Comparison of Chemical Grout Properties

Which grout can be used where and why?

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ABSTRACT

Chemical grout use began seriously some thirty years ago with the use of only a few types; silicates, acrylamide, epoxy, and some fatty acid derivates. Since then, the kinds of grout have proliferated with some of the originals still there, others dropping out entirely, and still others changing in type.

This paper is about the current uses of chemical grouts, the economics of product use, and a discussion of where specific products within a category can be used. Comparisons will be related to the ability of the grout to penetrate soils or to adhere to concrete, the cure time range of each type and actual practice in the field. Common problems solved with each type of grout and why each works or doesn't is discussed, as well as the effects of organic impurities and the acidity or alkalinity of the soil or rock. It should provide a useful overview for the engineer and practitioner.

The following grouts will be covered:

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ACRYLAMIDE GROUT

Description

Acrylamide is an odorless, colorless water soluble solid chemical used in making polymers and also used as a chemical grout. The polymer form is used to treat drinking water, and it is also used in the manufacturing of paints, plastic, and water absorption products such as diapers.

Acrylamide (the chemical formula is C_3H_5NO) is a monomer that is used as an aqueous solution in geo-technical grouting applications. Catalysts, activator and inhibitors are mixed together to obtain a grout polymer solution. When acrylamide monomer begins to polymerize or gel, it solidifies into a flexible gel that is impervious to water. The process through which acrylamide gains its strength is called free radical polymerization (chain growth of C=C units) that occurs rapidly and exothermically. Polymers are subunits (monomers) joined together like beads in a necklace. What holds a polymer together even though they are soft is chain entanglement; it is essentially impossible to unravel entangled chains. Uniquely, acrylamide is a low molecular weight nylon and it is inert to low concentrations of acids and bases usually found in groundwater.

When acrylamide monomer is properly mixed with activators and catalysts, it begins to cure, or "gel" as it is called, in a predictable and manageable manner; acrylamide has a controllable reaction time from 10 seconds to several hours. The gel time and set time are within 10% of each other. The gel time is controlled through the addition of catalysts in order to decrease the gel time, or it can be slowed with the addition of gel time inhibitors. Once the gel time is reached, this low viscosity grout solution forms an impermeable matrix of gel and soil that prevents the movement of water. Microscopic examination of the structure of acrylamide shows that the water is entrapped in a Bucky-ball like configuration, and is stable at 5-6% concentrations.

Typically, a minimum of 10%w acrylamide solution is needed to assure a good gel. Higher concentrations can be used to increase strength or to offset dilution which might occur during injection. The solution also has the ability to react in moving water during injection by using short gel times. The shooting concentration has a viscosity of one to two cps, not far off water. That viscosity can be increased with additives; whatever it is, it will remain constant during the injection period. The approximate cost of the material is in the range of $5.00 to $6.00 per gallon of grout mix. It is considered to be more expensive than suspended solids grouts like sodium silicate and cement grouts and less expensive that other acrylic or polyurethane grouts.

Applications

Acrylamide grouts are used in a variety of industrial, commercial, and municipal applications. As a monomer, it is used as a soil stabilizer to stop leaks in sewers of all types, and to impede water in tunnels, dams, mines, shafts, pits, and other underground structures. These uses as a chemical grout date back to the 1950s.

The geo-technical applications are diverse, and acrylamide grouts have been proven to be the preferred solution in a variety of documented applications. For example, acrylamide based grouts solved leakage problems in a tailings dam for a large copper/gold mine in

Argentina. The case study explains why acrylamide is needed to achieve lower levels of impermeability than that obtained with cement based grouts alone. Other such geo-technical applications of acrylamide based grouts include: constructing a grout curtain at the Rocky Reach Dam on the Columbia River; improving oil production in a water flood cave in Oklahoma; sealing sandstone to permit shaft sinking in a coal mine in Scotland; shutting off seepage at a missile silo site in Nebraska; hazardous waste containment at a United States Government site in Oak Ridge, Tennessee; sealing leaks in salt domes in Louisiana and other states; and numerous other applications. Its versatility is great.

The extremely low viscosity of acrylamide along with the chemical characteristics inherent in the free radical polymerization of acrylamide monomers makes this grout the preferred solution for creating impervious water barriers and stabilizing soils in a wide-variety of geo-technical situations.

