

Military geology and the Gulf War

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ABSTRACT

Engineering geologists and hydrogeologists assigned to the 416th Engineer Command (ENCOM) supported the planning and execution of construction and tactical operations during the Gulf War. Military geology applications included locating potential quarry sites for sources of construction aggregate and fill, evaluating terrain features such as sabkhahs to assess cross-country mobility, and developing water sources.

Sources of construction aggregate were needed to support sustainment engineering requirements in building and maintaining roads, heliports, and aircraft parking aprons in Saudi Arabia. Technical advice and assistance were provided to host nation forces who supported the production and transportation of aggregate from the source to the stock pile.

Terrain analysis contributed to the success of the ground war. Obsolete or inaccurate maps were updated with new satellite images and field reconnaissance. Areas with inadequate terrain data were investigated to document natural as well as man-made obstacles. Coastal sabkhahs were evaluated and tested to determine their effect on mobility. Extensive surficial samples were collected for detailed geologic analysis, and field-expedient methods to improve trafficability were recommended.

Military hydrogeologists and engineers worked closely with the Saudi Ministry of Agriculture to design and site new water wells. Several water wells were drilled by military teams to support operations deep in the desert.

Satellite images, aerial photographs, maps, existing reports, and field reconnaissance were utilized to evaluate geologic conditions, thorough knowledge of which greatly contributed to the success of the ground war.

INTRODUCTION

Engineering geologists assigned to the 416th Engineer Command (ENCOM) supported the planning and execution of construction and tactical operations during the Gulf War. Military geology applications included evaluating terrain features such as sabkhahs to assess cross-country mobility, locating potential quarry sites for sources of construction aggregate, and developing water sources.

Physiography

Operations Desert Shield and Desert Storm occurred in northeastern Saudi Arabia, southeastern Iraq, and Kuwait from August 1990 to March 1991. This area is part of the eastern physiographic region of Saudi Arabia (Ministry of Agriculture, 1984). The terrain is generally flat lying and includes the As Summan Plateau, the Gulf Coastal Plain, and the Ad Dibdibah Plain (Fig. 1).

As Summan Plateau. Chapman (1978) described the As

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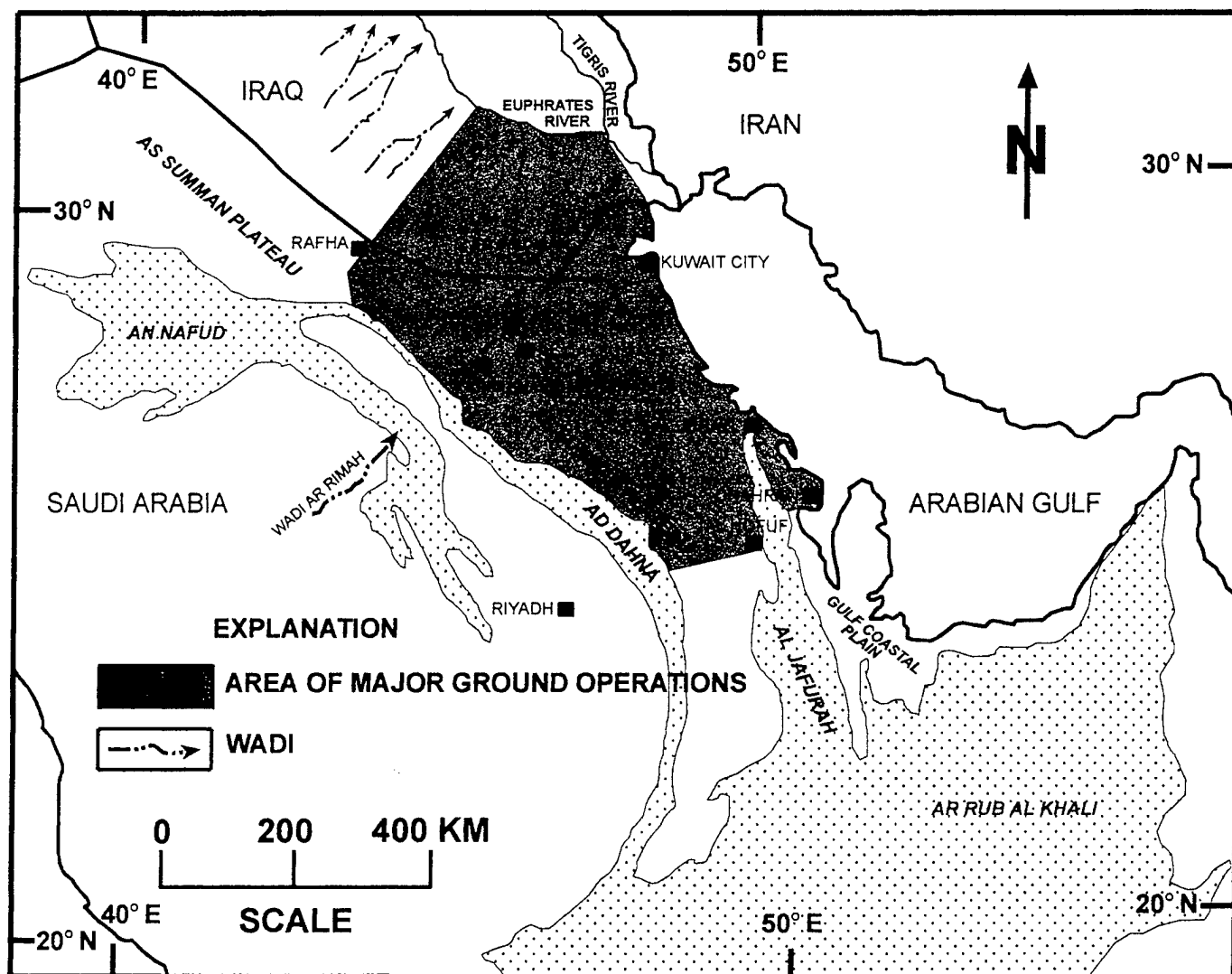


