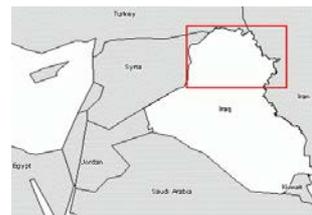


PHOTO ALBUM

KARST OF MIDDLE EAST

by ZORAN STEVANOVIĆ¹

KARST OF NORTHERN IRAQ



Iraqi territory lies in the border between two main geostructural units: Arabian part of African platform and Asian branches of Alpine geosyncline. The largest part of northern Iraq belongs to the second unit. In general, three major tectonic zones are developed in northern Iraq (from North to South): Thrust Zone; High Folded Zone; Low folded Zone. About 35% of northern Iraq is covered by carbonate rocks with different degree of karstification. Many large caves and karstic springs that existing in the area are the consequence of well developed karstic aquifers and intensive groundwater circulation.

Two main aquifer systems developed in carbonate rocks are generalized in the region:

1. *Karst aquifer "Bekhma"* (including Naopurdan, Qamchuga, Dokan, Kometan, Bekhma, Aqra, Sarmord and other Cretaceous / Paleocene age formations developed mainly in carbonate facies (limestones and dolomites and their varieties). The aquifer system is widespread in northern and central northern Iraq;
2. *Fissured-karstic "Pila Spi" aquifer* in the central-southern area (Eocene limestones, including Sinjar and Khurmala carbonate formations of similar ages).

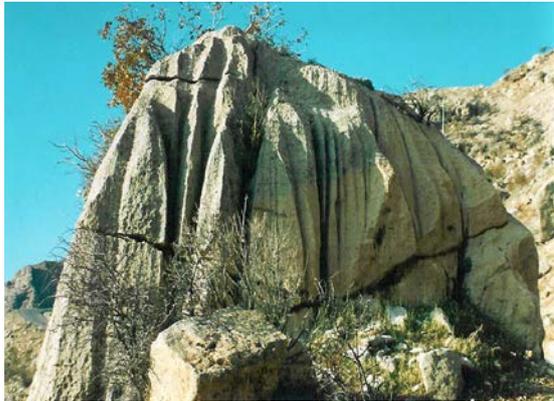
Karst aquifer "Bekhma" contains large groundwater reserves, but varying in space and time. This aquifer is highly fissured, characterised by great thickness and large surface area. The high discharge capacity often characterises deep wells drilled in the karstified rocks. In most cases their depth ranges between 100-150 m. During pumping tests the registered yields sometimes reached 40-50 l/s, with very little drawdown.

Fissured-karstic aquifer "Pila Spi" also contains medium to large groundwater reserves. This aquifer (up to 200 m thick) is characterised by a continuous surface extension in the NW-SE direction in the central and southern area of northern Iraq. The aquifer is of great significance to

¹ Professor Zoran Stevanović working for the three years as Consultant of the FAO/UN in Iraq (2000-2003). He was the Technical officer and Head of Groundwater Unit in FAO Programme in Northern Iraq under UN SCR 986. Stevanović was author and officer in charge of the project "Sustainable Groundwater Use for Irrigation Purposes in Northern Iraq" which included groundwater (GW) assessment and groundwater exploitation components (executed by the unit with some 200 employees, half of them drilling crews for 22 operational rigs). Under this project complex geological and geophysical surveys of the region, 500 deep wells, 25 geological and hydrogeological maps (1:500.000 and 1:100.000 scales), establishment of GW network in Northern Iraq (some 300 water points) as well as creation of GW Database, have been also executed. The results are published into two volumes of "Hydrogeology of Northern Iraq" (2004, FAO Rome).

