24-045

Geology Says Otherwise

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Here's what I've been wondering.

If fire hides in wood
what hides in a stone?

(from Alyson Hallett, 2013, *Conversation with a Pebble*)

INTRODUCTION

I spent 41 years as a geologist with the US Geological Survey (USGS) conducting geologic studies and preparing peer reviewed maps and reports describing the results of those studies. Since retiring from the USGS in 2011, I have been a consultant specializing in aggregates and other industrial minerals. Consequently, I have had the opportunity and pleasure to apply the information contained in those kinds of geologic maps and reports to real-life situations.

About half of my consulting is performing due diligence for mineral resource evaluations of one type or another where resource information has been provided by the property owner. Many of those jobs necessitate that I conduct desktop studies followed by field work. I then use my information to review and comment on the written reports of others; reports variably referred to as geologic reports, resource studies, reserve analyses, and so forth. While there are many well written reports addressing geologic resource issues, I was surprised to see that there are also a significant number of so-called geologic reports that only pay cursory attention to geology. Unfortunately, that lack of rigorous geologic investigation commonly leads to erroneous conclusions.

This paper addresses three such reports covering concrete sand, metallurgical gravel, and proppants (frac sand). Although all three examples are located in the Gulf Coastal Plain Province, I do not reveal the exact location of any of the properties for purposes of confidentiality. Furthermore, I have generalized the site descriptions and illustrations. However, all the descriptions faithfully define the geologic situation.

The three case examples are arranged from the least to the most complicated.

"SUCH QUANTITIES OF SAND"

The Walrus and the Carpenter
Were walking close at hand;
They wept like anything to see
Such quantities of sand.

(From Lewis Carroll, 1871,
The Walrus and the Carpenter)

A person was considering developing a potential sand deposit located on a property in the Gulf Coastal Plain a few miles coastward from the Piedmont Uplands. The property purportedly was underlain with high quality construction sand. The property lies partially in a bottomland floodplain of a sluggish river with backwater ponds and swamps. Swamp forests consist mostly of oak-dominated hardwoods. The bulk of the property lies on a gently sloping valley side with terraces covered with a mixture of hardwood/pines and dense overgrown clear-cut areas.

Potential Minerals Reported

Two existing geologic reports described the potential for sand on the property. One report stated, "The sand encountered proved to be fine to coarse grain and fits the specification for construction, mortar and specialty sands [golf courses, blasting, grinding, etc.]" Even more convincing, that same report stated "The test drilling of 70 plus test holes on the 300 acres *** *shows a tremendous amount of course sand* and lesser amount of gravel." (Text in bold italics emphasized by me.) The report backs up the claim by including sieve analyses and logs of test holes in the report and by referring to logs of drill holes in other older reports.

Existing Technical Reports

There was a conspicuous absence of geology in both reports. The only discussion of geology in the first report was the statement, "*Geologically, the material deposits are located in high terrace gravels of quaternary age. These deposits are described as 'lenticular beds of poorly sorted sand, ferruginous sand, silt, clay, and gravelly sand. Sand consists primarily of very fine to very coarse poorly sorted quartz grains, gravel composed of quartz, quartzite, and chert pebbles.'*"

In the absence of geology, the entire evaluation of the sand was based entirely on drill hole logs that contained lengthy sections of tan or pink silty sand. And kicking the dirt in a casual reconnaissance of the site could leave a trusting person with the impression that the site indeed contained "such quantities of sand."

In-Depth Geologic Study

I was retained by a client to evaluate the existing reports and to opine on the report's description of the quality and quantity of sand.

The data gleaned from the existing reports were of uncertain and conflicting quality. There were considerable discrepancies between test hole logs and sieve analyses. In addition, the Fineness Modulus* was reported for a number of samples, but some of the values reported were not correctly calculated. My reconnaissance visit revealed much sand but the presence of pinkish sand in the higher terraces seemed oddly out of place compared to the tannish sand in the floodplain. Consequently, my initial review of the existing data lead left me with a low level of confidence.

A new geologic study and drilling program were proposed to increase the confidence level of the sand resource estimates. Two USGS regional geologic maps were accessed to evaluate the regional geology; 1) a digital geologic map of the state, and 2) a map showing surficial materials of the area. Both of those maps would have been available to the authors of the client-supplied reports, although the latter report may not have been available as a digital product.