Acrylamide grouts, because of their low viscosity, are often the only grouts that can penetrate leaky areas which remain open even after extensive alternative grouting techniques. A key advantage is that acrylamide grouting methods provide for soil stabilization in addition to creating an impermeable water barrier. Acrylamide has a very wide range of gel times and is predictable, stable, and non-toxic and non-reversible in cured form.

Limitations

Acknowledging these unique advantages there are, however, certain limitations to their application. Because of the chemical make-up, proper safety precautions must be followed particularly during the mixing phase of the solution. The material is not desirable or suitable for potable water applications. The grout is subject to shrinkage and pre-mature polymerization if exposed to constant UV rays. The material will degrade over time if exposed to continual freeze-thaw and wet-dry cycles. The grout has demonstrated good chemical resistance except to more harsh acids or chemicals. Acrylamide does not adhere to concrete surfaces and will not stretch in a moving crack, so it is not recommended for above grade applications and crack sealing. Acrylamide reacts more slowly in the presence of petroleum products such as oil or gasoline, and there are a number of other less significant factors to consider in predicting gel times. The presence of some minerals in the mix water may have an affect on the gel time, but acrylamide grout can be mixed in brine which is helpful for grouting a salt mine.

Additives are available which can allow acrylamide to tolerate and perform under specified degrees of these conditions, however, certain circumstances will warrant a distinctive alternative than acrylamide grouts. Despite these limitations, a geo-technical engineer utilizing the principle of selecting the most suitable materials for any specific location will make acrylamide grouts with their versatility a popular solution for geo-technical applications.

N-METHYLOLACRYLAMIDE GROUT

Description

The main use of this grout, which is in the acrylate class, is in places where acrylamide cannot be used because of the toxicity of several of its components in such applications as repair of lines where the drinking water will be affected and therefore the health of the community may be affected. It is not as stable as acrylamide under constant head pressure of the groundwater and is especially bad where acidic conditions and organic contaminants are present.

N-Methylolacrylamide (NMA) is an extremely low viscosity aqueous solution of acrylic resins, often abbreviated as acrylates. With the addition of catalysts, it produces an impermeable and cohesive gel grout to stop leaks. Cure time may be closely controlled from a few seconds to several hours even in flowing water. NMA is inert and essentially non-toxic when it has been properly catalyzed. NMA is easy to work with but requires safety precautions when handling or mixing.

NMA has almost the same viscosity as water (1 to 2 cps) and it can be pumped anywhere water will flow at the same flow rate/pressure relationship required for water. Therefore, it works well in fine sands and soils as well as tight silty soils; it works in deep cracks without going to extremely high pressure.

Gel time for any given catalyst ratio will increase as the temperature of the grout solution decreases, and will decrease as the temperature of the solution increases. As a rough rule of thumb, gel time is reduced by half if the temperature of the grout solution rises 10 degrees Fahrenheit. Ultraviolet rays from sunlight also initiate gelation. For this reason, the solution must be kept out of direct sunlight. Shelf life of NMA is six months minimum, when stored at temperatures from 41 to 86 degrees Fahrenheit.

Portable pump systems can be purchased from about $8,000 up to $20,000. A television inspection and grouting combination truck for municipal and geo-technical applications can be purchased from $150,000 to $190,000. The average price per mixed gallon ranges from $5 to $8 a gallon.

Applications

NMA is widely accepted in industrial, commercial and municipal applications. Because the behavior of the materials can be controlled under leak flow conditions, NMA is ideal for controlling water seepage in soil, sand, rocks and cracks and joints in sub grade structures. General uses are for tunnels, dams, soil stabilization and sewer joint grouting. Many municipalities also utilize NMA for reducing infiltration in their sewer collection systems. Numerous cities that have grouted successfully for over twenty-five years are Tampa, FL, Lancaster, PA, Salem, OR, St. Louis, MO, and Orlando, FL to name only a few. It has been used for years in the Toronto subway system to stop leaks into the subway tunnels.

Limitations

NMA should not be used for potable water, above grade structures or when there is a danger of contamination of ground water. Its catalyst system does not allow the flexibility of cure time that the acrylamide system has. NMA does not adhere to concrete surfaces and will not stretch in a moving crack, so it is not recommended for above grade applications and crack sealing. As with acrylamide, the gel time of NMA is affected by a number of factors, but the most significant are temperature and catalyst concentration. Mix water should be chosen carefully as some minerals affect the gel times.