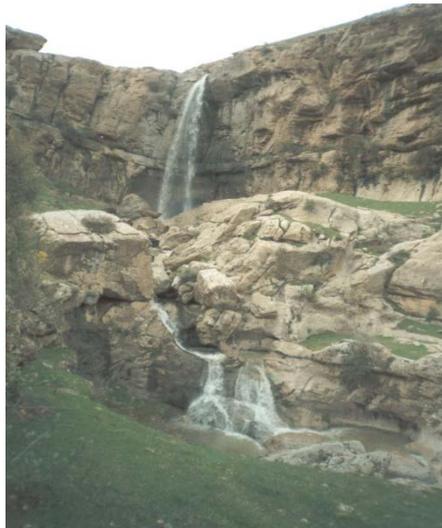
the irrigation and water supply of large towns (Dohuk, Salahaddin and Koysinjaq). In general, the base of karstification is deeper than 80 m, and many wells drilled in this aquifer reach a total depth of 120-150 m. A high permeability usually enables a high discharge from the pumped well, and the estimation of the specific capacity shows some outstanding values, particularly for the wells drilled in the Pila Spi aquifer (e.g. 20 l/s/m' to 50 l/s/m' Kani Sheitan). The Pila Spi aquifer is often covered by younger Lower Fars sediments, thus typically confined conditions are created. High artesian pressure and discharge of around 50 l/s were observed when a few drilled wells reached the Pila Spi limestones at 50 m or more.

Out of 450 deep wells drilled under FAO Programme in northern Iraq (2000-2002), some 60 wells were drilled in Bekhma and 82 deep wells in Pila Spi aquifer. These wells have a total potential capacity of over 1 m³/s. Once the average capacity of deep wells in these two aquifer systems was compared, it was noticed that Pila Spi wells are generally more productive (av. yield is 8.3 l/s, while Bekhma wells' optimal capacity is equal to 5.9 l/s).



Carbonate karst

Karrens in highly karstified massive limestones of the Late Jurassic (Naopurdan Fn., Korak Mt., Erbil gov, left.); Folded Cretaceous limestones of Pira Magroon anticline (near Dokan, right)



Highly folded Cretaceous limestones Dokan Fm. at Dokan Lake bank (left); Small waterfall activating only during the floods, Cretaceous limestones Qamchuga Fm. (Rawanduz, right)

Photo album



Eocene Pila Spi Fm. limestones, vertical eroded strata (Darbandikhan, left); Entrance to world's famous Shanadar cave, one of the oldest discovered and investigated settlements where skeleton of Neanderthals were found (Mergassor, Erbil Governorate)



Speleo-themes from Baston cave (Bekhma limestones, Bradost Mt., left) and Kuna Ba cave (Pil Spi limestones, Gulan Mt., right)



One of the largest karstic springs in the region, Bekhal gravity spring, near Rawanduz ($Q_{min} = 0.7 \text{ m}^3/\text{s}$)



Gali Ali Beg (Rawanduz, left) and waterfall on travertine deposits near Dohuk

Eveportic karst



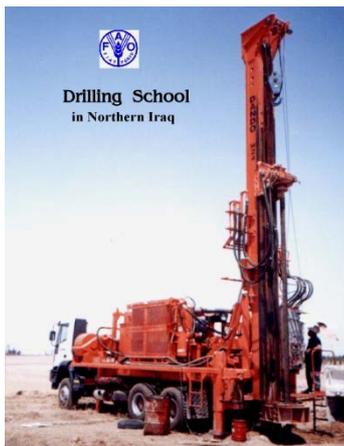
Awa Spi spring ("White water") sulfuric water spring issued from Eocene Pila Spi Fm. in contact with Miocene Fars Fm. (Sangaw, Garmian area, left) and salty karstic spring Qayatool (Sangaw, Garmian area)



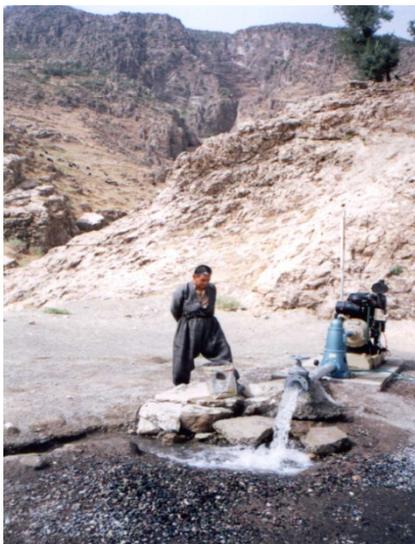
Mamlaha sulfuric spring (Raniya area)



