*Journal of Earth Sciences and Geotechnical Engineering, vol. 6, no.1, 2016, 19-27*
*ISSN: 1792-9040 (print), 1792-9660 (online)*
Scienpress Ltd, 2016

# Fracking - Prevention of Leakage of Oil and Gas from Abandoned Holes in Consolidated Rock

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## Abstract

Fracking of deep shales is used in the US for making otherwise unavailable gas and oil in dense rock exploitable but can cause problems by leakage to the ground surface or shallow aquifers of such matter and of water contaminated by chemicals used for release of the precious substances. The issue is primarily boring disturbance causing a high-permeable annulus around boreholes that interacts hydrologically with natural fracture zones, and secondarily, malfunctioning concrete liners. A novel approach for new holes is to eliminate leakage by constructing long-lasting linings, and chemically stable concrete plugs where permeable fracture zones are intersected. The vertical parts of abandoned holes can be sealed by construction of concrete plugs where such zones are intersected and by installing clay seals in between. For holes to be abandoned, long-term sealing is provided by installing very dense smectitic clay plugs that are chemically compatible with the concrete.

**Keywords:** Clay, Concrete, Deep borehole sealing, Fracking

## 1 Scope

Leakage of gas, oil and chemically contaminated water along boreholes from gas- and oil-bearing strata up to shallow aquifers is commonly counteracted by casting concrete liners of the boreholes, and installation of steel tubes that extend horizontally from them at depth for catching the gas and oil. Boring is made by use of drill bits that damage the rock by forming an annual 50-100 mm excavation-disturbed zone (EDZ) with

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significantly enhanced hydraulic conductivity [1, 2]. This zone interacts hydraulically with natural fracture zones that are effective conductors for oil and gas and contaminated water that can migrate up to aquifers. A common principle is to isolate boreholes above exploited gas- and oil-bearing strata from the rock by lining the holes with Portland-cement concrete for tightening the contact between the steel tubes and the EDZ. Such concrete, with traditional mixed-in organic fluidizer, is short-lived and new concrete types have been tested for improved longevity as described in the paper. For abandoned production holes discussed in this paper, sealing of the entire hole length can be made by combining very tight expandable clay plugs where the rock has few fractures with concrete plugs of a new type cast where fracture zones are intersected (Figure 1). The concrete consists of low-pH cement with low concentration for minimizing degradation by erosion and dissolution, and properly graded silica-rich aggregate, and talc as fluidizer. A suitable composition is computer-derived based on packing theory [3]. Local reaming is made for cutting off the EDZ and the holes are re-bored to the original diameter when the concrete is largely hardened (Figure 1). The space in axial direction between the concrete plugs is filled with coupled perforated tubes with dense expandable smectite clay using available technique [1].

## 2 Concrete Plugging-Novel Experience

### 2.1 General

Ordinary concrete liners and plugs are chemically unstable since the Portlandite component, $Ca(OH)_2$, forming a grain-connecting film, dissolves, and the organic fluidizer is eaten by microbes. Concrete constructions are hence estimated to be reliable barriers for only about 100 years according to planners and designers of repositories for radioactive waste. In the case of liners in boreholes for fracking, the conditions involving erosion and water flow in the rock surrounding them are much more severe and degradation of the concrete will start already after 10-50 years. For radioactive repositories much emphasis has been put on development of long-lasting concrete of which one, described here, is proposed for sealing boreholes, shafts and tunnels. It is based on low-pH cement and silica-rich aggregate, and has talc for conditioning, short-term ductility and long-term strengthening. It has a very low content of cement and a granular composition that gives minimum porosity by being designed on the basis of packing theory [3], Figure 2. The concrete is ductile

