Application of Physical-Chemical Properties of Bentonite Utilized In Construction, as viewed Through the TRIZ Prism.

Abram Teplitskiy, PhD, Scientific Consultant, Dallas, Texas, USA
Richard Gee, P.E., President, GEE Consultants, Dallas, Texas, USA
Roustem Kourmaev, President, KRUS Company, UFA, Russian Federation
tepl@sbcglobal.net

The most important step in TRIZ (Theory of Inventing Problem-Solving) is the utilization of different physical, chemical, geometrical, biological, etc. principles for solving specific problems in different fields of practice. For example, consider the use of the **Reuleaux Triangle** for drilling square holes in different materials, application of **caterpillar principle** to make pauses for penetrating cone testing in soil while the machine is moving, utilization of changes of magnetic properties of a magnet while heating through the **Curie point** to build type of **perpetual motion**, and so on. Such principles are 'working" tools in **Theory of Inventing Problem-Solving (1,2).** Over past 35 years**,** using these basic principles and TRIZ, we have developed a family of inventions that build upon the unique physical and chemical properties of **Bentonite**.

Short Historical Background of the Use of Bentonite: Early Americans found bentonite vital to their lives. Pioneers found moistened bentonite to be an ideal lubricant for squeaky wagon wheels. The mixture was also used as a **sealant for log cabin roofing**. The Indians also found that **bentonite could serve as a soap**. Small amounts of Wyoming bentonite were first commercially mined and developed in the Rock River area during the 1880s. Newer, more substantial deposits were discovered in other parts of Wyoming during the 1920's and the first processing plant in Wyoming was built during this period. Since that time many other processing plants have been built for the purpose of processing Wyoming sodium bentonite. Over time, the uses of bentonite spread into more current applications including papermaking technology, wastewater purification, and even into different aspects of nano-technology because of nano-sizes of bentonite particles. In this article we will discuss applications utilizing bentonite's unique properties in construction

Physical Properties of Bentonite: Two basic bentonite properties - **thixotropy** and extremely high capabilities for **water-absorption** are a large part of the basis for successful bentonite application in construction**.** Thixotropy is well known property of bentonite-water slurries: behaving like a liquid when stirred or shaken, and setting back to gel when allowed standing.

The utilization of the **Thixotropic** properties of bentonite is demonstrated in a trench filled with bentonite slurry, as shown in **Fig.1.** Bentonite slurry is often used to solve problems in the construction of borings or excavating trenches in water-saturated soils. Water-saturated soils have a greater tendency to collapse due to their moistened and resulting weakened state. If the trenches or borings are filled with bentonite slurry (in its liquid state), the slurry then converts to its gel state, thus supporting the walls of the trench or boring. To install casing in the boring or prefabricated concrete structures such a pipe in a slurry filled trench, the slurry need only be stirred to revert to its liquid state. A continuous under ground wall constructed using this technology is often called a **cut-off-wall.**

Large Scale Applications of Bentonite: Bentonite is also used to solve larger problems as well. To increase the capabilities for generating electricity at an existing plant, it was necessary to construct a hydro accumulation power station in the Kiev Region of Ukraine. In order to make to make the power station functional it required the building of an elevated water reservoir. During the night time (when consumption of electricity was minimized) water would be pumped from a lower reservoir to an elevated reservoir (using energy from the energy from the power station). Then, during the day time (when consumption of electricity was at its maximum) water from elevated reservoir would fall under the gravity force to the lower reservoir, rotating turbines, and contributing in generating electricity. **Cut-off-wall** technology was utilized for construction the upper reservoir, and it was actually the most effective method of construction in water-saturated soils encountered in this region.

Density of Bentonite Compared to Water: Due to the density of bentonite slurry being higher that that of water, bentonite slurry protects a trench from water inflow from outside sources. “Water-soil-bentonite” mixtures inside the trench form a “**clay-lock**”. Moreover, the walls of the trench dry out over time, and develop a bentonite clay crust, which improves the stability of the trench.

Fig.1.
General Look of a trench filled with Bentonite Slurry

Reversible Viscosity: Due to thixotropic properties of bentonite slurry, it could keep its slurry state for nearly unlimited amount of time, and as result trenches are able to keep their shape. Another technological advantage of bentonite slurry is reversibility of

its viscosity. Contractors can place any structural element required within bentonite slurry.