Rawanduz River gorge below historical Rawanduz town the former kapital of Iraqi Kurdistan



DANDO drilling and service rigs operational under FAO Programme in northern Iraq



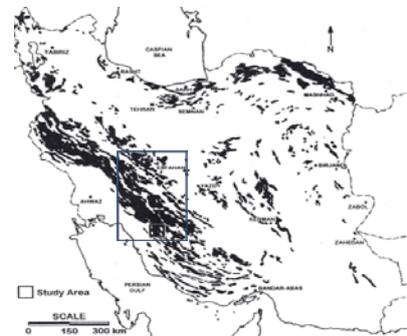
Wells drilled near Shaqlawa (left) and in Garmian area (right)



Highly productive wells in northern Iraq. Swarawa near Qaradagh (Sulaimani Governorate, left) and Kani Shekhan (Chwarta)

KARST OF SOUTH-CENTRAL IRAN²

The photos present karstic terrains of central and south Iran in wider area of Shiraz, Ishafan and Kaseroun. Between elongated mountain ranges of High and Lower Zagros (continuation of Alpine orogenic belt) built from carbonate and evaporitic rocks there are wide valleys filled by younger, mostly Miocene sediments. The late define main groundwater pathways and drainage zones. Study area is rich in various and specific geological and karstic features and phenomena. Among them, of particular importance are salty diapir dome of Konarsiah, salty springs and lakes, large karstic springs Shehpeer, Berhan, Margoon, Sasan, karstic poljes (e.g. Dasthe- Arjan), caves (e.g..Shapour).



² The photographs were made in 2013. during field trips of karst in south-central Iran in occasion of official visit and lecturing of Prof. Zoran Stevanović aiming at establish institutional cooperation between Centre for Karst Hydrogeology FMG and University of Shiraz, Iran. The author had an opportunity to be guided by Dr Ezzat Raeisi, Dr Mahdi Zarei, Dr Zargham Mohammadi, and PhD students Naderi and Zare, during field trips and gratefully acknowledges the support, data provision, and guidance of Dr Ezzat Raeisi and his staff.

The hydrostratigraphic column is as follows:

- Bakhtiari Fm, alluvium and deluvijum, locally up to 200m thick;
- Mishan Fm. – Upper Miocene, low permeable marls, clays;
- Gashsaran or Razack Fm. Miocene low permeable marls, and evaporites;
- Asmari Fm. - Oligocene – Lower Miocene, karstic aquifer in limestones;
- Pabdeh – Gurpi Fm., Upper Cretaceous – Paleocene, impervius claystone, marls;
- Sarvak Fm. – Upper Cretaceous, karstic aquifer, limestones
- Hormous Fm. – Proterozoic – Cambrium, metamorphites, Fe sandstones, schists, evaporites (anhydrites, halites)



Asmari limestones near Kaseroun



Barme Firouz anticline, Sarvak Fm. limestones

Sinkhole (doline) and callapsed sinkhole in Hormous, Konarsiah diapir



Evapotiric karst, Konarsiah salt diapir



Evapotiric karst, Konarsiah salty spring

Photo album



Karrenfeld in Barme Firouz anticline, Sarvak Fm. limestones(left) and margin with alluvial ponor (swallow hole) at the bottom of Dashte Arjan karstic polje (right)



Shapour cave carved in Asmari limestones and vauclosian Atashkade spring



Shehpeer spring (left) and impressive Margoon waterfall spring (right)



Salt deposits at the marginal part of Shiraz salty lake (up and down, left)



Dug well carved in limestones and debris of Sarvak Fm. for water supplying of Persian imperial capital of Persepolis