for fine aggregate. Samples from four other sites in the Verde Formation with data had material with values between 25 and 54 percent and a median of 43 for the no. 40 mesh sieve, which is nearly completely within the standard range estimated for fine aggregates.

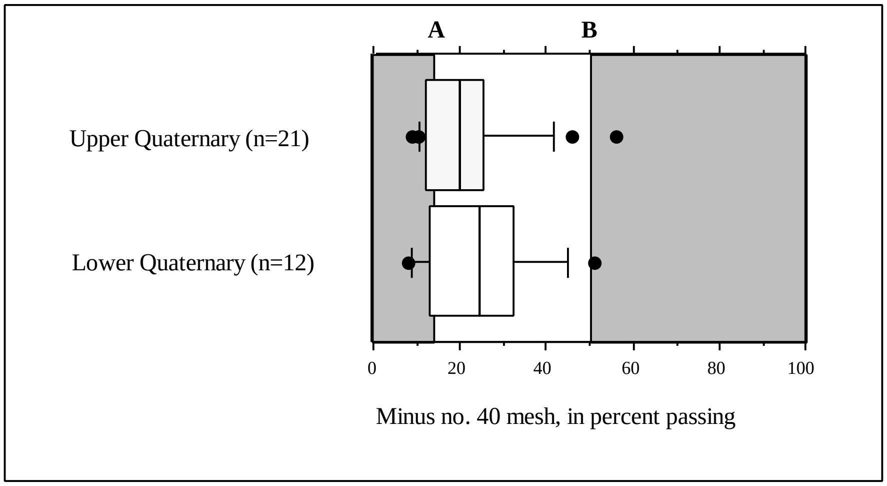

Figure 7. Boxplots of material passing the no. 40 mesh sieve (0.42 mm). Sieve size not applicable to coarse aggregates standards. Most samples are within permissive range (A to B) for use as fine aggregate (ADOT, 1992).

No. 200 mesh sieve

Material passing the no. 200 mesh sieve (or fines) has clast sizes of 0.074 mm or less. Maximum amounts of fines allowed in various types of aggregate usage are shown in figure 8. The most tolerant use has a maximum of 10 percent. The solid line at 15 percent (E) is the common maximum fines observed in most sand and gravel operations in the US. Only a quarter of upper Quaternary sites exceed the 10 percent maximum of minus 200 mesh material as compared to about half of the samples from lower Quaternary sites (fig. 8). Nearly all upper Quaternary sites are less than the 15 percent maximum seen in sand and gravel operations as compared to a quarter of lower Quaternary sites (fig. 8). While aggregate sources with more fines can be exploited, operations can have limited life, particularly if the large volume of fines generated cannot be readily disposed of.

The median of samples from upper Quaternary sites is 4 percent fines; for lower Quaternary sites, it is 10.5 percent fines. Are there statistically more fines in the latter? A comparison of percent fines from the two types of sites was made using the Mann-Whitney U test (U Prime= 173, p=0.077 (adjusted for ties)) and suggests there is **not** a significant difference at the 5 percent level.

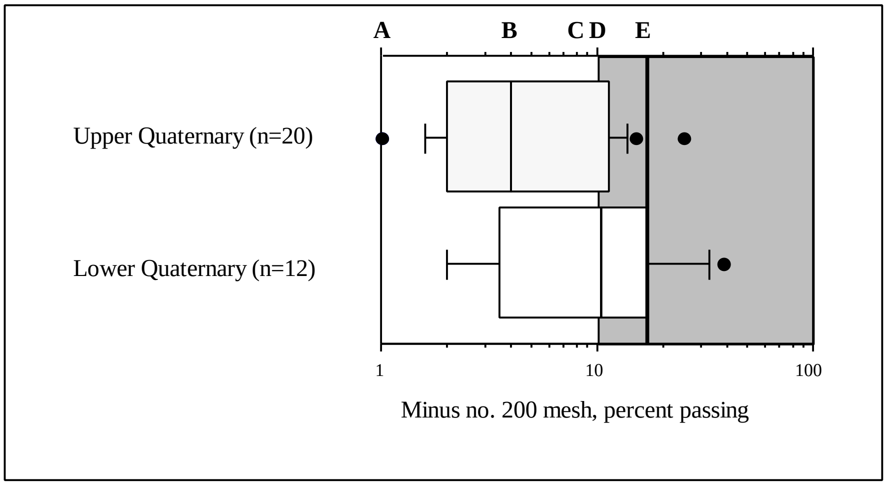

Figure 8. Boxplots of material passing the no. 200 mesh sieve (0.074 mm). Note percent passing is given in units of logarithm base 10. Maximum allowed in coarse aggregate by ADOT (199) is one percent (A), fine aggregate is four percent (B), subbases and bases classes 1-2 is eight percent (C), and class 4-5 is 10 percent (D). Solid line at 15 percent (E) is the common maximum minus 200 mesh observed in most sand and gravel operations in the US.