Figure 1. Regional map with physiography and place names adapted from Holm (1960). Stippled pattern represents major sand sheets. Area of major ground operations (shaded) extended over parts of the As Summan Plateau and Ad Dibdibah Plain.

Summan Plateau as a long, flat, barren, hard-rock plateau of varied width, trending north from a point about 300 km south of Al Hofuf northwestward across northeastern Saudi Arabia. The maximum width of the plateau is 250 km (Fig. 1). The As Summan Plateau is a prong of the larger Syrian Plateau. In Iraq, Syria, and northern Saudi Arabia the plateau is a vast desert of gravel and rock plains underlain by Cretaceous and Tertiary sedimentary rocks and Pliocene basalt. The plateau slopes eastward from an elevation of nearly 400 m at its western margin to about 245 m on its eastern edge. Bedrock is exposed in some parts of the plateau, but in many areas it is covered by surficial deposits that may be 30 m thick.

Gulf Coastal Plain. The Gulf Coastal Plain lies between the As Summan Plateau and the Arabian Gulf. It is an expanse of flat lowlands covered by sand and gravel that averages 160 km in width. It is composed of dunes, sabkhas, and sandy plains

that slope toward the Arabian Gulf. Low rolling plains are covered with a thin mantle of sand from Al Jubayl northward toward Kuwait City. The sand mantle averages 1 to 2 m thick but may be considerably thicker in dune areas. The roots of shrubs and grasses hold the sand in hummocks ranging in height up to 2 m and form an irregular, hummocky terrain called "dikakah." From Al Jubayl to Al Hofuf is a wide belt of drifting sand and dunes that merge with the Al Jafurah sand area and the Ar Rub Al Khali farther to the south. The shallow nearshore waters of the gulf may shift the coastline back and forth across a width of several kilometers. Large sabkhas occur along the coast and are commonly saturated with brine and encrusted with salt. Barren-rock terrain developed on Eocene, Miocene, and Pliocene limestone is exposed in areas not covered with sand or sabkhas (Chapman, 1978).

Ad Dibdibah Plain. The Ad Dibdibah Plain occurs in the area southwest of Kuwait. It is a large triangular-shaped gravel plain. With its apex near Al Qaysumah, it spreads northeastward almost to the Tigris and Euphrates valleys. It is composed of cobbles and pebbles of igneous and metamorphic rocks and limestones with finer sediments. The cobble and pebble sizes decrease toward the northeast. The Ad Dibdibah gravel plain is considered to be the delta of the Wadi Ar Rimah–Wadi Al Batin drainage system, which transported rock debris from the Arabian Shield area during one of the pluvial periods (Chapman, 1978). In many areas, the average thickness of surficial materials overlying a hardpan is less than 1 m. To the observer on the ground the plain appears to be perfectly flat, but actually it is an undulating surface with enough local relief, on the order of 20 m, to be tactically significant in many areas.

