Ground-Water Exploration in Al Marj Area, Cyrenaica United Kingdom of Libya

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1757-A

Prepared under the auspices of the United States Operations Mission to Libya and in cooperation with the Government of Libya

Newport and Haddor—GROUND-WATER EXPLORATION IN AL MARJ AREA, LIBYA—Geological Survey Water-Supply Paper 1757-A

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By T. G. NEWPORT *and* YOUSEF HADDOR

CONTRIBUTIONS TO THE HYDROLOGY OF AFRICA AND THE MEDITERRANEAN REGION

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

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GROUND-WATER EXPLORATION IN AL MARJ AREA, CYRENAICA, UNITED KINGDOM OF LIBYA

By T. G. Newport and Yousef Haddor

ABSTRACT

The present report, based largely on fieldwork during 1959–61, describes the results of reconnaissance hydrogeologic studies and exploratory drilling to evaluate the general water-bearing properties of the rocks and the availability of ground-water supplies for irrigation, stock, and village uses in Al Marj area. These studies and the drilling were conducted under the auspices of the U.S. Operations Mission of the International Cooperation Administration.

Al Marj area, located in the Province of Cyrenaica on the southern coast of the Mediterranean Sea, contains a land area of about 6,770 square kilometers. Along the Mediterranean shore is a narrow coastal plain that rises evenly to the base of an escarpment that forms the seaward front of an undulating plateau known as Al Jabal al Akhḑar. The climate is semiarid; seasonal rainfall occurs during the winter months. Owing to orographic effects, the rainfall is somewhat higher in the Jabal than in the coastal plain. The average annual rainfall ranges from about 250 millimeters in the coastal plain to 450 millimeters on the Jabal. All the streams (wadis) of the area are ephemeral and flow only in response to heavy rains of the winter season. From a drainage divide on the Jabal some streams flow north and northwest toward the sea and the others, south and southeast to the interior desert. Solution features, such as limestone sink holes, are common in the coastal plain and a large solution depression occurs near Al Marj.

The rocks of Al Marj area consist predominantly of limestone and some sandstone and shale; they range from Cretaceous to Miocene age. On the coastal plain Miocene limestone is locally mantled by Quaternary alluvial, beach and lagoonal deposits. The Miocene and older beds have a regional southerly dip. These rocks are broken by northeast-trending normal faults in the coastal and inland escarpments.

The ground-water reservoir is contained chiefly in fractures, bedding planes, and solution openings in the limestone country rock. The upper limit of this reservoir is marked by a water table which generally lies within 40 meters of the land surface in the coastal plain but is 100 meters or more below the surface of most of the Jabal and the interior desert. The ground-water reservoir is replenished chiefly by infiltration from surface-water runoff in wadis and to less extent by direct infiltration of rainfall. Ground water moves north and northwest toward the Mediterranean Sea and south toward the interior desert from a ground-water divide near the crest of Al Jabal al Akhḑar. Discharge of ground

water takes place by submarine outflow, spring flow, evapotranspiration, and withdrawals from wells.

Wells, springs, and cisterns furnish almost all water supplies for municipal, village, stock and irrigation purposes. Bengási, Al Marj, and Al Abyār are the only centers of population with municipal distribution systems. Drafts from individual dug wells used for irrigation in the coastal plain generally are no more than 10 to 15 cubic meters per day. In the Jabal and the interior desert drafts from individual stock and village wells are generally less than 10 cubic meters per day and from most wells only a few thousand liters per day.

Some 21 test wells were put down during the present investigation to depths ranging from 30 to 309 meters. The yields obtained by test pump and bailer ranged from 45 to 0.6 cubic meters per hour. With few exceptions, well yields sufficient for stock and village requirements were obtained. Well yields sufficient for irrigation even on a moderate scale, however, are not everywhere available.

In the Jabal and the interior desert the ground water is generally of good to fair chemical quality and suitable for most purposes. In the coastal plain, however, the ground water is in places moderately to highly mineralized, and consequently for irrigation use it must be applied to the land under optimum crop, soil, and drainage conditions.

INTRODUCTION

The present report, which describes ground-water exploration in Al Marj area, Cyrenaica, is part of a larger program of ground-water investigations in the United Kingdom of Libya. This program, carried on by geologists of the Geological Survey, U.S. Department of the Interior, assigned to the International Cooperation Administration's United States Operations Mission to Libya and has been in progress since 1952. The senior author, a member of the Geological Survey, was assigned to work in the Province of Cyrenaica from April 1959 to June 1961. He was ably assisted by Yousef Haddor, drilling technician of the Government of Libya.

The fieldwork on which this report is based included reconnaissance hydrogeologic studies and exploratory drilling to evaluate the general water-bearing properties of the rocks and the availability and quality of ground-water supplies for irrigation, stock, and village uses. An integral part of the exploratory program was the training of Libyan technicians in the operation of percussion-drilling machines. Fieldwork on a collateral investigation of the ground-water resources of the Bengási area (W. W. Doyel, written communication), which lies south of Al Marj area was completed in 1958.

Acknowledgment is made to the Governor of Cyrenaica, the Nazirs of Agriculture, past and present, the Nazirs and officials of the Public Works Department, and the Administrators of the districts in which the work was done. The help given by various members of the U.S. Embassy, U.S. Operations Mission (USOM), petroleum companies, and many other individuals is gratefully acknowledged.

LOCATION AND CULTURAL FEATURES

Al Marj area is located on the southern coast of the Mediterranean Sea in the Province of Cyrenaica (Wilāyat Barqah),[1] Libya. The principal cities, Al Marj (formerly Barce) and Bengási (Banghāzi), are 1,160 and 1,046 kilometers, respectively, by road east of Tripoli (Tarābulus), Libya (fig. 1). The land area, which covers about 6,770 square kilometers, includes a strip of the coastal plain northeast of Bengási (population 69,718 in 1954) and the western part of Al Jabal al Akhḑar (Green Mountain), in which Al Marj (population 9,992) is the principal agricultural center. The area contains a few permanently settled small villages, chiefly in cultivated areas, but many of the inhabitants are nomads who follow their herds over available grasslands or seminomads who live both by their herds and by cultivation of unirrigated land. The Bengási-Al Abyār road and the Libyan coastal highway, with short laterals, are the only improved roads in the area. A narrow-gage railroad runs from Bengasi to Al Marj.

Over most of the coastal plain the soil cover is thin, and much of the surface consists of rocky outcrops. Where soil and water for irrigation are available, vegetable gardening is carried on and date palms are cultivated. Grain crops grown by dry-farming methods are planted after the first rains in November or December and harvested in May or June. In the Jabal grains are cultivated and also olives, almonds, grapes, and vegetables.

CLIMATE

The climate of Al Marj area is characterized by low precipitation, high evaporation, and a wide range in temperature. During occasional winter snowstorms on the Jabal temperatures as low as (—3.9° C) 25° F, have been reported, and in summer temperatures as high as (52° C) 125° F have been reported in the coastal plain. During the winter months ideal weather prevails in most of the area with pleasantly warm days and cool nights. In summer the days are normally hot, but the nights are relatively cool because of wind movement and low humidity.

As is characteristic of the Mediterranean region, the rainfall is seasonal, occurring almost entirely in the winter months (fig. 2); owing to orographic effects, more rainfall occurs on the Jabal than in the coastal plain (fig. 3). The average annual rainfall is 282 mm (millimeters) at Al Abyār, 454 mm at Al Marj, 251 mm at Banīnah, 273 mm at Bengási, and at Sidi Rahuman-Al ‘Awaylyah. The highest

[1] Transliteration of most of the geographic names used in this report conforms to the system adopted by the U.S. Board on Geographic Names, BGN/PCGN system. Other names are left in their conventional forms.