Data from the one pit found in Verde Formation gravels has 10 percent of the material passing the no. 200 mesh sieve which is at the maximum allowed for some types of aggregate subbases and bases (ADOT, 1990, Table 303-1) and within the range seen in many commercial aggregate operations. Samples from four other sites in the Verde Formation with data had material with fines between 8 and 45 percent and a median of 28.5. percent.

Los Angeles degradation test (LADT)

The test used to evaluate the resistance of a coarse aggregate to degradation by abrasion and impact is the Los Angeles degradation test (Meyer and Zeinak 1991) or LADT. In accordance to ADOT (1990, p. 718) standard specifications “the percent of wear of coarse aggregate at 500 revolutions, when tested in accordance with the requirements of AASHTO T 96, shall not exceed 40.” The same requirement is also specified for the class of aggregate 1 to 4 for material used in subbases and bases (ADOT, 1990, p. 140).

In this study only 10 of the 50 sites have LADT results including eight observations in the lower Quaternary sites, one site in upper Quaternary material and one from a site in the upper Tertiary Verde Formation gravels. All test results are well below the 40 percent noted in the standard and are given together as a single boxplot (fig. 10). The minimum result is 19 percent (upper Tertiary Verde Formation gravels), the maximum is 22 percent from a upper Quaternary site. The median for all observations is 21. 5 percent; half the sites are between 20 and 24 percent (fig. 9).

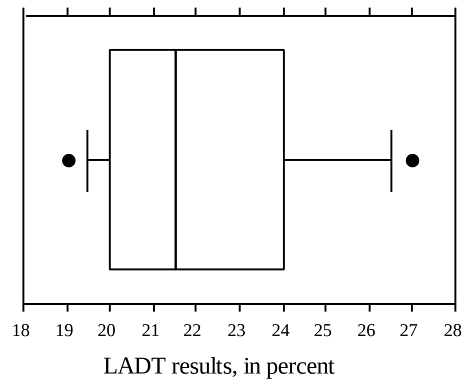

Figure 9. Boxplots of test results of resistance of a coarse aggregate to degradation by abrasion and impact of the Los Angeles degradation test (AHD, 1972).

Plastic index (PI)

The plastic index (PI) is one of several ways to measure the presence of sensitivity to moisture change and is important when plans call for aggregate to be used in Portland cement or asphalt concrete. It's also one consideration in highway and other types of foundation construction. According to White (1991, p. 13-42) it "is the difference in the Atterberg liquid limit and plastic limit moisture contents." A PI of 4 is the maximum allowed as stipulated in ASTM D 3515 for materials used in asphalt concrete mixtures (White, 1991).

In this study PI observations for lower Quaternary sites have a median PI value of 7.5, which is virtually identical to the PI value of 8 for upper Quaternary sites. Distribution of values is comparable between the two groupings but more upper Quaternary sites have lower (and desirable) PI values (fig. 10).

The one pit found in Verde Formation gravels has a PI value of 44 which does not met specifications (fig. 11). PI test results from four other sites in the Verde Formation with data had material with PI values between 11 and 38 and a median of 34. These values are well above the range given in specifications.

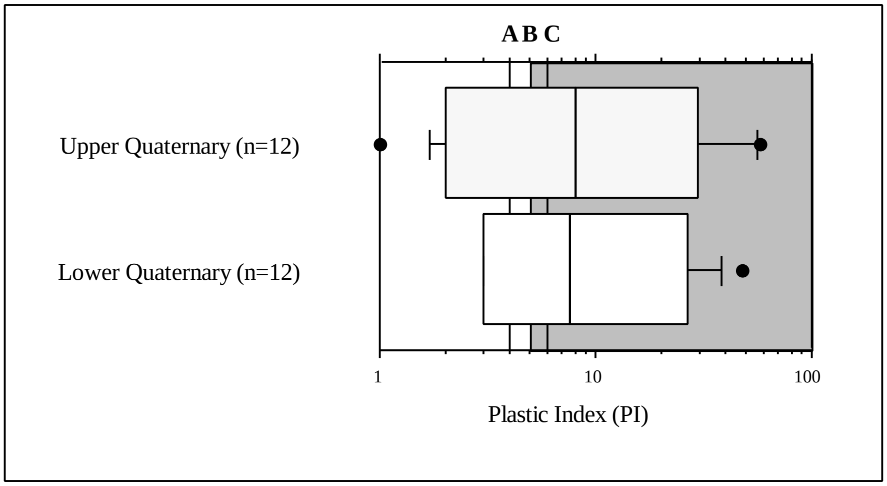

Figure 10. Boxplots of PI values of plastic Index (PI) values for sites in upper and lower Quaternary alluvial materials. Note percent passing axis is given in units of logarithm base 10. The shaded area to the right of the horizontal line at B are PI values unacceptable for materials used in asphalt concrete mixtures under standard ASTM D 3515. In ADOT (1990) specifications, aggregate used in subbases and bases classes 1-3 has maximum PI of 3 (A, above) and classes 4-6 has maximum PI of 5 (C, above).