Geology

The Arabian Peninsula comprises the Arabian Shield and the Arabian Shelf. The Arabian Shield occupies the west-central one-third of Saudi Arabia and consists of igneous and metamorphic rocks of Precambrian age. These rocks are folded, faulted, and uplifted to form the Asir and other mountains along the Red Sea. The Arabian Shelf overlies the Arabian Shield over the eastern two-thirds of Saudi Arabia, southeastern Iraq, and Kuwait. The Arabian Shelf is a series of sedimentary formations ranging in age from Cambrian to Pliocene, dipping from the center of the Arabian Peninsula eastward toward the Arabian Gulf. In central Arabia the beds dip gently and uniformly northeast, east, and southeast from about one degree in older units to less than half a

degree in the Upper Cretaceous and Eocene beds (Chapman, 1978). The sedimentary rocks consist mainly of limestone, sandstone, and shale with an aggregate thickness of strata of 5,500 m; they thin toward the west. The As Summan Plateau and Gulf Coastal Plain are part of the Arabian Shelf (Fig. 2).

TERRAIN ANALYSIS

Although the terrain of the As Summan Plateau and Gulf Coastal Plain is generally flat, areas of sand dunes and rounded hills, 5 to 10 m high, concerned military planners. Terrain analysts contributed significantly to the success of the ground war by delineating areas where cross-country movement could be adversely affected by sand areas, wadis, and sabkhas. Obsolete or inaccurate maps were updated with new satellite images and field reconnaissance. Both Landsat and Systeme Probatoire d'Observation de la Terre (SPOT) satellite images were used in terrain analysis. Landsat Thematic Mapper system multispectral bands 2, 4, 7 (blue, green, red) with 30-m-resolution elements were used by Rinker et al. (1990) to produce rapid-response terrain analysis for the eastern physiographic region of Saudi Arabia, southern Iraq, and Kuwait. Areas with inadequate terrain data were investigated by ground reconnaissance teams to document natural as well as man-made obstacles.

Sand areas

Approximately one-third of the Arabian Peninsula is covered by mobile sand in one form or another. Three major sandseas

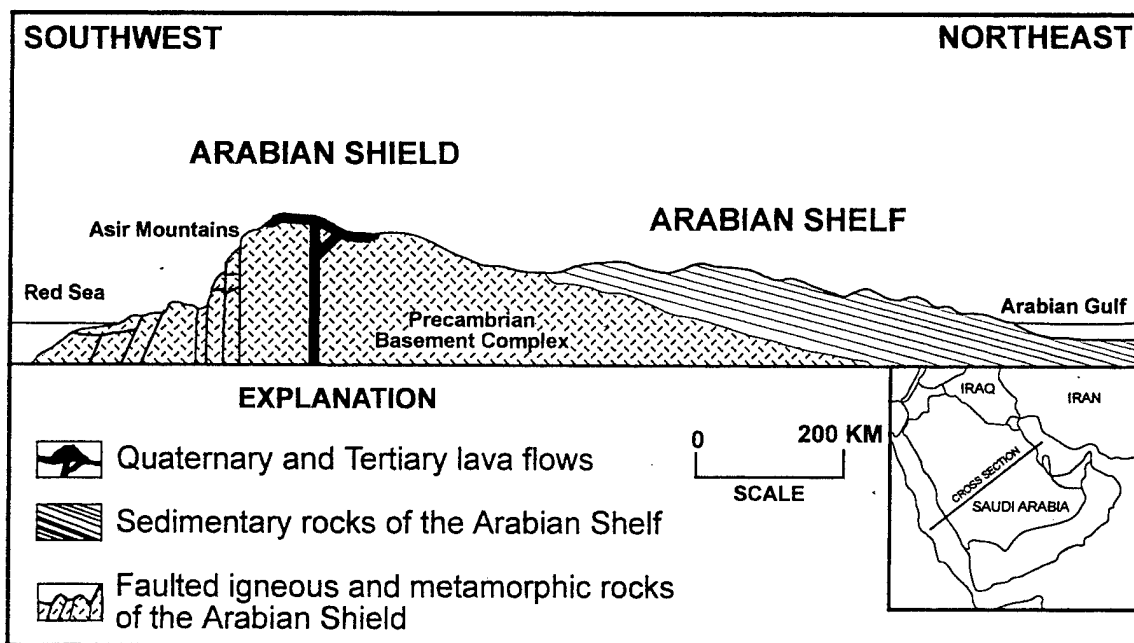


Figure 2. Generalized southwest to northeast geologic cross section across the Arabian Peninsula showing the Arabian Shield and Arabian Shelf, modified from Ministry of Water and Agriculture (1984).