ACRYLATE GROUTS

Over the past twenty five years several acrylate grouts have been introduced into the sewer sealing and geotechnical markets. These materials have not gained widespread acceptance because they have been weak gels that will swell considerably in the presence of water. Although classified by their suppliers as "non-toxic" due to an LD_{50} equal to or greater than 5000 mg/kg of body weight, outright failures of these products have been documented leading to a general avoidance in the grouting community.

POLYURETHANE CHEMICAL GROUTS

Description

Polyurethane chemical resins used for grouting started with only two water activated materials which were and still are used for a wide variety of applications ranging from sealing active water leaks to stabilizing soils. The technologies were invented by the Japanese in the late 50's and purchased by 3M Company who came out with 3M 5600 and 5610 which were the first systems available to the commercial market. These early systems were the basis for what has now evolved into a wide variety of resins, which are available from numerous manufacturers. These first two resins represented both of the systems that are currently available (they are called hydrophobic and hydrophilic) resins while the number of resins with differing properties has grown tremendously. It wasn't until the late 80's, before 2-component, non-water reacted systems became available. Those products are chemically reacted urethanes and do not use water at all. They do not adhere to concrete or stretch in a moving crack, and they are not useful as soil stabilizers. They can be used as joint fillers which are basically dry at the time of application. All of these systems have been proven through long-term durability testing to have a half-life of 175 years when not exposed to UV rays.

HYDROPHILIC GROUT SYSTEMS

Description

Hydrophilic expansive grouts react upon contact with water, absorb water while curing, and cure to a flexible foam or gel. They are generally used to seal leaks in joints or cracks and to repair leaking water-stops. Hydrophilic expansive foam grouts chase and absorb the water in the crack and in all of the fractures that branch off from the main crack. A key characteristic of any liquid is its viscosity (cps) compared to water. Water has a cps of 1, where hydrophilic expansive grouts could range from 300-2500 cps. The lower the cps (the lower the viscosity) of any hydrophilic expansive grout the better suited for tighter cracks (for better penetration) and for applications that might require greater travel. The higher the cps (the higher the viscosity) of any hydrophilic expansive grout the better suited for high flow/high volume applications so as not to become diluted. Hydrophilic gel grouts work by stabilizing the soil outside the structure, like acrylamide. The grout prepolymer is usually mixed with water at ratios of 6:1, 8:1, and up to 12:1 (water to polymer ratio) to obtain a gel ranging from firm to weak.

Applications

Hydrophilic expansive foam grouts have an initial cure and final cure. The initial cure is the time it takes for the polyurethane grout to foam up, and the final cure is the time it takes for the grout to fully expand. This final cure time, which may take up to 12 hours, is critical to the success of the grouting process. Hydrophilic foams have been successfully used in above- as well as below-grade applications, but hydrophilic gels should be used below grade as they will shrink in a dry environment.

Hydrophilic expansive gel grouts can be mixed with large amounts of water to offer an alternative grouting material in areas such as curtain grouting, manhole grouting, and soil stabilization. Most polyurethane grouts are considered to be "non toxic" although safe handling procedures should be closely followed with these and all other chemicals.

Hydrophilic expansive foam grouts are typically single component products requiring small delivery systems for the injection process. These types of grouts are used in below grade structures, basements, and other areas that are often wet, such as subways and interior portions of a concrete dam. If injecting a hydrophilic gel grout for soil stabilization, manhole grouting, or curtain grouting a multi-ratio delivery system would be needed. Pumping systems for hydrophilic foam grouts tend to be high pressure and low volume, while the gels utilize high volume and lower pressure systems.

Some hydrophilic foam grouts are certified to be used with potable drinking water systems. These hydrophilic grouts have been certified by UL or by NSF if used in accord with the American National Standards Institute (ANSI) 61 testing standards.

Typical costs for a hydrophilic grout range from $45 to $65 per gallon. The expansion rate of hydrophilic foam grouts can be up to 5 to 7 times its original volume, and hydrophilic gels typically do not gain volume upon curing.