Of the twenty drill holes I had planned, only 13 were completed. Shortly after drilling commenced it became evident that there was much more silt and clay in the pink silty sand deposits than was described in the existing reports. Sand suitable for use as concrete was encountered in only three of the new bore holes; all three were in the modern flood plain (i.e., the first terrace above the stream surface). The remaining ten drill holes, all located on terraces above the modern floodplain, were barren of sand suitable for use as construction or other more demanding applications.

Six side-by-side analyses (see Figure 1 for an example) were conducted comparing the test hole logs in the existing reports to logs from new drill holes located very nearby. Four of the six comparisons were significantly different; clean sand that had been reported in the existing drill holes was totally absent or was excessively laden with silt. This cast doubt on all the old drill holes.

A brief analysis of the regional geology was conducted as part of the study. The regional study extended into the piedmont where particular attention was given to a map unit described as micaceous saprolite. The saprolite (shown by the purple section in Figure 1) formed on a gneissic rock directly along strike with the purported sand deposit. It was determined that the pink, micaceous silty, clayey sand described in the existing reports was the same as the silty saprolite exposed along strike in the nearby Piedmont. The original sand report that had been prepared without

* The fineness modulus is an empirical value that describes the average size of particles in a sample of aggregate. It is calculated by adding the total percentage of the sample of an aggregate retained on each of a specified series of sieves, dividing the sum by 100.

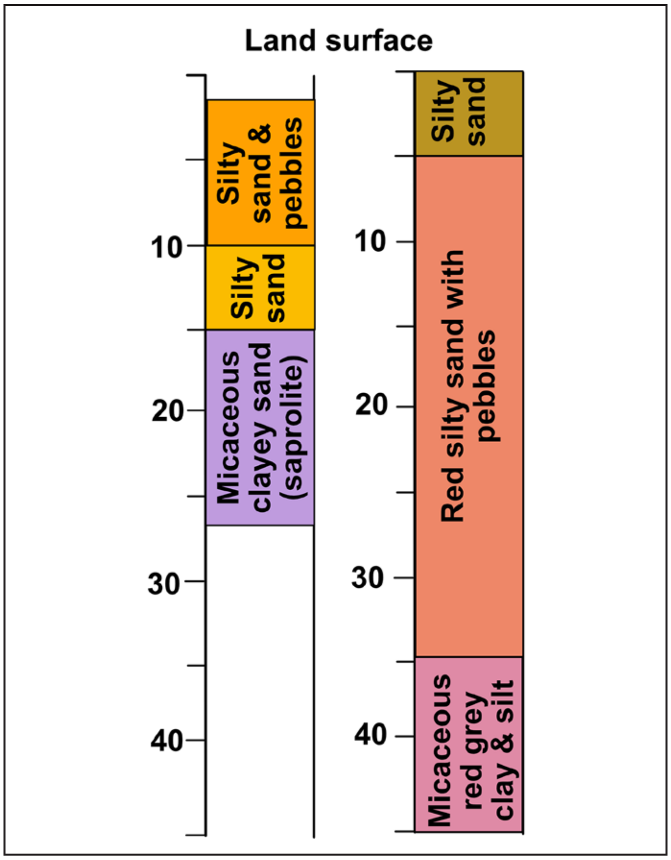

Figure 1. Side-by-side logs showing sand at site considering geology (lefft log) and without geology (right log)

knowledge of the nearby outcroppings of micaceous saprolite erroneously inferred that the mica-rich sand was an actual fluvial deposit of sand. If the existence of saprolite along strike had been known to the original investigator, he or she may have had different conclusions and recommendations.

The plans to develop the property as a sand mine were abandoned.

The lesson here is to understand the site in the context of the greater regional geologic setting.

"THE OLE GRAVEL PIT"

> In my golden years, I reflect back to years done reveling memories of the Ole Gravel Pit, so beloved.
>
> (From Idchev, 2020, *Reflections of the Ole Gravel Pit*)

A person had accepted a property located in Gulf Coastal Plain sediments as collateral for a loan and, by default of payment on the loan, obtained ownership of the property. According to existing reports, the property was underlain with metallurgical gravel. The owner of the property was attempting to interest a person to partner with him to develop the metallurgical gravel.

Potential Minerals Reported

Metallurgical gravel is high purity quartz gravel and is the primary ingredient in the manufacture of silicon and ferrosilicon metal. The highest-quality ferrosilicon is made in an electric arc furnace by reducing silica with coke in the presence of iron (usually derived steel scrap or iron ore). The most popular grade of ferrosilicon contains 75 weight percent (wt%) silicon, but the amount can range from 15–90 wt% depending on the application. The preferred size for metallurgical gravel is ¾ inch to 5 inches because impurities tend to be concentrated on the surface, and the larger volume objects have a smaller surface area to volume ratio than smaller objects.