occur: the An Nefud, the Ad Dahna, and the Ar Rub Al Khali. In the northwestern part of the peninsula, the An Nefud occupies a broad basin covering an area of approximately 57,000 km² with reddish sand and rolling dunes. The An Nefud is devoid of streams and oases and has sparse vegetation. The Ad Dahna is a long narrow belt of shifting sand and dunes extending nearly 1,300 km in a broad arc from the An Nefud in the north to Ar Rub Al Khali in the south. It lies between As Summan Plateau on the east and the cuesta region on the west, an area in central Arabia where upturned edges of sedimentary beds form west-facing escarpments along the eastern edge of the Arabian Shield. The sand of Ad Dahna is bright red-orange owing to an iron oxide coating of the grains. The Ar Rub Al Khali, or Empty Quarter, in southern Arabia is the largest continuous sand body in the world. The region covers a total area of 600,000 km²; the sand is red-orange and medium to fine grained like that of the An Nefud and Ad Dahna (Chapman, 1978). Although Operations Desert Shield and Desert Storm avoided the major sand seas of the Arabian Peninsula, localized sand bodies and hummocky areas of dikakah presented trafficability problems, especially to large trucks operating off existing roads.

Trafficability most often depended on the degree to which the sand had been compacted by the wind. In sand-dune areas, trafficability depended on the types of dunes and their associated interdune areas. On dunes with asymmetric slopes, the gentler windward slope was wind compacted and could usually support foot and light vehicular traffic. The steep lee slope, or slip face, could not support either foot or vehicular traffic without avalanching (Rinker et al., 1991). Most of the sand-induced trafficability problems occurred in dikakah, areas of sand drift, and in loose sand in wadi channels. In general, these areas were only significant locally. Areas of dikakah were depicted on existing maps and were further delineated with satellite images.

The U.S. Army field manual *Desert Operations* (U.S. Army Armor School, 1977, p. 2–22) states that “dust and sand are probably the greatest danger to the efficient functioning of equipment in the desert.” Helicopters in particular were affected because of their normally low operating altitudes. Sand abraded leading edges of rotor blades, rotor heads, and exposed flight control surfaces. Sand ingestion by engines and disorientation created by blowing dust and flying sand also were operational hazards (U.S. Army Armor School, 1977). Military construction in sandy areas was complicated by the excavation problems that resulted from lack of cohesion and the need to protect horizontal structures from drifting sand. Potential problems occurring in dikakah, loose drift sand, sand sheets, sand dunes, and loose sand in wadi channels were for the most part minimized by avoiding these areas. Where necessary, sand was stabilized with various types of mattings, grids, and dust pallatives. Dust pallatives cover the dust source areas with a thin protective layer, cement dust particles together, or cause dust particles to agglomerate into larger particles not readily airborne. Bituminous materials and oil were two common pallatives used to stabilize sand and control dust.

Wadis

For military terrain analysis in desert environments, Rinker et al. (1991) described wadis as channels that were dry or had only intermittent or ephemeral streamflow. They ranged in size from small gullies less than a few meters wide and deep, to large broad valleys several kilometers wide and tens of meters deep, to large, deep mountain canyons hundreds of meters wide and deep. They were classified as wadi washes that were dry, intermittent, or ephemeral drainage courses marked by deposits of alluvial material that were not confined to a specific channel. The channels were commonly braided and covered an area up to several kilometers wide. These broad deposits on open valley floors were, in most places, generally good surfaces for travel. In the Desert Shield/Desert Storm area most of the wadis either were small gullies a few meters wide and deep, or broad valleys several kilometers wide with very little relief. Many of these wadis became the axis of advance for the coalition forces attacking into the southern Iraqi desert.

The largest wadi in the Desert Shield/Desert Storm area is Wadi Al Batin. This wadi appeared clearly on satellite images and maps as one of the most distinct features in the area, which led to some initial misconceptions as to its military significance: “Wadi Al Batin appeared to be a geologic rift—a formidable obstacle—but on the ground it turned out to be passable for both tracked and wheeled vehicles” (Brinkerhoff et al., 1992, p. 60). Military planners initially believed that Wadi Al Batin could not be traversed, which would have significantly affected the battle plan for Operation Desert Storm.

A thorough analysis of maps and Landsat satellite images by Rinker et al. (1990, p. 5–6), which was confirmed by field reconnaissance during the war, determined that:

From Hafar al Batin to north of the border with Kuwait, the wadi is about 12.5 kilometers wide. North of the border it broadens out and the southeastern rim becomes indistinct. Near Hafar al Batin the wadi depth is about 60 m (JOG sheet), 50 m near the border, and less than 25 m in the northern part. This means a cross section of gentle slopes. A drop of 60 m over about 6 kilometers (half the wadi width), or about 1 m per 100 m, a 1% slope. The main channel slope ranges from about 1% in the southwest to nearly level in the north.