How dependent is PI on how much minus 200 mesh material (or fines) is in the sample? Could removing fines possibly effect PI? Inspection of figure 11 suggests that as amount of minus 200 mesh materials declines below about 20 percent, PI also shows a systematic decline as well. In fact, for material collected in lower Quaternary sites, a fairly strong relationship is suggested and reflected by the following regression equation:

Log (PI) = 0.245 + 0.07 * (minus 200 mesh, in percent passing) (1)

where Log is logarithm base 10. The R^2 suggests that 86 percent of the variation in log (PI) can be explained by knowing how much fines pass the 200 mesh sieve. An estimate of PI is therefore possible given knowledge of percent fines, or at least this is so for lower Quaternary sites. This type of estimate is not expected to replace sampling and laboratory determination if a site were actually under consideration for production of aggregate. Note the scatter between log (PI) and fines for samples collected at upper Quaternary sites is much greater and the relation between the two is much weaker. This suggests that if sand and gravel operators in the Verde River Basin remove fines from materials with a maximum of 20 percent fines, a decline in PI may occur in material from pits in lower Quaternary units as opposed to that in the upper Quaternary.

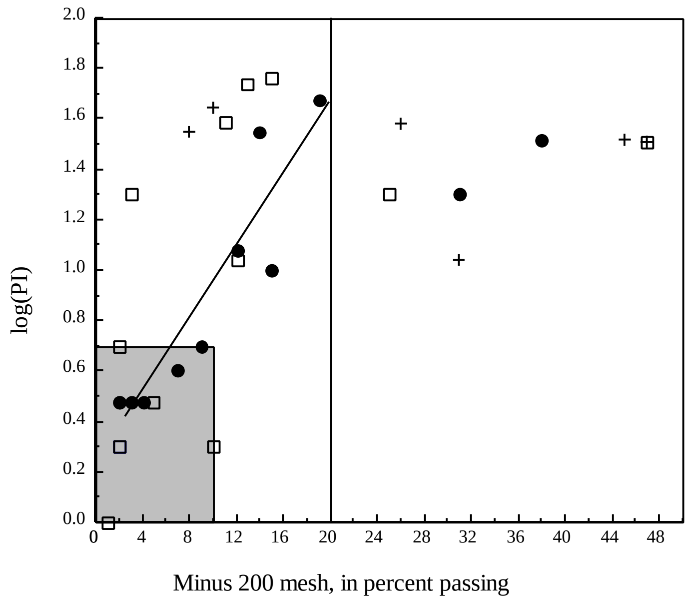

Figure 11. Scatter plot of log (PI) and minus 200 mesh material. Note "log" in log (PI) is for logarithm base 10. Solid points are for lower Quaternary sites, open squares are for upper Quaternary sites, pluses are upper Tertiary Verde formation, and square/plus combination from site of unknown surficial geology. Shaded area is the compliance zone for samples meeting BOTH the maximum allowed for ADOT subbase and base class materials (see fig. 10) and PI for ADOT (1990, p. 140) aggregate classes 4-6 for use in subbases and bases (see fig. 12). See text for equation and explanation of boundary at 20 percent passing on the minus 200 mesh axis

Between 20 and 50 percent, PI appears to be independent of the amount of minus 200 mesh material reported (fig. 11). This includes all sites from the Verde Formation (which also are seen for samples with less than 20 percent fines) and for the site with unknown surficial geology.

It is important to remember that a relation like the one in figure 11 may be present between two variables but it need not necessarily mean changing one will in fact effect the other at a given site! PI may be associated with a size component that may not necessarily be removed by reducing the amount of fines! Other unrecognized facts not considered may also be important and missing from this evaluation. This is a small data set as well. More observations would be needed to verify the relationship suggested. Better yet, a test is needed to see if removing some fines also would also cause PI to decline.

Volume change

Significant expansion or shrinkage due to change in moisture content is undesirable in construction materials. Aggregate is expected to be inert and exhibit little volumetric change when exposed to the common weather conditions of the building site. Most volume changes due to moisture are related to permeable pore space. Breakdown of grains during wetting and drying cycles may also contribute to volume change and needs to be considered in unbound use (Marek, 1991).