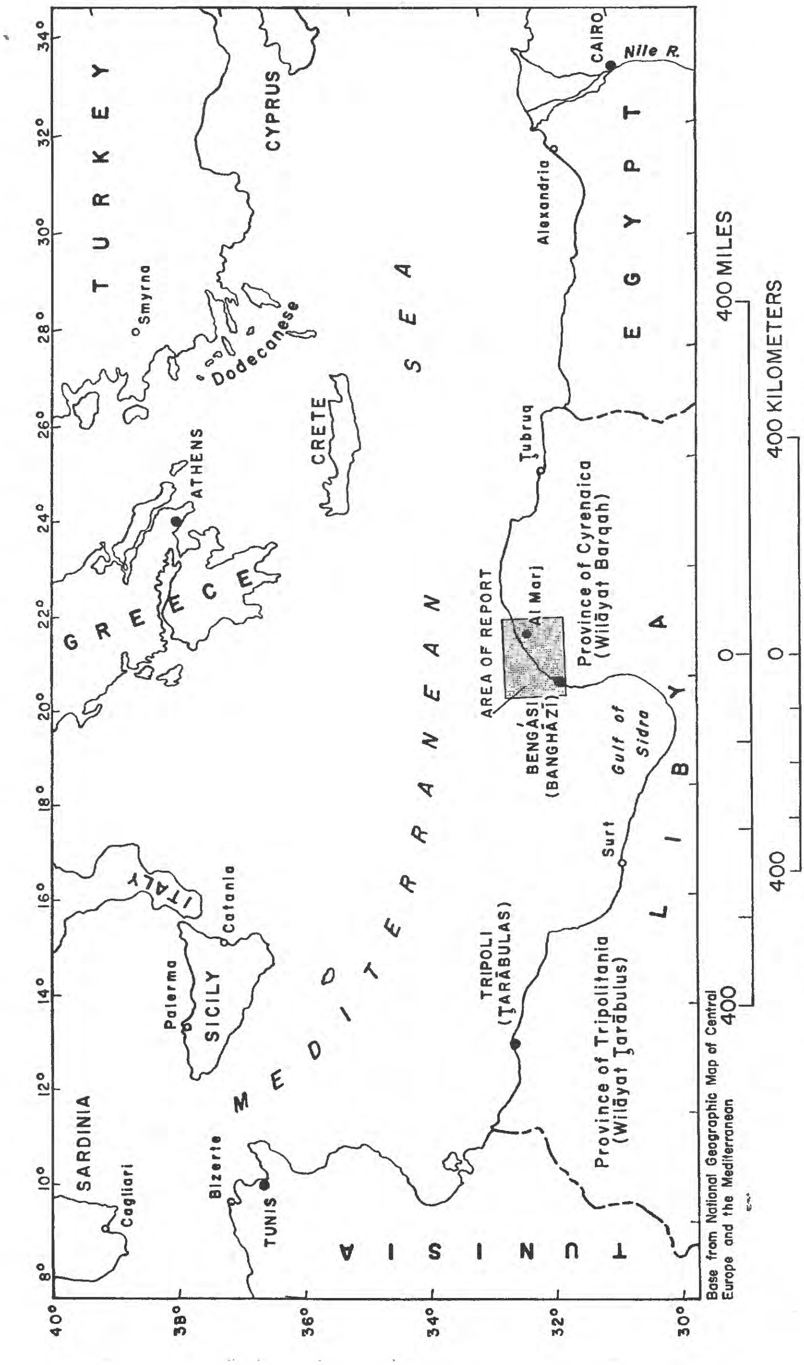

FIGURE 1.—Map of Mediterranean region showing location of area of investigation.

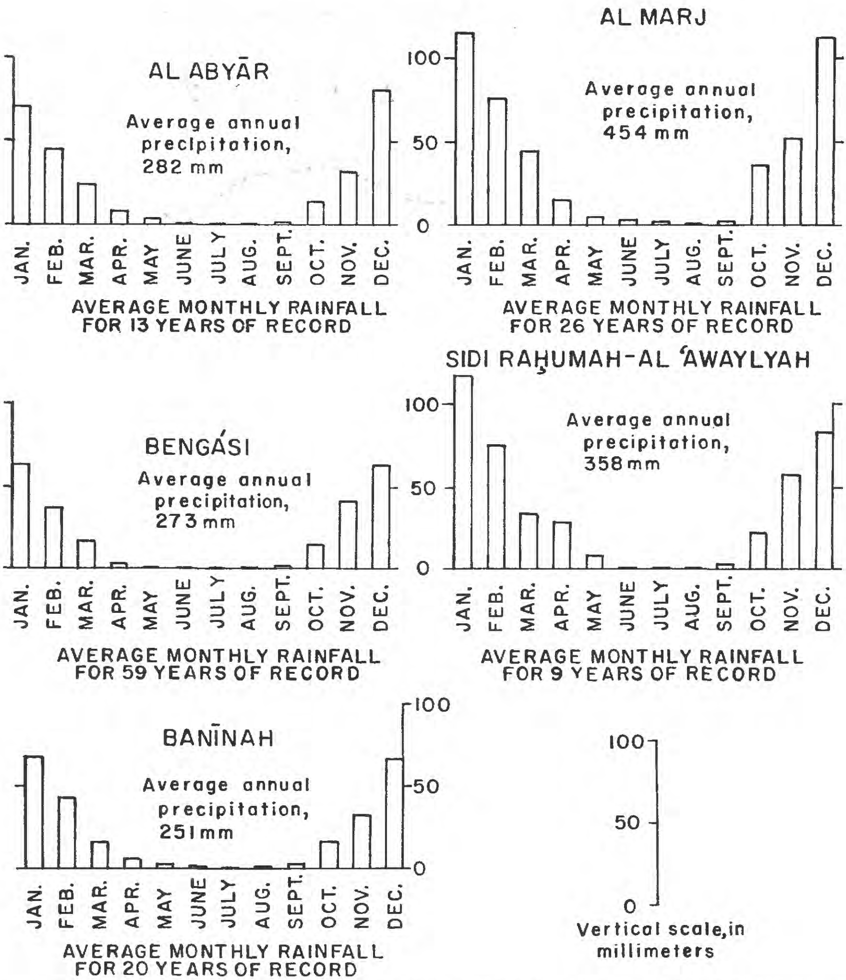

FIGURE 2.—Average monthly precipitation at Al Abyār, Al Marj, Bengási, Sidi Raḫumah-Al ʽAwaylyah and Banīnah.

recorded annual rainfall of 889 mm occurred in 1938 at Sidi Rahumah-Al ʽAwaylyah, which lies about 12 kilometers northeast of Al Marj.

TOPOGRAPHY AND DRAINAGE

The principal topographic features of Al Marj area include a narrow coastal plain and part of a dissected plateau known as Al Jabal al Akhḍar. The coastal plain is about 30 kilometers wide at the southern edge of the map area but narrows toward the north as the shoreline and the coastal escarpment of the Jabal converge.

Bordering the sea is a narrow beach and sand dune area, and in places behind the dunes are salt marshes. The coastal plain rises