Further analysis predicted that the wadi was trafficable in all directions except for local obstacles such as rocks or loose sand. South of Hafar al Batin, the wadi is more incised and is characterized by rocky sideslopes and steep walls. Between King Khalid Military City and the Ad Dahna sands, few trails lead into the wadi. It was critical for operations planners to understand that for military operations conducted north of Hafar al Batin the wadi was not an obstacle, but farther south it could be. The characteristics of Wadi Al Batin helped shape the overall strategy of outflanking the Iraqi army in Kuwait by rapidly shifting forces west of the wadi just prior to the attack into the southern Iraqi desert.

Sabkhahs

Sabkhahs are common along the coastal plain from Kuwait to the southern end of the Arabian Gulf. Johnson et al. (1978) defined sabkhahs as saline flats underlain by clay, silt, and sand, and often encrusted with salt that are equilibrium surfaces whose level is largely controlled by the local ground-water table. Rinker et al. (1991) described two types of sabkhahs on the Arabian coast. One is arenaceous, or sand filled, and the other is argillaceous, or clay filled. The arenaceous sabkhah is formed by the in-filling of embayments of the sea with eolian sand and is typical of sabkhahs along the coast of the eastern physiographic region of Saudi Arabia. During dry periods, capillary water in the sand evaporates and concentrates as a brine near the surface, producing a soft quicksand of low bearing strength. Evaporation of standing water forms a coating of salt crystals, which can thicken into a crust. Sabkhahs are a concern for cross-country mobility because vehicles crossing sabkhahs may break through the surface crust and become mired in the mud.

Operation planners for Operation Desert Shield were concerned about trafficability along the large coastal sabkhahs near the Kuwait border. One initial concern was whether Iraqi armored columns could cross the large coastal sabkhahs from Kuwait into the eastern physiographic region of Saudi Arabia. In addition, it was important to delineate the sabkhahs and determine which ones would impede movement. Sabkhah trafficability is a valid military concern as failed crossings have resulted in the loss of life. For example, in December 1940 the British army forces attempted to cross a sabkhah covered by enemy antitank guns while pursuing Italian forces west of Buqbuq, Egypt:

Here the 3rd Hussars . . . anxious to close the range regardless of opposition, weaved aside to avoid the fire, drove hard into the salt pans and bogged to their belly-plates. Soon a line of wallowing Mark VIs were a row of burning hulks, the victims of an ill-considered attempt at charging an unshaken enemy across impossible ground (Macksey, 1971, p. 86).

Because the available maps indicated the presence of sabkhahs in almost every topographic low, some concern existed about their widespread occurrence. A terrain team with a heavily loaded five-ton dump truck and water trailer utilizing Geographic Positioning Systems (GPS), moved from map-designated "sabkhah" to "sabkhah" near the Kuwait border to establish the fact that most of those shown could be described more accurately as playas, and as long as they were dry were no impediment to cross-country mobility (Fig. 3).

Rinker et al. (1990, p. 9) encountered the same problem when comparing maps with satellite images: "The JOG sheet (NH 38-12) shows the area as wadis and sabkhahs. Note: no indication of such patterns [sabkhahs] in the image." As Landsat satellite image maps became available they were utilized to help distinguish sabkhahs from playas. Many sabkhahs on Landsat Thematic Mapper images featuring multispectral bands 2, 4, 7 (blue, green, red), have a distinct dark-brown tone

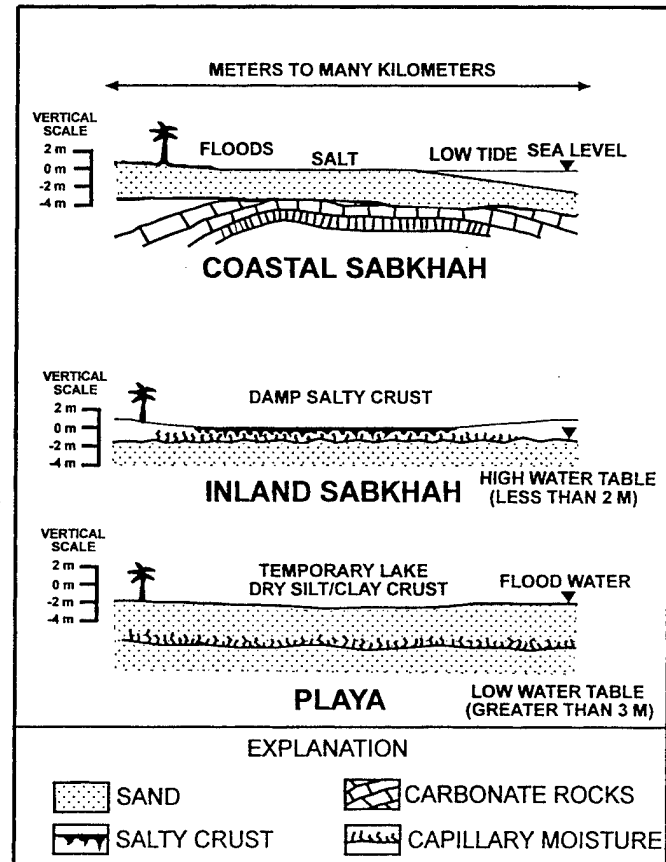


Figure 3. Idealized cross-section of sabkhahs and playas, modified from Fookes (1976). Coastal sabkhahs are influenced by tidal action and may be flooded during high tides. Inland sabkhahs are influenced by high water tables and the capillary moisture maintaining a damp salty crust. Playas are intermittent lakes with dry silt and clay crusts.

