TRANSPORT CONTAMINATED GROUND WATER IN FRACTURED CHALK

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ABSTRACT:

During the past two decades, law – permeability rocks have gained attention as potential natural barriers against the transport of pollutants from waste disposal sites. However, although the primary porosity and permeability of these rocks is extremely low, fractures, joints, and other discontinuities may form pathways for rapid water flow and solute migration, posing the threat of contaminant escape from waste sites and other potentially polluting facilities.These conduits, where active and interconnected, may transmit contaminants from land surface to groundwater at a much faster rate than the migration of contaminants through a permeable vadose zone. Moreover, small volumes of contaminated groundwater might spread over relatively large portions of the subsurface due to the small storage capacity of these discontinuities. The heterogeneity of these rocks – an almost impermeable matrix crossed by highly transmissive conduits – results in a complex structure with dual permeability , the exact spatial distribution of which is unknown.

1. INTRODUCTION

Extensive areas in Western Europe and the Middle East are underlain by Upper Cretaceous and Tertiary chalk formations (Downing et al. 1993). Chalk formations may be very transmissive ' to water (e.g., the British Chalk) or hydrocarbons (e.g., the North ' Sea oil Fields), but may also have the form ofaquitards (e.g., in the the south area of East Azarbaijan »). Because the chalk matrix is generally of low permeability (Downing et. al. 1993), the intensity of its fracturing and the hydraulic features of these fractures control its overall capacity to transmit fluids and solutes. The successful siting of high-yielding water supply wells, oil exploration boreholes, or effective monitoring wells to trace subsurface contaminants depends on, their intersection of the most transmissive fractures crossing the chalk formations.

2. HYDROGEOLOGICAL FRAMEWORK

For the last 30 years, the South area in East Azarbaijan in Iran (Figure 1) has become a prime target for siting a variety of chemical industries rejected by, or transferred from, more populated areas. In addition, the National Site for the Treatment and Isolation of Hazardous Waste has been operating there since 1996(The Ministry of the Oil). The aridity of the South area (230 mm/yr rainfall) and the low permeability of the underlying Eocene chalk (~2 md) were considered major assets in preventing potential ground water contamination resulting from these activities. This concept of a natural barrier to contaminant migration was challenged, however, when monitoring wells for the National Site for Hazardous Waste were first constructed in 1995. Ground water in these wells (at -18 m below land surface) displayed high concentrations of heavy metals and organic compounds (The Ministry of the Oil). Nativ and Nissim (Nativ et. al 1992) suggested that the numerous fractures crossing the chalk matrix (Bahat 1975) serve as preferential flowpaths for contaminant migration from land surface. Indeed, preferential water flow and solute transport across the vadose chalk was demonstrated using chemical and isotopic tracers (Nativ et. al. 1995). It appears that only a small fraction of the infiltrating water penetrates the nearly saturated, low-permeability chalk matrix (Foster 1975). Most of the water bypasses the matrix as it infiltrates the water table from land surface via the fracture system.

The low-permeabilily chalk formations in the South area in East Azarbaijan in Iran contain brackish water and are not considered a major ground water resource. However, potential natural leakage of contaminated ground water from these formations into the adjacent Coastal Plain Aquifer (in the Ormia River at Figure 2) is a major concern. Consequently, in 2001, the Ministry of the Environment initiated a survey to (1) assess the extent of ground water contamination in the area of the industrial complex (using data from 14 existing boreholes as well as data from newly bored holes), and (2) provide guide-lines and protocols to properly monitor this complex.

3. SITING PROCEDURE

3.1 Spatial Distribution of the Piezometric Heads

A map of the water table measured in all boreholes penetrating the chalk aquitard indicated ground water flow from east to west, similar to the topographical inclination. However, the correlation between these two surfaces was incomplete (Figure 3). Some of the water level mounds (e.g., zones A, B, and C; Figure 3) were clearly located in topographical lows, suggesting leakage from local surface sources. The general hydraulic gradient suggested that monitoring boreholes should be placed west of potentially contaminating facilities. However, the presence of the water level mounds and the distribution of the fracture systems required the monitoring of all potential flow directions from these mounds, and a consideration of the anisotropy in solute transport imposed by the prevailing fracture system.