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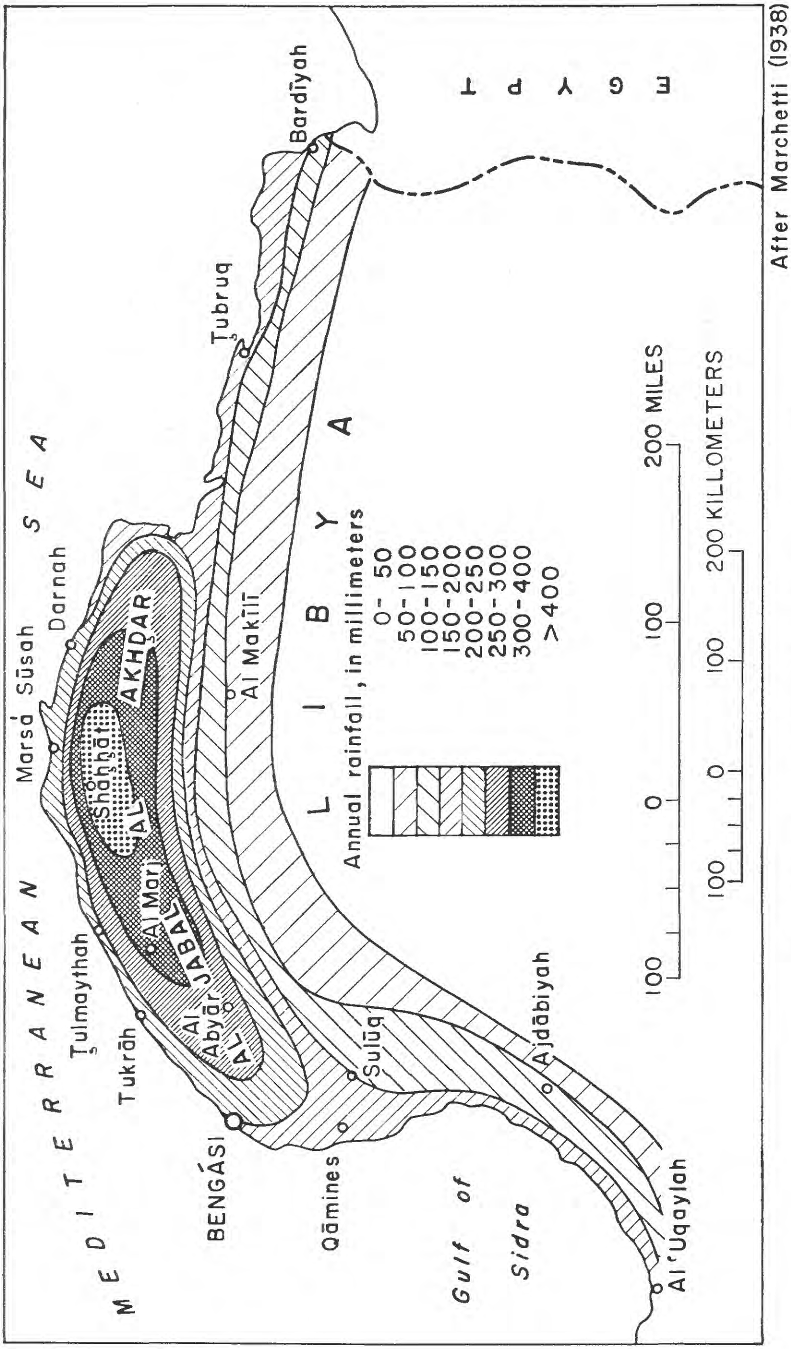

FIGURE 3.—Map showing distribution of rainfall, northern Cyrenaica.

evenly from the shoreline and salt marshes to altitudes of about 150 to 180 meters at the base of an escarpment that forms the seaward front of Al Jabal al Akhḑar. This escarpment rises sharply from the coastal plain to an elevated plateau which ranges in altitude from about 250 to 370 meters above sea level. The escarpment and the adjoining surface of the plateau are dissected by the ravines of numerous ephemeral streams (wadis), whose local relief ranges from a few tens to about 80 meters. These streams may flow during the rainy season, but only occasionally does the runoff reach the sea. A second escarpment, trending subparallel to the coastal escarpment and lying about 20 to 25 kilometers inland, begins about 20 kilometers south of Al Marj and extends northeast and east of the map (pl. 1) area for more than 200 kilometers. Near Al Marj depression the base of this escarpment lies at an altitude of about 310 meters, and the escarpment, 6 to 12 kilometers west and southwest of the rim, reaches altitudes ranging from 500 to 650 meters.

The coastal plain is underlain chiefly by limestone, covered in places by a mantle of unconsolidated deposits. Solution of the limestone by percolating water has produced many sinkholes in the coastal plain, especially in the southern part of the map area. A particularly impressive sinkhole occurs at the base of the coastal escarpment about 6 kilometers east of Banīnah. This sinkhole has vertical walls and an almost circular outline. The maximum measured depth is 38 meters, and the diameter is 44 meters. The bottom is above the water table. Large solution openings also occur in the vicinity of Al Kuwayfīyah, and a substantial ground-water flow is channeled through some of these openings. The undulating plateau of Al Jabal al Akhḑar also is underlain largely by gently dipping thin-bedded to massive limestones. Solution caves and sinks occur locally, but the largest solution feature is the depression at Al Marj. This depression contains a thick deposit of "terra rosa" soil, presumably residual from solution of limestone.

Practically all the streams of the area are ephemeral and carry runoff only in response to heavy and prolonged rainfall. When sufficient rain falls on Al Jabal al Akhḑar to cause runoff, the part of the runoff which flows toward the sea mostly seeps into the ground along the base of the coastal escarpment or into the salt marshes near the coast but the part which flows southward seeps into the sands and pervious rocks of the interior desert.

Just northeast of Al Marj, surface runoff collects in a large depression that contains an ephemeral lake (pl. 1). Most of the water that accumulates in this lake evaporates, but some percolates downward through the underlying clay and limestone to the water table. This lake fills with water about once every 5 years, commonly in January or February, but is generally dry by late summer. It is estimated that about 5,000 hectares are flooded at the maximum stage of 5 to 8 meters. The lake forms in a large depression, some 10 kilometers wide and 17 kilometers long. The low point of the lake floor is 276 meters above sea level, and the rim is approximately marked by the 300-meter contour. The water table under this depression is about 100 meters below the lake bottom. The depression has apparently been formed by solution and possibly also by slumping in the limestone country rock. Local earthquakes occur occasionally at Al Marj, and some of them are strong enough to damage buildings. These earthquakes may result from collapse or subsidence in cavernous limestone near or beneath the depression, but they may also be related to movements on the fault line just east of Al Marj.

Another ephemeral lake forms in a wadi about 6 kilometers west of test well 3 when there is sufficient rainfall on the southern slope of Al Jabal al Akhḍar to cause surface runoff. The lake occasionally fills during the winter months; however, storage is relatively small, and the water evaporates or infiltrates and the lake is generally dry by May or June. The depth to the water table beneath this lake is estimated to be about 200 to 250 meters.

Many cisterns located in the wadis of the area fill with water when there is surface runoff. Collectively, these cisterns hold many thousands of cubic meters of water that is used for the livestock during the dry season.

GEOLOGY

All the rocks in Al Marj area are sedimentary, and almost all are marine limestone, although interbedded sandstone, sand and clay occur locally. The oldest known beds are of Late Cretaceous age, but these rocks appear only in an inlier (Hey, 1956, p. 4) in the Jardas al 'Abīd area and also on the coast near Tukrāh and Ṭulmaythah (Marchetti, 1938, p. 127; fig. 4, this report). Eocene and Oligocene limestones are more widespread, but occur mainly in Al Jabal al Akhḍar area. The coastal plain is underlain by limestones largely of Miocene age, which are locally mantled by Quaternary alluvial, beach, and lagoonal deposits.

Through most of Al Marj area the regional dip of the Cretaceous and Tertiary formations is gently to the south but is modified by faulting. The seaward escarpment of Al Jabal al Akhḍar has been attributed to faulting (Marchetti, 1934, p. 324), but Pleistocene marine erosion has modified the fault line (Hey, 1956, p. 2–3). This fault line may correspond to the fault reported by Cotterell[2] in the vicinity of Banīnah and may pass into a monoclinal fold just east of

[2] Cotterell, A. P. I., and Son, 1949, Cyrenaica water resources: London, 4 pts. [Unpublished consulting report for British Military Government]

