Assessment of the sand and gravel resources of the Lower Boise River Valley Area, Idaho

Part one: geological framework of the sand and gravel deposits

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Open-File Report 01-130

2001

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

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Introduction

The USGS has undertaken a first order evaluation of sand & gravel resources in the Lower Boise River Valley in response to rapid urban expansion in the Boise-Nampa-Caldwell corridor in southwest Idaho. The study is intended to provide land-use planners and managers, particularly in the Bureau of Land Management, with a foundation of knowledge that will allow them to anticipate and plan for demand for and development of sand and gravel resources on public lands in response to the urban growth. Attributes under study include: regional geology of both alluvial source areas as well as deposits; fluvial processes that led to deposition of the sand and gravel deposits; spatial distribution of the deposits; quantity and quality of materials in the deposits; and the suitability of the deposits for a range of applications. The study will also examine and attempt to model the association between fluvial processes, deposit characteristics, and physical specifications for various applications of sand and gravel. The results will be presented in a series of sand and gravel assessment reports of which this is the first.

This initial report provides a regional geological overview of west-central Idaho, including the Western Snake River Plain, and a synthesis of available information on the geology and distribution of sand and gravel deposits in the Lower Boise River Valley from about Boise, Idaho, to the junction of the Boise River with the Snake River at the Idaho-Oregon border. The overview is particularly concerned with those aspects of geology that may have effected the development and preservation of sand and gravel deposits in the area. It is provided to help users to better understand and utilize the sand and gravel assessment reports to follow. The geology outside of the Boise River Valley is also discussed, as there may be a need by planners and others concerned about future aggregate supplies to look beyond the local area, the focus of this series of assessments, for alternative sources of sand and gravel.

The Appendix of this report presents an overview of a classification system for alluvium, particularly sand and gravel deposits, after Miall (1996). A range of important characteristics of lithofacies types and architectural elements of sedimentary and colluvial deposits are described. These diagnostic features may be helpful in developing geologic models useful in the assessment of sand and gravel deposits (Miall, 1996). Those facies and architectural elements that are most likely to be suitable sources of sand and gravel are explicitly noted and presented in a classification matrix in the appendix. The success of the classification will be dependent on how well sand and gravel deposits are described as well as an understanding and recognition of facies identification criteria given by Miall (1996).

Not all sand and gravel deposits are alike. Many sand and gravel deposits lack an acceptable grain-size distribution, contain contaminants that are either expensive or impossible to remove, or possess other properties that detrimentally effect behavior when used as aggregate. Although some sand and gravel deposits may be suitable for certain aggregate uses, they may also be unsuitable for others. Deposits suitable for use in concrete must meet higher specifications than materials used in road subgrades. Although the scope of this assessment is limited to aggregate-quality sand and gravel, it also will consider deposits that are recognized (developed or undeveloped), not clearly identified but suspected to be present, and extensions of probable deposits.

Sand and gravel deposits are best understood by examining information about all parts of the river basin in which they are located. This includes consideration of the types of source rocks present, the kinds of weathering and erosional processes have been and are likely operating, and the sediment transport mechanisms that have been involved. Other factors worth noting include the types of contaminants present, factors leading to the preservation of deposits, and post-depositional modifications that affect the quality of the sand and gravel.

Geology of Boise River Basin

The Boise River watershed has two physiographically distinctive parts. The upper part is a high elevation mountainous upstream catchment basin containing a number of tributaries, and is designated as the Upper Boise River Basin in this study. The bedrock is dominated by granitic and associated host rocks that are largely contained in the Idaho batholith (fig. 1). The lower part of the watershed is a large, low relief valley in upper Cenozoic volcanic and sedimentary rocks and is designated as the Lower Boise River Valley in this study. The valley is within a broad alluvial trough identified as the Western Snake River Plain (fig. 1) (Malde and Powers, 1962). The geology of the Upper Boise River Basin is discussed first, with special consideration of the rock lithologies as sources of sand and gravel in the Boise River. Discussion of the geology of the Lower Boise River Valley is divided into pre-Late Pleistocene, and Late Pleistocene and younger units. The pre-Late Pleistocene units generally underlie potential aggregate sources within the Late Pleistocene and younger deposits, and in some cases serve as sources of clasts to the younger sand and gravel deposits.

Sand and gravel deposits of the Lower Boise River Valley are located in the active river flood plain and terraces that begin at Lucky Peak Dam, east of Boise, and extend downstream to the Snake River (fig. 1). Most of the alluvium in these deposits is derived from rocks in the Upper Boise River Basin. The total length of the Boise River is about 96 km and the Upper Boise River Basin water shed of the Boise River has a total area of approximately 7,250 km^2--predominantly that part of the basin upstream of the Lucky Peak Dam (fig. 1). Above the Lucky Peak Dam the river is eroding and transports sand and gravel with minor deposition. Below the Lucky Peak Dam the river not only transports sand and gravel but also has deposited, and probably continues to deposit, significant amounts of sand and gravel in a corridor crossing the Western Snake River Plain. This part of the Boise River system is targeted for sand and gravel assessment and includes terraces and other alluvial feature shown in figure 2, the location of which is also outlined in figure 1.

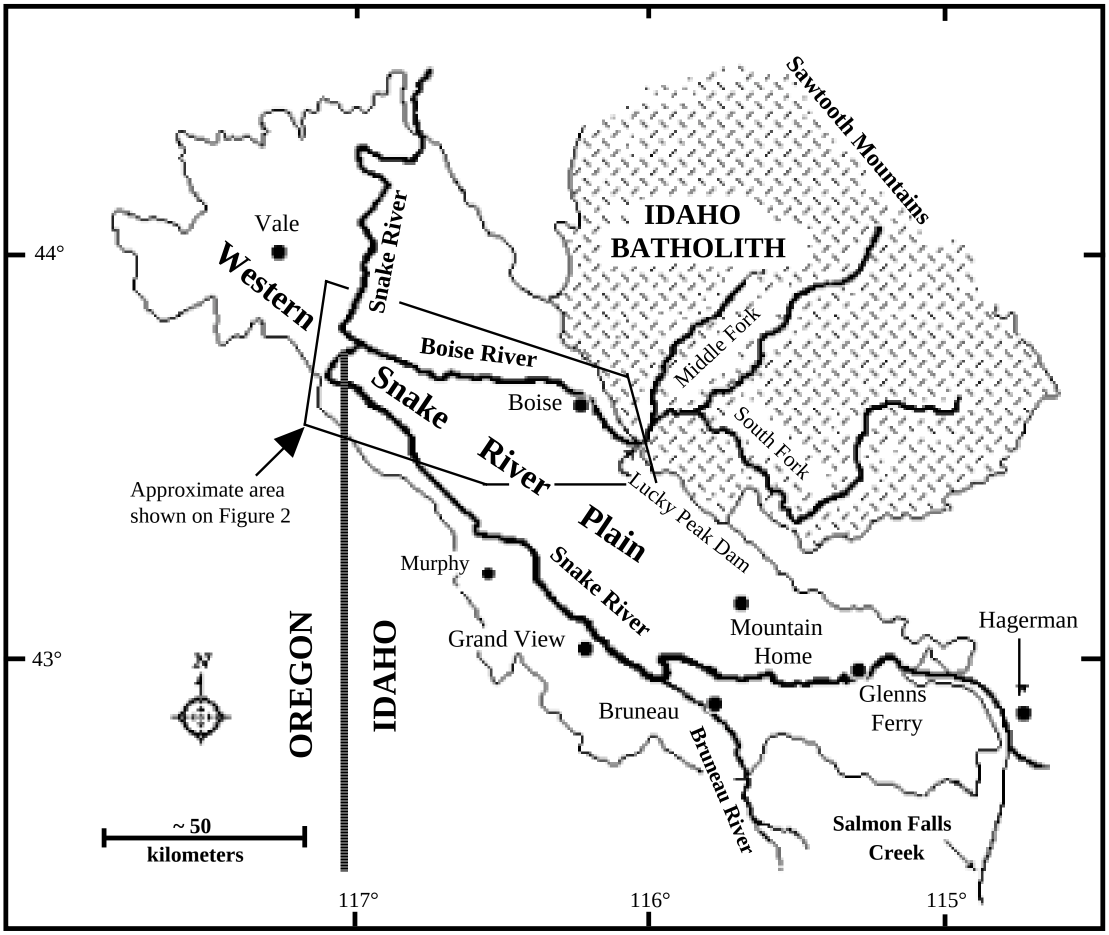

Figure 1. Sketch map of the western Snake River Plain (modified after Malde, 1991).

Geology of the Upper Boise River Basin

The bedrock of the Upper Boise River Basin is dominated by a number of large and small batholith bodies of Cretaceous age identified as parts of the Idaho batholith, that have intruded Precambrian biotite schist and other layered metamorphic rocks. Pegmatite and aplite dikes followed batholith emplacement. A second group of Tertiary batholith bodies were then intruded. The last major geologic events included a series of Tertiary basalt flows (some of which blocked stream channels upstream of Lucky Peak dam) and glaciation in the Sawtooth Mountains (fig. 2). Rocks are described below from oldest to youngest with particular attention to those undesirable characteristics that may effect sand and gravel lithology.

The Precambrian biotite schist, high-grade gneisses and migmatities have a near-horizontal foliation (Maley, 1987) and are often interlayered (Kiilsgaard and others, 1970). These have a relative small outcrop area compared to the large and numerous intrusive bodies they host. These metamorphic rocks are possible sources of undesirable material, as the platy or elongated characteristic of many metamorphic rocks is not desirable in rocks used as aggregate. Platy minerals, like micas, encountered in these rocks (as well as in lower concentrations in plutonic rocks discussed later) can be a problem in some aggregate uses. Quartz subject to metamorphism, as found in these Precambrian rocks, can become beta-quartz that can exhibit an aggregate-silica reaction (West, 1994). Where present, beta-quartz reacts with Portland concrete to form gels that weaken structures. Weathering and fluvial transport may preferentially reduce some of these lithologies in clasts before deposition has occurred in the Lower Boise River Valley.

Metamorphic rocks are present but deeply weathered and altered by geothermal activity (Wood, 1983) along the west margin of the batholith (just east of Boise, fig. 1). Intense disaggregation of these outcrops renders them unlikely sources of much sand and gravel. They may have contributed clays and other fine materials that are undesirable if found in large amounts in sand and gravel deposits.