The property lies in the Fall Line Hills ecoregion. The site consists of two cultivated terraces on a hillside underlain by gravel of unknown thickness and buried at an unknown depth. A small stream runs through the valley bottom, separating the farmland on the terraces on one side of the valley from the opposing heavily-wooded hillside. Wooded wetlands occupied most of the stream valley. An abandoned gravel pit was located on the property extending between the two terraces, and exposed gravel at both terraces. The gravel in the pit was originally discovered in the bottom of a deep ravine flowing through the sloping land between the two terraces. Were it not for the ravine, gravel probably would have gone unnoticed and The Ole Gravel Pit probably never would have existed. Local lore was that the ole gravel pit provided material for a nearby interstate highway

Existing Technical Report

An existing report prepared for a previous owner detailed a drilling program of at least 39 auger holes supplemented by about 20 track hoe test pits. Drilling was conducted mostly in the upper terrace and the wooded part of the property, whereas, the test pits were exclusively in the cultivated fields on the lower terrace.

Thirty-nine samples were combined and divided into three larger samples for testing for use as metallurgical gravels. All three samples met quality requirements. In addition, the report stated, "From a conservative perspective based on the information at hand, the total reserve base of silica sand and gravel is in excess of 50 million tons." The report supported the possibility for marketing the material by noting the presence of a metallurgical gravel pit in a nearby valley bottom. There was neither an explanation of how the 50-million-ton volume was calculated, nor a divvying up of sand versus gravel. Figure 2a shows the impression that the

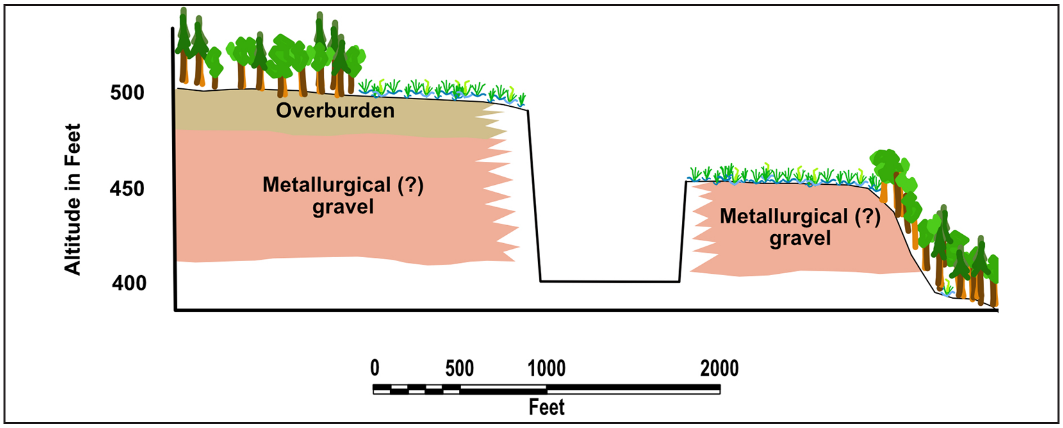

Figure 2a. Distribution of potential metallurgical gravel when not considering geology

existing technical report conveys. The saw-tooth contacts indicate the lack of any discussion of the pit in the report.

In spite of the optimistic estimates, the report called for more drilling. Therefore, in the year prior to my arrival the landowner contracted for a flight auger and drilled in the exact same locations as the filled track hoe test pits on the lower terrace. All drill holes showed sand and gravel from top to bottom. The backhoe also dug a number of test pits in the wetlands, which revealed white quartz gravel similar to the metallurgical gravel being produced in a nearby pit. That gravel was off-limits because it was located in the wetlands.

In-Depth Geologic Study

I was retained by a potential partner to determine the quality and quantity of the metallurgical gravel, to determine the amount of overburden, and to opine on the reasonability of reopening the Ole Gravel Pit to mine and process the metallurgical gravel. Although I was retained by the potential partner, he and the landowner freely exchanged data and ideas with one another.