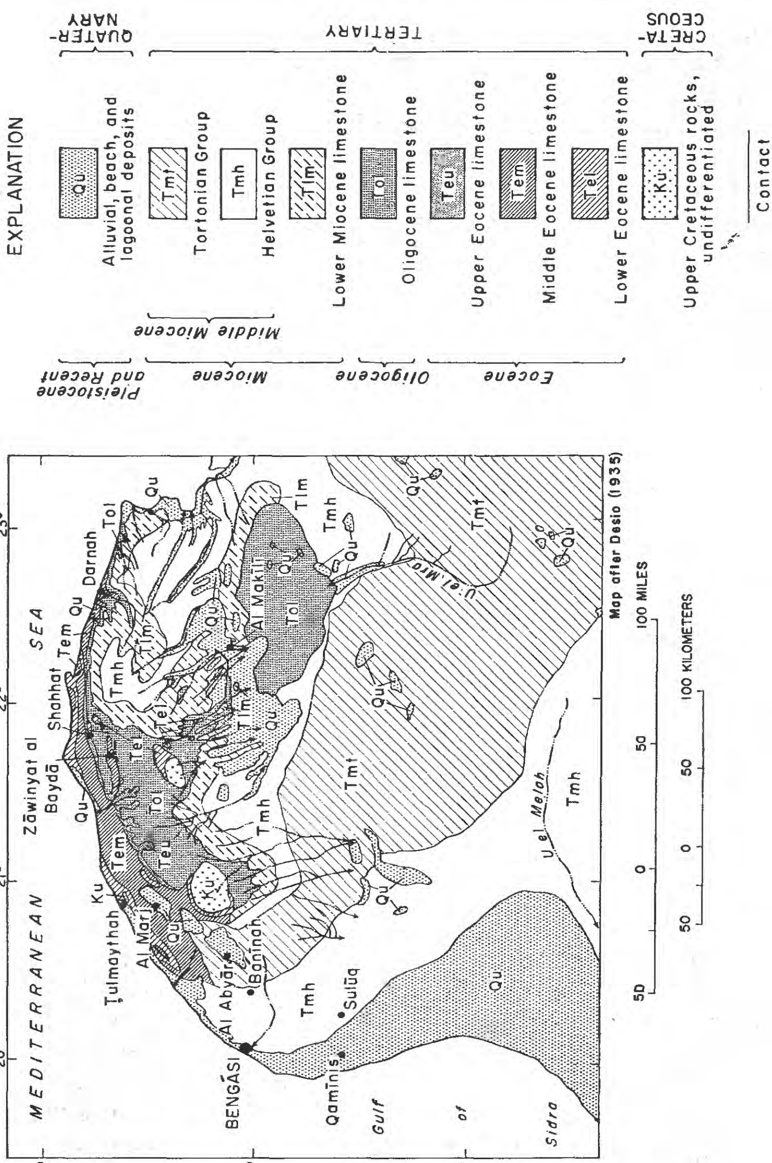

FIGURE 4.—Geologic map of northwestern Cyrenaica.

Tukrāh. The inland escarpment which lies east of Al Marj has also been attributed to normal faulting modified by marine erosion (Hey, 1956, p. 2). Along both fault escarpments the down-dropped block is to the northwest. A fault trending subparallel to the inland escarpment and passing into a monocline is also reported on the northwest side of the Cretaceous inlier at Jardas al 'Abid (Hey, 1956, p. 4).

The rock formations at or near the surface in the area are exclusively consolidated to semiconsolidated sedimentary rocks of Cretaceous to Quaternary age. These sedimentary rocks, collectively known as bedrock, are locally mantled by windblown sand, by stream deposits of silt, sand, and gravel in wadi and in local alluvial fans along the base of the coastal escarpment, and by beach and lagoonal deposits along the shoreline. The bedrock formations consist largely of limestone with some friable sandstone and clay shale whose lithologic character and water-yielding properties are summarized in table 1. These formations have not been differentiated in the field by the writers; however, they are largely a sequence of bedded limestones whose hydrologic properties are similar. In the zone of saturation they yield water to wells and springs principally from fractures, bedding planes, and solution openings. The lithologic character of the rocks of Al Marj area, as demonstrated by representative well logs, is shown graphically in plate 2. As indicated, limestones predominate, and these have been penetrated to a depth of 309 meters at Al Abyār in test well 5; this deepest test well was put down during the present investigation.

GROUND WATER

OCCURRENCE

Available data from wells and springs and from surface geology indicate that Al Marj area is underlain by a regional ground-water reservoir in which water circulates almost entirely through fractures, bedding planes, and solution openings in the limestone country rock. In addition, bodies of ground water perched on clay or shale beds occur locally. The upper limit of the regional ground-water reservoir is marked by a water table. In most of the area the first water reached in putting down wells is unconfined (under water-table conditions), but water in deeper water-bearing rocks is generally confined (under artesian pressure). For example, in test well 3 near Al Kharrūbah, water reached at a depth of 259 meters was under sufficient pressure to rise 45.7 meters, or to a level 213 meters below land survace.

Although sufficient data were not available from the present investigation to construct an accurate water-table map of the Bengási-Al Marj area, it is known that the water table has considerable relief. Bodies of water perched above the general water table complicate

TABLE 1.—*Generalized stratigraphic section for Al Marj*

[After Desio (1935)]

System	Series	Group	Formation	Lithologic description	Water-bearing character
Quaternary	Recent		Sand dunes, lagoonal clays, alluvium, and delta fans.	Sand dunes along coast, lagoonal clays in salt marshes, alluvium in wadi channels, alluvial fans at base of coastal escarpment and on inland margin of coastal plain.	Dune sand important principally because of its high absorptive capacity. Yields some fresh water to wells, but quality in places is bad.
	Pleistocene		Gargaresc Sandstone	Sandstone, calcareous, friable, irregular massive, red to white; many fragments of shells.	Yields a little water of poor quality to wells.
			Cerithium Vulgatum Sand	Sand, bedded, unconsolidated; many shell fragments.	May yield water to wells where present below the water table.
			Crostone di Steppa	Caliche, massive, some nodular, brick-red to yellow.	Not a source of water.
Tertiary	Miocene	Tortonian	Fuelhat Limestone	Limestone, sandy, fossiliferous; topped by hard gray limestone.	May yield small amounts of poor-quality water from fractures, bedding planes, and solution openings but is not an important source of water.
		Helvetian	Bengási Limestone	Limestone, sandy, silty, white. Forms all the coastal plain of Bengási.	Yields small to large supplies of water where present below water table; principal source of water for Bengási municipal wells; water is of fair chemical quality.
		Lower Miocene		Limestone, hard, crystalline, gray.	May be generally above the zone of saturation.
	Oligocene			Limestone that ranges from hard, dense, and gray to sandy, massive, fossiliferous, and tan.	May yield small to moderate amounts of water. Several springs rise from this formation.
	Eocene	Upper Eocene	Slonta Limestone	Limestone, fossiliferous, white to pink. Crops out on face of inland escarpment.	Yields some water to intermittent springs.
		Middle Eocene	Derna Limestone	Limestone, soft to dense and hard, fossiliferous, white to creamy.	Yields small to large amounts of water. Many springs flow from this formation.
		Lower Eocene	Apollonia Limestone	Limestone, dense to chalky, white to gray; some chert.	Yields small to moderate amounts of water where present below the water table. Several springs flow from this formation.
Cretaceous	Upper Cretaceous		Gerdes al Abid Limestone	Limestone, marly to hard, yellow and gray.	Yields small amounts of water to springs.
			Tocra Limestone	Limestone, hard to soft, white and yellowish white; some chert.	Yields small amounts of water to springs.

interpretation of the data. From sea-level datum on the coast, the water table rises inland to a ground-water divide that apparently lies near the crest of Al Jabal al Akhḑar. The water level at test well 11 is about 209 meters above sea level. Water levels in the vicinities of test wells 10, 16, 17 and 19 are between about 170 and 195 meters above sea level. Probably perched water bodies are tapped by nearby test wells 12, 15 and 20, in which water levels are approximately 217, 243 and 263 meters above sea level, respectively. To the southwest, water levels are about 128 meters in altitude at test well 8 and only 10 meters at test well 5. Because there is a lack of data on the altitude of the land surface in the vicinity of test well 3, the altitude of the water table there was estimated roughly to be about 75 meters. Land-surface altitudes used in these computations were estimated from published maps. From these data, the pattern of surface drainage, and sparse data from outside the report area, it is inferred that in Al Kharrūbah area the water table slopes south toward the interior desert.

The depth from the land surface to the water table depends on the relative difference between the altitudes of the land surface and the water table. In wells of the Al Marj area this difference ranges from a few meters to more than a few hundred meters. Near the salt marshes on the coast and at a few perennial spring heads, however, the water table crops out at the surface. In sand-dune areas along the shore, the water table is generally within 2 to 6 meters of the land surface. Elsewhere in the coastal plain depths to water generally range from about 5 to 40 meters. In the inland parts of the plain and near the base of the seaward escarpment of the Jabal depths to water are still greater, as for example at Banīnah in test well 4 where the water level is 83 meters below land surface. The water table in the Jabal area itself is commonly more than 100 meters below the surface. The deepest water level observed among the test wells put down during the present investigation was at test well 5, where the depth to water is 265 meters. The depths to water and total depths of test wells are indicated by well-location symbols in plate 1.