Figure 2a is an elevation view of protective wall being constructed using a specialized pier-drilling rig, bentonite slurry and reinforced concrete. **Figure 2b**- is a plan view of the same installation, showing cross-sections of pier holes to be filled with bentonite slurry and forming a solid temporary trench. As intersecting reinforcing steel cages is inserted into the pier holes the bentonite reserves its viscosity, returning to its liquid state. After reinforcing steel is installed and secured, Portland cement concrete is pumped through the bentonite slurry to the bottom of the trench, thus forcing the slurry up to and out of the tops of the piers. Other versions of the same technology have been developed, including installation of polymer films vertically in the excavated trenches filled with bentonite slurry by self-unrolling due to special weights fastened to initial end of the film.

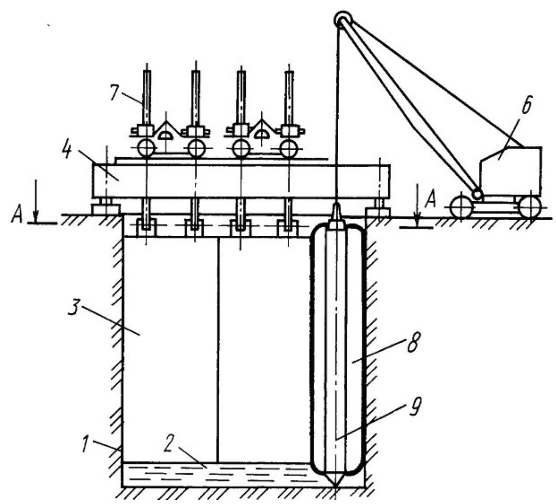

Fig 2a.
Public Domain- RU Patent # 2,123,558
Installation of Prefabricated Concrete Panels
Under Bentonite Slurry

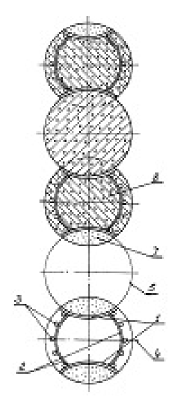

Fig. 2b.
Public Domain – RU Patent # 2,148,123
Installation of cross-cut ground piers under
Bentonite Slurry

Pipeline Installation in Slurry Filled Trenches: Trenches filled with bentonite slurry also could be used for laying pipelines in areas with prevailing water-saturated soils and high water table. One version of such a technology is shown in the **Figure 3.**

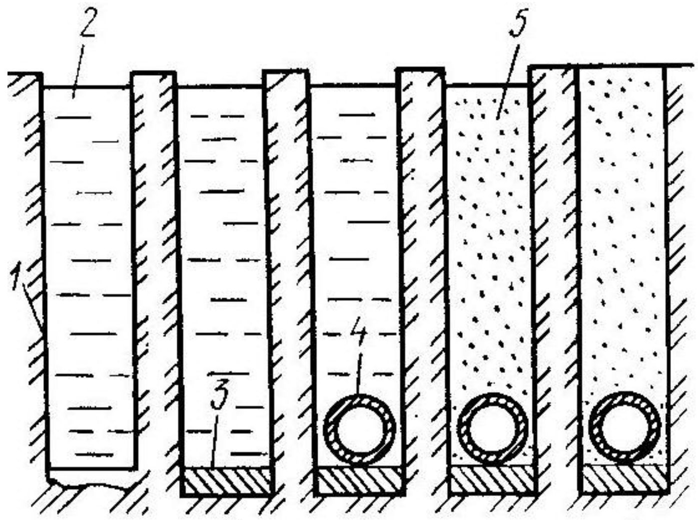

Fig. 3
Technology of laying big diameter pipelines in a trench under bentonite slurry in water-saturated soils
1 – Trench; 2 – bentonite Slurry; 3 – leveling soil layer; 4- pipe, 5 – backfill.

The above illustrated technology was developed in Ukrainian Construction Technology Institute, and included digging a trench with simultaneously filling the trench with bentonite slurry, leveling the bottom of the trench, installing pipes, and backfilling. Because large diameter of pipe was utilized, this allowed pressurizing of the pipe junctions from inside of pipes, after pumping out the slurry **(3)**.