Data is available giving maximum 24-hour swell of 21 samples measured using AASHTO 101, Method B (AHD, 1972). Standards in use at time of testing set the maximum allowed swell of 0.06 for use in all classes of mineral aggregate and one class of aggregate for cover materials and slurry seal (AHD, 1972, Table 703-1 and 704-1).

Only two lower Quaternary sites have swell measurements; one is at Pit No. 7777 with a value of 0.06 and the other is Pit No. 1885A with a value of 0.05 (Appendix A). Observations for the 19 upper Quaternary sites are nearly equally divided between youngest undivided alluvial fans, stream terraces, activate channel deposits (unit 7N) and young alluvial fans (unit 4, Table 1A). Swell values are comparable in both units (fig. 12). Slightly less than half of the upper Quaternary sites have values meeting specification. Swell in this data is also found to be independent of how much material is less than the 200 mesh sieve.

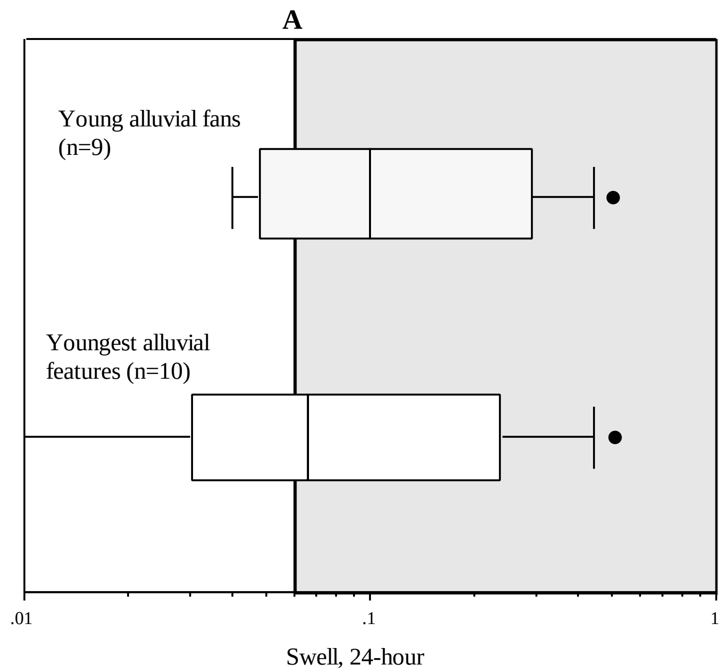

Figure 12. Boxplots of swell values for sites in Quaternary alluvial materials classified by morphology and age (Appendix A). The shaded area to the right of the horizontal line at A (swell of 0.06) are swell values unacceptable for use in all classes of mineral aggregate and one class of aggregate for cover materials and slurry seal (AHD, 1972).

Evaluation of pit distribution and geology

The historical location of pits is dependent on distance to construction sites and the presence of suitable material. The question of access is critical as it is transportation that is commonly the dominant component of aggregate cost. The closer the production and consumption sites, the cheaper the material. Property ownership and zoning is also part of the access question. In the Verde Valley study, absence of pits in certain units may reflect these controls or they may reflect absence of suitable construction material.

What does it tell us about units if sand and gravel pits are missing due to geology, and not the factors identified above? Table 4 gives the area of exposure of each unit shown on Plate 1 and the number of pits found on each (excluding those

Table 4. Comparison of numbers of aggregate and borrow pits by surficial geology. Four pits were not classifiable using tract definitions but most of these sites are suspected to be in non-gravel facies of the Verde Formation.

Grouping used in Evaluation	Unit[5]	Abbrev. Description	Area (km^2)	No. of distinct outcrops[6]	Total no. pits	Nonborrow-types pits[7], in percent
Upper Quaternary	7N	Youngest undiv. Alluvial fans, stream terraces, active channel dep.	60.8	31	22	54[8]
do	6	Young stream terraces (Chuckwalla Terraces)	6.47	36	6	50[9]
do	5	Young alluvial fans (Chuckwalla Gp.)	45.52	143	3	33
Lower Quaternary	4	Old stream terraces (Montezuma Terraces)	3.33	65	3	0[10]

[5] Units are shown on plate 1

[6] Number of distinct outcrops is based on number of polygons on plate

[7] Pits classified as unknown are assigned “borrow” for this calculation

[8] Surficial classification for three sites from Cox (1995) or determined otherwise but not shown in unit 7N (Pl. 1).

[9] Surficial geologic classification for three sites from Cox (1995) and not shown to be in unit 6 (Pl. 1).

[10] Surficial geologic classification for all sites from Cox (1995) not shown to be in unit 4 (Pl. 1).