The water table in Al Marj area fluctuates with changes in the water in storage in the ground-water reservoir. If the withdrawal from the reservoir exceeds the replenishment, the water table declines; conversely, if replenishment exceeds withdrawal, the water table rises. Thus, the long-term rises or declines of the water table reflect the rates at which the ground-water reservoir is replenished or depleted. The ground-water reservoir is in equilibrium when the recharge equals discharge. The water table, however, is seldom stationary for long periods; thus, periodic water-level measurements in observation wells over periods of several years or more are necessary to understand fully the nature of changes in storage in the ground-water reservoir.

The ground water varies considerably in chemical quality from place to place in Al Marj area, but detailed analyses are not everywhere available. For descriptive purposes the following empirical terms have been adopted to indicate the general nature of water quality in this area with respect to tolerance by plant, man, and beast.

Rating	*Approximate dissolved solids (ppm)*
Good quality	<1, 500
Fair quality	1, 500–3, 000
Poor quality	>3, 000
Fresh water	<3, 000
Brackish (moderately mineralized) water	3, 000–6, 000
Salty (highly mineralized) water	>6, 000

The ground water beneath the coastal plain of the Al Marj area offers the best potential for irrigation use by pumping from wells, but quality control is essential in planning the utilization of this water. In the vicinity of the shore, the fresh water of the ground-water reservoir is in contact with salt water along an interface, or zone of diffusion. Therefore, before more intensive development is undertaken, it is important that the hazard of salt-water contamination from the Mediterranean Sea and from the coastal salt marshes be recognized and that the relationship between salt water and fresh water in the coastal zone be understood. This relationship, known as the Ghyben-Herzberg principle, results from the fact that the specific gravity of water increases with the amount of dissolved minerals in the water. Fresh water, containing less dissolved minerals, is lighter and will float on the salt water. In the coastal zone the depth to which fresh water occurs below sea level is determined by the head of the fresh water above sea level and by the difference in specific gravities of the two waters. Under conditions of equilibrium, 1 meter of fresh-water head above sea level will balance about 40 meters of fresh water below sea level. This means that if the fresh-water head is lowered 1 meter by pumping or by other means, the fresh water-salt water interface will rise about 40 meters. This is illustrated in figure 5. Thus, in order to avoid the eventuality of salt-water contamination, substantial withdrawals should not be made from wells adjacent to the coast nor should water levels in pumping wells be depressed below sea level for prolonged periods.

Three test wells (6, 7, and 9), all located about 2 kilometers from the Mediterranean shore, point up the fact that brackish water may occur at considerable distance inland, at least in parts of the coastal plain. Test well 6 at Al Kuwayfīyah, drilled to a total depth of

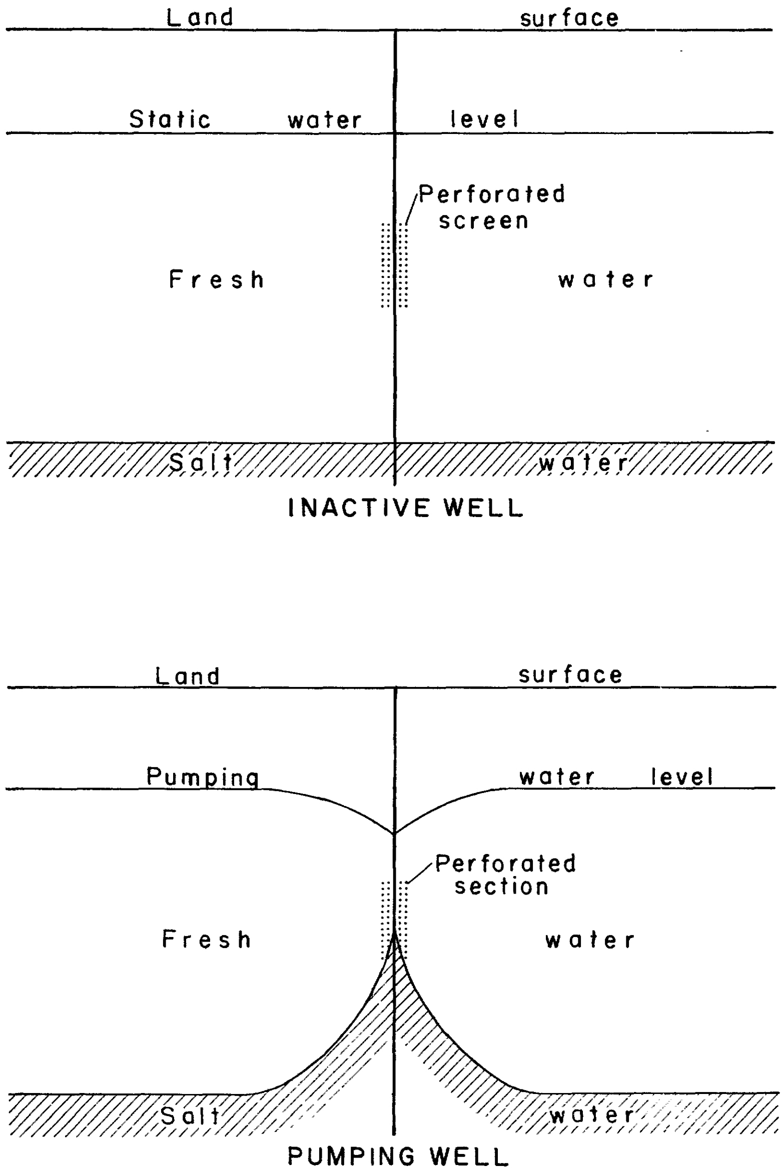

FIGURE 5.—Fresh-water and salt-water relationships in vicinity of nonpumping and pumping wells.

44.2 meters, reached brackish water in limestone at a depth of 26.8 meters. The hole was back-filled with cement to a depth of 13.7 meters above the top of an apparently impervious rock layer. Brackish water was produced by the well. A 48-hour pumping test caused no significant change in the chemical quality of the water. In test well 7, located about 5 kilometers northeast of Al Kuwayfīyah, brackish water was reached at several horizons in limestone between 5.8 meters and the bottom of the well at 30.5 meters. Test well 9, about 1 kilometer southeast of Barsis, was drilled to a depth of 48.7 meters. During a pumping test the water initially was brackish, but after 18 hours of pumping the water became very salty. The change in quality with time and the location of the well suggest that the well is at or very near to an interface of fresh and salt water.

Pumping from the pool of Umm Aqdayh, about 1 kilometer north of test well 6, for 9 hours at a rate of 500 cu m per hr (cubic meters per hour) did not change the chloride content of the water. In a subsequent test at a pumping rate of about 1,350 cu m per hr the chloride content increased from 1,300 ppm (parts per million) to 3,800 ppm after 6 hours and to 4,500 ppm after 7½ hours.

SOURCE, MOVEMENT, AND DISCHARGE

The ground-water reservoir underlying Al Marj area is recharged by direct infiltration from precipitation and also by infiltration from surface-water runoff in wadis and from ponded water in ephemeral lakes. Such recharge probably occurs only during or after relatively intense or prolonged rainstorms. Recharge from dispersed or light rain is probably negligible. Also it is probable that in years with below-average rainfall, very little or no recharge occurs.

Direct infiltration from rainfall is not considered particularly important as a source of recharge in Al Marj area, because the bulk of the rain that falls is used by growing plants, evaporates, or runs off on the surface. In some places, however, where bore limestone is exposed, water from rain sinks in directly or after running on the surface for a few tens of meters or less. This is especially true in the coastal plain where fissures, enlarged by solution, intercept the runoff. Recharge by influent seepage from irrigation ditches on the coastal plain and by infiltration of water applied to cultivated land probably also is not large. This source of recharge has been reduced, particularly since the USOM program of canal lining has been introduced. The chief source of recharge in the area is probably influent seepage from runoff through the unconsolidated deposits in the wadi channels. On Al Jabal al Akhḑar runoff is restricted to the wadis, in which infiltration is rapid owing to coarse materials. Along the base of the coastal escarpment the runoff from the wadis spreads out and sinks into pervious limestones. When runoff occurs, recharge also takes place in the wadis that drain south and southeast from the Jabal toward the interior desert.