Much of the bedrock in the Upper Boise River Basin consists of granitic rocks of the Atlanta lobe of the Idaho batholith (Maley, 1987). The batholith complex is comprised of many coalescing and nested plutons, most of which are not mapped. The Atlanta lobe of the Idaho batholith is a typical pluton that is 200 km long and 48 km wide (Maley, 1987). Biotite granodiorite is the principle rock type (Kiilsgaard and others, 1970). The Boise River drains the southern third of the predominantly late Cretaceous age Atlanta lobe (Armstrong and others, 1977). Plutonic rock composition changes spatially within the Atlanta lobe. The west side contains more tonalites or quartz diorites compared to the east side that contains more granodiorites or granites (Maley, 1987). In general, SiO_2 increases to the central part of the lobe of biotite granodiorite and then decreases to the east edge. East of the core area, SiO_2 is lower, but CaO, MgO, and Al_2O_3 concentrations are higher (Maley, 1987). Some of the minerals associated with these batholithic rocks are coarse grained (up to an inch in diameter) including quartz, plagioclase, biotite, and hornblende (Maley, 1987). Depending on how this bedrock weathers and erodes, some gravels and cobbles from these outcrops may be included among alluvial gravels. As a rule, clasts composed of coarse-grained minerals generally make poorer quality aggregate when compared to finer-grained ones containing the same minerals. This is related to the greater number of mineral boundaries and greater likelihood that intergranular boundaries among fine-grained minerals are more tightly fixed.

Batholith rocks, like the metamorphic rocks described above, are weathered and locally leached by geothermal activity (Wood, 1983) along the west margin of the batholith (east of Boise, fig. 1). Outcrops of the batholith are smooth and rounded and have a chalk white appearance--light gray to very light gray. Intense disaggregation of these outcrops (as with the metamorphic rocks) makes them a source of clays and other fine materials that are undesirable if found in large amounts in sand and gravel deposits.

Pegmatite and aplite dikes followed in placement of the batholithic rocks (Maley, 1987). Pegmatites may be problematic inasmuch as they are coarse grained, but aplite dikes may be a source of suitable aggregate material.

Also included in the Upper Boise River Basin are all, or parts, of three major Tertiary plutons, including the Dismal Swamp Pluton, the Twin Springs Pluton and the Sawtooth batholith. About 20 percent of the Idaho batholith is composed of granitic rocks of Tertiary age; in fact, more than 40 Tertiary plutons are recognized (Maley, 1987).

Bedrock of the Sawtooth Mountains (fig. 1) includes an exposed Eocene granitic pluton (Kiilsgaard and Bennett, 1983). These Tertiary plutons vary compositionally from quartz monzonite to granite and exhibit characteristics suggesting shallow emplacement (Maley, 1987).

Some rocks associated with the Tertiary plutons may also be sources of contaminants, especially altered rocks associated with Tertiary base- and precious-metal mineralization. For example, probable Tertiary mineralization is found in the Sawtooth Range where garnet-epidote skarns are overprinted by base- and precious-metal mineralization (Kiilsgaard and others, 1970). Some rocks may also have undergone extensive hydrothermal alteration rendering them unsuitable for use as aggregate. Again, the presence of altered rocks and sulfide minerals can be considered a source of undesirable contamination if they survive transportation in the Boise River and its tributaries.

Investigations elsewhere have shown that catchment basins that have undergone glaciation are likely to produce larger sand and gravel deposits under some conditions (Bliss and Bolm, 2000). A relatively small part of the Upper Boise River Basin has been glaciated, mainly at the headwaters of the Middle and South Forks of the Boise River in the Sawtooth Mountains (fig. 1). Kiilsgaard and others (1970) describe prominent glacial features including hanging valleys, cirques with lakes, matterhorns, aretes, and glacial moraines of various types, that are the product of at least two glacial episodes affecting these mountains. Glacial moraines provide a rich source of unconsolidated clay, sand, cobbles and boulders for fluvial transport and subsequent deposition as sand and gravel deposits.

Basalts also occur in the Upper Boise River Basin, particularly along the South Fork of the Boise River (fig. 1; also in greater detail in Howard and others, 1982, fig. 1). About two million years of erosion of these flows has contributed basaltic clasts to alluvium in the Boise River. Evidence for at least five episodes of basaltic flows is present, one of which Howard and others (1982) suggest traveled 60 km and was able to reach the Lower Boise River Valley just to the west of Lucky Peak Dam. The flows would have dammed the South Fork and on occasion the Boise River. Some flows show evidence of deposition in water ponded by previous flows. These flows would have interrupted the normal river dynamics in a way that resulted in periods of unusual low and high discharges in the Boise River related to ponding and breaching of some of the basaltic dams. All terrace deposits younger than two million years in the Lower Boise River Valley were probably affected to some degree by these events. Contribution of volcanic clasts to some of the sand and gravel deposits must have occurred. Basalts, particularly those that are glassy, may not perform well as aggregate.

Geology of the Lower Boise River Valley

Pre-Late Pleistocene geology of the Snake River Plain

Introduction

The following summary provides a brief overview of the rocks found in the western Snake River Plain including the area of the Lower Boise River (fig. 1). However, the focus is on geology largely located outside of the area of Lower Boise River that is covered in detail later. Some of these rocks have contributed material to sand and gravel of Pleistocene age that could be considered sources of aggregate in the assessment. Late Pleistocene units are also included in this overview if they are found outside the area of the Lower Boise River.

Pre-Late Pleistocene rocks that contain sufficient gravel and sand may also be considered a possible minable source of sand and gravel. Basalts are the predominant consolidated rock found in the Western Snake River Plain and can be viable sources of aggregate if crushed. These units may be a direct source of aggregate given adequate quality, quantity, favorable economics and extractability conditions among other considerations. Consolidated bedrock is not explicitly considered for aggregate in the assessment to follow but lithological descriptions are provided in order to suggest other possible sources of aggregate in the Western Snake River Plain outside of the Boise River Valley given sufficient demand and supply shortages from other sources.

Upper Cenozoic sediments and volcanic rocks located in the Western Snake River Plain, predominantly in Idaho but also in Oregon, are all continental which Malde and Powers (1962) divided into four general units: (1) an unnamed sequence of Miocene age, (2) the Idavada Volcanics, (3) the Idaho Group, and (4) the Snake River group.

(1) An unnamed sequence of Miocene sediments and volcanic rocks

These rocks are located at the base of the material that filled the graben-like structure (McIntyre, 1972) that underlies the Western Snake River Plain. The volcanics are both basaltic and rhyolitic and are several hundred meters thick. The rhyolitic rocks contain noticeable phenocrysts of quartz, sanidine, and oligoclase and local hornblende and biotite (Malde and Powers, 1962).

(2) Idavada Volcanics

Overlying the unnamed sequence of Miocene sediments are the Idavada Volcanics that may be a thousand (or more) meters thick. This unit consists mostly of welded ash and vitric tuff containing few quartz or sanidine phenocysts and no hornblende or biotite (Malde and Powers, 1962). In the Western Snake River Plain, fossils suggest that the Idavada Volcanics is early Pliocene. In the Eastern Snake River Plain, a middle Pliocene age is suggested (Malde and Powers, 1962). However, Armstrong and others (1975) propose that the Idavada Volcanics is Miocene based on an isotopic data of 9.7 m.y. and

8.4-8.5 m.y. on whole rock samples from the type area at Idavada, Twin Falls, Idaho. The fossil flora at Trapper Creek is of a Miocene age as well (Axelrod, 1964). Clemens and Wood (1993a, 1993b) propose that the Idavada Volcanics are Miocene in the range of 9-14 Ma.

The Idavada Volcanics crops out along both the northeast and south-southwest margins of the western Snake River Plain (Malde and Powers, 1962). Some clasts derived form the Idavada Volcanics are likely vitric, that is, consisting of more than 75 percent glass, and if present in sand and gravel deposits, will constitute an undesirable contaminant since glass is undesirable in aggregate. Glass is highly reactive with the alkali in Portland cement. Rocks of the Idavada Volcanics do not crop out significantly in the Boise River Basin so they are unlikely direct contributors to the sand and gravel deposits of the Lower Boise River Valley. This can be viewed as desirable as their might have added reactive glass to the deposits.

<u>(3) Idaho Group</u>

Above the Idavada Volcanics is the Idaho Group, 1000 meters or more of predominantly fluvial and lacustrine sediments interbedded with basalt flows. Malde and Powers (1962) describe the sediments as consolidated but not lithified; they are dominantly sand or clay with lesser gravel, volcanic ash, and diatomite. Outcrops of rocks of the Idaho Group are widespread in the western Snake River Plain (Malde and Powers, 1962, fig. 2). Rocks that may be comparable to the Idaho Group in lithology and age are found in the Boise Front (fig. 2) but may not be a part of the Idaho Group as identified (see below). The Idaho Group have been divided and described (unless noted otherwise) by Malde and Powers (1962) and summarized in ascending order:

> **Poison Creek Formation** (lower Pliocene) is at the base and contains predominantly volcanic ash, clay, and sand. Massive volcanic ash and tuffaceous material may be lacustrine. Lesser amounts of thinly bedded granitic sand and gravel are likely fluvial. Extraction of sand and gravel for use as aggregate may be possible from these same beds given adequate thickness, grain-size distribution, quality, and extractability among other factors. It should be noted that granitic gravel may continue to disaggregate during erosion and continued transport and might no longer be found as gravel-sized material if redeposited.
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> **Banbury Basalt** (middle Pliocene) consists of "massive dark-brown weathered basalt flows and coarse and fine tuff beds." (Stearns, 1936, p. 435 as cited by Malde and Powers, 1962, p. 1204). Some of the basalt contains olivine; some fluvial interbedded sand and gravels are reported together with clay, silt, and diatomite in lake deposits.
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> Weathered basalt does not make a competent aggregate when crushed. Basaltic and related rock types also can be mechanically weakened by the presence of the round grains of olivine, particularly if

abundant. Olivine's rounded crystal form does not interlock well with other minerals or the matrix (Dunn, 1991).

Chalk Hills Formation (middle Pliocene) is dominated by large amounts of siliceous volcanic ash with lesser silt and sand. Opal is present in some of the ash and, like glass, can react with the alkali in Portland cement. It is an undesirable contaminant in sand and gravel deposits. These opals may not be found far from the outcrops of the Chalk Hills Formation, as opal is commonly fragile and may readily be destroyed during weathering and erosion.

Glenns Ferry Formation (upper Pliocene and lower Pleistocene) is a complex mix of lacustrine, steam and flood plain deposits that crop out widely in the western Snake River Plain (Malde, 1972; Kimmel, 1982; Middleton and others 1985). Lacustrine facies are dominant in both volume and in outcrop. Typically, the Glenns Ferry Formation is a monotonous, massive, tan silt, though nonindurated, and can stand as cliffs as high as 30 m. Kraus and Middleton (1987) describe the Glenns Ferry Formation as consisting of deposits from a single or weakly multistory channel system that commonly encloses an extensive quantity of overbank sediments. The Glenns Ferry Formation is the product of relatively rapid subsidence. Sediment accumulations over 300 m thick are found at Glenns Ferry (fig. 1).

Malde (1972) describes a 200-m section of uniform silt and fine lacustrine sediments that intertongues with coarser sediments of floodplain origin. Also present are volcaniclastics, siliciclastics, locally thick carbonates, volcanic ash, and lava flows (Malde, 1959) as well as oolites and algal limestone.

One bed, 13 to 18 km east of Glenns Ferry (fig. 1), is 45 m of massive arkoic sand and fine granitic gravel. Extraction of sand and gravel for use as aggregate may be possible from this sand and gravel bed (and possibly other comparable beds not yet identified) given that overburden isn't too thick and it has suitable grain-size distribution as well as an acceptable quality.