The heterogeneity of the chalk formations is generated by the numerous fractures intersecting the porous (40%), low-perme-ability (~2 md) matrix. The dual permeability is manifested by a several orders of magnitude difference between ground water flow velocity ..i ihe matrix and fractures in the vadose zone (0.06 m/yr vs. 1.5 m/yr, respectively (Nativ et. al. 1995)).

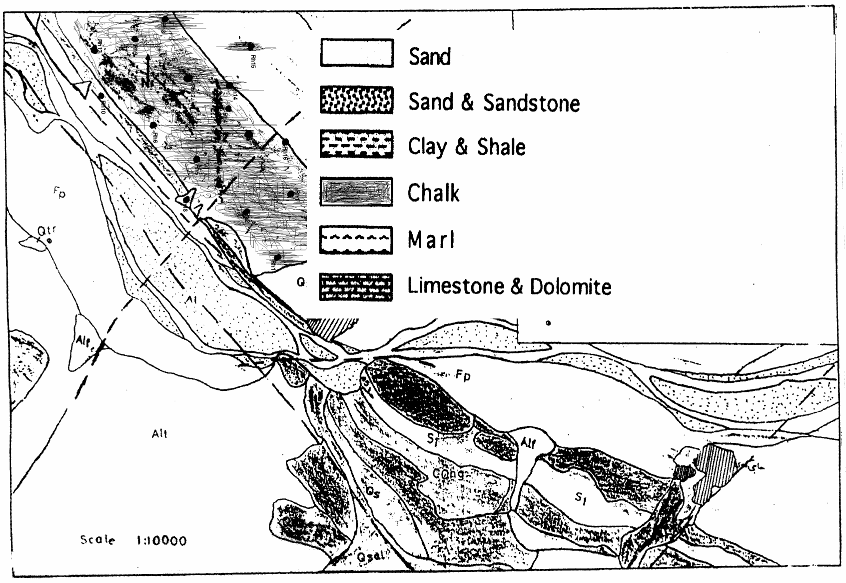


Figure 1. Location map for East Azarbaijan (The Ministry of the Oil 1999-2001; the Ministry of the Environment 2001-2003) .

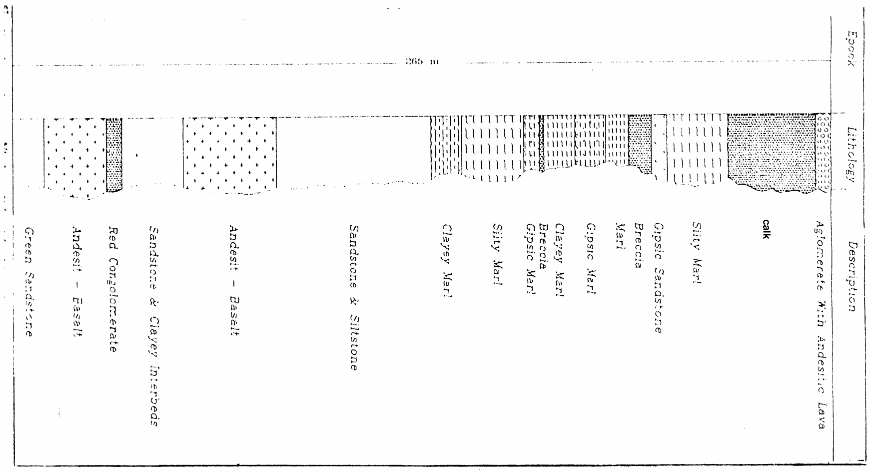


Figure 2. Upper Red Formation Mieen of East Azarbaijan (The Ministry of the Oil 1999-2001; the Ministry of the Environment 2001-2003).

Another facet of this heterogeneity is the variable chemical and isotopic composition of the chalk groundwater observed in adjacent (< 250 m apart) boreholes (Nativ et. al. 1992).These variations were found to be unrelated to either ground water evolution along apparent flowpaths or spatial variations in precipitation amounts.

