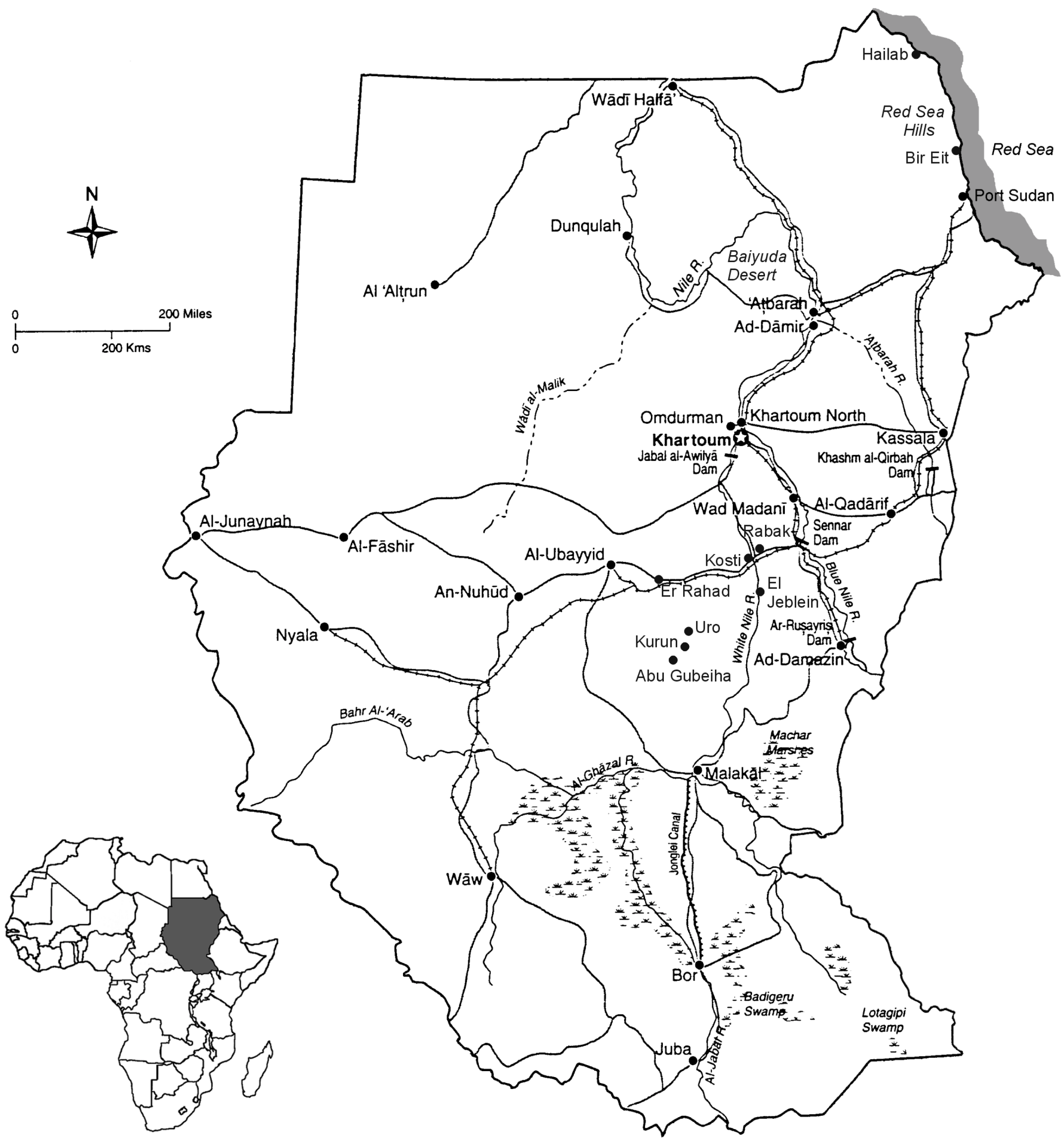
Sudan

Total population (July 2000 estimate): 35,080,000
Area: 2,505,810 km^2
Annual population growth rate (2000): 2.84%
Life expectancy at birth (1998): 55.4 years
People not expected to survive to age 40 (1998): 26.6% of the total population
GDP per capita (1998): US $1,394