Water in the ground-water reservoir of Al Marj area moves along flow lines that are oriented in the same direction as the slope of the water table. Generally, ground water moves north and northwest toward the Mediterranean Sea and south toward the interior desert from a ground-water divide near the crest of Al Jabal al Akhḍar. If all other factors are constant, the rate of movement is proportional to the hydraulic gradient. In some places the slope of the water table is very steep, as for example between well 20 and the coast where the gradient is apparently about 23 meters per kilometer. Elsewhere the slope of the water table seems to be relatively flat, as for example between well 4 and the coast where the gradient is only about 0.8 meter per kilometer.

Ground water of Al Marj area moves almost entirely through joints, bedding planes, and solution openings in the limestone country rock. Cavernous openings resulting from solution of limestone are relatively common and are penetrated when drilling wells. For example, a water-filled void in limestone was reached in test well 5 at a depth of 290 meters. Sinks and caves in limestone, however, are more numerous in the coastal plain and near the shoreline where natural ground-water discharge converges along flow lines and dissolution by entrained carbonic acid is concentrated on the country rock. Limestone sinks and caves are particularly evident in the part of the coastal plain lying between Bengási, Banīnah, and Sīdī Khalīfah. In one such cave near 'Ayn Zayyanah (pl. 1) ground-water velocity was measured by a cork float, and the water was found to be moving toward the sea at a rate of about 0.25 meter per second. Dye experiments using potassium uranian dye to measure ground-water velocities in limestone caves near 'Ayn Zayyanah were also made, but these were not successful.

Water is discharged from the ground-water reservoir of Al Marj area by submarine outflow, spring flow, evapotranspiration, withdrawals from wells, and infiltration. Discharge of ground water by outflow below sea level probably forms an important element of the total discharge. Springs and seeps occur at several places near the coast. They also occur in several ravines and wadis of the coastal escarpment (pl. 1). Most of the springs in the coastal escarpment and farther inland are intermittent. They may flow for a few months after the winter rainy season but generally go dry by midsummer. The chief perennial springs with substantial discharge are those at 'Ayn Zayyanah near Al Kuwayfīyah, where water issues near sea level from solution channels and fractures in limestone and moves into a sinkhole pool known as Blue Lagoon. The pool empties through a narrow breach in coastal sand dunes into the Mediterranean Sea. The water is salty with a chloride content of about 7,450 ppm. Brackish water (about 4,900 ppm chloride) is found in a spring-fed pool, known locally as Rommels Pool, which is 5 kilometers northeast of

Bengási. Other spring-fed pools that contain brackish water lie inland from 'Ayn Zayyannah and Rommels Pool. Chloride contents reported for some of them range from about 700 to 1,300 ppm. Another brackish-water spring, known as 'Ayn as Salmānī, occurs in the salt-flat area northeast of Bengási. About 6 kilometers east of Bengási are Lete Grottoes, a chain of collapsed caverns in limestone through which brackish ground-water circulates. The Blue Lagoon and the other pools are formed in solution depressions similar to those that are common along the Mediterranean coast in Libya and Egypt.

Discharge from the ground-water reservoir by evapotranspiration takes place where the water table is at or within a few meters of the surface. Such discharge is probably concentrated chiefly in and near the salt marshes along the coast (pl. 1). Water is withdrawn from wells for municipal, village, stock, and irrigation purposes throughout the area, but the draft is concentrated chiefly in the coastal plain. For example, there are about 200 wells, mostly used for stock, village and irrigation purposes, in the coastal plain but less than 150 wells scattered throughout the remainder of the report area. The withdrawals from individual irrigation wells in the coastal plain are estimated to range generally from about 10 to 15 cubic meters per day. Thus the gross draft from these wells in the plain may approximate 2,000 to 3,000 cubic meters per day. In addition, about 11,850 cubic meters a day are withdrawn from wells and infiltration galleries for the Bengási municipal supply. The drafts from wells in Al Jabal al Akhḑar are generally smaller than those in the coastal plain, owing to the greater depths to water and to the consequent difficulty and expense of lifting the water to the land surface. In the Jabal and the interior desert the gross draft of water from existing wells may be no more than a few thousand cubic meters per day.

UTILIZATION

Wells, springs, and cisterns furnish almost all water supplies for municipal, village, stock, and irrigation purposes in Al Marj area. Springs and cisterns are used seasonally for small village and stock water supplies, but during prolonged dry periods these are not as dependable as wells. Bengási, Al Marj, and Al Abyār are the only centers of population with municipal distribution systems. Bengási obtains its water supply from (1) a system of infiltration galleries and wells at Al Fuwāyhat, near the southern edge of the city, that furnishes about 3,750 cu m per day and (2) four wells near Banīnah that collectively can yield about 12,750 cu m per day, although their normal production is about 8,000 cu m per day. It is estimated that four other wells in the Banīnah area, which are available for standby use, can produce an additional 9,500 cu m per day. Water from the

Al Fuwāyhat source contains about 550 ppm chloride and that from the Banīnah wells from about 200 to 490 ppm. A shallow collecting gallery at Al Manāstīr in a sand-dune tract on the coast about 5 kilometers north of the city formerly furnished about 340 cu m per day to the Bengâsi supply, but this source has been discontinued in favor of the Banīnah wells. The water from Al Manāstīr contains about 1,100 ppm chloride.

Some smaller villages have wells equipped with windmill or hand-lift pumps but no system of water distribution. Water from dug wells used principally for nomads' herds at many points is lifted by no more than a simple handline and goatskin bag. The draft from individual village and stock wells is generally less than 10 cu m per day, and from most wells it is only a few thousand liters per day.

Irrigation by water from wells is practiced chiefly in the coastal plain, where water is relatively near the surface, that is, at depths of less than 25 meters. Most of the wells are dug and commonly penetrate water-bearing material no more than a meter or two. Water from dug wells is withdrawn mostly by a "dalu," a skin bag raised and lowered on a rope that is passed over a windlass or sheave and hitched to a donkey, camel, or cow. Most dug wells will only yield water for a few hours at a stretch, because either the water level is drawn down to the bottom of the well or the mineral content of the water increases to an undesirable concentration. Individual wells, using a dalu, generally will yield only about 10 to 15 cu m per day, a quantity sufficient to irrigate an hectare or two of garden, grain, or fruit crops. An irrigated tract typical of the coastal plain is located in the vicinity of Al Kuwayfīyah, where large-diameter dug wells, 6 to 9 meters deep, yield water sufficient for irrigation of small garden plots. The water contains about 2,600 ppm dissolved solids and occurs in nearly flat-lying limestone. The fresh water tapped by the wells apparently floats on salty water. The common local practice of constructing wells that bottom only a meter or two below the water table is advantageous; the fresh water drawn from wells is skimmed off the underlying salt water.

TEST DRILLING

During the course of the present investigation (1959–61) and in years immediately prior to the senior author's assignment in Libya, some 21 test wells were put down in Al Marj area to determine the depth to water and the quantity and quality of water locally available for irrigation, stock, and village use. The wells were put down to depths ranging from 31 to 309 meters. The yields obtained by test pump and bailer ranged from less than 0.6 to 45 cu m per h. The test wells, all 6-or 8-inches in diameter, were drilled by the Libyan-

American Joint Services using percussion-drilling machines. A few of the wells were not completed or failed to reach water, owing to limitations of the drilling equipment, lack of casing, or inexperience of drilling crews; but from most wells hydrologic data of significant interest were obtained. On completion of each well, a bailing test was made in order to clean the hole and to determine if enough water was available to warrant installation of a turbine test pump, which could be used only where the water level was less than 75 meters below land surface. In most of the test wells, however, the water level was at a greater depth. Each test well is described briefly in following paragraphs; and the locations, together with relevant hydrologic data are shown in plate 1. Selected graphic logs of test holes are shown in plate 2.