that can help distinguish them from playas (Fig. 4). But if sabkhahs are covered by dust or sand, their tone may be very similar to that of playas.

In general, playas may be described as enclosed shallow depressions in desert basins that contain deposits of evaporites from the impoundment of episodic stream flow. When dry they support foot and vehicular traffic and aircraft operations (Rinker et al., 1991). In Saudi Arabia, non-saline playas well above the water table composed of silt, fine sand, and clay had been labeled on military maps as sabkhahs. Although resembling playas, sabkhahs are characterized by the presence of salt, and the term "sabkhah" always refers to the saline, puffy, crust-surface flat basins that intersect the water table and cannot be assumed to be trafficable.

Johnson et al., (1978) described sabkhahs as either coastal or inland. Coastal sabkhahs are supratidal surfaces produced by depositional offlap of marine sediments, sometimes with the addition of eolian sediments. The associated brines are primarily from seawater. Inland sabkhahs may be many kilometers from the coast and at elevations as high as 150 m (Chapman, 1978). They represent

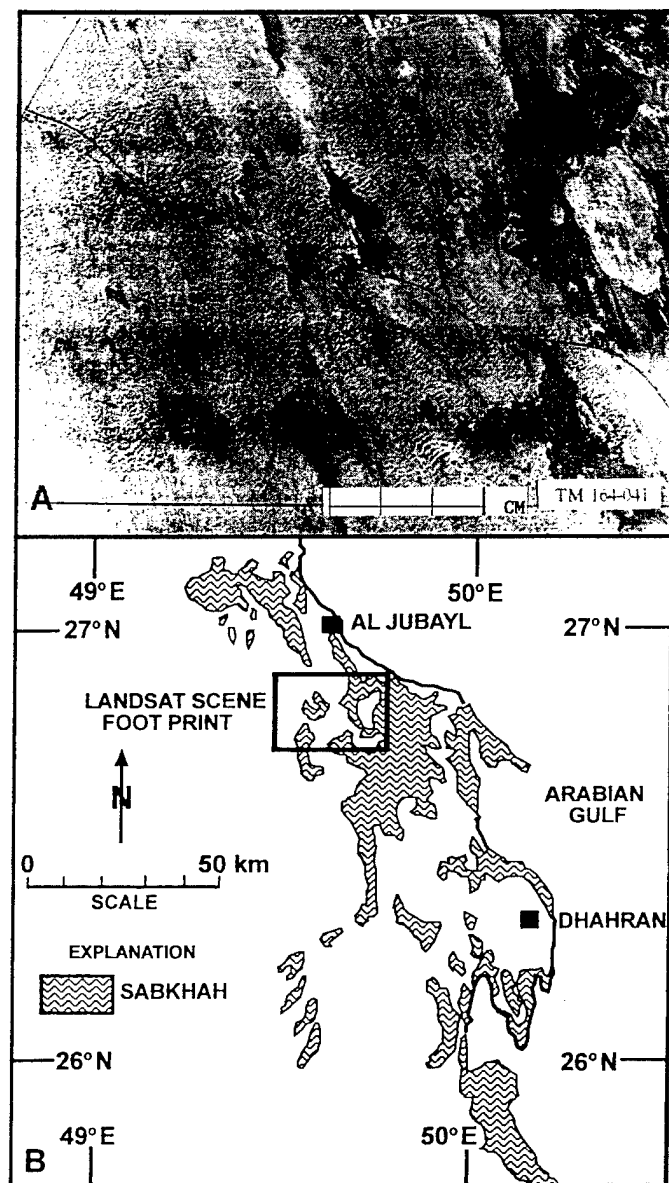


Figure 4. A. Sabkhahs and sand dunes on Landsat Scene 164-041 (09/07/87) in eastern Saudi Arabia. Sabkhahs appear as dark tone and smooth texture in contrast with the light tone and texture of surrounding sand sheets and dunes. B. Sketch map of area of Landsat scene 164-041 (09/07/87) on coastal region map modified from Johnson et al. (1978).

areas of equilibrium between eolian sedimentation and deflation, a condition controlled by the elevation of the local water table (Johnson et al., 1978). The base level of deflation is just above the capillary fringe in the sediments above the water table. Evaporation of ground water causes the formation of brine and the precipitation of evaporite minerals. The report of the U.N. Food and Agriculture Organization (1979) indicates that a discharge line of sabkhahs and springs is continuous from northwestern Iraq, through the Euphrates region into western Kuwait, and through the coastal region of Saudi Arabia and into the Ar Rub Al Khali.