Although there was an abundance of existing auger hole data, there was a complete lack of details regarding how those data were used to determine reserves (more appropriately potential reserves). The existing report did not even mention the geology as exposed in the Ole Gravel Pit. Although the landowner and potential partner had been through the pit, they had not studied the pit in any detail. For example, they had not done the simple job of determining the altitude of the top or the bottom of the gravel in the pit walls.

Scheduling set by the client and the owner of the property limited my time in the abandoned pit to a chauffeured drive-through on an all-terrain vehicle. That was sufficient to determined there was significant overburden on both the higher and lower terraces but insufficient to get actual measurements. The time spent in the pit was short because neither the client nor the landowner were comfortable projecting knowledge from the pit to the surrounding area. Furthermore, although there was a dearth of geology in the existing reports, the client was not interested in having me conduct a geological study. He and the landowner were looking for "hard proof" from new drilling and test pits.

A 12-inch solid stem flight auger and a track hoe were made available to assist me in my evaluation. The first task was to drill two holes within about 10 feet of two of the previous drill holes on the higher terrace. The side-by-side comparisons showed that the original study grossly underestimated the overburden on the higher terrace.

The drilling that the landowner had done in the footprints of the track hoe test pits on the lower terrace showed that gravel extended to the land surface. I tested that observation with an auger hole drilled adjacent to, but not directly in, one of the track hoe test pits. To the contrary, there was approximately ten feet of overburden before encountering gravel. Apparently, the owner encountered blended backfill material and erroneously assumed that the gravel deposit extended continuously from the land surface to the bottom of the deposit.

Abundant, highly weathered, weak silica gravel (locally referred to as "sugar rock") was encountered in the test pit. Sugar rock cannot be used as metallurgical gravel, and is commonly passed up for use as construction aggregate.

The track hoe was used to excavate a continuous trench from the crest of the lower terrace to the floodplain in the valley. Beginning about 10 feet below the crest of the terrace, a weathered silica gravel with a disoriented fabric was observed on the entire hill slope.

I encouraged the client to accompany me to the gravel pit where I gave a verbal report to help him visualize the

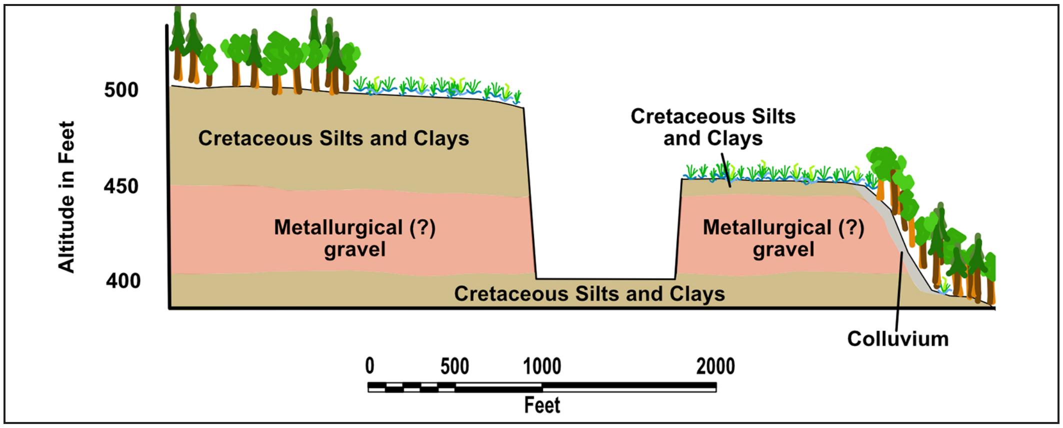

Figure 2b. Distribution of potential metallurgical gravel when considering geology

deposit of potential metallurgical gravel (Figure 2b). The gravel under the terraces was correlated to a gravel outcrop on a terrace on the opposing hillside at the same elevation as the gravel under the terraces. It was hypothesized that the gravel deposit originally occurred as a buried layer under the terraces that extended across the valley when it was full of sediment and had been eroded away in the valley during the formation of the valley. The lack of fabric in the gravel on the hillslopes indicated a colluvial mass wasting origin of the white metallurgical gravel in pits on the lower terrace.

The presence of "sugar rock" and the heavily oxidized surfaces on the gravel clasts demonstrated the low quality of the buried gravel. It was hypothesized that erosion broke down the weak, weathered gravel (sugar rock) into smaller, strong, coherent, unweathered metallurgical gravels that were naturally rounded by fluvial processes and ultimately deposited in the wetlands.