Grouping used in Evaluation	Unit[11]	Abbrev. description	Area (km^2)	No. of distinct outcrops[12]	Total no. pits	Nonborrow-types pits[13], in percent
do	3	Old alluvial fans (Montezuma alluvial fan complex)	51.22	119	9	56
do	3N	High & old alluvial fans (Oxbow Gp.)	27.10	109	1	100
do	2	Basin-fill gravels (facies of the Verde Formation)	25.5	37	1	0

described by Cox). Also given is the percent of the pits designated as nonborrow. Material from borrow pits have the least stringent geotechnical requirements. Nonborrow pits have better quality material so that they meet specifications for a range of nonborrow uses. Units with more nonborrow pits can be regards as likely, on average, to provide better quality construction material. Some units are transected by roads and it appears they may be lacking pits because they have substandard material. The units are discussed from oldest to youngest unit below:

Verde Formation (including unit 2). The oldest unit in the investigation has a comparably large exposure area as shown in Pearthree (1993), House and Pearthree (1993), and House (1994). Most of the Verde Formation is too fine-grained to be used as aggregate. Some carbonate facies are known to be present in the Verde Formation and may be suitable for crushed stone, but were not considered in this study. The gravel facies of the Verde Formation has an outcrop area of 25.5 km^2 in the study area (unit 2, Plate 1), but has limited access since it is found on the upper slope of the valley side. Only one site is noted (Appendix A, pit no. 7455) which was a source of borrow material (Appendix B). The gravel facies was reportedly used as a source of materials outside of the study area but it is not known if it was for borrow or nonborrow uses. Given sites with adequate volumes and quality, the gravel facies of the Verde Formation may be a suitable source of some types of aggregate in the future.

Oxbow Group (unit 3N). The unit contains the high and old alluvial fans with an area of 27.1 km^2 and only one pit that was identified as a source of borrow (Appendix A, pit no. 6411). Most of the Oxbow Group crops out in the upper slopes of the valley, but it has a number of exposures in the lower part of the valley and is commonly crossed by roads. This suggests that material quality may be poor for use as aggregate.

---

[11] Units are shown on plate 1

[12] Number of distinct outcrops is based on number of polygons on plate

[13] Pits classified as unknown are assigned "borrow" for this calculation

Montezuma alluvial fan complex (unit 3). Old alluvial fans (unit 3, Plate 1) have 9 sites of which 5 provided material higher in quality than that provided by borrow pits (Table 4). Most sites are located at the lower ends of the fans, which are readily accessible to the road running parallel to the Verde River. This unit has the most nonborrow pits of the lower Quaternary units.

Montezuma Terraces (unit 4). Poor quality material appears to be found in this unit consisting of old stream terraces. Remains of the terraces are limited in areal extent (3.3 km^2), have highly fragmented outcrops (65 polygons in Plate 1), and many are near roads suggesting the materials they contain are not particularly desirable for use. None of the outcrops of old stream terraces have pits in the study area. However, three sites appear to be found in this unit in the study of surficial geology northeast of the Verde River by Cox (1995) where two are borrow pits and one has an unknown pit classification.

Chuckwalla Group (unit 5). Poor quality material appears to be found in the young alluvial fans. They crop out extensively (45.5 km^2) and are frequently crossed by roads but only three pits are recognized in this study. Two are sources of borrow. The Chuckwalla Group appears to have been avoided as a source of road-construction materials.

Chuckwalla Terraces (unit 6). This unit has a limited outcrop area of 6.47 km^2 and proportionally fewer pits (6) where half provided material higher in quality than provided by borrow pits (Table 4).

Youngest undivided alluvial features (unit 7N). This unit includes alluvial fans, stream terraces, and active channel deposits. Twenty-two of the 50 pits in the study are found in this unit with an outcrop area of 60.8 km^2. Over half are suitable for nonborrow uses (Table 4). This unit has numerically the most nonborrow pits as well as more nonborrow pits per unit area than any other unit in the study area.

The youngest undivided alluvial fans, stream terraces, and active channel deposits have been a better source of construction material than all other units. On the other hand, the two other units included in the upper Quaternary group--Chuckwalla terraces and the Cuckwalla group--have not been particularly promising sources of aggregate. Among those units in the lower Quaternary group (Table 4), only the Montezuma alluvial fan complex seems to have been a particularly rewarding source of nonborrow material albeit at a much less commonly than those pits found in the youngest undivided alluvial fans, stream terraces, and active channel deposits. Perhaps the great unknown of this study concerns the condition of the gravel facies of the Verde Formation. However, its greater age suggests the quality of materials it contains may not be promising for high-end construction use.

Conclusions

The evaluation of sand and gravel resources uses selected engineering characteristics from samples taken from pits found in the Verde River Basin. Geology of the pits was from a geologic map (Cox, this volume) compiled using surficial geology maps prepared by the Arizona Geological Survey, and field studies of selected sites. Engineering data was from AHD (1972). A number of qualifications about both the data and how the data were used are outlined in the introduction. Conclusions given here need to be considered within the context of these qualifications.