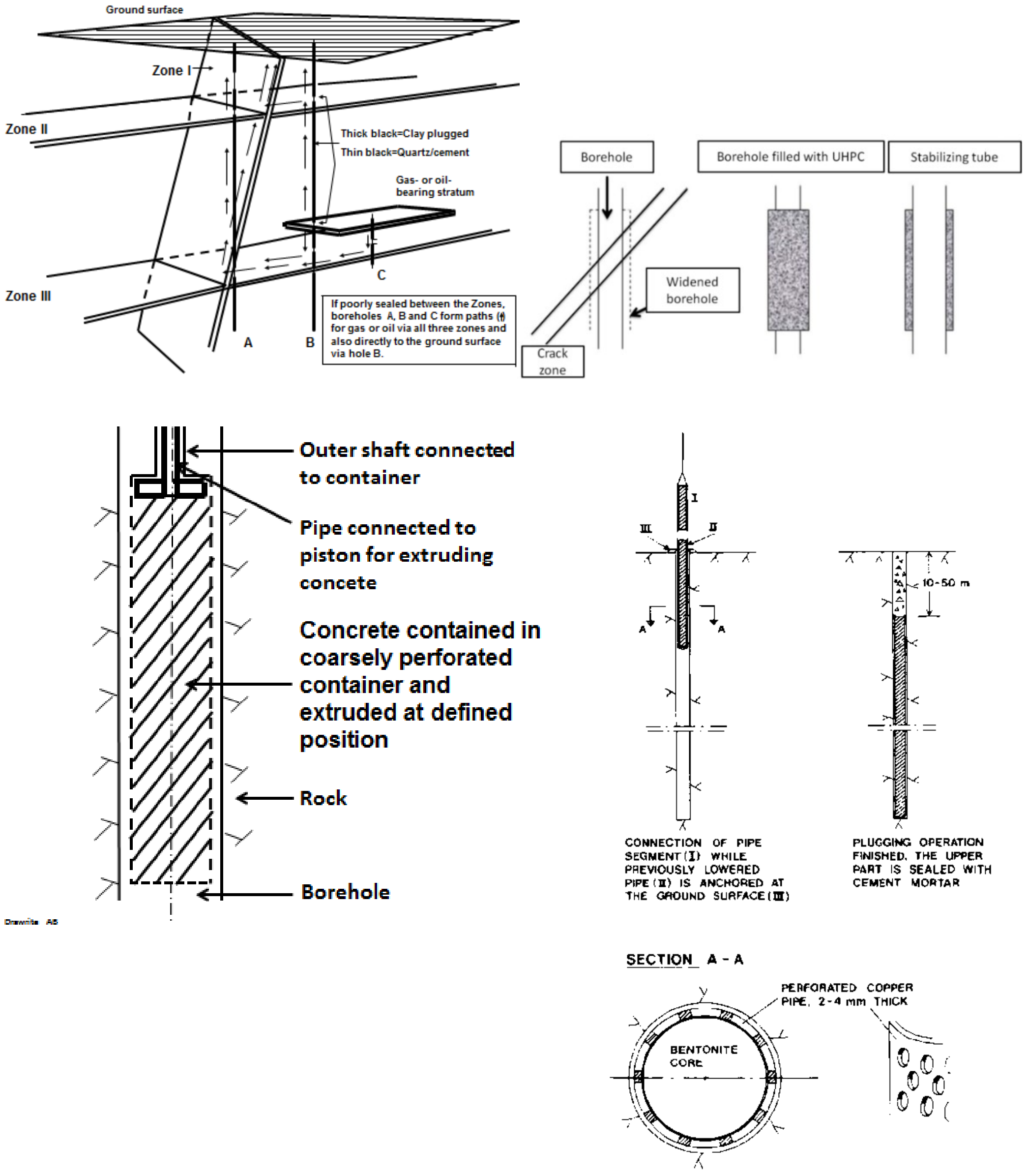

Figure 1: Upper left: Flow paths for gas and oil via short-circuiting boreholes. Concrete (quartz/cement) cast after reaming where fracture zones are intersected. Upper right: Reaming for casting concrete plug. Lower left: Equipment for placing a specific amount of coherent concrete. Lower right: Placement of clay seal of dense bentonite confined in perforated metal tube.

in the first week, which makes it establish tight contact with the rock under the axial pressure exerted by its own weight, and matures to an ultimate compressive strength that is higher than for Portland concrete. The relatively low pH of the concrete porewater (pH 10) means that it will not cause degradation of contacting smectite clay installed for sealing the boreholes after using them [3,4].