It was recommended that the Ole Gravel Pit not be reopened. The client decided not to partner in the mining venture. Nevertheless, the owner reopened the pit in an attempt to profitably mine the gravel. His attempt failed.

The lesson here is to utilize all local observation points available (pit exposure) – and cast about a little farther from the site (outcrop on adjacent hillside). Much of the expense of drilling and equipment rental could have been avoided if that geologic information had been considered.

"THIS GRAIN OF SAND"

Ah! If I had the eyes to see,
And brain to understand,
I think Life's mystery might be
Solved in this grain of sand.

(From Robert Service, *A Grain of Sand*, in, *Carols of an Old Codger*, 1955)

A client was considering purchasing a property. The purchase price was unexpectedly high due to the purported existence of large amounts of proppant (frac sand) underlying the entire property.

The property is mostly on an upland Flatwoods ecosystem. Flatwoods are located on poorly drained flats between rivers (interfluvial zones) on the Gulf Coastal Plain. A smaller part of the property occupies a lowland floodplain and low terraces of a sluggish, low gradient stream.

In the upland areas of this report, most of the Quaternary Gulf Coastal Plain deposits consist of three Pleistocene related formations, from oldest to the youngest, being: the Williana (Louisiana) or the Willis (Texas); the Montgomery (Louisiana) or the Lissie (Texas); and the Prairie (Louisiana) or Beaumont (Texas) Formations. Only two of these formations are relevant as far as the property in question is concerned; the Williana/Willis and the Montgomery/ Lissie Formations.

The lowlands and low terraces portion of the property are underlain at depth with either/or the Williana/Willis formation and the Montgomery/Lissie formations. Everywhere throughout the lowlands those two formations are overlain with the modern floodplain and two associated higher, older terraces. In more recent reports many of those terraces are referred to as the Deweyville Formation (Wisconsin or early to middle Holocene). For simplicity, throughout the remainder of this report the sediments underlying the modern floodplain as well as the higher terraces on the property in question are referred to as the Deweyville Formation.

Potential Minerals Reported

An active sand processing plant exists on one of the Deweyville Formation terraces. A dredge mines sand from ponds created in the floodplain and Deweyville Formation. The sand is processed into a variety of products including

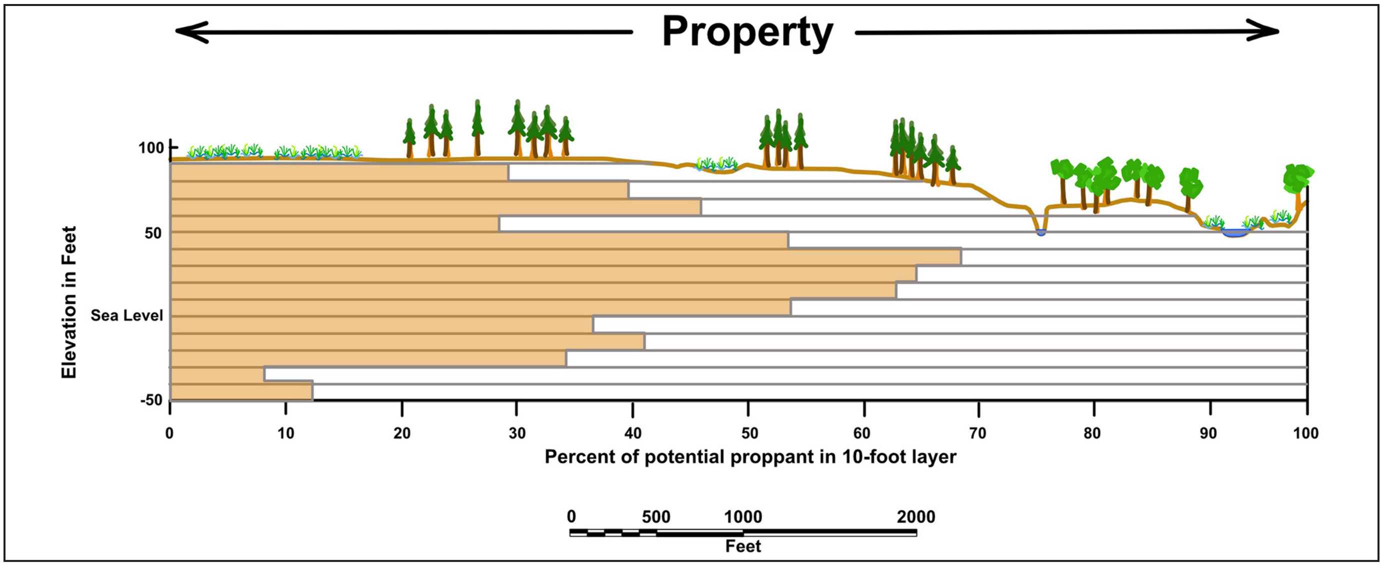

Figure 3a. Generalized cross section showing potential proppant at site in 10-foot intervals relative to elevation without consideration of geology

bank sand, concrete sand, pugmill proppant sand. No proppant production was reported until two years prior to the property purchase being considered.