Ideal technology for laying pipelines: Now imagine an **ideal technology** for laying pipelines: you assemble the sections of pipe together at the surface of the trench, and then by magic – the assembled section lowers to the bottom of the trench by itself. Such an "ideal" technology could eliminate presence of workers on the bottom of the trench, where the hazardous potential for collapse exists. To go from an "ideal" technology to "real" requires finding good ideas, utilizing your resources and developing durable technology.

We developed two versions for such an ideal technology by utilizing a so-called conveyer system of laying pipes. The first version was based on our experience of laying pipelines in tunnels. We proposed assembling the pipeline using the conveyer principle: sections of pipe were connected one after another, joints between pipes were tested, and connected sections were than hung from a monorail system, and advanced by monorail into the tunnel. After all the sections of pipe were assembled and advanced, hangers on the monorail were synchronously elided on the bottom of tunnel. So, ideal result was successfully realized.

In the case of the trench, however, we had another problem to solve – the stability of the trench in time, especially if a high level water table existed in the soil. But standard technology was already available for working under these conditions filling the trench with bentonite slurrywith high level of water table in the soil. But it is already a standard technology to work in such conditions – filling the trench with bentonite slurry. The assembled pipeline was dropped to the bottom of the trench filled with slurry, and rested on the bottom on the bottom of the trench. The bentonite slurry was then pumped out of the trench and can be used in other processes.

Another version for laying pipe in a trench again utilizes the conveyer principle, based on assembling and advancing sections of pipe at the surface of the trench filled with bentonite slurry (ends of pipes are plugged) (**4**). In this case, bentonite slurry, having thixotropic properties, will keep assembled pipes in a horizontal plane as a floating solid body, and facilitate advancing the assembled pipe sections horizontally. After assembling all the sections of pipe in a given area, testing joints between pipes completed; the assembled sections of the pipeline are than lowered to the bottom of the trench by simply pumping out the bentonite slurry. Notice, that in this case the thixotropic bentonite slurry has the properties of a liquid, and keeps the pipeline horizontal during pumping operations, in this way preventing any inclination. This technology is illustrated in **Figure 4**.

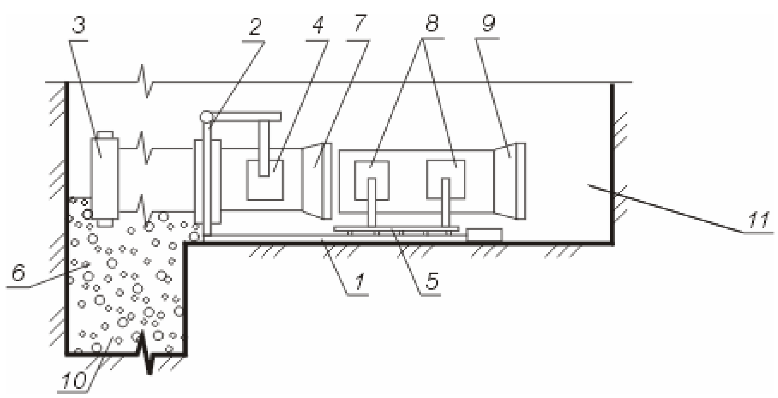

Fig.4.
Public Domain – RU Patent #2,123,630.
1 - platform; 2 - protective shield; 3 - plug; 4 - catch devices of the pipes; 5 - moving part of platform 1; 6 - bentonite slurry; 7, 9 - pipes; 8 - catch devices of the pipe; 10 - pipeline trench; 11 - equipment pit.

The above example utilizes the ability of bentonite slurry to instantly change from a solid state to a liquid, the property called thixotropy.

Another example of practical application of thixotropy is illustrated in **Figure 5.**

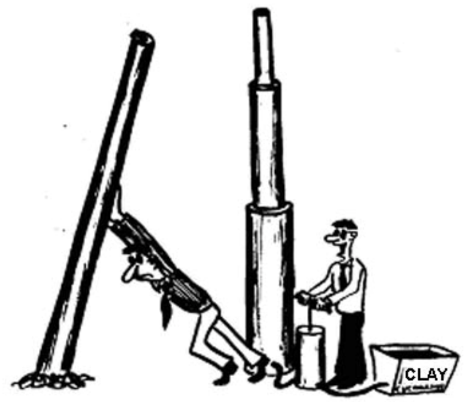

Fig.5.
Hydraulically Operated Telescopic
Lifting Machine Based on Thixotropy Principle.
Courtesy of Anatoliy Nelidin.