Sudan is the largest country in sub-Saharan Africa. The landscape of Sudan can be divided into several major physiographic zones: the northern desert, the mountainous Red Sea Hill area with altitudes reaching over 2,000 m, the western desert areas and volcanic mountains, and the clay plains and swampy areas in central and southern Sudan. The centre of the country is flat, with plains at altitudes between 300 and 800 m and mountainous areas such as the Nuba Mountains. The country is crossed by the two main arms of the River Nile, the White Nile that drains through the swampy areas of southern Sudan, and the Blue Nile, which flows from the Ethiopian Highlands.

Agriculture is the mainstay of Sudan's economy, contributing approximately 40% to the GDP and employing more than 70% of the working population. The main food crops of the subsistence farmers are sorghum, cassava and millet. The main agricultural export crop is cotton. Other main crops are sugar cane, groundnuts, sesame, wheat and gum arabicum.

Until very recently, the mineral industry of Africa's largest country has been very small. Apart from export minerals like chromite, gold and salt, Sudan produced only a few minerals, such as limestone and gypsum, for the domestic cement industry. Recent oil and gas discoveries have changed the energy sector and the economy of Sudan. The oil finds resulted in increased activities and the building of a pipeline to the Red Sea through which oil started to flow in August 1999. In the first and second quarter of 2000, Sudan produced 200,000 barrels of crude oil per day. The reserves of crude oil are estimated at 262.1 million barrels.

The long-lasting war in the southern part of the country with the associated large human costs and conflicts with neighbouring countries continues to be a hindrance to economic development, including the development of mineral and agricultural resources. Some 2.3 million people in Sudan are currently in need of emergency food assistance due to the long-running civil war.

Geological outline

Largely undifferentiated crystalline igneous and metamorphic rocks form the Proterozoic 'basement complex' that underlies large parts of Sudan. Pre-Neoproterozoic rocks include gneisses of Paleoproterozoic age and are part of the 'Saharan Metacraton' (Abdelsalam 2001). Parts of the Precambrian crust have been remobilized by the Pan-African thermo-tectonic rejuvenation episode between 900 and 550 million years ago. These basement rock formations outcrop in 5 uplifted Precambrian blocks separated by deep depressions which are filled with Phanerozoic sedimentary sequences (Khalil 2001).

Extensive areas of northern Sudan are covered by continental clastic sequences of the predominantly Mesozoic Nubian Series, and southern areas are covered by Tertiary-Quaternary unconsolidated surficial sediments. Some Tertiary and younger basalts occur in areas along the border with Ethiopia and northern Kenya. Approximately 100 anorogenic alkaline ring complexes have been delineated in Sudan (Vail 1985). In addition, small occurrences of carbonatite plugs and dikes are reported from the nepheline-syenite in the Nuba Mountains at Jebel Dummbeir (Mageed 1998).

Sudan is crossed by major fault systems and shear zones. Some of these shear zones have been repeatedly reactivated, including the Neoproterozoic to Cretaceous and Tertiary Central African Fault Zones. These fault zones can be traced across the African continent from Cameroon through the Central African Republic and across western and central Sudan into the Red Sea Hills.

Several large rift systems have been identified in central Sudan, the major ones being the Southern Sudan Rift, the White Nile Rift, the Blue Nile Rift and the Atbara Rift (Mageed 1998). The rift zones are generally northwest- to southeast-striking and exhibit half-graben symmetries. The basins are filled with sediments and igneous rocks, at some places more than 3.5 km thick. These extensive rift-related basins are the target for oil and gas exploration.