Evaluation of sites using ASTM, AASHTO and ADOT specifications provides insight into the quality of various surficial materials used in the past as sources of sand and gravel. Specifications are used to design aggregate mixes for use in asphalt and Portland concrete as well as other construction materials, so it comes as no surprise that most natural materials fail to meet these specifications in an unprocessed state. Nevertheless, comparisons like those found here help to give an idea about which surficial materials seem to be close to meeting specifications.

Of the 50 sites evaluated only one (Pit no. 6699) met all of the various specification given during this evaluation. As expected, engineering data from the upper Quaternary sites was more likely to meet specifications than data from sites in lower Quaternary materials (figs. 3-12). Upper Quaternary sites also usually exhibit less variability. However, five of the nine pits found in old alluvial fans (unit 3, Plate 1), included among the lower Quaternary sites, had characteristics sufficiently high for uses other than borrow material. Some of the Quaternary units lack pits, which may suggest that they contain unsuitable material (Table 4). Several of these units are widespread and many are crossed by roads suggesting accessibility.

A key factor in determining if a sand and gravel deposit will be worked is how much fine materials it contains. Both the lower Quaternary and upper Quaternary sites have material passing the 200 mesh sieve size (or fines) in sufficiently low amounts to be viable (fig. 9) as a source of aggregate (fig. 9, line E). However upper Quaternary sites have a median of 4 percent fines as compared to a median of 10.5 percent in lower Quaternary sites. While aggregate sources with more fines can be exploited, operations can be of limited life, particularly if the large volume of fines cannot be readily disposed. Fines are often a waste material creating considerable cost for aggregate operators. Sites with low fines are highly desirable and give upper Quaternary sites a distinct advantage.

What is the prognosis of future aggregate production in the Verde River basin given exhaustion of known pits and prohibition of new mining sites in youngest alluvial features (particularly in riparian areas)? Two surficial units may play a larger role in the short term--the old alluvial fans (Unit 3, plate 1) and possible gravel facies of the Verde Formation which need additional evaluation (at least in the context of this study).

In the longer term, the Verde River basin can be expected to go the way most areas in the US have gone when it comes to aggregate extraction and is a possible that the role of National Forest lands may become greater. As production declines from existing and perhaps from a few new sand and gravel pits in surficial sand and gravel deposits, producers will need to turn to crushing stone from quarries in suitable bedrock units. Many of these bedrock units may have their best exposures inside the Prescott or Coconino National Forests.

References cited

American Association of State Highway and Transportation Officials (AASHTO), 1993, Sizes of aggregate for road and bridge construction, *in* Standard specifications for transportation materials and methods of sampling and testing: American Association of State Highway and Transportation Officials, 16th edition, p. 14-15.

American Society for Testing and Materials (ASTM), 1996, Annual book of ASTM standards, Section 4, Construction: American Society for Testing and Materials, v. 04.02, 724 p.

Arizona Department of Transportation (ADOT), 1990, Standard specifications for road and bridge construction: Arizona Department of Transportation, Highway Division, 800 p.

Arizona Highway Department (AHD), 1972, A materials inventory of Yavapai County: Arizona Highway Department and Federal Highway Administration, 65 p.

Bressler, S.L., and Butler, R.B., 1978, Magnetostratigraphy of the late Tertiary Verde Formation, central Arizona: Earth and Planetary Science Letters, v. 38, p. 319-330.

Cox, L.J., 1995, An evaluation of sand and gravel resources in and near the Verde Valley of the Coconino National Forest, Arizona: U.S. Geological Survey Open-File Report 95-31, 30 msp, 1 pl., scale 1:126,720.

Drake, Bob, 1995, Comment--finding answers to the fines problem: Rock Products, v. 98, no. 9, p. 15.

House, P.K., 1994, Surficial geology of the southern Verde Valley, Yavapai County, Arizona: Arizona Geological Survey Open-File Report 94-23, 20 p., 3 map sheets, scale 1:24,000.

House, P.K., and Pearthree, P.A., 1993, Surficial geology of the northern Verde Valley, Yavapai County, Arizona: Arizona Geological Survey Open-File Report 93-16, 19 p., 4 map sheets, scale 1:24,000.

Lane, M.E., 1992, Mineral Appraisal of the Coconino National Forest, Arizona: U.S. Bureau of Mines Open-File Report MLA 11-92, 69 p., 2 appendices, 3 pls., scale 1:126,720.

McKee, E.H., and Elston, D.P., 1980, Reversal chronology from a 7.9- to 11.5- m.y. old volcanic sequence in central Arizona: Comparison with ocean floor polarity record: Journal of Geophysical Research, v. 85, no. B1, p. 327-338.