Limitations

Hydrophilic expansive foam grouts will stick to concrete and are not usually used in soil stabilization. They will stretch in a moving crack and are generally used in crack sealing or filling voids in joints or void areas in sewers and other underground structures. Hydrophilic gel grouts will not stick to concrete and are not recommended for moving cracks. They are used for soil stabilization, sealing sewer joints and manholes, and other underground applications. Due to their relatively short gel times and high viscosities compared to the acrylics, they are usually not used in sealing lateral sewers with remote lateral packers.

HYDROPHOBIC GROUT SYSTEMS

Description

Hydrophobic resins are water activated systems that require roughly 4% water to start the chemical reaction. They have expansive qualities, ranging from 6x up to 20x expansion and are generally referred to as "foams", sometimes as rigid foams. Due to the low water content they are considered non-shrink, as the foam matrix has so little water that even in extremely arid conditions they will maintain their cured form. One of the other characteristics is that they are controllable. Unlike hydrophilic, they have an additive that is referred to as an accelerator as it allows the applicator to control their cure time from 1 to up to 10 min. The accelerator is not to be confused as a catalyst as it does not start the reaction, but allows it to be controlled. Before the reaction can begin, the accelerated resin must still come into contact with water to start the reaction. While most of the hydrophobic and hydrophilic systems carry NSF or UL potable water approval, most manufacturers have only a few select resins that carry this approval, due to the costs incurred in getting approval.

Two-component systems can have high expansive properties with many of them capable of curing to a foam density of 6 lb/cu ft. Unlike the hydrophobic or hydrophilic systems, they do not require water as a catalyst as the reaction is started when Part A comes into contact with Part B in a static mixing tube. They are generally much faster reacting systems and can reach up to 25 times expansion in as little as 7 to 10 seconds. With the high expansion rates and extremely fast reaction times, they can have the potential to move structures and require extreme care when using.

Applications

Typical applications include sealing cracks/joints, creating a water impenetrable barrier between the backside of a structure and the soil matrix from the negative side, and stabilizing soils. Hydrophobic foams can also be used to fill voids or abandoned underground pipes, vaults, tanks, etc. A major advantage to sealing active leaking cracks/joints is that material is water activated as opposed to most materials that require the water intrusion to be eliminated before the repairs can be done. The cured resin is designed to accept movement, allowing the materials to be successful in applications subject to movement due to seismic activity, contraction/expansion or movement designed into the structure where a rigid material like epoxy is prone to failure.

Many below-grade structures start out with a membrane installed on the positive side as waterproofing. While these systems have proven to be effective, they, like many others, have a lifespan anywhere from 15 to 30 years. Once the systems lifespan is exceeded the owners are faced with the costly replacement that includes excavating to expose the failed system, removing and replacing. With the polyurethane systems a series of holes are drilled through the structure from the negative side and the resin is injected to create a monolithic barrier between the backside of the substrate and the soil. This application provides a long-term repair at a considerable savings.

Soil stabilization applications require an engineer to design the application. The materials are injected into the soil and can substantially increase the soil's compressive strength. They are used to stop settlement of structures and consolidate soils for mining/tunneling applications.

Limitations

As with all materials, Polyurethanes also have limitations. Hydrophobic polymers usually have better chemical resistance. To insure proper cross-linking during the reaction, water should be tested to insure a pH level of 10 or less. A pH close to neutral (7) produces the most ideally cured polymers. A pH below 7 slows down the reactivity and too far below 7.0 will "kill" the reaction. Higher pH will increase reactivity up to a pH 8-9, but after that will begin to degrade the quality (the water holding ability) of the cured polymer as the pH increases. Recall that pH 7 is neutral and as the pH falls exponentially toward 1, it becomes a stronger acid. As the pH climbs above 7, the same is true for increasing alkalinity up to the maximum of 14. While a water temperature of 50^{o}F degrees or higher is preferred, the materials have been successfully used with water temperatures near freezing. Below 50^{o}F the material will steadily decrease its cure rate as well as its physical characteristics, and once the water begins to crystallize, the resin cannot absorb it and the reaction will not occur.