The Glenns Ferry Formation commonly crops out in the Lower Boise River Valley particularly were it underlies the Tenmile Gravel (discussed at length below). The Glenns Ferry Formation is found along the southwest margins of the Lower Boise River Valley from southeast of Caldwell (fig. 2) to southeast of the junction of the Boise River with the Snake River (Othberg and Stanford, 1992).

Tuana Gravel (middle Pleistocene) is predominantly found on the south side of the Snake River about 200 m above river level (Malde and Powers, 1962). The gravels extend from the community of Hagerman, Idaho (fig.

1), where they are 60 m thick, to an outcrop 260 m thick, above the river 10 km southeast of Bruneau (fig. 1). Malde and others (1963) report that the gravels are found on a bench 245 m above river level east of longitude 116° W. Tuana Gravels found near Hagerman consist of at least five gray to brown beds of gravel (some pebble size) with silt and clay (which may be subaerial) and secondary carbonate (Malde and Powers, 1962). The base of the gravels at Tuana Creek unconformably overlies the Glenns Ferry Formation, capped here and at other outcrops with a meter-thick layer of caliche (Malde and Powers, 1962). The gravels may be remnants of two alluvial fans developed from the south, one from the ancestral Salmon Falls Creek to the east and the other associated with the Bruneau River to the west (fig. 1) (Malde, 1991).

The Tuana Gravel and the Tenmile Gravel below may be contemporaneous. The Tenmile found along the south side of the Lower Boise River Valley is addressed in the assessment that follows. Malde (1991, p. 253) noted that both gravels are “the first obvious sign in the geologic record of the vigorous Snake River that we know today.” Both gravels are the products of a high-energy fluvial system and both appear to be graded to a comparable base level (Malde, 1991).

Extraction of sand and gravel directly from the Tuana Gravel may be possible, but the presence of caliche is highly problematic since it reacts when used with Portland cement. The Tuana Gravel may represent a source of sand and gravel comparable in quality to that found in the Tenmile Gravel although its location is remote (Malde, 1991, fig. 2) from the major developing population centers of western Idaho.

Bruneau Formation (middle Pleistocene) contains sedimentary deposits and volcanic rocks predominantly deposited in lakes that formed behind lava flows that blocked the Snake River. Many outcrops are of filled canyons in the older formation of the Idaho Group where Bruneau Formation outcrops can be up to 240 m thick. The formation is predominantly fine-grained lake beds with minor stream sediments some of which consists of pebble gravel (Malde and Powers, 1962). The formation is a complex of individual units reflecting the many cycles of lava dams and subsequent breaching (Malde and Powers, 1962). A typical exposure is found south of Bruneau (fig. 1) with other exposures near Hagerman and Murphy (fig. 1).

Materials derived from the Idavada Volcanics dominate the Bruneau Formation (Malde and Powers, 1962). Beds of well-sorted pebble gravels are widespread and can be as thick as 8 m. Gravels are commonly iron stained. It is unknown if extraction of sand and gravel for use as aggregate is possible from the beds of well-sorted pebble gravels. However, mining may occur given the absence of other sources of aggregate, if the beds are not under too much overburden, the material has suitable grain-size distribution and is of acceptable quality. The presence of iron stains on the gravel may raise an esthetic concern as the presence of iron oxides may cause discoloration of cement surfaces.

Black Mesa Gravel (middle Pleistocene) consists of an 8 m thick layer of sand and gravel that is seen at Black Mesa 8 km southeast of Glenns Ferry (fig. 1). It is the youngest formation in the Idaho Group. The Black Mesa Gravel is also present as scattered outcrops for a distance of 24 km on a pediment west of Black Mesa. One outcrop is as thick as 76 m. Compositionally, the Black Mesa gravels are derived from the underlying Bruneau Formation and the Tuana Gravel. The gravels are brown and gray and some outcrops are capped with a caliche layer about one meter thick.

Extraction of sand and gravel directly from the Black Mesa Gravel for use in construction may be possible, but the presence of caliche in the near surface is highly problematic since it reacts when used with Portland cement. The Black Mesa Gravel may represent a source of sand and gravel comparable in quality to that found in the Tenmile Gravel of the Boise River Valley.

Ridges in the Boise Front (fig. 2) consist of unconsolidated and uncemented sedimentary rocks identified as part of the Idaho Group by Gallegos and others (1987). However, Othberg (written commun., Nov., 2000) notes that rocks of the Idaho Group were not mapped among those found in the Boise Front. Othberg and Stanford (1992) propose that the rocks are likely Tertiary; only the Pierce Gulch Formation is more precisely identified as being deposited in the late Pliocene.

Othberg and Stanford (1992) describe most of the sedimentary rocks found in the Boise Front belonging to one of two genetic assemblages—(1) sand and mudstone of stream and lake sediments and (2) alluvial fan deposits. They also identify sand of the Pierce Gulch Formation of possible late Pliocene and as an arkosic sand overlain with pebble to cobble gravel. This unit may be considered as a source of aggregate if sufficiently thick and extensive with acceptable characteristics. Gallegos and others (1987) describe the lithologies in this area as including quartz- and feldspar-rich sandstones with biotite, muscovite and fragments of volcanic rocks. Cementation, where found, includes silica, carbonate, zeolites and clays (Gallegos and others, 1987). These rocks are stream and lake deposits interbedded with occasional debris flows. Delta deposits with foreset beds are common, and wood fragments occur in some. The fan deposits consist of poorly sorted gravel with silt and sand. Some of the cobbles are subangular and occur with boulders in crudely stratified layers and lenses that suggest deposition by debris flows and ephemeral discharges (Othberg and Stanford, 1992). Also found are braided stream deposits, some with gravel, and fine-grained, offshore lake deposits. In general, the lithologies reported in rock outcrops in this area are not of the types suitable for aggregate. Sands may be less suitable due to high feldspar content. Organic matter is also present. It is detrimental because it weakens aggregate by causing unacceptable volume losses when it decomposes.

(4) Snake River Group

The Snake River Group, found mostly in the eastern Snake River Plain, is at the top of the stack of sediments and volcanic rocks described by Malde and Powers (1962). It accumulated during the present entrenchment of the Snake River Canyon and includes both some gravels and basalts that are recent. Because the rocks of the Snake River Group were deposited during a time of erosion, outcrops are discontinuous. Based on mollusk and mammal fossils, the Snake River Group is assigned to the late Pleistocene and Holocene. The formations within the Snake River are comparable in age to those described in the section that follows on the geology of the Boise River Valley.

Basaltic volcanic rock, including shield volcanoes, cones, and flows, dominates the surface of the West Snake River Plain. Volcanic flows are also present in the Upper Boise River Basin. Volcanic activity has likely played a role in restricting the Boise River in the Boise Valley to the north and northeast in the upper third of the lower basin area (fig. 2). Furthermore, Othberg (1994, fig. l5) showed that most lava flows flowed to the northwest. The olivine basalts tend to be medium to dark gray in color with phenocrysts of varying size and amounts (Othberg, 1994), and their flows tend to be no more than 4 m thick.

Volcanic flows cap some terraces and obscure the margins of others. This includes two different basalts over parts of Gowen terrace (Othberg and Stanford, 1992) and at least one flow over parts of the Amity terrace. The Slaters Flat basalt (Othberg, 1994, fig. 15) flowed down an earlier course of Blacks Creek (Othberg and others, 1996), which was cutting into the Tenmile terrace. The south margin of the Tenmile terrace is now along the south edge of the Tenmile Creek that, in turn, has also cut into the terrace. The Snake River Group has been described (unless noted otherwise) by Malde and Powers (1962) in the following units from oldest to youngest:

Madson Basalt consists of fine-grained black, diabasic basalt, so dense as to resemble slate with regular and tight columnar jointing (Stearns and others, 1938). Some of the basalt is likely highly impermeable. Malde and Powers (1962) observed that it is olivine basalt, fresh and columnar. The basalt occupied canyons of the historical Snake River and its tributaries. Four separate flows have been recognized on both sizes of the modern Snake River from sites north of Hagerman (fig. 1) and elsewhere in the east part of the West Snake River Plain. Outcrop thickness is at least 60 m, but interpretation of topographic relationships suggests the Madson Basalt may be as thick as 90 m (Malde and Powers, 1962).

The relative freshness and compactness of the basalt suggests that the basalt might be suitable for quarrying for crushed stone for use in aggregate given the usual considerations noted above especially if it is not too vitric and if olivine is not particularly abundant (Dunn, 1991).

Sugar Bowl Gravel is found 6 km northeast of Glenns Ferry (fig. 1) where it forms a 6 m deposit 73 m above the modern Snake River (Malde, 1991). It is found as caps on terraces and knobs particularly in the wider sections of the canyon found commonly at tributary junctions. Most outcrops of the Sugar Bowl Gravel are in a 45 km long reach of the canyon centered on Glenn Ferry (fig. 1) (Malde, 1991). The gravels occur parallel with the gradient of the modern river (0.38 m/km) where a large outcrop is found 13 km east of Glenns Ferry with an area of several square kilometers.

Lithologies found in the Sugar Bowl Gravel include quartzite, porphyry, granite, and conglomerate derived from the rocks of the Idaho batholith and associated metamorphic rocks. Also present, in limited amounts, are basalt, chert, and argillite derived from the Idavada Volcanics. Large pebbles and boulders found in upstream deposits are replaced by medium sized pebbles downstream. Gravels are capped with poorly indurated caliche (Malde and Powers, 1962). The composition and text of the gravels are interpreted by Malde and Powers (1962) as the result of seasonal melting of glaciers in the mountains north of the Snake River plain.

Lithologies in the Sugar Bowl Gravel are comparable to those of gravels found in the terraces of the Boise River Valley. Poorer quality material including chert and argillite derived from the Idavada Volcanics may reduce the overall quality. It is extremely likely that gravel from the Sugar Bowel Gravel have been extracted for use in aggregate and the size of the outcrops (or at least the one 13 km east of Glenns Ferry) suggests that significant quantities of sand and gravel, possibly suitable for use in aggregate, may be present.

Thousand Springs Basalt is named for basalt under which the Thousand Springs discharge at a location along the Snake River 8 km south of Hagerman (fig. 1). Three basalt flows fill one of the several previous canyons eroded by the Snake River. Thickness varies from 25 to 68 m in exposures along the Snake River canyon extending upstream to the east for about 40 km from Thousand Springs to Twin Falls. The basalt has an unweathered appearance, is columnar, and highly permeable. Compositionally, it is olivine basalt to porphyritic plagioclase-olivine basalt (Malde and Powers, 1962). Feldspar phenocrysts can be up to 5 mm long (Stearns and others, 1938). The coarser texture, presence of olivine, and high permeability suggest that overall the Thousand Springs Basalt may not be a particularly good candidate for crushed stone albeit some parts may be found to be more suitable.