3.2 Identification of the Prevailing Fracture Systems

Recognizing the importance of the preferential flow in chalk, considerable effort was made to identify the major hydraulically active fracture systems crossing the industrial complex. As part of this work, aerial photographs of the study area dating back to the early '40s, before it was leveled off for the industrial site, were processed using a special algorithm to identify surface lineaments that might represent major fractures or fracture zones. The algorithm searches the study area for straight-line segments (e.g., along stream channels) that may form a continuous lineament along a certain azimuth. Points that can be arranged along a line are identified; these lines are then classified according to their point density and orientation.
Lineament interpretation assumes linear characteristics for the fractures and joints. Obviously, some of the lineaments represent other linear features, e.g., fences, roads, and drainage patterns, some of which could not be decisively eliminated from the map. Therefore, the nature of these lineaments had to be verified in the field.

Field verification was done by mapping the orientation of fractures and joints intersecting the chalk formations outcropping along ephemeral streams (shown in Figure 1,4,5) and other man-made cuts,Not all the Lineaments actually representing fractures seemed hydraulically active or significant. Some appcared to be faults filled with finely crushed material,and bore little relevance to ground water flow.Attention was focused on large-extension.through-going,multilayer fractures and joints (Bahat, D. 1987).the depth of which can reach 50m bls (Figure4, 5).Obviously,these may be erossed by other fracture systems originating at greater depths.The intersection of such systems allows rapid cotaminant transport to great depths and distances.Figure1 displays the orientation of the predominant field-mapped fracture systems (the hydrologically less important systems are omitted).They appear as strsight lines,interpolated between the actual measurement point along the ephemeral systems and other cuts in the chalk.

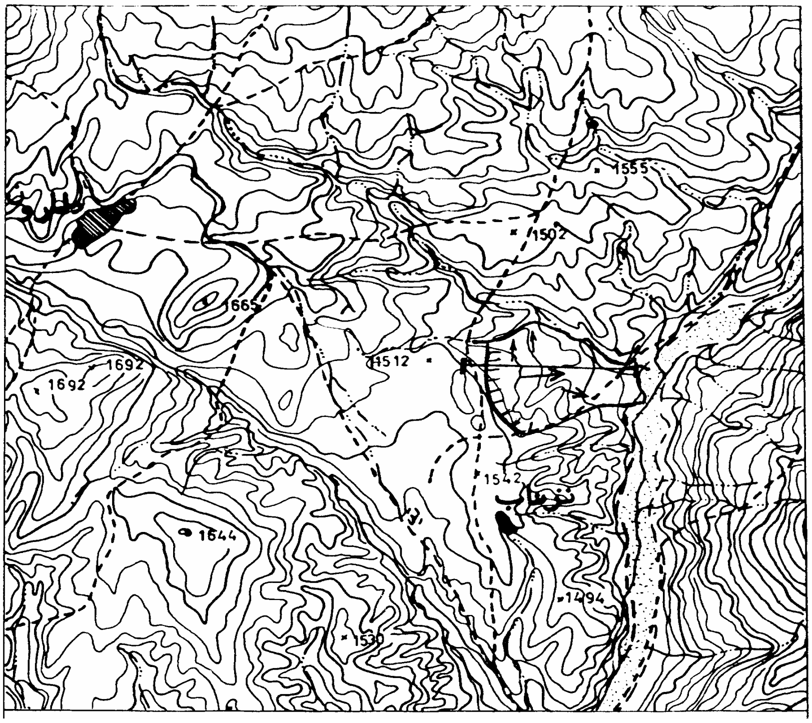
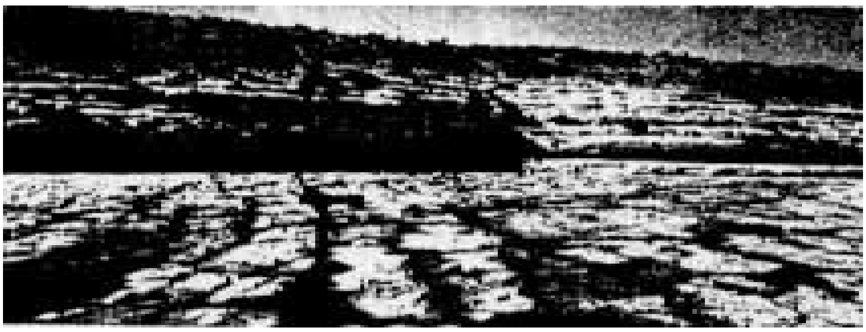
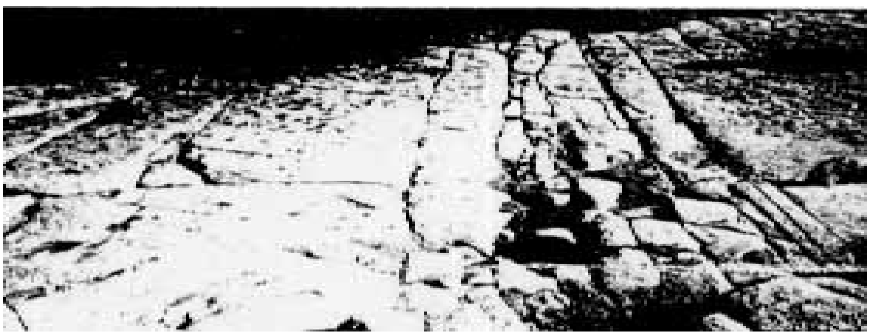