Existing Technical Report

A technical report on the potential for proppants and other sand products underlying the property was prepared on behalf of the owner. The technical report mentioned the Montgomery/Lissie Formation and the Deweyville Formation only once each in a short section called "Geologic Setting." That section essentially was a repeat of map explanations of the two formations. Other than that, neither of the two formations nor any other geologic discussions were contained in the report.

The scope of work included exploring the general subsurface conditions at the site and relevant engineering properties of the subsurface materials using geotechnical borings. The entire section of the report on grain size distribution was based almost exclusively on the laboratory analyses from 12 test holes, with no attempt to correlate test holes with one another. Two-foot samples were taken from test holes every ten feet. All of the drill holes were located in the upland Flatwoods; none was in the bottomland floodplain or low terraces.

The report contained an elaborate, unnecessarily complicated method to determine the amount of proppant-sized sand underlying the Montgomery/Lissie portion of the property. A simplified description of the methodology follows:

- Test hole samples (two-foot samples collected at ten-foot intervals) were sieved. The percent of material passing through the #40 sieve and retained on the #140 sieve* was measured for each sample and referred to as "percent recovery."
- Various laboratory analyses were conducted to determine the properties of the sand. It was reported that all of the sand met requirements for use as proppant.
- The percent recovery was calculated in 10-foot intervals (fig.3a)
- The average percent recovery rate per ten-foot interval, with respect to elevation, for all samples was calculated and applied to the volumes of ten-foot layers of the entire site. For example, the concentration of potential proppant is greater than 50 percent in the layers from sea level to 50 feet elevation, and is less than 50 percent in every other layer.
- The percent recovery for the ten-foot layers were summed to determine the total proppant available at the site.

In-depth geologic study

I was retained by a client to evaluate the existing report, to opine on the report's description of the quality and quantity

* This range was considered to be acceptable size material for proppant. For reference: The #40 sieve has a nominal opening of 0.420 mm, and the #140 sieve has a nominal opening of 0.105 mm. Sand is generally considered to be 2.0 mm to 0.0625 mm.