Test well 1 at lat 32°39′ N., long 21°02′ E., was drilled to a total depth of 103 meters, but water was not reached.

Test well 2, near Ar Rajmah, at lat 32°04′ N., long 20°20′ E., was drilled to a total depth of 203 meters. Again water was not reached, owing to bad caving in the hole and to lack of casing to control the caving. This well is located just east of the coastal escarpment and when completed can be used as a water-supply well for the village of Ar Rajmah.

Test well 3, near Al Karrūbah, at lat 32°02′ N., long 21°13′ E., was drilled to a total depth of 264 meters. Water under artesian pressure was reached at a depth of 257 meters in limestone, and the water rose to 213 meters below land surface. At the total depth the well was bailed for 6 hours at a rate of about 1.2 cu m per h. On completion of the bailer test, a short length of casing was installed, and the well was capped. The well is proposed for inclusion in the observation-well network for monthly measurement of water level. The water is of good chemical quality as indicated by the analysis given in table 2.

TABLE 2.—*Chemical analyses of water from selected test wells in the Al Marj area, Cyrenaica, United Kingdom of Libya*

[Chemical constituents in parts per million. Analyses by Chemical Laboratory, Libyan-American Joint Services]

Well	Depth of well (meters)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids	Specific conductance (micromhos at 25° C)
3	263	11-5-58	11	Tr.	100	182	98	79	354	1,070	1,730
4	142	5-22-59	18	Tr.	45	146	106	35	117	696	1,110
7	34	7-7-59	24	Tr.	--------	--------	264	92	1,160	--------	4,100
8	260	3-12-60	--------	--------	--------	--------	--------	--------	275	--------	1,430
10	140	6-2-58	23	Tr.	95	155	283	58	271	834	1,400
20	164	5-20-59	22	Tr.	138	134	195	30	172	944	1,520

Test well 4, near Banīnah, at lat 32° 05′ N., Long 20°14′ E., was drilled to a total depth of 142 meters. Water was first reached at a depth of 99.6 meters. As drilling progressed, a soft water-bearing sandy limestone was reached at a depth of 121 meters that continued to the bottom of the well. The static water level on completion of the well was 83 meters below land surface. The results of a bailing test at the total depth indicated that a moderate to large yield can be expected from this well. The Public Works Department of Cyrenaica installed a pump, and a short pumping test was made. No appreciable drawdown was observed after 4 hours of pumping at a rate of 45 cu m per hr. A chemical analysis given in table 2 indicates the water is of good quality.

Test well 5, near Al Abyār, at lat 32°11′ N., long 20°35′ E., was drilled to a total depth of 309 meters. A very small amount of water was first reached in limestone at a depth of 67 meters. As drilling progressed, this water, which is perched above a shale bed was sealed off when the well was cased to prevent the shale from caving and closing the hole. Water under artesian pressure was found in limestone at a depth of 285 meters. The water rose 20 meters, or to 265 meters below land surface. Penetration of a void from 290 to 291 meters did not change the water level or the chemical quality of the water noticeably. Between 295 and 305 meters a soft water-bearing sandy limestone was penetrated that is very similar to the limestone in the bottom of test well 4. In a bailing test at the total depth, the well yielded 1.2 cu m per hr with no measurable drawdown.

Test well 6, near Al Kuwayfīyah, at lat 32°12′ N., long 20°09′ E., was drilled to a total depth of 44.2 meters. This well is in an area that contains many limestone sinkholes some of which are shown in plate 1. Salt water was found in limestone at a depth of 26.8 meters. The hole was back filled with cement to a level 13.7 meters below land surface. Brackish water containing 1,160 ppm chloride was then drawn from the well. The turbine test pump was then installed, and a 48-hour test was made. With a static water level 4.3 meters below land surface and discharge of 30 cu m per hr the drawdown was 0.5 meter. Water samples taken every 2 hours during the pumping test indicated no change in the quality of the water.

Test well 7, near Sīdī khalīfah at lat 32°14′ N., long 20°11′ E., was drilled to a total depth of 30 meters. Brackish water was reached at a depth of 5.8 meters. Water samples taken from different depths in the well all contained dissolved solids in such high concentration as to make the water poorly suited for either human or agricultural use. A partial chemical analysis given in table 2 indicates a chloride content of 1,160 ppm.

Test well 8, about 13 kilometers southwest of Al Marj, at lat 32°24′ N., long 20°48′ E., was drilled to a total depth of 260 meters. Water of good chemical quality was reached at a depth of 217 meters. A bailing test made at the total depth indicates a sustained yield of only 0.6 cu m per hr. This well should have been drilled deeper, but owing to mechanical difficulties with the drilling machine the work was stopped. The chloride content of the water is 275 ppm.

Test well 9 near Barsis, at lat 32°29′ N., long 20°30′ E., was drilled to a total depth of 48.7 meters. The turbine test pump was installed, and a pumping test was made. With a water static level 14.3 meters below land surface and at a pumping rate of 13 cu m per hr, the drawdown was 6.1 meters. After 18 hours of pumping, the water became very salty, and the test was stopped. A short length of casing was installed, and the well was completed for water-level observations.

Test well 10, near Al Marj, at lat 32°28′ N., long 20°52′ E., was drilled to a total depth of 190 meters. Water of good quality was reached at a depth of 125 meters. After being backfilled to 140 meters the test well was bailed at a rate of 3.7 cu m per hr. This well was formerly used for water-level observations but is now (1960) a production well. As indicated by the analysis in table 2, the dissolved-solids content of the water was only 834 ppm.

Test well 11, at Farzūghah, at lat 32°29′ N., long 20°42′ E., was drilled to a total depth of 158 meters. Water of good quality was reached in limestone at a depth of 112 meters. A bailing test at the total depth indicated a low potential yield for this well. Because of the shortage of water in the area, however, a windmill and pump were installed so that the well could supply water for the village.

Test well 12, on Al 'Awaylyah West livestock farm, at lat 32°29′ N., long 20°49′ E., was drilled to a total depth of 185 meters. At the total depth a bailing test at a rate of 1.2 cu m per hr indicated no measurable drawdown from the static water level of 138 meters. A windmill and pump were installed on this well to provide water for the livestock farm.

Test well 13, south of Tukrāh, at lat 32 30′ N., long 20°32′E., was drilled to a total depth of 36 meters. Water of good chemical quality was reached at a depth of 12.2 meters below land surface. At the total depth the hole was bailed for 6 hours at a rate of 1.6 cu m per hr with no measurable drawdown. The quality of the water remained good throughout the test. This well is currently used for observation of water levels.

Test well 14, east of Tukrāh, at lat 32°32′ N., long 20°34′ E., was drilled to a total depth of 37 meters. The static water level was at 18.3 meters below land surface. At the total depth a short bailing test at the rate of 1.2 cu m per hr did not lower the water level appreciably. Water of good chemical quality was obtained from this well.

Test well 15, northwest of Al Marj, at lat 32°32′ N., long 20°53′ E., was drilled to a total depth of 76 meters. Water was reached in limestone at a depth of 47 meters. At the total depth the well was bailed at a rate of 2 cu m per hr with no measurable drawdown. When a turbine pump was installed, the well produced 5 cu m per hr. Casing was installed, but vandals filled the well with rocks.

Test well 16, 1 kilometer west of Al 'Awaylyah school, at lat 32°33′ N., long 20°59′ E., was drilled to a total depth of 146 meters. The static water level at the time of completion was at 126 meters. The well, which supplies part of the water used at Al 'Awaylyah school, yields 1 cu m per hr.

Test well 17, at Al 'Awaylyah school, at lat 32°33′ N., long 20°59′ E., was drilled to a total depth of 186 meters. Water was reached at a depth of 125 meters. The static water level at the time of well completion was at 111 meters. The chemical quality of the water was good. At the total depth a 6-hour bailing test at an average rate of 1.2 cu m per hr indicated a drawdown of 5 meters. Because of the shortage of water at the school, this well was developed as a supply well.