Imagine that "liquid state" bentonite slurry is pumped inside a telescopically extendable pipe. Under the action of the slurry, the telescopically connected sections of pipe would "expand" or extend. While being held in this expanded state for a short period of time, and due to its thixotropy, the bentonite slurry inside the pipe would convert to solid state. Such telescopically connected pipes would keep their position for any required amount of time.

We recommend including major bentonite slurry properties – **thixotropy** and **high water absorption** in Effects Part of **TRIZ.**

Directly the ability of bentonite to absorb big amounts of water we initially applied for calibrating nuclear gauges in wide range of moisture content of soil – practically from 0% to 100 volumetric percents. From above examples readers could conclude that bentonite slurry can be **preset** for any volumetric moisture content values. Probes of nuclear moisture gauges could be easily inserted in thixotropic bentonite slurry for calibration **(5)**. Also we patented a version of calibration device, in which we can recalibrate nuclear gauges using any type of casing pipes by inserting them in bentonite slurry with known values of moisture content. General scheme of such calibration device is shown in Fig.6. **(Fig 6.)**. By changing amount of water or/and amount of solid particles in mixture, calibration sample with any value of moisture content of soil could be prepared.

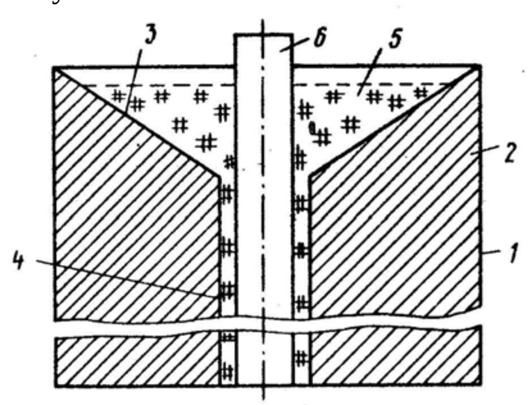

Fig.6.

Public Domain – SU Patent #409,119.
I – case; 2,3,4 – external block from solid material;
5 – bentonite slurry; 6 – backfilling material – mixture of bentonite slurry and soil.

Such equipment could be effective when it is necessary to recalibrate nuclear gauges to measure moisture content of soils up to 100% volumetric moisture content. Also, water-absorbing ability of bentonite is used for monitoring soil moisture in the field. A device for indicating the water content of a medium into which the device is inserted, and which includes a scale which mounts a body of a water-swellable hydrogel. The scale has marked thereon an indication of water content, such that contact of the hydrogel body with water or moisture in the medium causes a peripheral portion of the hydrogel to expand and such that the position of the expanded peripheral portion in conjunction with the scale indicates the water content of the medium. A direct way to use bentonite for measuring the moisture content of soil was proposed in England. It is based on another main feature of bentonite – ability of absorbing any amount of water. The scheme of this device is shown in the **Fig. 7**.

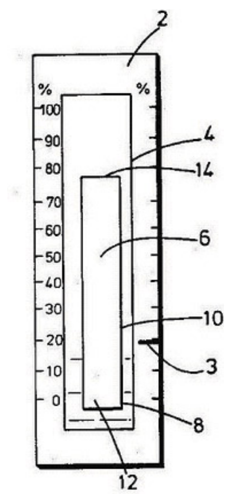

Fig.7.
Public Domain – US Patent #5,694,806
Field Moisture Meter based on water Absorption by bentonite

To indicate the water content of a medium, device needs to be inserted in soil under control. Bentonite moisture meter includes a scale, which mounts a body of bentonite, or other water-swellable hydrogel. The scale is marked in moisture content units, and therefore indicates water content of soil that contacts with hydrogel. Hydrogel expands and such that the position of the expanded peripheral portion in conjunction with the scale indicates the water content of the soil. The water absorption capability of bentonite is illustrated by our experimental data in Fig.8, where results of pressure swell tests of soil samples are plotted. Experiments were carried in Geotechnical Laboratory of **GEE Consultants, Inc.**