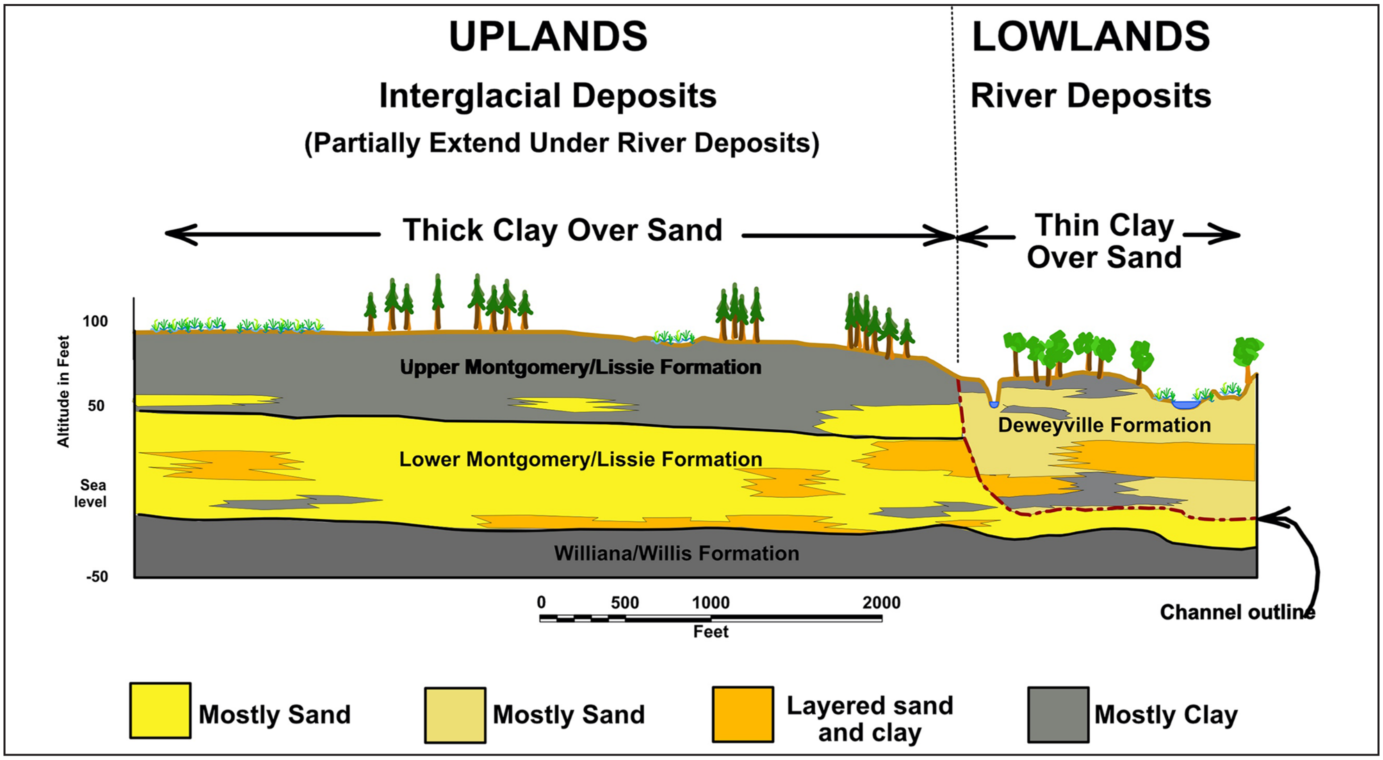

Figure 3b. Generalized cross section showing potential proppant at site in 10-foot intervals relative to elevation when considering geology

of sand, and if necessary, to prepare a new evaluation of the potential availability of the proppant at the site.

There were two main issues with the existing report: 1) The method to determine the "percent recovery" was derived from a study of proppant-sand-sized material underlying only the Montgomery/Lissie Formation portion of the site, and was then applied to the entire site including the Deweyville Formation. 2) The method made no distinction of whether or not the sand was mineable. Much of the sand was widely disseminated through layers of clay. A review of MSHA data showed that no sand of any type was being mined from the Montgomery/Lissie Formation; all the sand being mined in the area was from operations in the Deweyville Formation.

To better understand the geology at the site, a desktop study of the regional and local geologic system was developed based on small scale geologic maps. The desktop study was followed by a drilling and sampling program, core logging, laboratory analyses, and data evaluation. Based on the information from the literature, a conceptual geologic model was created (fig 3b).

- The property is underlain with a stack of two major geologic formations; the Williana/Willis and the Montgomery/Lissie.
- The Williana/Willis is buried everywhere on the property. The upper part of the Williana/Willis is consistently described in the literature as silty clay, which has no prospect for use as proppant. Therefore, for this study, the buried contact of the Williana/Willis with the Montgomery/Lissie Formation is considered to be the level below which no mining of sand would take place.
- The Montgomery/Lissie consists of a fining upward sequence of sediments; granular, fine to coarse sand with few pebbles in the lower portion; and very fine sand, silt, and clay in the upper portion.
- In the lowland valley traversing the property, the Deweyville Formation lies on top of the Montgomery/Lissie and Williana/Willis Formations. The Deweyville Formation is primarily sand and was identified as a likely source of proppant.

Thirty sonic drill holes were used to collect continuous samples on the property; 8 in the Montgomery/Lissie Formation and 12 in the Deweyville Formation. Drill holes commonly penetrated completely through the Montgomery/Lissie Formation and (or) the Deweyville Formation and extended at least ten feet into the Williana/Willis Formation. The samples supported all the assumptions in the conceptual geologic model.

It was determined that the lower, sandy part of the Montgomery/Lissie Formation cannot be mined economically due to the thick clayey overburden, and that the upper part of the formation (overburden) contained insufficient quantities of sand to make mining economic. This was supported by the regional study that showed the Deweyville was host to all sand operations in the area.

The price was renegotiated.

The lesson here is to consider the geology of the site in context with the regional geology.

SUMMARY

This paper describes three studies of specialty sand or gravel deposits; studies that essentially contained no meaningful discussion of geology. Instead, the studies relied completely on robust drilling and sampling programs as their primary source of data. As a result, the three studies fell short of their objectives of preparing reliable resource estimates.