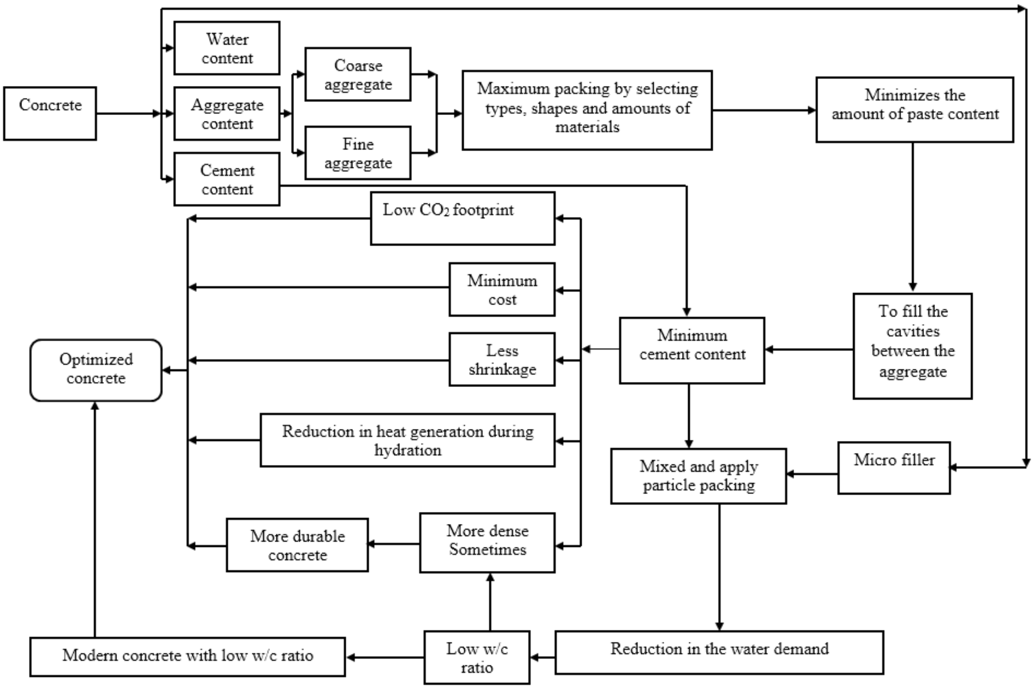

Figure 2: Chart for identifying suitable concrete recipe [4].

## 2.2 New Concrete for Borehole Sealing

Recent research has focused on concrete based on low-pH cement and talc as fluidizer for sealing very deep bored holes for disposal of high-level radioactive waste andcan be recommended also for sealing abandoned holes having been used for fracking. The work has included a series of compression tests of concrete with very low contents of MERIT 5000 cement (34 % $SiO_2$, 13 % $Al_2O_3$, 17 % MgO and 31 % CaO) and aggregate composed of crushed quartzite and silica flour with a grain size composition of: 100 % <4 mm, 93 % <2 mm, 70 %< 1 mm, and 30 % < 0.1 mm [3-5]. The content of cement is 6.5 %, talc 9.5 %, and aggregate 84 %. The water/cement ratio is 3.6 and the aggregate/cement ratio 12.8. The density is 2070 kg/$m^3$ and pH=10. Typical compressive strength values after 2-28 days of curing are indicated in Table 1. The evolution of stress and strain of concrete plugs cast in a deep hole has been modelled and the bearing capacity found to be sufficient to carry clay seals after less than a week [4].

Table 1: Average compressive strength in MPa of low-pH concrete (Merit 5000) and Portland cement concrete prepared with similar, low cement contents [3, 4].

| Duration (Days) | Portland Concrete | Merit 5000 Concrete |
|---|---|---|
| 2 | 0.5-0.6 | 0.01-0.02 |
| 7 | 0.6-0.7 | 0.1-0.4 |
| 28 | 0.8-0.9 | 1.8-2.7 |

### 2.3 Long-term Performance of Talc Concrete

The described grain-size distribution of the aggregate and the very low cement content minimize the change in physical performance of the concrete in the possible but unlikely case of complete loss of the cement [4-6].This would make the concrete behave as bottom moraine with very low compressibility and a pore size distribution that eliminates the risk of migration and loss of clay particles from contacting clay seals. In contrast with Portland concrete, having pH 12-13, the lower pH of the new concrete makes the quartz-rich aggregate stay largely intact for practically any time as demonstrated by numerous natural analogues. The longevity of the magnesium/silicate cement reaction products from talc/cement interaction is known to be very significant, hence making the assumption of total loss of cement improbable[2].

## 3 Clay Sealing-Adaptation of New Technique

### 3.1 Principle

The clay seals, placed in the former production holes filled with 1100-1200 kg/m$^3$ Na-smectite mud,can be made by using very dense smectite-rich clay. It is prepared by compacting air-dry clay granules under 150-200 MPa pressure to form blocks that are fitted in perforated metal tubes[6] from which clay moves out to form a tight annulus of clay in a few days (Figure 3). Problems with too rapidly maturing plugs appear if the time for installation of the clay plugs in very deep holes is more than one day but the problem can be solved by using nearly water-saturated clay plugs with lower dispersion potential obtained by use of “dry” water technique [7, 8], or by coating the plugs with a paste of mixed smectite-clay and talc just before installation [9].

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[6] For holes connecting a high-level radioactive disposal site with the ground surface copper or titanium tubes are most suitable but steel tubes are acceptable for sealing of abandoned gas- and oil production holes.

Figure 3: Plug of dense smectite-rich clay confined in perforated copper tube that has been partly coated with mixed talc/clay with the dry mass ratio 3.3/1 and submerged in distilled water for 3 hours. No migration of clay from the tube had occurred from the coated part while penetrated clay had begun to embed the tube in the uncoated part.