Crowsnest Gravel is found 6 km south of Hagerman and on upland plain west of the Snake River (fig. 1). The gravel is between 8 and 15 m thick with the base 60 m above the Snake River at an extraction pit at that location. Other outcrops are found as far as 16 km upstream from

Hagerman and have a distribution that suggests that the deposition was on a gradient [(1.1 m/km (Malde, 1991)] higher than that seen for the modern Snake River or the river that deposits the Sugar Bowl Gravels. The last outcrop downstream is at Grand View (fig. 1).

Unlike the Sugar Bowl Gravel, the Crowsnest Gravel contains different lithologies at different locations. Outcrops near Hagerman are dominated by clasts from the Idavada Volcanics as compared to outcrops between Hagerman and Murphy that contain clasts comparable to those in the Sugar Bowel Gravel (see above). However, Crowsnest Gravel contains more cobble-sized material. The presence of coarse sized clasts and the composition of the cobbles together with the steep gradients suggest deposits were a product of turbulent discharge from melting glaciers in the mountains north of the Snake River plain.

Extraction directly from the Sugar Bowl Gravel for use as aggregate is highly likely. Better quality material is likely present where the gravel contains less Idavada Volcanics.

Wendell Grade Basalt, together with the McKinney Basalt described below, replaced the Bancroft Springs Basalt as given in former usage (Malde, 1971). Both basalts are now considered to be upper Pleistocene and not Holocene as previously assigned (see Malde, 1971, fig. 2). Stearns (1936) describes the Wendell Grade Basalt as black, aphanitic pahoehoe basalt with a minimum thickness of 8 m. He also observed that it is vesicular and contains olivine. Malde and Powers (1962) describe the basalt as highly porphyritic plagioclase-olivine basalt. These characteristics, together with the porphyritic texture, make the Wendell Grade Basalt a less desirable candidate for production of crushed stone.

McKinney Basalt was expanded to include the Bancroft Springs Basalt, a unit name that is abandoned (Malde, 1971). The redefined McKinney Basalt was also reassigned to the upper Pleistocene and not Holocene in the revised stratigraphy of the Snake River Group of Malde (1971). The McKinney Basalt at Bancroft Springs, 11 km east of Glenn Ferry (fig. 1), is at least 90 m thick and fills a former canyon of the Snake River. The canyon it filled is of comparable depth to the modern one (Malde and Powers, 1962). Some lava is columnar; others have pillows. One olivine basalt is packed with rosettes of large plagioclases phenocrysts.

The presence of large crystal masses and olivine suggest that the McKinney unlikely to be a very good source of crushed stone. However, only geotechnical tests and evaluation during use in construction materials will provide the needed information about its suitability.

Yahoo Clay is a 27-m-thick lacustrine laminated clay with a minor silty clay deposited in an impoundment behind the McKinney Basalt (Malde,

1982) at the mouth of Yahoo Creek 6 km south-southwest of Hagerman (fig. 1).

Melon Gravel is found 17 km south of Hagerman and to the east of Salmon Falls Creek (fig. 1). The deposit consists of a large bouldery bar that is more than 1.5 km long, 0.8 km wide and 46 m thick (Malde and Powers, 1962). The Melon Gravel is recognized as far as 90 km down stream to below Murphy (fig. 1). The gravels are interpreted to be the products of rapidly moving deep water related to the discharge of Lake Bonneville, a large, late Pleistocene lake in Utah (Gilbert, 1890) and present from about 15 to 17 ka. Remnants of that once large body of water include the Great Salt Lake and Utah Lake of Utah. At its maximum size, the ancient lake covered an area of about 51,700 km^2, comparable to the size of Lake Michigan, and it extended into both Idaho and Nevada (Morrison, 1991). The flood occurred during a rapid 108 m lowering of its outlet into the Snake River at Red Rock Pass in about 14.5 k (Trimble and Carr, 1961; O'Connor, 1993). Red Rock Pass is in southeastern Idaho and well to the southeast of the area shown in figure 1. It is estimated that about 4750 km^3 of water was released (Othberg and others, 1996). Othberg and others (1996) provide an overview of the Bonneville flood as well as a map (Othberg and others, 1996, fig. 11) that shows both the flood route and approximate areas of inundation along the Snake River in Idaho. Evidence for, and modifications to, alluvium is present throughout the Snake River Canyon and many tributaries including the Boise River Valley that is examined in the greater detail below. Malde (1971) observed that the appearance of the Snake River canyon has changed little from the modifications imposed by the Bonneville flood.

An approximately 10 km long bar in the Snake River canyon southwest of Nampa (fig. 2) was one of the largest produced by the Bonneville flood. It contains basaltic boulders that have intermediate diameters of 4.6 m and are estimated to weigh 140 metric tons (Othberg and others, 1996). Typical bar size is 1.5 to 2.5 km long and around 0.8 km wide (Malde, 1968). Boulders developed from the Thousand Springs Basalt tend to be larger than those developed from the more weathered basalts of the Glenns Ferry Formation or the Banbury Basalt (Malde, 1968). Boulders in some deposits are dominated by basalt of the Bruneau Formation (Malde, 1968).

The Melon Gravel and other sand and gravel deposits produced by the Bonneville flood contain a mix of lithologies include remobilized flood plain material and eroded inundated terraces and canyon wall colluvium. Bedding is unrefined where some layers do exhibit crude sorting into contrasting layers (Malde, 1968). Gravels contain many different lithologies and physiographic features at different locations (Malde, 1968). The gravels are found in enormous streamlined bars commonly found at midcanyon and tributary canyons of the Snake River blocked by heaps of gravel (Malde, 1968). Basalt boulders are prominent in deposit veneers where many deposits consist of poor sorted boulders and coarse sand but little silt or fines in surface exposures. However basalt boulders may or may not be significant at depth.

Bonneville flood gravels found at Twin Falls, Idaho (just off the right edge of fig 1 and south of an extension of the Snake River to the east) were a major source of gravel extraction that also included rounded boulders of basalt with diameters larger than 3 m (Malde, 1991). At some locations, much of the sand is basaltic (Malde, 1968), making it less suitable for use in aggregate as compared to quartz rich sand. Some outcrops are contaminated with rounded chunks of sedimentary material--silt or diatomite--that are not desirable if the outcrops is worked directly as a source of aggregate. The complex nature and variability of the Melon Gravel and other sand and gravel deposits produced by the Bonneville flood made generalization about its suitability as a source of aggregate difficult.

Source of sand and gravel clasts in the Lower Boise River Valley

Some of the units discussed above have contributed directly to the sand and gravel deposits in the Lower Boise River Valley. However it is also likely that clasts from these units have been deposited in younger units, which, in turn, have contributed to sand and gravel in the terraces to be assessed. The units are part of the alluvial depositional history of the area.

Sources of sand and gravel clasts in the Lower Boise River Valley (fig. 2) include an unknown amount of material recycled from older to younger alluvial terraces. One possible source of sand and lesser amounts of gravel clasts to the Pleistocene sand and gravel deposits of the Lower Boise River Valley is from the weathering and erosion carried by tributaries draining predominantly Tertiary sediments that occur in the Boise Front as discussed above. The watersheds of most streams and ravines on the north side of the Lower Boise River Valley are in Tertiary sediments, and most streams are ephemeral. Modern sediments found in current drainages with watersheds dominated by Tertiary units described above (as well as weathered and geothermally altered granites) consist of medium to coarse sand interbedded with silty fine sand and silt (Othberg and Stanford 1992). The description of the modern streambed deposits suggests that the Tertiary units may have contributed some sand but likely little gravel to the modern flood plain.

Some tributaries have watersheds that include Tertiary fan deposits consisting of poorly sorted gravel with silt and sand. Some of the cobbles are subangular and occur with boulders in crudely stratified layers and lenses that suggest deposition by debris flows and ephemeral discharges (Othberg and Stanford, 1992). Other rocks noted in the tributaries from Lucky Peak Dam to Boise include Tertiary Bonneville Point gravels (fig. 2) and Tertiary basalt volcanic assemblages with a mixed package of subaerial lava flows,

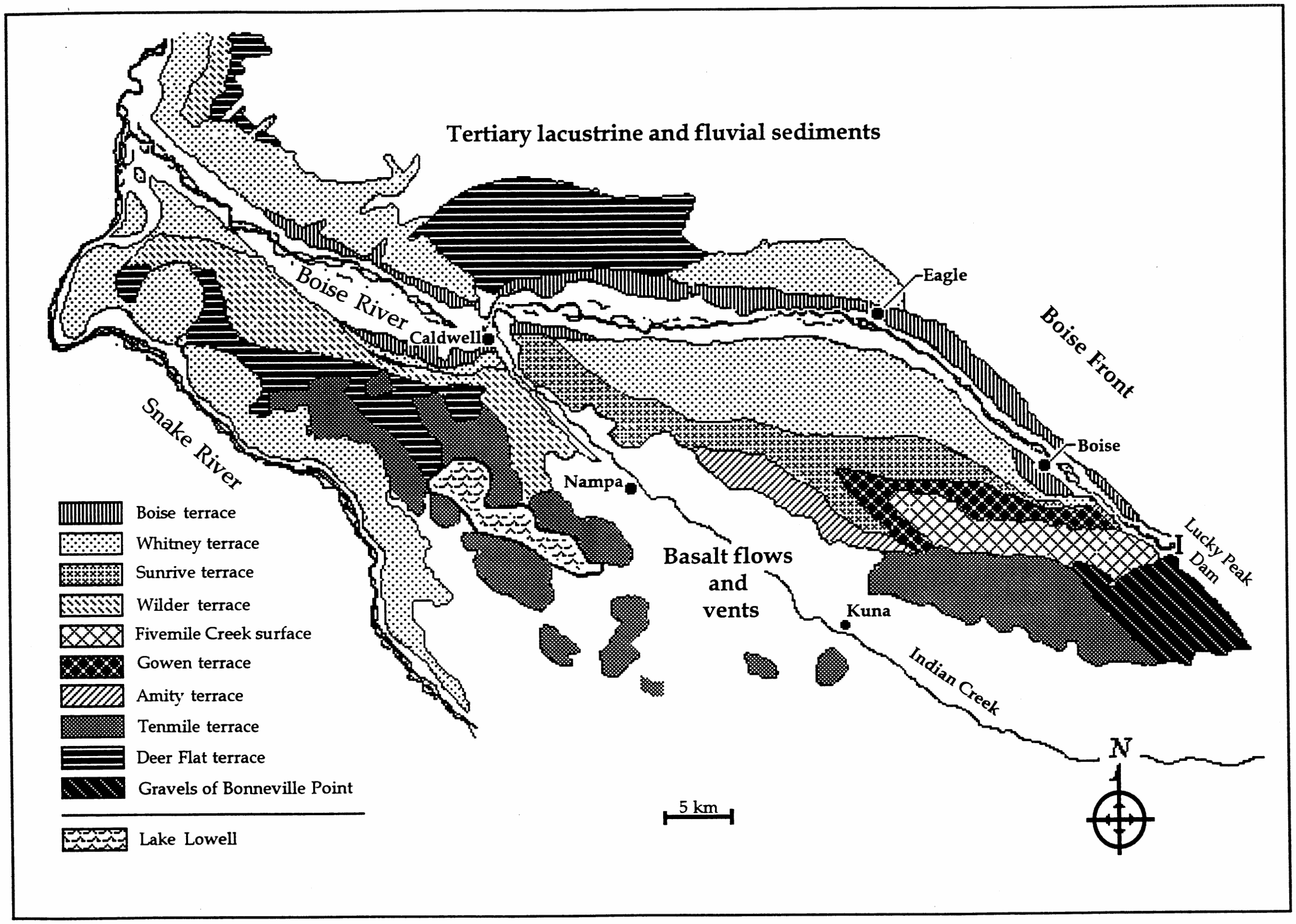

Figure 2. Generalized areas of major terraces and other features of the Lower Boise River Valley and adjacent areas, Idaho and Oregon (modified after Othberg and Stanford, 1992; Othberg, 1994; and Othberg and others, 1996). Whitney terrace includes sandy silt of Bonneville Flood and gravel of the Bonneville flood-scoured Whitney terrace (Othberg and Stanford, 1992). Deer Flat terrace includes gravel of Deer Flat terrace, and gravels of Deer Flat terrace and pre-Deer Flat terraces, undivided (Othberg and Stanford, 1992). Glenns Ferry outcrops are present adjacent to, and northwest of Lake Lowell and have been included with the Tenmile terrace or Deer Flat terrace.

subaqueous and water modified lava flows, and tuff and volcaniclastic sediments. Lava can be as thick as 73 m, and tuffs and volcaniclastic sediments occur up to 61 m thick (Othberg and Stanford, 1992).