The first study described an abundant, widespread deposit of concrete sand that the owner was considering developing. Because there was no geologic information in the study, a new regional geologic study was conducted to provide background data that the existing report neglected. The new geologic study identified saprolitized granitic bedrock in the nearby Piedmont that was on strike with the purported sand deposit. It was hypothesized that saprolite, not sand, underlaid most of the property. A drilling program on the property in question confirmed that was the case. It was determined that there was insufficient concrete sand on the property to economically be mined, processed, and marketed.

The second study described an abundant, widespread deposit of metallurgical gravel that the landowner, along with a potential partner, were proposing to mine. There was no geologic information in the existing report and the client did not want a regional geological study. New drilling and track hoe excavations quickly proved that the gravel was covered with too much overburden to profitably mine, and that the gravel clasts were too weak to meet specifications for metallurgical purposes. A visit to an abandoned gravel pit accompanied by a short verbal tutorial on the regional geology, conjured up while sitting on the drill rigs, convinced the potential partner to abandon the project. The landowner tried to mine the gravel but was not successful.

The third study described an abundant, widespread deposit of proppant (frac sand) underlying a property that was being offered for sale at a price that included an assumed value of a large deposit of proppant. The report contained no helpful geological information and ignored the complex geologic processes that formed the various types of geologic deposits. A step-wise approach to study the geology, first of the region, and then of the property, confirmed the presence of two radically different geologic formations on the property, with potential proppant limited to only one of the formations. The amount of proppant that could be mined, processed, and sold at a profit was drastically reduced. The negotiated price was reduced accordingly.

Geology can play a critical role in the evaluation of mineral resources. Failure to consider geology can lead to an over-optimistic estimate of resources.

What hides in a stone?

*** pebble says,
I am hiding all the world's memory.

(from Alyson Hallett, *Conversation with a Pebble*, in
Suddenly Everything)

Geology can reveal all the pebble's memories.

24-046

Geopolymerization of Mining Tailings as an Alternative for Its Use in the Construction Industry

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ABSTRACT

The use of mining tailings-based geopolymer binder as a substitute for cement can be an interesting alternative to the problem of final disposing of large volumes of them. Indeed, mining tailings have a high silica content, which makes them suitable for geopolymerization. The tailings samples contain Cu, Pb, Zn, As, Sb, Cd and Bi, mainly. X-ray diffraction results show that the tailings are composed of quartz, SiO_2 (81%). Geopolymerized tailing samples (GTPS) were obtained by varying the ratio of SiO_2/Al_2O_3 and SiO_2/NaOH. The compressive strength of the GTPS varied between 2 MPa and 8 MPa. The electrical conductivity in the leaching tests varies between 13.91–16.11 mS/cm^2 indicating that ions are present in the solution. However, the pH = 10.5 indicates that acidity is not being generated. The element that mostly leaches is iron. The highest percentage of leaching is observed for cadmium (69%) and chromium (93%). The concentrations of elements are under the maximum permissible limits for water according to the Peruvian legislation. However, mass transfer leach tests and immersion leach tests must be realized.

INTRODUCTION

Mining is an important industry in the economy of many countries. For mining operations to develop, the movement of large volumes of material is necessary. In this sense, this industry generates a variety of solid and semi-solid waste, with tailings being one of the largest volume products generated [1]. In fact, the mining industry generates a huge amount of mine tailings from the excavation of minerals in the form of waste rock from mineral processing [2]. In this sense, it is necessary to implement an adequate management system for the waste generated [3,4].

In recent years, the mining industry around the world has focused its efforts on minimizing this waste, either by reusing it in its operations with the cut-and-fill method [5,6] or looking for alternative uses in society [7]. Another problem with tailings is related to the handling of large volumes that must be disposed of safely [8–10]. One way to reduce or minimize the volume of this waste is to use it as raw material for the production of inputs for other industries [11], such as construction [10, 12–16]. The literature has shown that it is possible to use copper tailings [2,17,18], gold [18–22] and iron [23–30] mixed with geopolymers [18,23,25] as partial Cement substitute for concrete or making construction bricks. In this sense, the use of geopolymerized mine tailings is a new trend of great relevance in the mining industry and especially useful for the reuse of tailings [31–33, 34]. In this article, the preliminary results of obtaining geopolymerized cement from mine tailings are presented.