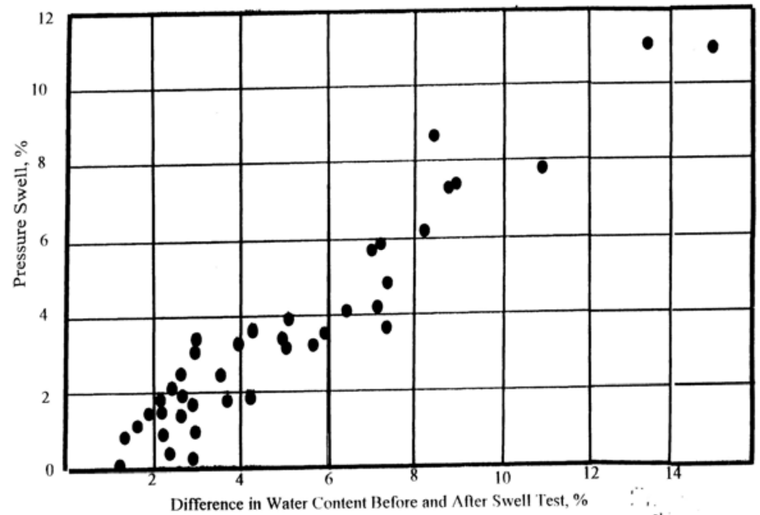

Fig.8.
Illustration of the ability of bentonite to absorb water under pressure

Because of extremely high water absorption capacity, bentonite is a very effective water-protective material, and used in "self-healing" shields, for example for roof structures. An example of such "**self-healing**" shield for flat roofs is shown in **Fig. 9**.

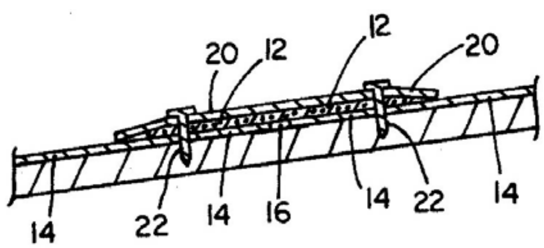

Fig.9.
Public Domain - US Patent # 5,158,803.
Method of patching Flat Roof.

Flat roofs have historically been patched after a rainstorm has abated and the roof dried. The invention illustrated in **Fig.9** gives an alternative for building maintenance personnel wherein they may readily stop a leak in progress during a rainstorm by the application of specially dried or dehydrated, formulated and sized particles of bentonite (sodium montmorillontie). Sealer instantly absorbs several times its weight of water between the plates, and swells at least 10-12 and ideally 15 times its original size forming a gel which blocks the leak. Permanent roof repair can easily be accomplished after the roof dries by sweeping up the bulk of now dried sealer and applying conventional organic roof repair products such as tar, caulking and the like. Residual amounts of sealer does not interfere with the adhesion or spread rate of such products.

Particle size is not the only means to obtain optimum expansion of a sealer. The absorption of as little as 100 parts per million, but preferably 150 to 200 parts per million by weight of hydrophillic wetting agents or surfactants onto the surface of a sealer particle enhances the absorption of water into the particle and thus rate and volume of swelling. Such products are well known and include but are not limited to benzene alkyl sulfonates; linear alkyl sulfonates; fatty alcohol sulfonates; ethylene oxide adducts of fatty alcohols, glycols, glycerol and sorbitol, alkylaryl polyether alcohols and the like. Optimum selection of surfactants is determined by dissolving 1% by weight or less of the surfactant in water. Surface tension of such solutions are preferred because cationic centimeter. Nonionic surfactants are preferred because cationic or anionic surfactants may be ionically attracted to sealer, plating out and interfering with the absorption of water, flow into crevices or cracks and subsequent expansion to block the leak.

Another effective application of bentonite as a sealer is geosynthetic shield in diverse variety of structures like landfills, dams, etc. In Fig. 10 a fragment of such geosynthetic shield is shown. Such clay liner shields are used in constructing low permeability barriers in the bottom of landfills and man-made bodies of water. The liner is provided in the form of a layer of bentonite preferably disposed between a primary carrier sheet and a