Hydrostatic pressure has similar effects on the resins. Starting at one atmosphere, the material reaction time as well as the expansion and swelling begins to lessen, and after 10 atmospheres they will still react, but at an extremely slower rate and without any expansion or swelling. The water/diisocyanate reaction creates carbon dioxide and hydrostatic pressure controls the amount of CO^2 that can dissolve into the water column. High pressure and colder water temperature will produce the least amount of foaming in the cured polymer while lower pressure and warmer water increase the foam yield. Grouts that reacted on a "desktop" at room temperature without any containment form the maximum amount of CO^2 hence the larger amount of cured foam. High concentrations of hydrocarbons will not allow proper cross-linking of the molecules and the material will not react. Hydrophobic foams tend to be rigid and some will not stretch, meaning they are not the best product for a moving crack. All urethanes are adversely affected by UV rays and high temperatures, say in excess of 200 degrees F.

ULTRAFINE CEMENTITIOUS GROUT

Description

Ultrafine cementitious grout, also called microfine grout, has been produced for almost 30 years and has been refined over that time span to stabilize weak soils, repair dams, tunnels, and bridge supports. The first use of ultrafine cementitious grout came as engineers sought to add strength to concrete used for construction of new high rise buildings and bridges, where weight was a costly penalty. Ultrafine grout can be formulated to permeate most any granular soil including fine sands. Ultrafine cementitious grouts are composed of a finely ground mixture of Portland cement, pumice, and dispersant.

A key characteristic of ultrafine grout is the particle size (typically in microns). Research and experience have shown this particle size is critical in determining the permeability of the ultrafine grout into the soil. There are two forms: a Standard grade whose sieve analysis is 90% less than 8 microns and an average analysis of 4 microns, and there is a Premium grade with a sieve analysis of 90% less than 5 microns and having an average size of 2.5 microns. Both products are subject to excellent gel time and set time control from a few minutes to several days allowing great flexibility in use. The product has an unlimited shelf life as long as it is kept dry just as Portland cement has.

The unit of measure for this product is 20 kg (44 lb.) bags; there are typically 54 bags per pallet, with an average cost of $0.65 cents per pound. At a mix concentration of 1:1 by weight, the cost for a completed grouting job would be around $400.00 to $600.00/ cu yd.

Applications
Two major applications came early: they include a project using grouting to encase the contents of radiation burial trenches at the Oak Ridge National Laboratory (ORNL) in TN, and a salt grouting requirement to reduce leaks at the crude oil storage caverns of the Strategic Petroleum Reserve at Weeks Island, LA.

In an application in salt formation grouting at Weeks Island, LA, adding a product (called wetter water) used by fire departments to increase the rate at which water can be delivered, increased the flow rate about 30% greater than using the ultrafine cement alone. This moves this new microfine cement into a category which was only served by the higher cost acrylamide; that is, microfine alone may do the whole job of soil stabilization and result in a stronger and/or more permanent construction.

Standard drilling equipment of the rotary type should be used to perform the drilling as specified. Water or air should be used for removing cuttings from the hole during drilling phase. The grouting equipment shall be capable of supplying, mixing, stirring and pumping the grout as specified. A progressive cavity pump or other positive displacement pump capable of generating pressures up to 100 psi and with a pumping capacity of up to 30 gallons per minute is usually required. In general, each application is unique and the grout mixture's gel and cure times are adjusted based on specific requirements.

Limitations
Utilizing the correct equipment and having an experienced applicator are key issues when applying this product.

EPOXY GROUTS

Description
Epoxies consist of two components that react with each other forming a hard, inert material. Their bond with most substances is great enough to overcome their very different hardness and modulus. Part A consists of an epoxy resin and Part B is the curing agent, sometimes called the hardener.

The curing agent selection plays the major role in determining many of the properties of the final cured epoxy. These properties include pot life, cure or drying time, penetration and wet-ability. Curing agents come in many different chemical flavors, all based on amines or amides.

The well known adhesive strength of epoxies is due to strong polar bonds it forms with the surfaces it comes in contact with. On dry surfaces the bond between the surface and the epoxy displaces the air, which is fluid. The same can be true on wet surfaces and even completely underwater. As with all adhesive applications, the cleanliness of the surfaces or cracks to is often the paramount limitation. Underwater applications are becoming more common with the advancement of these types of products. Epoxies are almost totally UV resistant.

Application

One of the main uses in the geotechnical field is to repair concrete, so soil or other penetrating and waterproofing grout will not flow back to the surface. In the mining industry, these types of resins are used to cement in casings where the pressures may be as high as 1,000 psi. These two-component epoxy resins have better expansive properties than some hydrophobic type products. One unique characteristic is that these types of products do not require water for the reaction to begin; this reaction takes place when Part A comes into contact with Part B in the delivery system.