Test well 18, near Al Bayāḍah, at lat 32°33′ N., long 21°15′ E., was drilled to a total depth of 142 meters. Drilling was stopped before water was reached because of insufficient drilling cable.

Test well 19, north of Al Marj, at lat 32°36′ N., long 20°57′ E., was drilled to a total depth of 152 meters. The static water level at the time of well completion was at 120 meters below land surface. The chemical quality of the water is good. At the total depth the drawdown in a bailing test was 4 meters at a discharge rate of 1.2 cu m per hr.

Test well 20, at Baṭṭah, at lat 32°40′ N., long 21°07′ E., was drilled to a total depth of 164 meters. Water of good chemical quality was reached at a depth of 98.4 meters. At the total depth no measurable drawdown occurred when the test hole was bailed at 1.6 cu m per hr. A windmill and pump were installed on this well to supply the village with water. As indicated by the chemical analysis in table 2, the water contains only 944 ppm dissolved solids.

Test well 21, east of Tukrāh, at lat 32°31′ N., long 20°36′ E., was drilled to a depth of 46.8 meters. The static water level was at 30.6 meters below land surface. The well was bailed at 1.2 cu m per hr.

CHEMICAL QUALITY

As is characteristic of semiarid and arid regions of the world, the ground water of the Al Marj area is moderately to highly mineralized. This condition presumably results from a relatively slow rate of ground-water circulation through the rocks in comparison with the rate at which soluble salts become available for dissolution by percolating water.

Analyses of water from selected wells given in table 2 and chloride analyses and specific-conductance measurements made in the field indicate that the ground water in the Al Jabal al Akhḑar and in the interior desert is of good to fair quality, generally containing less than 1,500 ppm of dissolved solids. In parts of the coastal plain, however, as for example at test wells 6 and 7, at ‘Ayn Zayyanah, and at test well 9 near Barsis, the ground water is highly mineralized. On the other hand, at test well 4 near Banīnah and at test wells 13 and 14 near Tukrāh the ground water is of good quality.

The variable quality of the ground water in the coastal plain points up the need for closer evaluation of areal distribution of salinity before further development of water for irrigation is undertaken. Water having a dissolved-solids contents even higher than 1,500 ppm, however, can be used successfully for irrigation in the coastal plain, if salt-resistant crops are cultivated, the water is properly applied to the land, and the soil is well drained. Use of highly mineralized water for irrigation no doubt requires considerable experience and judgement on the part of the cultivator if crop failures are to be avoided.

CONCLUSIONS

The ground-water reservoir in Al Marj area is likely to be the chief source of sustained water supplies for some years to come. The amount of water, however, that can be withdrawn from the reservoir without excessive lowering of ground-water levels depends on the transmissibility, storage capacity, and recharge to the reservoir. None of these factors were evaluated quantitatively during the present investigation but should be before any intensive development is undertaken, particularly in the coastal plain. Quantitative studies are difficult in limestone terranes and may require many tests before valid results can be obtained.

With respect to irrigation from ground water on a moderate scale, only the coastal plain can be considered, because elsewhere in the area water in wells would be too deep for economical pumping. Even in the coastal plain, pumping from wells located within a few kilometers of the shoreline could lead, with time, to salt-water contamination in areas of withdrawal. As suggested by the evidence of test wells 6, 7, and 9 and other shallow wells, salty or brackish water may be present in a considerable part of the shoreline zone of the ground-water reservoir. Also much of the ground water beneath the coastal plain may be moderately to highly mineralized. Consequently, for successful irrigation the water must be properly applied to the land under conditions of good subsoil drainage.

With respect to well yields and water quality, the part of the coastal plain between Al Kuwayfīyah and Banīnah merits exploration by test drilling. This area has not yet been adequately explored and may be underlain by water of fairly good quality.

In Al Jabal al Akhḑar and the interior desert to the south, the depth to water is commonly more than 100 meters, so that pumping for irrigation except for small-scale subsistence requirements, is probably uneconomical. Small village and stock water supplies can generally be obtained from wells in most places, and the ground water is generally of good to fair chemical quality. The chief problems are the technical and financial resources necessary for the construction of deep wells and the installation and maintenance cost of pumping equipment for high lifts.

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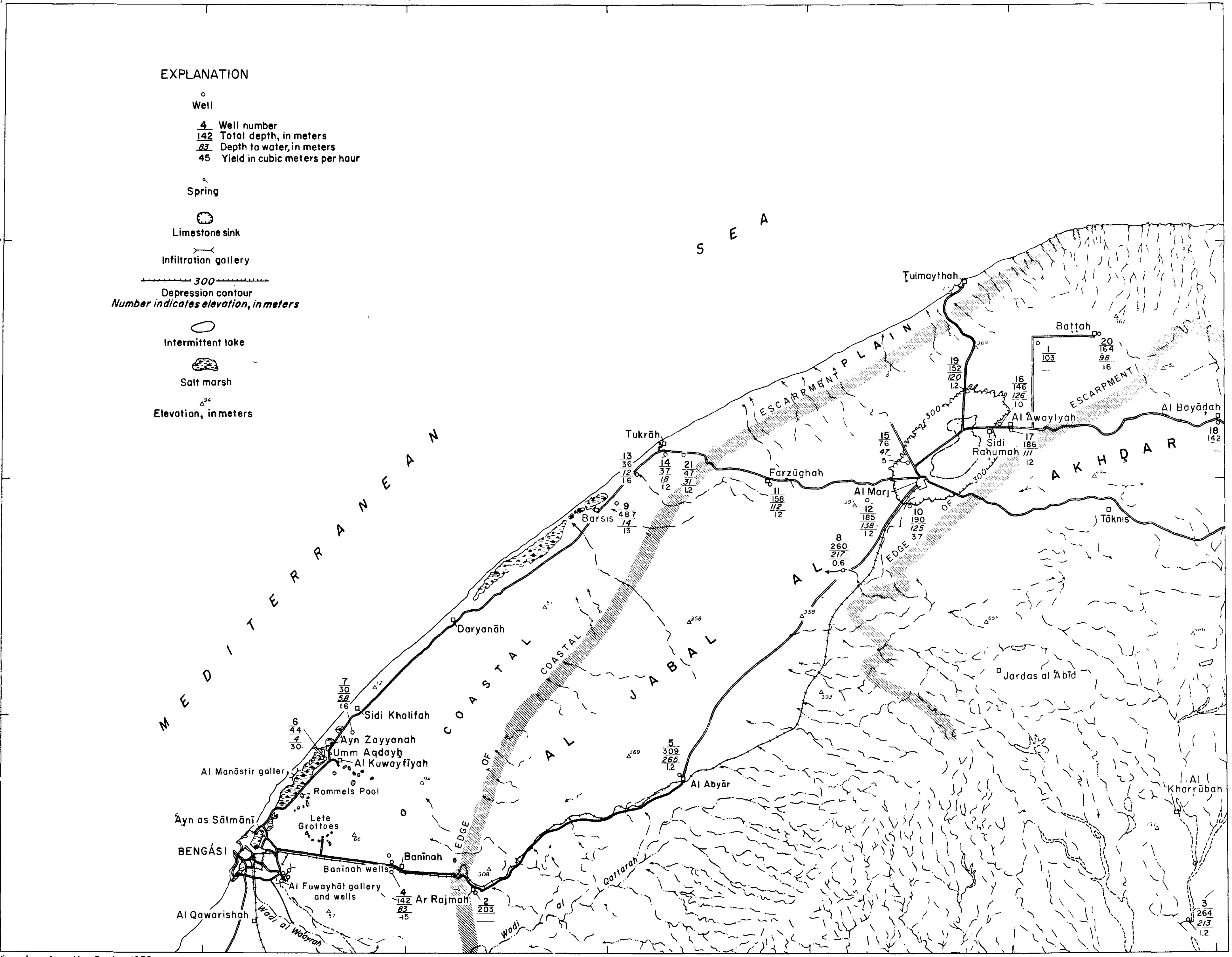

MAP OF AL MARJ AREA SHOWING LOCATIONS OF WELLS AND SPRINGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETER

678729 O - 63 (In pocket)