Under current climatic conditions, tributaries found in the Lower Boise River Valley have significant discharges restricted to rare storm events. While considerable material can be transported, the bulk of the material is expected to be sand or silt size. The magnitude of past contributions of sand and gravel clastic from tributaries to alluvial deposits is unknown.

Sediments found in modern drainages with watersheds dominated by Tertiary basaltic volcanic rocks in the Lower Boise River Valley consist of medium to coarse sand interbedded with silty fine sand and silt (Othberg and Stanford, 1992).

Late Pleistocene and younger deposits

The Boise River crosses into the Snake River Plain near Lucky Peak Dam (fig. 1), and the valley transitions to one dominated by remnants of fluvial deposits. These remnants are observed as a series of terraces stepping upward and away from the modern flood plain due to progressive down cutting of the Boise River. Tertiary sediments of the Boise Front are also present below Lucky Peak Dam for about 32 km along the northeast side of the valley (fig. 2) (described above). Part of the modern flood plain follows the approximate contact of the Idaho batholith with volcanic rocks and sediments of the Snake River Plain (fig. 2). Othberg (written commun., Oct., 2000) also describes the river as following a fault zone with in slices of volcanic and sedimentary rocks. These rocks are in fault contact with the granites of the Idaho batholith northeast of the river. Basalt flows have discharged from south of the general course of the river, and the net effect has been an overall displacement of the river course to the north and east away from the centers of volcanism. Basalts are also present in the adjacent parts of the Upper Boise River Basin, particularly along the South Fork (fig. 1). Basalts have also helped to preserve (as well as limit access to) parts of some terraces. Creeks that contribute to the Lower Boise River Valley and have headwaters in the lower reaches of the Boise Front have eroded terraces. Streams that join the Boise River below the Boise Front contribute little additional water in their natural condition under current climatic conditions.

Terraces associated with the Lower Boise River Valley are among the most numerous found in any watershed entering the Snake River Plain (Othberg, 1994). Othberg and Stanford (1992) identify nine Pleistocene terraces of the ancestral Boise River in the lower valley. Terrace deposits commonly rest unconformably on Tertiary sediments that consist of light-colored gravels of granitic and felsic clasts as well as beds of sand, silt and clay eroded from the upper catchment. Pleistocene terrace deposits described by Othberg (1994) contain imbricated pebble to cobble gravel interbedded with thin lenses of sand. The gravely parts are poorly sorted and crudely bedded. Othberg (1994) suggests that the terrace deposits are the product of braided streams.

All terrace deposits are expected to exhibit an overall decline in grain size with distance downstream, and this is one characteristic of the Lower Boise River Valley deposits that will be examined in the sand and gravel assessment to follow. Boulders locally noted in deposits just downstream from Lucky Peak Dam would be expected to occur less commonly farther downstream. Terrace deposits in the lower valley near the junction with the Snake River lack cobbles (Othberg, 1994). However, gravels found in the terraces are reported to have similar textures regardless of age (Othberg, 1994) suggesting that the hydrology of deposition for all the terraces was similar.

Lithological composition of the clasts is comparable for most of the terraces as well. Some of the younger have on the order of 10 percent Pleistocene basalt clasts mostly derived from a basalt flow located near and above Lucky Peak Dam (fig. 1). Terrace gravels, as described by Othberg and Stanford (1992), have a stratified bedding containing lenses of cross-bedded sand. Gravel-sized clasts are well rounded, and the material is poorly sorted.

The terraces are products of repeated erosion of the basin fill sediments followed by gravel deposition on the new erosional surface by a braided-channel river. It is a pattern seen elsewhere in western U.S. Pleistocene river systems carrying glacial meltwaters (Othberg, 1994). Some of the terraces may have been deposited by meltwaters, others not. Do meltwater-deposited terrace gravels have different characteristics from those deposited by nonglacial stream flows?

Othberg (1994) describes the terraces downstream in the Lower Boise River Valley as exhibiting similar patterns of grain-size variation with distance downstream. Grain size ranges from large cobbles and pebble gravels seen downstream from the Lucky Peak Dam site, to small and medium pebble gravels near the Snake River (fig. 2). Development of some type of a quantitative relationship between grain size and distance downstream from Lucky Peak Dam will be explored during the sand and gravel assessment that follows this report.

Gradient variations in the slope of terrace surfaces most likely have been modified by tectonics (Othberg, 1994, fig. 31). One effect of tectonics is that the Gowen and Sunrise terraces and the surface on the Fivemile Basalt now appear to converge

Although terrace deposits are found from Lucky Peak Dam to the junction of the Boise River with the Snake River, those below Caldwell (fig. 2) have been subsequently eroded or are masked with fine-grained sediments, or both (Othberg and Stanford, 1992). These features are thought to be byproducts of the catastrophic flow of the Bonneville flood discussed previously.

Along both sides of the Snake River, the Bonneville floodwaters expanded into low-lying areas, as well as ponded behind restrictions where the canyon walls narrowed (Othberg, 1994). One such restriction was at Hells Canyon downstream from the junction of the Boise River. A temporary lake formed flooding the lower end of the Boise Valley extending about 12 km above Caldwell (fig. 2) with an estimated shoreline elevation of 747 m (Othberg and Stanford, 1992). The lake is estimated to have been present for 12 weeks (O’Connor, 1993). Compared to the currents that existed in the flooded main channel of the Snake River, the flooded Boise River was tranquil, representing a slack water environment. Here, sediment-charged water was sufficiently still to deposit layers of silt and clay. Fine-grained lake sediments are as thick as 6 m in the Lower Boise River Valley. They thin eastward, up valley, and toward the margins of the lake. Flood sediments are not recognized east of Caldwell (fig. 2). This is most likely due to the relatively cleaner waters of the Boise River in this part of the ponded lake. It may also simply be due to the short duration that the lake was at its maximum (Othberg, 1994). However, lake currents present in parts of the lake stripped soils and loess off of terraces. The currents also scoured and redeposited terrace gravels, and developed channels in terrace surfaces. The currents appear to have been restricted to areas near the present Snake River (Othberg, written commun., Oct., 2000). The destruction of terraces, or their burial with sediments, or both, makes terrace identification difficult. Consequently, identifying areas suitable for future development of sand and gravel production sites is also more problematic.

Alluvial deposits considered as possible sources of sand and gravel and created by the Boise River, from oldest to youngest, are in the following sections.

Gravels of Bonneville Point

The oldest deposit that may be a product of the ancestral, late-Tertiary Boise River is the gravel at Bonneville Point (Othberg and others, 1996). This unit is limited to a rectangular outcrop area of about 68.7 km^2 southeast of Boise (fig. 2) bounded by the granitic rocks of the Idaho batholith to the east, Fivemile Basalt to the north, and Slaters Flat Basalt to the south. The Tenmile gravels overlie the gravel of Bonneville Point to the west. This unit has clasts, as reported by Othberg and others (1996), that are lithologically comparable to clasts found in the Tenmile terrace gravels (see next). However, the Bonneville Point gravels exhibit more weathering and are thinner bedded and finer grained (Othberg and others, 1996).

Gravels of Tenmile terrace

The Tenmile terrace is the oldest major terrace of the Pleistocene. The main body of the terrace covers an area of about 83 km^2, south of Boise (fig. 2) with an overall maximum length of about 19 km and a maximum width of about 5 km. Terrace deposits have a thickness of about 50 m (Othberg and Stanford, 1992). The main body of the terrace is highly dissected with ravines and small valleys with a northwest-southeast fabric likely related to similarly oriented faults observed in gravel pits and road cuts (Othberg, 1994). This part of the Tenmile terrace is designated as the upstream Tenmile terrace in the assessment to follow. Scattered remnants of terraces also included in the Tenmile terrace by Othberg and Stanford (1992) are found southwest of Indian Creek (fig. 2). These fragments of the Tenmile terrace are designated as the downstream Tenmile terrace for purposes of analysis. The downstream Tenmile terrace deposits are also deeply eroded, and the erosional features show the same orientation as seen in the deposits in the upper Tenmile terrace. Note that the outcrops of deposits of the downstream Tenmile terrace also include considerable area of the Glenns Ferry Formation on figure 2.

Savage (1958) describes the deposits of Tenmile terrace as a mix of silt, sand and gravel with pebbles and cobbles of sandstone, orthoquartzite, and arkose. Some sands are also arkosic. Othberg and others (1990) describe the gravel clasts as being dominated by granitic rocks and porphyritic felsites. The gravels are imbricated with cut-and-fill channels, inclined bedding and cross bedding, and are interbedded with sand lenses. Savage (1958) suggests that deposition was from southwest flowing streams. Some of the deposits may be the product of torrential discharges emanating from melting glaciers found above 1,500 m at the head of the Upper Boise River Basin. Savage (1958) also suggested that the gravels are comparable in appearance to valley train material found downstream from active glaciers. A large, angular silt block that occurs near Kuna, Idaho (fig. 2), is surrounded by coarse gravels that Savage (1958, fig. 14) concluded resulted from the placement of a body of silt that was frozen during deposition. Fault and drag structures present in the upper Tenmile terrace are reported by Savage (1958) and Othberg and Stanford (1992).

Othberg and Stanford (1992) note that the Tenmile terrace rests on the Plio-Pleistocene Glenns Ferry Formation. The upper surface exhibits obvious patterned ground, possibly related to permafrost conditions, and may be mantled with loess 1-2 m thick (Othberg and Stanford, 1992).