Coastal and inland sabkhahs were evaluated in the field and tested to determine their effect on mobility. Heavy trucks and trailers were used to test sabkhah trafficability and pulled out where necessary. Field-expedient methods to improve trafficability were recommended; they included utilizing geotextile membranes and constructing causeways. Multispectral images can assist military planners in differentiating sabkhahs and playas by their texture and tone, but only direct observation can determine their potential trafficability.

MILITARY CONSTRUCTION

Sources of construction aggregate were needed to support sustainment engineering requirements in building and maintaining roads, heliports, and aircraft parking aprons in Saudi Arabia. Historically, construction has played a paramount role in providing the logistical support needed by U.S. combat units. Movement of these units and support units within a theater depends on lines of communication. Because of the limited number of existing roads and the difficulty of off-road mobility in the desert, considerable effort was required to construct and maintain roads forward to maneuver units. The harsh Middle East environment presented critical horizontal construction problems related to the lack of water, temperature extremes, dust, lack of construction materials, and soil conditions (Kao and Hadala, 1981). Difficult soil conditions included unstable soils (e.g., drifting sand), aggressive salty ground (e.g., sabkhahs), unsuitable construction materials (e.g., silt, fine sand, soft carbonate rock), and those soils subject to rapid erosion by wind and flash floods.

Fookes (1976) described engineering properties of various geographic units found in desert areas. He divided desert regions into four geographic zones: (I) mountain slopes, (II) the apron fan or bajada, (III) the alluvial plain, and (IV) the base plain, which includes sabkhahs, playas, salt playas, salinas, and sand dune areas. The eastern physiographic province of Saudi Arabia, the southeastern Iraqi desert, and Kuwait lie within the base plain (IV) engineering zone. This zone includes desert flats, playas and sabkhahs, and sand dunes. Fookes (1976) described this zone as the most widespread of all the zones and the one with the most engineering problems, including erratic behavior of load-bearing materials, migrating dunes, saline soil, sabkhahs, crusts, and a lack of coarse materials needed for military construction of roads and airfields.

Aggregate for military construction was not a logistical constraint in Saudi Arabia, although the quality of available materials was, in places, unsuitable for long design-life commercial projects. Limestone is the major construction aggregate in the Gulf and is extensively quarried for road metal, aggregate, and to a small extent for building stone (Johnson, 1978). Marl and marly shale are excavated for use as impermeable barriers by commercial interests, primarily for underlayments for garden areas around building sites and for military road construction in some areas. Although sand is plentiful, most of it is too fine grained, too badly graded, and too chemically impure to be used in any form of construction other than as fill. In Kuwait, "gatch," the

local term for a variety of marine-deposited sandy soils, can be used in road bases. It is composed of grains of silica sand and clay materials (Evans, 1977).

Sand and desert gravel were abundantly available to support military construction but not in concentrated deposits that were easy to exploit. Military geologists conducted reconnaissance to locate potential quarry sites in the northern and eastern provinces of Saudi Arabia for sources of construction aggregate. Existing geologic maps and global positioning receivers were critical in this effort. Existing sources were identified and technical advice and assistance were provided to host-nation forces who supported the production and transportation of aggregate from the source to the stock pile. More than 500,000 m³ of gravel were procured to repair and maintain 2,200 km of roads, construct two 48,000-person enemy prisoner-of-war camps, construct numerous helipads/aircraft bed-down sites, and assist in constructing theater logistic bases. In addition, 170,000 metric tons of asphalt, and 93,000 m³ of ready-mix concrete were used to improve and repair existing facilities for expanded military use (Mulcahy, 1992).

WATER SUPPLY

Water supply is one of the most important logistical concerns of military operations in a desert environment. In the Desert Storm theater of operations, the average rainfall is approximately 100 mm per year; no surface-water supplies exist in the area. The gently dipping sedimentary formations of the Arabian Shelf contain virtually all of the naturally occurring fresh water in the Arabian Peninsula. Aquifers of the Arabian Shelf are composed of sandstone, limestone, and dolomite, which have large areal extent and great volumes of stored water. Nine major aquifers are producing water in large volumes for industrial, agricultural, and public supply uses in Saudi Arabia (Ministry of Agriculture and Water, 1984).