Figure 3. Water levels (above) vs. topography (below) in the East Azarbaijan area.



(a) The most predominant frscture system crossing a cliff



.(b) in an ephemeral wash in the central part of the study site

Figure 4. Multilayer joints in one of the East Azarbaijan ephemeral streams

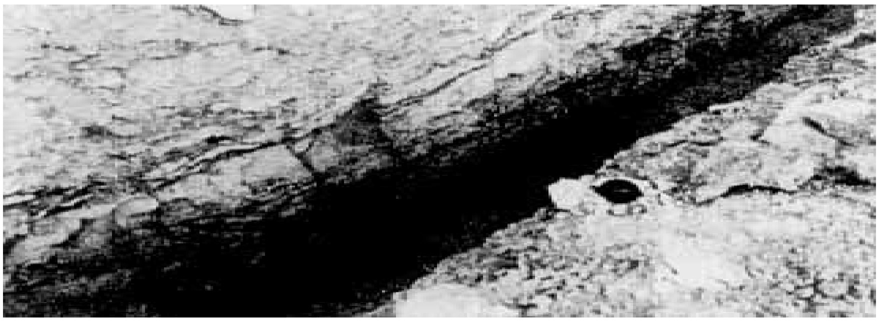


Figure5. A segment of a trench exeavated to identify the precise location of the predominant fracture system at a drilling site.The depth of the trench is one meter below the top of tee massive chalk.A ienscap was placed for a scale.

4. BOREHOLE

4.1 Borehole Depte

The potentially enhanced downward As(Arsnec)migration resulted in our restricting the depth of most monitoring boreholes to the upper 50 m of the total chalk thickness (~290 m), which were expected to be most heavily contaminated(The Ministry of the Oil).

4.2 Borehole Logging

The logs run in the various holes were intended to provide information regarding the vertical distribution and characteristics (e.g., orientation, aperture) of the intersected fractures for later estimation of on- and off-site contaminant spreading. For this purpose, caliper and TV camera logs were run in selected holes. Because the logged boreholes were shallow (<100 m), temperature variations among the fluxes contributed from the various fractures were expected to be-negligible and temperature logs were avoided(The Ministry of the Oil).

A comparison of the various data sets from the eight logged coreholes (Table 1) indicated that large features show up well both in the cores and on the logs. However, microfractures and even some small-aperture multilayer fractures were not detected by either log. Consequently, the total number of fractures observed in the cores was significantly larger than that seen on the video films produced by the TV camera, Ihe latter being larger than the number implied from the caliper log(The Ministry of the Oil).

4.3 Borehole Completion

The shallow (up to 50 m deep) monitoring boreholes and coreholes were cased only against the upper 1 to 5 m ofunconsol-idated sediment cover (sand, loess, and weathered chalk). This is because the ground water fluxes discharged from the fractures intersected by the holes had to be tested (using straddle packers) to better assess the rate of contaminant spread in the various intersected fracture systems; casing the boreholes would have prevented these tests. Only the deeper coreholes were cased against the upper 30 to 40 m interval, to avoid contaminant migration from the upper section to deeper formations. The lower interval (60 to 70 m) in these coreholes was left uncased for similar tests. Previous experience with uncased vertical boreholes in the area has indicated that the chalk formations are sufficiently cohesive to not require the casing support. Our recent experience with the slanted boreholes suggests that if the casing against the unconsolidated sediment cover is properly set, and the skin is removed from the borehole walls by water jet stream, these holes are unlikely to be blocked and can be left uncased for future tests(The Ministry of the Oil).