Gravels of Deer Flat terrace

The Deer Flat terrace is readily recognized in some outcrops. However, its deposits interfinger with considerable alluvial fan material that Othberg and Stanford (1992; 1993) identify as “Gravel of Deer Flat and pre-Deer Flat terraces undivided.” For this review, all deposits of the Dear Flat terrace will be treated as a single assemblage within an area of 264 km^2. Most of the terrace is found in two areas--one north, northeast and the other south, southwest of Caldwell (fig. 2). The terrace complex appears to include remnants of at least two recognized terrace systems above the modern floodplain of the Boise River. The terrace stands at 34 and 61 m above Boise River suggesting that (a) it is the product of two separate alluvial surfaces or (b) at a minimum parts of the terrace have been shifted by faulting (Othberg, 1994). Terrace deposits are commonly 10 m thick and include sandy pebble and cobble gravel at the surface, to increasingly coarse pebbly sand at depth. Interfingering of ancestral alluvial fan material is largely derived from Tertiary sand and mudstone of stream and lake sediments (Othberg and Stanford, 1992). The terrace deposits rest on Tertiary sediments and are capped with loess 0.5 to 1 m thick (Othberg and Stanford, 1992)

Some deposits of the Deer Flat terrace found northwest of Lake Lowell and southwest of Caldwell (fig. 2) are located between the Snake River and Boise River and may contain a mixture of alluvium from both rivers. Othberg (1994, p. 32) describes the terrace here as “an abandoned channel confined between hills surrounding Lake Lowell * * *” (fig. 2). Part of the terrace northwest of Lake Lowell is covered by thick loess deposits (Othberg, 1994).

Gravels of Amity terrace

The Amity terrace is situated about 61 m above the modern Boise River (Othberg, 1994) and occurs in a relatively small area (30 km^2) north of Kuna and east of Nampa (fig. 2), predominantly as a two-km-wide strip (fig. 2). The alignment of the terrace margins suggests that the gravels may have been faulted (Othberg and Stanford, 1992). Materials found in the terrace deposits include sand mixed with pebble- or cobble-sized material at the top and coarse pebbly sand to a depth of likely no more than 10 m (Othberg and Stanford, 1992). Gravel clasts are predominantly granitic and porphyritic felsites comparable to those in the Idaho batholith and associated host rocks (Othberg and others, 1990). Loess deposits of 0.5 to 2 m are observed in less eroded upper surfaces (Othberg, 1994). The Amity and Deer Flat terrace deposits may represent the first record of incision of the Boise Valley and should be correlated until data shows it to be otherwise (Othberg, 1994).

The Amity terrace has been significantly modified since deposition. A number of escarpments, all with a northwest orientation, suggest faulting (Othberg, 1994). Remnants of the terrace adjacent to Tenmile terrace also have been uplifted 18 m above the rest of the terrace (Othberg, 1994) likely from faulting. The terrace has a high flat upper surface that has been considerably modified by erosion along the northeast margins. Erosion has locally stripped both soils and the loess that mantle the terrace. Soils found on the Amity terrace upper surface include the Pipeline soils that have soil profiles as thick as 1.65 m and the Elijah silt loam soils with profiles as thick as 2.44 m (Collett, 1980)

Parts of the Amity terrace have been covered along the southwest margin by undivided basalt flows of Indian Creek (Othberg and Stanford, 1992). Othberg (1994) identified the flows covering the Amity terrace as the basalt of the Hubbard Reservoir. The basalts have multiple flows consisting of olivine basalt of an aplitic texture although some flows have small olivine and plagioclase phenocrysts (Othberg and Stanford, 1992).

Gravels of the Gowen terrace

The Gowen terrace is about 49 to 58 m above the modern Boise River with an area of about 34 km^2 (Othberg, 1994). The terrace deposit is composed of sandy pebble and cobble gravels (Othberg and Stanford, 1992). Lithologies of clasts are predominantly granite and porphyritic felsite. About 5-10 percent of the gravel clasts are a gray unweathered basalt (Othberg and others, 1990). Gowan terrace runs below the ridge crest of the Tenmile terrace southeast of Boise (fig. 2). It is capped with 1-2 m of loess and is covered on the east end by basalts (Othberg and Stanford, 1992). The thickness of the terrace deposits southwest of Boise is 9 to 14 m (Othberg and others, 1990). East of Boise (fig. 2), deposits in the Gowen terrace are about 4 m thick (Othberg and Burnham, 1990).

Gravels of the Sunrise terrace

The Sunrise terrace is about 35 m above the modern Boise River with an area of about 110 km^2 (Othberg, 1994). The terrace occurs as a long, irregular strip that runs from south of Boise to Caldwell (Fig. 2). Terrace deposits include sandy pebble- and cobble-gravels. Lithologies of clasts are predominantly granite and porphyritic felsite in Sunrise terrace deposits found southwest of Boise (fig. 2.) About 5-10 percent of the gravel clasts are a gray unweathered basalt (Othberg and others, 1990). Much of the terrace is capped with loess 1 to 2 m thick (Othberg and Stanford, 1992). The thickness of the terrace deposits is thought to be at least 12 or 13 m (Othberg and others, 1990; Othberg and Stanford, 1993).

Gravels of the Wilder terrace

The Wilder terrace is 40 m above the modern Boise River (Othberg, 1994). Deposits consist of sandy pebble and cobble gravels that range from 5 to 24 m thick where deposits upstream appear to be thicker than those downstream (Othberg and Stanford, 1992). The terrace, extensively modified by the Bonneville Flood slack water, occurs in a strip about 3 km wide from Lake Lowell to Caldwell (fig. 2) then west as a narrow band to the Snake River valley (fig. 2). The terrace mostly consists of fine-grained slack water deposits left by the flood. Elsewhere floodwater removed the terrace deposits leaving local remnants of several-meter-thick alluvial gravels. Othberg (1994) suggested that the Wilder terrace surface may be comparable in age to the Sunrise terrace, but the terraces do have different gradients that may reflect tectonic deformation that occurred in the Nampa-Caldwell area (fig. 2) (Othberg, 1994).

Gravels of the Whitney terrace

The Whitney terrace is about 24 to 31 m above the modern Boise River near Boise and around 18 m at the confluence with the Snake River (fig. 2) (Othberg, 1994). The Whitney, covering an area of about 180 km^2 (Othberg and Stanford, 1993), is the largest terrace complex seen in the Lower Boise River Valley. Deposits consist of sandy pebble and cobble gravel between 5 and 24 m thick (Othberg and Stanford, 1992). Lithologies of clasts are predominantly granite and porphyritic felsite in Whitney terrace deposits found southwest of Boise (fig. 2). Some terrace deposits are covered by 1 to 2 m of loess (Othberg and others, 1990).

Remnants of the Whitney terrace west of Caldwell may be present in areas where outcrops are covered with 3 to 6 m of sediments deposited from slack water of the Bonneville flood (fig. 2). Some of the Whitney terrace affected by the Bonneville flood was scoured and eroded by several flood channels particularly those deposits near the Snake River (Othberg and Stanford, 1992). The primary exposure of the terrace is found along the south side of the valley extending from just east of Boise to 8 km east of Caldwell (fig. 2). The terrace is up to 7 km wide south of the town of Eagle. The terrace is also recognized in several areas along the north side of the Boise River east and west of Eagle (fig. 2). Othberg and Stanford (1992) also identify other terraces along the Snake River as likely extensions of the Whitney terrace where the remnants are also covered with sediments from slack water of the Bonneville flood.

Gravels of the Boise Front terraces, undivided

A series of terrace surfaces occurs in canyons, gulches and divides along the margin of the Boise Front foothills (Othberg and Stanford, 1992). The total estimated area of these terraces is 1.5 km^2, and the deposits vary in thickness from 1 to 6 m (Othberg and Stanford, 1993). Terrace deposits include subangular boulders together with sandy pebble and cobble gravels (Othberg and Stanford, 1992).

Gravels of the Boise terrace

The Boise terrace is 3 m above the Boise River floodplain (Othberg, 1994). The terrace is located along most of the north side of the river from Boise to Caldwell (fig. 2). Othberg and Burnham (1990) describe the gravel clasts of the deposits in the Boise Terrace east of Boise (fig. 2) as predominantly granitic and porphyritic felsites with about 5-10 percent gray unweathered basalt. The gravel deposits in the terrace are up to 14 m thick (Othberg and Burnham, 1990); deposits range from 11 to 15 m near Eagle (fig. 2). Below Caldwell, the terrace gravels were apparently reworked or removed by late stages of the Bonneville Flood, particularly in areas near the Snake River (Othberg, written commun., Oct., 2000). Clays layers that range in thickness from 1 to 2 m are restricted to the floodwater near Caldwell (fig. 2). Above Caldwell, the surface is notably undissected, and it is capped with a thin layer of loess. Soil development suggests the terrace was developed in the late Wisconsin (Othberg and Stanford, 1992).

Gravels of the Modern floodplain, Boise River

The modern Boise River floodplain contains a mix of gravel, cobbles, and sand where cobbles and gravel are more dominant in the upper reaches of the stream and sand and pebbles more dominant at the junction with the Snake River (Othberg, 1994). The lithologies seen in the gravel clasts are comparable to deposits seen in many of the terraces. The dominant rock types include granitic rocks and porphyritic felsites joined with 5-10 percent gray unweathered basalt. Well logs suggest a gravel thickness of 7-10 m in the modern floodplain near Eagle (fig. 2) (Othberg and Stanford, 1990). The length of the floodplain from Lucky Peak Dam to the Snake River is about 90 km. The area of the modern floodplain is the undesignated strip containing the Boise River on figure 2.

The relationship between clast sizes and distance downstream will be explored quantitatively as part of the assessment of sand and gravel in a subsequent report. The modern floodplain is typically about 2 km wide but narrows to 100-200 meters wide as it passes across displaced Indian Creek basalt flows at Caldwell that are associated with a major fault zone (Othberg, 1994, fig. 30). The floodplain is about 5 km at its widest.

The Boise River has, throughout much of its history, behaved much like most gravel-bed rivers elsewhere in the world (Galay and others, 1995). These are rivers, as a group, that emerge from mountain ranges into wide valleys or basins, some that result in fans but almost all developing a braided channel (and perhaps other channel patterns) in which most of the gravel is deposited. Extraction of sand and gravel directly from the active channel (or modern flood plain) of rivers, as has been done in the Boise River, is common in other parts of the world. It is here that the best quality aggregate for cement is commonly found. This is particularly true of the middle to lower part of the braided reach (Galay and others, 1995) and perhaps also true for deposits found in the modern flood plains and terraces along the Boise Valley as shown in the assessment in a subsequent report.

Closing Remarks

The primary source of aggregate in the Lower Boise River has been sand and gravel deposits found in the modern flood plain and in a series of stepped Pleistocene to Plio-Pleistocene terraces on both sides of the valley (fig. 2). At least 10 terraces are recognized from 3 to about 150 m above the present river level. The sand and gravel deposits found beneath the terrace surfaces reflect variation in climate, erosional and depositional rates, and fluctuation in the fluvial system all of which affected the suitability of these sand and gravel deposits for construction or other end uses. Weathering and post depositional modifications to the deposits also effect the suitability for aggregate. As a rule of thumb, the older the sand and gravel is, the more likely it will perform less well in construction material.