Two of these aquifers, the Umm er Radhuma and Wasia aquifers, are the primary water producers in the Desert Shield area. The Umm er Radhuma provides water for most of the irrigated farms in the region from 10 to 400 m depths; the deeper Wasia aquifer provides drinking water from 70 to 800 m depths for large villages such as Hafar al Batin. The Umm er Radhuma aquifer provided water for numerous existing water wells that were used by U.S. forces as water-supply points. The Umm er Radhuma aquifer crops out along the border with Iraq and Jordan in a 50- to 100-km-wide band 1,200 km long (Ministry of Agriculture and Water, 1984). It crops out or is near the surface in much of the Desert Shield build-up area and has excellent water-bearing properties. The water quality is generally better near the outcrop and recharge areas and becomes more saline eastward (Fig. 5).

Hydrogeologic data were provided by the Saudi Ministry of Agriculture and Aramco, and military hydrogeologists and engineers worked closely with the Saudi Ministry of Agriculture to design and site new water wells. Several water wells were drilled by military teams to support rear-area operations deep in the desert, whereas others were drilled by commercial drilling com-

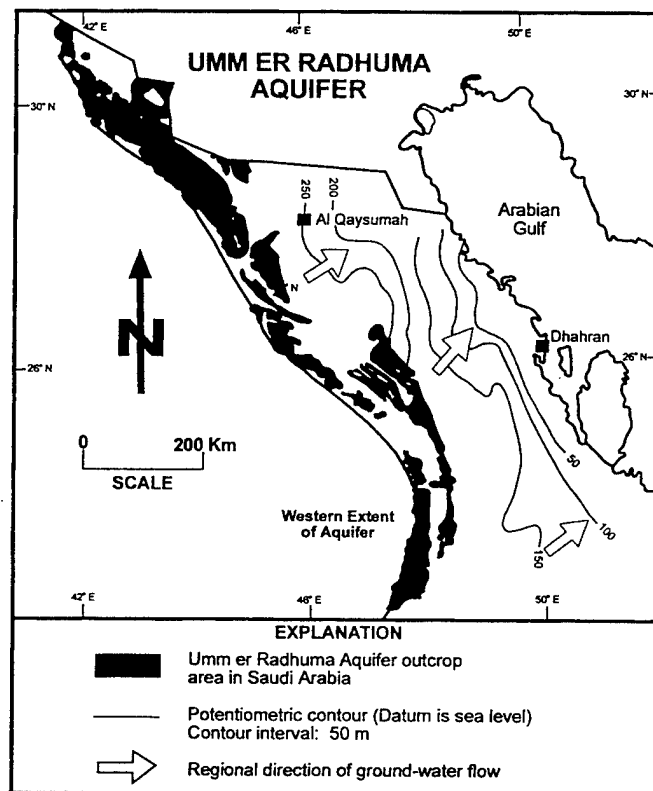


Figure 5. Outcrop area and extent of Umm er Radhuma aquifer in Saudi Arabia, modified from Ministry of Water and Agriculture (1984). Regional ground-water flow is toward the Arabian Gulf. Ground water is generally fresh in the outcrop zone and becomes more brackish toward the coast.

panies under contract to support military operations. The depth of these wells averaged 300 m.

Satellite images and aerial reconnaissance photographs were used to identify existing wells, especially in denied areas of the southern Iraqi desert. In northern Saudi Arabia, center-pivot irrigation farms and the more traditional ridge and furrow irrigated farms appear on satellite images. Water wells or springs are associated with each irrigated area. Most of these irrigation wells tap the Umm er Radhuma aquifer, although many of the water wells shown on existing maps were either dry or unusable. All potential water sources had to be verified with ground reconnaissance.

The influx of several hundred thousand soldiers into the northern Saudi Arabian desert created a tremendous water demand in a largely uninhabited region. Fortunately, the region is the recharge and outcrop area of one of the most productive aquifers in the Arabian Peninsula where the ground-water resource is well understood and exploited. This allowed for the temporary support of a large population without disrupting existing municipal or agricultural supplies.

CONCLUSIONS

During the Gulf War military geologists contributed to the success of the planning and execution of both tactical and strate-

gic operations in Saudi Arabia, Iraq, and Kuwait. Military geologists supported the terrain analysis that allowed operational planners to devise the decisive strategy that ultimately won the war. Military geologists supported the development of infrastructure to support the tremendous logistical effort required to sustain modern mobile warfare by identifying, developing, and managing sources of construction aggregate. In addition, military geologists identified the sources of subsurface water supply that insured that water never became a logistical constraint to ground forces operating deep in the desert.

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