### 3.2 Geotechnical Properties of Smectite-rich Clay Seals

The clay seals formed by the ultimately homogeneous smectite clay embedding and filling the metal tubes in which they are confined in the installation phase, are expandable and very low-pervious. The tightness guarantees that contaminated water and gas from the lower parts of the boreholes cannot leak up through them and reach shallow aquifers, and the expandability provides tight contact with the surrounding rock and sealing of the adjacent EDZ. Typical physical properties of fully hydrated and matured clays for use in boreholes are summarized in Table 2.

### 3.3 Long-term Performance of Clay Seals

The longevity of smectite seals depends primarily on the temperature. For lower values than 60-75$^{o}$C a number of tests and natural analogues indicate almost no degradation while more than 100$^{o}$C causes changes indicated in Figure 4. The mechanisms behind this are well known and verified by natural analogues [1, 10-13].

Table 2: Clays for plugging of 80 mm boreholes with 76 mm metal tubes down to 2 km depth in salt, Ca-rich groundwater [9].

| Clay | Initial dry density, kg/m$^3$ | Density of saturated homogeneous plug, kg/m$^3$ | Hydraulic conductivity of clay plug, m/s | Swelling pressure of clay plug, kPa |
|---|---|---|---|---|
| Montmorillonite | 1850 | 2000 | 8E-13 | 4700 |
| Montmorillonite | 1500 | 1800 | 6E-11 | 1000 |
| Saponite | 1850 | 2000 | 7E-13 | 5000 |
| Saponite | 1500 | 1800 | 3E-12 | 2000 |
| Mixed-layer montmorillonite/illite, 25-35 % expandable | 1850 | 2000 | 2E-11 | 700 |
| Mixed-layer montmorillonite/illite, 25-35 % expandable | 1500 | 1800 | 7E-11 | 200 |
| Mixed-layer montmorillonite/illite, 60-70 % expandable | 1850 | 2000 | 5E-12 | 2000 |
| Mixed-layer montmorillonite/illite, 60-70 % expandable | 1500 | 1800 | 3E-11 | 600 |

## 4 Essentials Derived from Ongoing Projects of Borehole Sealing

- Borehole sealing using the principles described in the paper has been successfully applied in a 500 m deep 80 mm diameter vertical investigation borehole in Finland. In Sweden a 200 m long subhorizontal 56 mm borehole has been effectively sealed,
- low-pH concrete seals mature slower than those of Portland concrete but become 2-3 times stronger,
- smectite seals are physically and chemically stable up to 75°C also in contact with talc concrete. Heating to 100°C causes some stiffening by cementation effects but the sealing ability is still considerable since the expandability is largely retained. Heating to 150°C causes considerable stiffening but not complete loss of ductility and expandability as demonstrated by natural analogues [1].

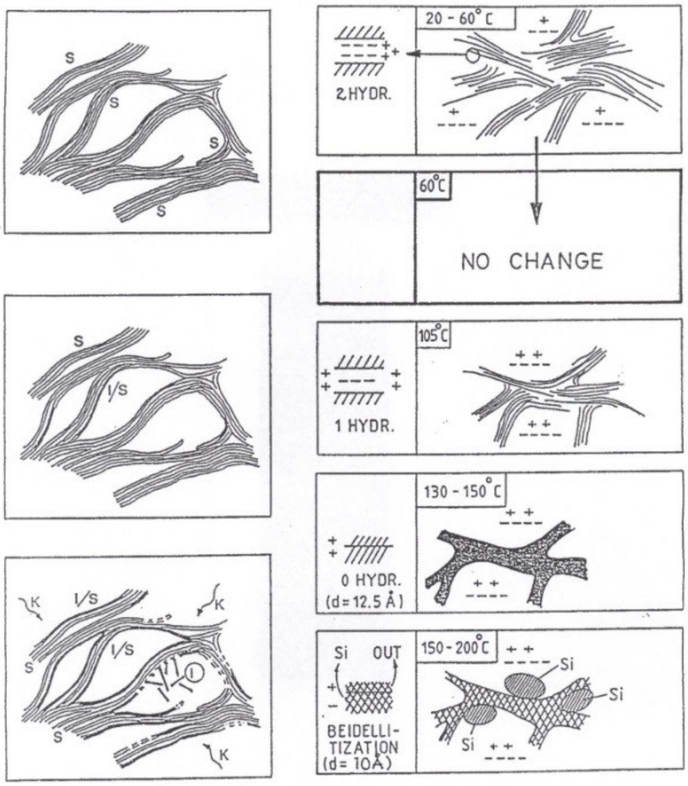

Figure 4: Processes in conversion of montmorillonite (S) to illite (I) via I/S minerals, and temperature-related microstructural coagulation and Si-cementation [9]. + and - in the right figure column denote cat- and anions in interlamellar hydrates and extralamellar ("free") porewater.

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