Costs are in the $100.00-$150.00 per gallon range, basically non-toxic (0% VOC's).

Limitations

Only mix the amount of epoxy that you can use in ½ the pot life. Materials will start to thicken at this point and are more difficult to work with. Keep in mind that large batches will set up faster than smaller batches. Start by mixing small batches and then increase your batch size slowly, to insure that you do not loose your mix. It is very important to mix all epoxy thoroughly as is called for in each product's data sheet. When mixing epoxy resins, always mix Part B into Part A, scraping all of the resin out of both containers. Injection epoxies can be mixed with a two component in-line mixer. Do not stir epoxy by hand only; instead use a low speed drill mixer of proper size. Typically warmer epoxies set much faster than cooler epoxies.

Generally epoxy resins will have either good chemical resistance or good heat resistance, but not both. Another characteristic of this type of product in its cured state is the lack of flexibility, and the system might be prone to failure if movement occurs due to seismic activity, and or expansion/contraction.

ARCHEOLOGICAL GROUT

Description

Archeologists began a new application using hydrophilic resins and silk screens to capture and lift three dimensional images from construction dig sites. This application, know as "peeling," was developed back in the 1950's, largely by an Indian scientist named Bouma who worked on deep sea sand deposits. The Japanese started using the peeling technique on cores that included deposits from tsunamis around 5-10 years ago. In 2001 this technique was used to gather data after a violent tsunami in Peru. In 2005 these hydrophilic grouts were used after the Tsunamis that struck Sumatra, Indonesia, and as recent as the Katrina aftermath. This technique will help establish a record of the sometimes horrific event so it can be studied and analyzed in the hope of advancing early warning systems.

Applications

In many areas after a tsunami, sand is carried from one place to another along the ocean front and left it in a layer across the beach as the water goes down. Often a foot or more of sand covered the areas hit by the tsunami. Geologists are extremely interested in this sand because it is the most durable evidence left by a tsunami. As the water recedes, the shoreline is again bared and the coastal sands can be studied. Like forensic scientists at a crime scene, geologists collect samples of this sand to understand both recent and prehistoric tsunamis.

When a Tsunami inundates hundreds of kilometers of coastline, geologists must travel fast to get samples before reconstruction destroys the information they provide. One of the fastest sample collection techniques utilizes hydrophilic grouts to produce what the originators called the technique, a "sediment peel."

This is done by pressing a silk screen against and into the wall of a dig site and brushing on a heavy coating of resin. As the screen is saturated the resin soaks into the soil and once water is sprayed onto the resin saturated screen the resin locks the soil in place on the screen. The geologist now has a permanent record or "map" of the soil strata that can be rolled up, stored as one would store a core, and studied at a later time. The sediment peel is not only a good way to preserve sediments for transport, but it also provides additional structural information that would be lost if the sample were to fall apart.

Specifically, at the ACEH Banda site on the Indian Ocean side of the ravaged peninsula, a sand cliff with bright multicolored layers was bared, an exposed beach some 6-8 feet high. About 20 feet of the sand cliff was protected with a sediment peel. The surface was covered and injected with archeological grout, to be taken down some days later when it could be studied at leisure. It was found that a bright layer of silt and clay several feet high was carbon dated at 300 million years *earlier* than the surrounding sands which were laid down recently.[c]

Other applications for the geotechnical engineer

One of the new requirements of the geotechnical community is that you must watch out whenever you are required excavate when you encounter buried historic and prehistoric items. This is occurring across the world. This new Archeological Grout can be injected in a place where a core is required. This will solidify the soil and allow it to be cored with a thin walled bit and the sample can be sectioned and looked at later. This can save extended excavation work

Limitations

Care must be given on how this evidence is stored. It is moisture sensitive and will shrink if kept above the ground for very long. Additionally, the grout is sensitive to UV light degradation both when it is mixed and after it is cured. A mailing tube taped shut or a container used to store cores is also excellent.

This article was written with the assistance of Dennis Oetting, Frank Aguilar, John Wager, and Margie Meredith, who are all employees of Avanti International.

[c] Private communication from geologist Brentwood Higman