Menges, C.M., and Pearthree, P.A., 1989, Late Cenozoic tectonism in Arizona and its impact on regional landscape evolution, *in* Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Tucson, Arizona Geological society Digest 17, p. 649-680.

Marek, C.R., 1991, Basic properties of aggregate, *in* Barksdale, R.D., ed., The aggregate handbook: Washington, D.C., National Stone Association, p. 3-1 to 3-81.

Meyer, D.A., and Zeinak, S.P., Jr., S.P., 1991, Structure and economics, *in* Barksdale, R.D., ed., The aggregate handbook: Washington, D.C., National Stone Association, p. 2-1 to 2-17.

Nations, J.D., Hevly, R.H., Landye, J.J., and Blinn, D.W., 1981, Paleontology, paleoecology, and depositional history of the Miocene-Pliocene Verde Formation, Yavapai County, Arizona: Tucson, Arizona Geological Society Digest 13, p. 133-150.

Pearthree, P.A., 1993, Geologic and geomorphic setting of the Verde River from Sullivan Lake to Horseshoe Reservoir: Arizona Geological Survey Open-File Report 93-4, 25 p., 5 map sheets, scale 1:24,000.

Péwé, T.L. 1978, Terraces of the lower Salt River Valley in relation to the late Cenozoic history of the Phoenix basin, in Burt, D.M., T.L., eds., guidebook to the geology of Central Arizona: Arizona Bureau of Geology and Mineral Technology Special Paper 2, p. 1-14.

Twenter, F.R., and Metzger, D.G., 1963, Geology and ground water in Verde Valley-the Mogollon rim region, Arizona: U.S. Geological Survey Bulletin 1177, 132 p., plate, scale 1:62,500.

Weir, G.W., Ulrich, G.E., and Nealey, L.D., 1989, Geologic map of the Sedona 30' x 60' quadrangle, Yavapai and Coconino Counties, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1896, scale 1:100,000.

White, T.D., 1991, Aggregate as a component of portland cement and asphalt concrete, *in* Barksdale, R.D., ed., The aggregate handbook: Washington, D.C., National Stone Association, p. 13-1 to 13-69.

Appendix A. Selected engineering data used in evaluation of pits in the Verde River Basin (AHD, 1972).

[Geology based on Plate 1 (this volume) with some modifications (see text) and Cox (1995). **Column Headers**: Pit numbers--numeric for AHD (1972) sites; CX preference for sites noted by Cox, PI--plastic index, ABS (500)--Los Angeles durability test (500 revolutions); Swell--maximum, in inch., in 24 hour when tested accordance with the requirements of AASHTO T 101, Method B; S--sieve; IN--inch; **Pit Class**: AB--aggregate base; BR--borrow; cover material; MA--mineral aggregate; SM--select material; SB--special backfill; SS--subgrade seal; UN--unknown, no data; **Geology** (numeric or alphanumeric as used on Plate 1 and alphabetic if not): 2--Verde Formation gravels (Tvg); 3--old alluvial fans; 4--old stream terrace; 5--young alluvial fans; 6--younger stream terraces; 7N--youngest alluvial features (fans, terraces, active channel deposits undivided); VF--Verde Formation, either lacustrine (Tvl) facies or undifferentiated (Tvu); UNK--unknown.]

Pit Number	Pit Class	PI	ABR (500)	Swell	S-3/4 IN	S-#4	S-#10	S#40	S#200	Geology
1541	BR	11		0.05	77	56	46	27	12	5
1542	SB	2		0[1]	89	77		46	10	6[2]
1884	BR	20			88	74	65	51	31	4[2]
1885	BR	10			93	70	47	27	15	4[2]
1885A	AB		22	0.05	69	43	31	12	2	6[3]
1886	AB		21	0.24	74	57	46	24	5	7N
2425	UN									7N
2426	UN									4[2]
2783	UN									7N
2784	UN									6
2785	UN									7N[2]
2790	UN									7N[4]
2792	UN									6
2793	UN									7N
2796	UN									7N
5217	MA		22	0.01	78	59	48	20	1	7N
5219	UN									7N
5220	CM	20		0.17	62	37	30	20	3	7N[5]

[1] Value has been set to 0.001 for use in evaluation.
[2] Surficial geology determined from Cox, 1995.
[3] Surficial geology determined from Cox, 1985; possible pit geology is VF (non-gravel facies) and YTR which is selected.
[4] Surficial geology can not be determined from Cox, 1985; however topography suggest site in YST.