How much sand and gravel suitable for use is likely present in deposits found in the modern food plain and in the terraces? This is the key question that we hope can be answered by the sand and gravel assessment that will be presented in subsequent reports. In addition, the assessment will also focus on how much of the sand and gravel that is likely suitable for use as construction aggregate as expressed by results of standardized tests examining physical and chemical properties of the material.

This preliminary report provides a regional geological overview of the Boise River watershed in west-central Idaho including the Western Snake River Plain. Most of the aggregate found in the Lower Boise River Valley were derived from the high elevation, high relief mountainous upstream catchment of the Upper Boise River Basin. The upper watershed is dominated by granitic and associated host rocks and is physiographically different from the lower relief downstream reach that is dominated by upper Cenozoic volcanic and sedimentary rocks where the sand and gravel deposits are found in the Lower Boise River Valley. The character and composition of the deposits inherent to each terrace in the Lower Boise River Valley is variable, reflecting a range of depositional environments. However, the alluvial deposits are, among the terrace in which they are found, very similar.

As sand and gravel have broad uses, some sand and gravel deposits will meet required specifications for some applications and not others. Sand and gravel deposits suitable for construction and other uses are expected to be within an acceptable size distribution, contain few contaminants, and meet other rigorous specifications. Sand and gravel resource availability will be examined within the context of both land ownership and land use. The subsequent assessment will consider deposits that are recognized (developed or undeveloped), not clearly identified but suspected to be present, and their extensions.

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Appendix. **Classification of fluvial deposits**

Introduction

Pleistocene terrace deposits are a major source of sand and gravel for use in construction in the Lower Boise River Valley. The deposits from each terrace are comparable in texture and appearance. Sand and gravel is, by definition, coarse-grained, and the deposits are products of a coarse-grained alluvial system traditionally believed to be braided streams (Billi and others, 1987). Terrace development likely reflects the effects of both climate changes as well as tectonic processes.

Overview of coarse-grained fluvial systems

Galay and others (1995, fig. 22.4, after Sutek Service Ltd. and Kellerhals Engineering Service Ltd., 1989) suggested that voluminous supplies of gravel produce streams with at least three channel patterns--braided, anastomosed, and wandering. As will be shown below, these are not the only possible channel patterns. All rivers with high gravel content, no matter the channel style, are more likely to have greater lateral instability, valley slope, and high bed-load to total-load ratios (Galay and others, 1995). Each of the channel patterns has different geomorphology. For example, islands are largely absent in braided rivers. In anastomosed rivers, islands at high flow are likely to be split or anastomosed as well. Bar development in braided rivers is mid-channel and diamond shaped. In anastomosed and wandering rivers, bars are likely diagonal, point, or mid-channel. Lateral activity can be irregular in wandering and anastomosed rivers but can produce avulsion in all three types (Galay, and others 1995). How these differences in fluvial styles effect (or reflect) sand and gravel characteristics related to aggregate uses is unknown.

Billi and others (1987) note that numerous researchers have found that coarse-grained fluvial deposits can also be deposited by meandering rivers or low-sinuosity (irregularly sinuous) rivers such as those predominantly encountered in modern systems. Billi and others (1987) also show how gravel fabric and cross-stratification can be used to interpret deposits associated with low-sinuosity rivers. How this fabric and cross-stratification may be reflected in sand and gravel characteristics important to use in aggregate is unknown.

As noted previously, coarse-grained fluvial systems may develop where glaciation has occurred in the watershed. Desloges and Church (1987) note that glacial processes are less effective than fluvial processes in mixing sediments from different sources. Again, how clearly this will be reflected in sand and gravel characteristics important to use as aggregate is unknown. Gravels eroded from glacial moraines can be expected to have a larger portion of cobbles and boulders (Bliss and Bolm, 2000). These can in places be crushed to augment grain sizes found to be deficient in the sand and gravel deposits.

A standardized description of fluvial deposits

Finding a way to consistently describe fluvial deposits has been the subject of considerable interest by sedimentologists, geomorphologists and others. Miall (1996) has taken considerable effort in developing a consistent vocabulary using standardized architectural elements as well as standardized lithofacies. Although the presence of a system is important, ease of use is equally important. The overview that follows examines a part of the system developed by Miall (1996). Note that gravel is abbreviated as "GVL," sand as "SND" and silt as "SLT" in parts of this overview. How the classification system will fit into the assessment of sand and gravel to be presented in subsequent reports is undetermined.

Architectural elements, as used by Miall (1996), are distinct depositional units with recognizable bounding surfaces. These elements are strictly descriptive, not genetic. A sedimentary lithofacies is a body of sediments or sedimentary rock that is genetically related and commonly contrasted with adjacent bodies of sediment. Many sedimentary lithofacies can be products of different depositional environments. Interpretation of the lithofacies together and within the regional geologic context is necessary to make genetic assignments. Lithofacies, as used here, are characteristics that allow a larger sedimentary unit to be subdivided in a way that reflects characteristics that should be important to sand and gravel deposit definition. One can expect that a genetic explanation may not be possible everywhere and that sand and gravel models must be sufficiently “descriptive” to allow recognition where a genetic explanation is not possible.

Lithofacies

Fluvial deposits are dominated by clastic material. The simplest classification is a three component one--using gravel, sand, and fine-grained materials. Fine-grained components can include mud, silt, and very fine-grained sand. Some lithofacies (not considered here) also contain organic matter that is an undesirable contaminant for aggregate applications.

Table 1 presents a list of 20 lithofacies classes (modified after Miall, 1996) with associated names, descriptions, structures, and genesis. The classes are arranged from coarser grain sizes in the lower numbers through finer grain sizes in the higher numbers. Most gravel (as well as boulders and cobbles) found in sand and gravel deposits will be from lithofacies 1-7. However, lithofacies 1 and 2 are matrix supported, so one may expect considerable sand and fine-grained material as well. Minor amounts of gravel are likely in lithofacies 8-9 and 11-13. The gravels are suspected to be present in these lithofacies based on the identification of "pebbly” in the description of Table 1. Sand is dominant in lithofacies 8-15 but will likely be encountered in all lithofacies listed in

Table 1 albeit in minor amounts in lithofacies 16-21 and perhaps in lithofacies 1-7. Sources of undesirable fine-grained material (less than 0.074 mm) are likely found in small amounts in lithofacies 1-7 and likely in greater amounts in some of the sand dominated lithofacies 8-14. Fine-grained materials dominate lithofacies 16-19, and they should be avoided where encountered with sand and gravel deposits. Lithofacies 19 and 20 consist of vegetated swamp materials and soil horizons with chemical precipitates, respectively, both of which are undesirable in aggregate sources.

Table 1. Lithofacies classification (modified after Miall, 1996)
[GVL--gravel; SND--sand; SLT--silt.]

Lithofacies No.	Lithofacies Name	Description	Structure	Genetics
1	**Gmm**	GVL, matrix-supported, mass	Weak grading	Plastic debris flow, high-strength & viscous
2	**Gmg**	GVL, matrix-supported	Inverse to normal grading	Pseudoplastic debris flow, low strength, viscous
3	**Gci**	GVL, clast-supported	Inverse grading	Clast-rich debris flow (high strength) or pseudoplastic debris flow (low strength)
4	**Gcm**	GVL, clast-supported, mass	None commonly seen	Pseudoplastic debris flow (inertial bedload, turbulent flow)
5	**Gh**	GVL, clast-supported, crudely bedded	Horizontal bedding, imbricated	Longitudinal bedforms, lag deposits, sieve deposits
6	**Gt**	GVL, stratified	Trough cross-beds	Minor channel fills
7	**Gp**	GVL, stratified	Planar cross-beds	Transverse bedforms, deltaic growths from older bar remnants
8	**St**	SND, fine to very coarse, may be pebbly	Solitary or grouped trough cross-beds	Sinuous-crested and linguoid (3-D) dunes
9	**Sp**	SND, fine to very coarse, may be pebbly	Solitary or grouped planar cross-beds	Transverse and linguoid (2-D) dunes
10	**Sr**	SND, very fine to coarse	Ripple, cross-laminated	Ripples (lower flow regime)
11	**Sh**	SND, very fine to coarse, may be pebbly	Horizontal lamination	Plane-bed flow (critical flow)

Lithofacies No.	Lithofacies Name	Description	Structure	Genetics
12	**Sl**	SND, very fine to coarse, may be pebbly	low-angle ($<15^0$) cross-beds	Scour fills, humpback or washed-out dunes, antidunes
13	**Ss**	SND, very fine to coarse, may be pebbly	Broad, shallow scours	Scour fill
14	**Sm**	SND, fine to coarse	Massive, or faint lamination	Sediment-gravity flow deposits
15	**Fl**	SND, SLT, mud	Fine lamination, very small ripples	Overbank, abandoned channel, or waning flood deposits
16	**Fsm**	SLT, mud	Massive	Backswamp or abandoned channel deposits
17	**Fm**	Mud, SLT	Massive, desiccation cracks	Overbank, abandoned channel, or drape deposits
18	**Fr**	Mud, SLT	Massive, desiccation cracks	Root bed, incipient soil
19	**C**	Coal, carbonaceous mud	Plant, mud films	Vegetated swamp deposits
20	**P**	Paleosol, carbonate (calcite, siderite)	Pedogenic features, nodules, filaments	Soil with chemical precipitation

Architectural elements

Introduction

Miall (1996) develops a basic set of eight architectural elements that can be found in various combinations in fluvial system channels (Table 2). One additional element, floodplain fines (FF), is also considered here as it one of the elements of overbank environment that may be found in abandoned channels (Miall, 1996). The elements are the channel, gravel bars and bedforms, hollow deposits, sediment gravity-flow deposits, sandy bedforms, downstream-accretion macroforms, lateral accretion deposits, and laminated sand sheets. Each architectural element will be discussed in turn. Each element can consist of one or more lithofacies as given in Table 1. If these elements are sufficiently large they can be readily identified on low-level aerial photographs of modern rivers. One or more of these elements may be encountered in sand and gravel deposits suitable for aggregate. Relationships between elements can be complex, reflecting multiple truncations of one or more previous deposits and the overprinting of one or more new ones! The discussion that follows is more extensive for those architectural elements that are more likely to be likely sources of suitable sand and gravel. A summary of architectural elements and lithofacies is given in the matrix presented in Table 3. Architectural elements are also classified according to their potential for being a suitable source of sand and gravel based on the descriptions provided by Miall (1996). This is also reviewed in the text below.

Table 2. List of architectural elements after Miall (1996).

ARCHITECTURAL ELEMENTS	
Class	**Description**
CH	Stream channels
GB	Gravel bars & bedforms
HO	Hollow deposits
SG	Sediment gravity-flow deposits
SB	Sandy bedforms
DA	Downstream accretion macroforms
LA	Lateral accretion deposits
LS	Laminated sand sheets
FF	Overbank fines

Architectural elements likely to have gravel

Stream channels are the most common elements found in fluvial systems (identified as element **CH** by Miall, 1996). All lithofacies assemblages are possible in any combination in channels (Miall, 1996, Table 4.3). Sediment body types included fingers, lenses, or sheets with concave-up erosional bases where both scale and shape are highly variable.