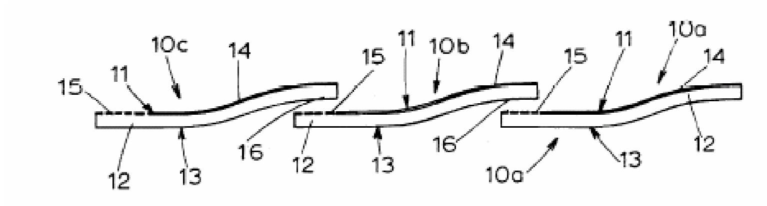

Fig.I0.
Clay Liner.
Public Domain – US Patent # 5529438

cover sheet. At least one outer edge of either the cover sheet or the primary carrier sheet is made from a material that allows substantial bentonite migration through or includes a slit that enables bentonite to migrate through while the remaining areas of the cover sheet or primary carrier sheet are fabricated from a fabric that does not permit substantial bentonite migration. When two liners are disposed adjacent to each other in the bottom of the landfill or pond, the two liners are overlapped so that the more open portion of one liner engages the adjacent liner. Upon activation, the bentonite migrates through the more open fabric to create a seal between the two adjacent liners. The result is a **self-sealing** geosynthetic clay liner system.

Another type of geosynthetic clay liner (with a low permeability or controlled permeability intermediate sheet) is shown in **Fig. 11**. This liner includes two outer sheets with two layers of bentonite and an intermediate sheet disposed therebetween. The intermediate sheet may be rippled or deformed to enhance the structural stability of the liner. The intermediate sheet may be chosen from a material with low or ultra-low permeability characteristics or may be chosen from a material with controlled or directional permeability characteristics.

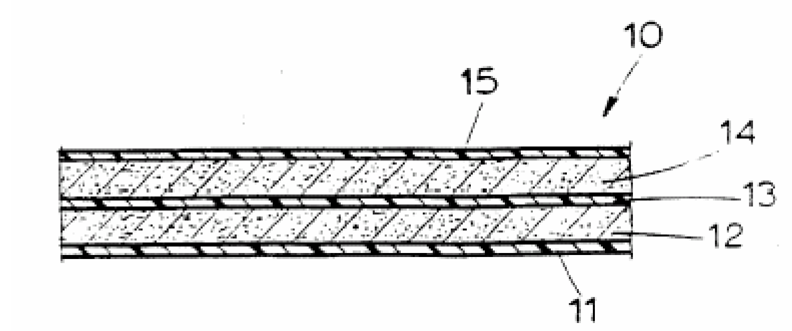

Fig.11.
Geosynthetic clay liner
Public Domain-US Patent # 5589257

Besides usage of prefabricated bentonite-geosynthetic liners, we have experience of "erecting" a simplest type of bentonite water protective shield – mixing underlying soils with bentonite at the construction sites. We also recommend including **self-healing** ability of bentonite-soil mixtures to the "**Effects Block**" of **TRIZ**.

Finalizing this article, we would like to mention that it was developed others valuable applications of bentonite – in water purification, papermaking, as surfactant in laundering, etc.

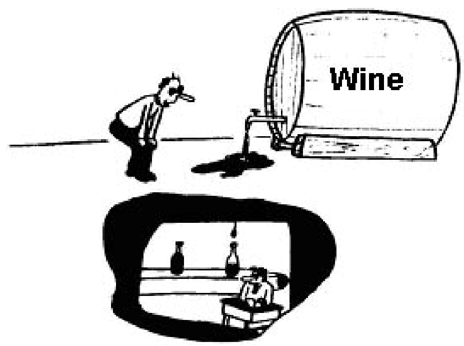

Fig. 12.
Based on Bentonite Wine Purification Technology.
Courtesy of Anatoliy Nelidin

Taking into account that final information remembered better, we would like to present here some information about usage of bentonite in sorbent technologies, and we can say in sorbent medicine, which includes usage of enterosorbents for medical purposes, including absorbing radioactive nuclides from inside human body, which became of a high priority, especially in Ukraine after Chernobyl catastrophe.

As example of invention from sorbent area look over Russian Federation Patent #**2229336.** This invention describes an inorganic sorbent, which was developed for purifying water, and contained manganese dioxide with bentonite clay carrier. Method of conditioning this sorbent includes consequently thermal and acidic activation of bentonite clay, with next ratio of these components: manganese dioxide – 10-14% bentonite clay –

the rest.

Other examples of bentonite applications for different purposes readers could find by providing patent search in areas of interest on World Wide Web, including www.uspto.gov, www.delphion.com. www.rupto.ru, etc.

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tepl@sbcglobal.net
(972) 385-9994