Corehole Name	Logging Length (m)	Number of Fractures Observed in Cores	Number of Fractures in TV Camera Log*	Number of Fractures in the Caliper Log**
RH-1	33	34	21(61)	15(71)
RH-5	40	27	27(100)	10(37)
RH-11	40	51	27(52)	19(70)
RH-15	30	25	15(60)	4(26)
RH-23	27	12	10(83)	
RH-123	17	13	9(69)	
RH-101	61	24	9(38)	
RH-111	65	46	26(57)	

* The ratio of the number of fractures observed in the TV camera Log to that observed in the core (%) is in parentheses.
** The ratio of the number of fractures observed in the caliper logs to that observed in the TV camera log (%) is in parentheses. Caliper logs were not performed in the RH-23 , RH-123 , RH-111 coreholes[11] .

Table 1. A Comparison between Fractions Observed in Cores and Coreholes Using a TV Camera and Caliper Loges

5. MONITORING

Following are preliminary monitoring considerations and observations.

5.1 Natural Water Level Variations

During the first year of monitoring, the hydraulic head in all boreholes was manually monitored almost every other month. This high measurement frequency was meant to reveal changes in lateral flow directions (and contaminant transport) resulting from differential response to major precipitation and flood events. The observed seasonal variations in the hydraulic head (which amounted up to 2 m) were, however, overwhelmed by the steep hydraulic gradient (50 m drop in hydraulic head over a distance of 5 km (Figure 3)) which preserved all lateral flow directions throughout the year. On the basis of these observations, measurements frequency could be reduced to twice a year (during the rainy and dry seasons).

5.2 Water Level Response to Pumping

All newly drilled holes were purged several times following the completion of their drilling to evacuate the fluids used for the drilling of the coreholes, or those introduced to me boreholes by the water jet stripping the low-permeability skin from the boreholes" walls. Purging was made by air-lift pump or submersible Grundfos® pump operating at their maximum capacity. Full recovery of water levels in all these holes was observed within hours to days, confirming their intersection with hydraulically active fractures. Such fast recovery was documented in only two of the 10 boreholes (vertical and unaligned with the fractures) that existed on site prior to our investigation. Purging the rest of the old holes took a few hours, with recovery requiring weeks(the Ministry of the Environment 2001-2003).

5.3 Ground Water Sampling

All boreholes were sampled once for the analyses of major ions, trace elements, organic (volatile as well as less volatile) constituents, and isotopic (As,Pb,Co,Cd) composition. This detailed analysis was designed (1) to evaluate the complete composition of contaminated ground water on site, (2) to select representative indicators for ground water contamination for future monitoring, and (3) to identify chemical or isotopic parameters that would help distinguish between several potential polluting sources.

5.4 Spatial Distribution of Solutes

Most of the newly drilled boreholes contained contaminants, supporting the assumption that the targeted fracture system into which they were drilled indeed intersected the polluting facilities and drain them. The need to individually monitor each of these fracture systems was clearly demonstrated by the anisotropic spatial distribution of the contaminants. Contaminant concentrations differed by several orders of magnitude in adjacent boreholes aligned with different fracture systems.

6. CONCLUSIONS

The strong heterogeneity in the hydraulic properties of low-permeability fractured formations turns the siting, drilling, and completion of monitoring boreholes into a major challenge. Because of the extensive fracturing of the otherwise low-permeability chalk formations, the common protocol for siting monitoring wells in aquifers downstream of a potentially contaminating facility had to incorporate the prevailing fracture system into the siting criteria. Large-extension, throughgoing multilayer fractures and joints were identified in the study site using aerial photographs, lineament tracing techniques, and field measurements. The presence of these prevailing fracture systems at each drilling site was confirmed by trenching, and slanted borehole were drilled to intersect these fractures below the water table. Most boreholes were dryaugered, a technique which enabled at a relatively low cost immediate ground Water sampling and the sampling of vadose chalk for contaminant analyses. More expensive coreholes were carefully placed to obtain a reasonable spatial coverage of fracture distribution with depth. Such information could not be fully achieved from TV camera and caliper logs in boreholes, as only fraction of the fractures documented in the cores were also spotted on the logs. The number of deep monitoring boreholes was restricted to minimize vertical contaminant spread through the uncased boreholes.

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