Pit Number	Pit Class	PI	ABR (500)	Swell	S-3/4 IN	S-#4	S-#10	S#40	S#200	Geology
5221	MA	3		0.5	68	45	36	15	3	3
6408	BR	39			92	81	68	27	11	5[6]
6409	BR	35			75	60	52	28	14	3
6410	MA	3	20	0.1	56	35	27	9	2	3
6411	BR	47			68	56	49	34	19	3N
6412	BR	58			67	44	40	25	15	5[7]
6422	MA		20	0.05	70	47	38	17	3	6[2]
6423	BR	55		0.07	73	51	39	25	13	7N
6424	MA	1	27	0.38	66	45	35	11	1	7N
6698	MA	3		0.04	49	30	23	8	2	3
6699	SM	2		0.06	72	55	47	21	2	7N
6967	MA				51	33	24	9	2	7N
6968	SM	5			65	44	34	20	9	3
7184	SM	5	21	0.17	75	53	35	12	2	7N
7455	BR	44	19	0.36	74	50	39	21	10	2
7470	SB				93	86	77	56	13	7N
7471	BR	12		0.04	93	84	64	31	12	3
7472	BR	35		0.27	87	75	56	25	8	VF
7532	BR	32			85	72	65	54	47	UNK
7533	BR	33			89	72	56	42	38	3[8]
7534	BR	33			89	72	64	54	45	VF
7727	MA		24	0.51	62	37	25	13	4	7N
7728	BR	11			96	86	68	46	31	VF[9]
7729	BR	38			66	52		41	26	VF
7777	MA	3		0.06	68	43	29	11	4	3
7835	BR	20			72	56	49	39	25	7N
8004	AB	3		0.05	87	52	32	12	5	5[10]
8005	AB	4			100	54	42	22	7	3
8094	MA	2	26	0.03	68	46	34	10	2	7N
8239	MA				98	51	38	20	6	7N

[5] Possible pit geology is VF (non-gravel facies) or YST which is selected.
[6] Possible pit geology is YAF or YST; road access suggests likely YAF.
[7] Site classification revised to surficial geology tract 5 (Pl. 1) during final report revision and data from this site was not used.
[8] Possible pit geology is VF or OAF which was selected.
[9] Surficial geology can not be determined from Cox, 1985; possible Verde Formation.
[10] Possible pit geology is YST or YAF which is selected based on topography.

Pit Number	Pit Class	PI	ABR (500)	Swell	S-3/4 IN	S-#4	S-#10	S#40	S#200	Geology
8251	UN									6
8276	CM				58	41	33	13	3	7N
CX01	UN[11]									VF
CX02	BR[12]									VF
CX03	BR[12]									VF
CX04	BR[12]									VF
CX05	UN[11]									5
CX06	UN[13]									7N

[11] Cox describes site as a "gravel pit."
[12] Identified as a borrow pit on the USGS Cottonwood quadrangle, scale 1:24,000.
[13] Site location of commercial sand and gravel operation--Superior Sand and Gravel.

Appendix B. Standard size of processed coarse aggregate for road and bridge construction in 19 classes in AASHTO specification M 43-88 (ASSHTO, 1993). [Entries in table are given as minimum followed by maximum if two values.]

Amount finer than each laboratory sieve (square openings), weight percent

Class No.	4 in 100 mm	3.5 in 90 mm	3 in 75 mm	2.5 in 63 mm	2 in 50 mm	1.5 in 37.5 mm	1 in 25 mm	0.75 in 19 mm	0.5 in 12.5 mm	0.375 in 9.5 mm	No. 4 4.75 mm	No. 8 2.36 mm	No. 16 1.18 mm	No. 50 300 µm	No. 100 150 µm
1	100	90-100		25-60		0-15		0-5							
2			100	90-100	35-70	0-15		0-5							
24			100	90-100		25-60		0-10	0-5						
3				100	90-100	35-70	0-15		0-5						
357				100	95-100		35-70		10-30		0-5				
4					100	90-100	20-55	0-15		0-5					
467					100	95-100		35-70		10-30	0-5				
5						100	90-100	20-55	0-10	0-5					
56						100	90-100	40-85	10-40	0-15	0-5				
57						100	95-100		25-60		0-10	0-5			
6							100	90-100	20-55	0-15	0-5				
67							100	90-100		20-55	0-10	0-5			
68							100	90-100		30-65	5-25	0-10	0-5		
7								100	90-100	40-70	0-15	0-5			
78								100	90-100	40-75	5-25	0-10	0-5		
8									100	85-100	10-30	0-10	0-5		
89									100	90-100	20-55	5-30	0-10	0-5	

Class No.	4 in 100 mm	3.5 in 90 mm	3 in 75 mm	2.5 in 63 mm	2 in 50 mm	1.5 in 37.5 mm	1 in 25 mm	0.75 in 19 mm	0.5 in 12.5 mm	0.375 in 9.5 mm	No. 4 4.75 mm	No. 8 2.36 mm	No. 16 1.18 mm	No. 50 300 µm	No. 100 150 µm
9										100	85-100	10-40	0-10	0-5	
10										100	85-100				10-30