Channel-fill elements can be separated from other elements (in cross-section perpendicular to paleo-flow) by sloping channel margins. Channels are commonly multistoried with each story bounded by an erosional surface (Miall, 1996). The angles of channel margins can in places indicate channel width; steep to vertical margins indicate narrow channels as compared to gentler margins that indicate a wider channels. Sheet-like channels commonly have nearly imperceptible margins (Miall, 1996). Channel deposits typically gave grain sizes that fine upward where channels are filled by simple vertical aggradation as a result of progressive abandonment or flash floods (Miall, 1996). Miall (1996, p. 131) notes that, "most coarse (gravel, sand) deposits in fluvial systems are deposited in channels." Channels are promising as a source of sand and gravel for use as aggregate.

Gravel bars and bedforms (element **GB**), by their very definition, constitute a promising source of sand and gravel for construction aggregate given adequate thickness, volume, etc. Three closely related gravel lithofacies (Hein and Walker, 1977 as cited by Miall, 1996) are: bedded and imbricated (Gh), planar cross-bedded (Gp), and trough cross-bedded (Gt). These are three types of mesoforms found in gravel bars and bedforms (Miall, 1996). This element, GB, is important in gravel-dominated, braided rivers where transport occurs as random pulses of several hours duration resulting in bar erosion and channel evulsion (Miall, 1996). Gravel may initially occur as thin layers, perhaps no more than a few clasts thick, which grow upward downstream to form thick horizontally stratified sheets up to about 1 m in thickness (Miall, 1996).

Hollow deposits (element **HO**) are described by Miall (1996) as being trough-shaped indentations in the stream bed, probably the product of deep scouring where channels converge, and can be up to six times as deep as the channels with which they are associated (Cowan, 1991, as cited by Miall, 1996). They are encountered in gravel-braided and sand braided systems (Miall, 1996) and may be present in deposits left by the Boise River. Siegenthaler and Huggenberger (1993, as cited by Miall, 1996) report hollow-like structures in Pleistocene gravels in Switzerland. In braided systems, the scouring can be three times the mean channel depth and tends to occur upstream from large emergent bars (Cant and Walker, 1976). In the Westwater Canyon Member of the Morrison Formation, Cowan (1991) reports that hollows are 20 m deep and 250 m wide with an upper surface that is concave-up with fourth-order surfaces and basal surfaces dipping as much as 26°. Deposits are not cylindrical in shape as expected in channel deposits but scoop-shaped (Miall, 1996). Because hollows develop below the channel base, chances of preservation are improved (Miall, 1996). Lithofacies present in the Westwater Canyon Member (Cowan, 1991) and identified in Table 1, include only Sh (horizontal laminated fine to very coarse to pebbly sand) and Sl (low-angle cross bedded sand). However, Miall (1996, Table 4.3) also suggests that the number of possible lithofacies assemblages found in hollows is far greater including Gh (clast-supported, crudely bedded gravels), Gt (stratified gravels), and St (solitary or grouped crossbeds of fine to very coarse to pebbly sand).

Sediment gravity-flow deposits (element **SG**) may contain considerable sand and gravel but may be an unlikely source of sand and gravel suitable for aggregate. Sand and gravel deposits with 15 percent or more silt, possible characteristic of gravity-flow deposits, commonly are not worked. Contamination of flow deposits with organic debris may also be a problem. Lithofacies located in flow deposits include both matrix-supported and clast-supported. Beds are commonly between 0.5 to 3 m thick, where flows can be up to 20 m wide and several kilometers in length downstream (Miall, 1996). Multiple pulses may stack flow deposits, resulting in a composite thickness of several meters. Flow deposits have lower edges that are irregular where deposition occurs passively on existing surfaces of all types. Texture is disorganized and commonly distinctive.

Lithofacies commonly found in flow deposits are either matrix supported with weak grading or inverse to normal grading (lithofacies Gmm, Gmg), or clast-supported with inverse to no grading (lithofacies Gci, Gcm). Matrix supported lithofacies are rich in fines and are the product of plastic to pseudoplastic debris flows, although clastic supported lithofacies are only produced by pseudoplastic debris flows (Miall, 1996).

Flow deposits are not described (or perhaps not recognized) in the Boise Valley alluvial deposits but may be present in Bonneville Point gravel due to its proximity to the Boise Front. Clast supported lithofacies are more likely to be possible sources of sand and gravel for aggregate.

Architectural elements <u>not</u> likely to have gravel

The following elements may contain sand but are not likely to have much gravel. Although many of these architectural elements may be a source of fine aggregate, the primary objective of the study is recognizing sources of sand <u>and</u> gravel. These are given briefly below for the sake of completeness.

•**Sandy bedforms** (element **SB**) are identified by Miall (1996, Table 4.3) as having six principal lithofacies assemblages. They are St, Sp, Sh, Sl, Sr, and Ss (Table 1). Pebbles (some of which are sufficiently large to be considered GVL) may be present in lithofacies St and Sp.

•**Downstream-accretion macroforms** (element **DA**) are described by Miall (1996, Table 4.3) has having six principal lithofacies assemblages. They are St, Sp, Sh, Sl, Sr, and Ss (Table 1). Pebbles (some of which are sufficiently large to be considered GVL) may be present in lithofacies St and Sp.

•**Lateral accretion deposits** (element **LA**) are described by Miall (1996 Table 4.3) as having six principal lithofacies assemblages. They are St, Sp, Sh, Sl, Sr, and Ss (Table 1). These same lithofacies are found in downstream-accretion macroforms noted above. Pebbles (some of which are sufficiently large to be considered GVL) may be present in lithofacies St and Sp. Less commonly found in this element are lithofacies Gm, Gt and Gp that also contain GVL.

•**Laminated sand sheets** (element **LS**) as described by Miall (1996, Table 4.3) consist of lithofacies Sh and Sl (Table 1). Minor Sp and Sr may also be found. Only Sp may contain material sufficiently large in grain size to be identified as GVL.

•**Overbank fines** (element **FF**) as described by Miall (1996, Table 4.3) consist of lithofacies Fm and Fl (Table 1). The element is commonly interbedded with element SB and is prevalent in abandoned channels (Miall, 1996).

Role of architectural elements and lithofacies in aggregate assessment

Can the application of architectural elements and lithofacies to the analysis of fluvial deposits provide insight into sand and gravel resources in deposits formed from braided rivers? Sources of sand and gravel are located in many elements. Some elements are dominated by gravel- and sand-rich lithofacies, but these elements can also contain lithofacies rich in undesirable fines. Lithofacies are classified using grain size (gravel, sand, silt) and, by definition, are useful to resource assessment. Can lithofacies and architectural elements be used to make better estimates of sand and gravel?

For a long time, braided rivers were thought to have random depositional patterns lacking cyclical patterns of any sort. However, work by Miall (1973) and Cant and Walker (1976) found that some deposits formed by braided rivers do exhibit cyclical patterns that can be recognized when using statistical techniques of Markov chain analysis of the bedding sequence. In fact, Cant and Walker (1976) initially developed the concept of lithofacies to allow surface designation for use in Markov analysis. Miall (1977) developed a four-lithofacies model for braided rivers that are cyclical.

Both architectural elements and lithofacies are potentially useful in sand and gravel assessment but require the recognition of and reporting on sedimentary features used by the classification system as observed in pits and elsewhere. It is possible that quantitative relationships between geomechanical characteristics (Los Angeles Abrasion test, sand equivalency test and others) and lithofacies, and perhaps even architectural elements, are present, but these have yet to be demonstrated.

Likelihood of suitability for aggregate construction

Based on the character criteria described for the various types of lithofacies (Table 1) and architectural elements (Table 2), it is evident that certain types have a higher likelihood than others to contain a substantial proportion of sand and gravel that may meet minimum geotechnical specifications for use in construction aggregate. Some other types, such as swamp deposits, are known to be unsuitable for such applications. Based on these criteria, a simple classification matrix, shown in Table 3, is used to assign each lithofacies type associated with certain architectural elements a “likelihood of suitability” that it will meet the minimum construction aggregate specifications. This classification matrix is based strictly on hypothetical physical and chemical characteristics for a range of sedimentary structures that may occur on the Lower Boise River Valley. It is not based field observations or data collected in the study area. However, the classification matrix may serve as a useful screening tool when investigators, land planners, or others seek to identify sedimentary features as potential exploration targets for high quality construction aggregate.

Table 3. Sedimentary sources of sand and gravel aggregate based on descriptions of architectural element (table 2) and lithofacies (assigned by number) (Miall, 1996).

[NO. is the lithofacies class number (see text). Assignments of "likelihood of suitability" (color code describe below table) is a subjective assignment using the anticipated lithologies associated with each lithofacies class and architectural element combination with the expectation that it will contain a substantial proportion of sand and gravel that may meet minimum geotechnical specifications for use in construction aggregate.]

NO.	CLASS	GRAIN SIZE	ARCHITECTURAL ELEMENTS								
			CH	GB	HO	SG	SB	DA	LA	LS	FF
1	Gmm	GVL, matrix-supported, mass	**Gmm**			Gmm			Gm		
2	Gmg	GVL, matrix-supported	**Gmg**			Gmg			Gm		
3	Gci	GVL, clast- supported	**Gci**			**Gci**					
4	Gcm	GVL, clast-supported, mass	**Gcm**			**Gcm**					
5	Gh	GVL, clast-supported, crudely bedded	**Gh**	**Gh**	**Gh**						
6	Gt	GVL, stratified	**Gt**	**Gt**	**Gt**				Gt		
7	Gp	GVL, stratified	**Gp**	**Gp**					Gp		
8	St	SND, fine to very coarse, may be pebbly	St		St		St	St	St		
9	Sp	SND, fine to very coarse, may be pebbly	Sp				Sp	Sp	Sp	Sp	
10	Sr	SND, very fine to coarse	Sr				Sr	Sr	Sr	Sr	
11	Sh	SND, very fine to coarse, may be pebbly	Sh		Sh		Sh	Sh	Sh	Sh	
12	Sl	SND, very fine to coarse, may be pebbly	Sl		Sl		Sl	Sl	Sl	Sl	
13	Ss	SND, very fine to coarse, may be pebbly	Ss				Ss	Ss	Ss		
14	Sm	SND, fine to coarse	Sm								
15	Fl	SND, SLT, mud	Fl								Fl
16	Fsm	SLT, mud	Fsm								
17	Fm	Mud, SLT	Fm								Fm
18	Fr	Mud, SLT	Fr								
19	C	Coal, carbonaceous mud	C								
20	P	Paleosol, carbonate (calcite, sidrite)	P			C					

Explanation

Likelihood of Suitability for Aggregate Construction

- **High**
- **Moderate**
- Low
- Too fine for construction aggregate
- Organic and other contaminants unsuitable for construction aggregate