AGROMINERALS

Phosphates

Several types of phosphate occurrences and deposits have been reported from Sudan: phosphates in pegmatites, phosphates in sediments, and phosphates in uraniferous breccias.

Interesting for potential agricultural applications are the phosphate occurrence of Hailab and the two uraniferous phosphate occurrences at Kurun and Uro.

Hailab phosphate rocks

Information on the sedimentary phosphate rocks from Halaib District, 300 km north-northwest of Port Sudan, is sparse. Here, Upper Cretaceous to Tertiary phosphorites occur in association with clastic sediments and thick evaporites (Whiteman 1971). No data on volume and grade or geological details are currently available.

Uro and Kurun phosphate rocks

Two occurrences of phosphate breccias (Uro and Kurum) were discovered in the northeastern Nuba Mountains in 1983 during exploration work by geologists of the German Geological Group (Mageed 1998).

The phosphate mineralization of Uro (11^{o}40'N; 31^{o}23'E) is associated with a uranium anomaly on the northeastern border of the Nuba Mountains, some 250 km southeast of El Obeid (Al-Ubayyid). Secondary Al-rich phosphates occur in a north-south striking breccia zone within graphite schists. Chemical analyses from 12 trench samples, from the middle portion of the Uro anomaly contain 6.44% P_2O_5. In addition, small amounts of phosphates with mean P_2O_5 concentrations of 5.77% were detected in samples from small (30 x 5 m) lens-shaped quartzite breccia bodies in the northern part of this anomaly (unpublished reports by BGR, quoted by Mageed 1998).

The uranium concentrations in these rocks ranged from 61-602 mg U kg^{-1}, with a mean of 397 mg U kg^{-1} (Mageed, quoting unpublished reports of Brinkmann 1985). Sam *et al.* (1999) calculated the mean uranium activity concentrations from 17 samples of Uro at 336 mg U kg^{-1} (range 100-1117 mg U kg^{-1}). Green and yellow wavellite and crandallite minerals were found as crusts in the surficial environment. Relatively high concentrations of As, Mo and Hg indicate a hydrothermal origin of this occurrence, although the identified mineralization is found in the secondary weathering environment. Obviously, it is important to explore deeper levels of this mineralization and establish grade and volume.

Another uranium anomaly associated with phosphate mineralization was discovered 1 km south of Kurun (11^{o}35' N; 31^{o}25'E), about 15 km northeast of the village of Abu Gubeiha and approximately 25 km south of the Uro anomaly. The phosphate mineralization at this west-southwest- to east-northeast-striking elongated hill (length 500 m, width 100 m in the west, 200 m in the east, height 25 m above the surrounding plain) is concentrated in a brecciated zone in graphite schist. The breccia fragments consist of graphite schist, chert, quartzite and apatite. Secondary Al-phosphates (crandallite, woodhousite and wavellite), as well as variscite and Cu-bearing phosphates (turquoise), are weathering products of the underlying phosphate-rich breccias (Mageeed 1998).

Chemical analyses of 52 surface samples taken on a grid showed P_2O_5 concentrations between 0.27 and 36.48%, with a mean of 20.06%. The mean Fe_2O_3 concentration in these surface samples was 11.75% (Brinkmann 1985, quoted by Mageed 1998) and the mean U concentration was 139.6 mg kg^{-1} (range 20-504 mg kg^{-1}). The highly elevated copper and mercury concentrations (mean 2,187 mg Cu kg^{-1}, 334.13 μg Hg kg^{-1}) are indicative of a hydrothermal origin of these anomalies. The reserve estimate for the Kurun mineralization is based on the chemical analyses of supergene secondary phosphates that rest on a zone of apatite-rich breccia.

A preliminary resource estimate at Kurun indicates 1.68 million tonnes of phosphate ore grading 20% P_2O_5, which amounts to about 336,000 tonnes of P_2O_5. The depth is calculated to the base of the hills (12 m in the west and 20 m in the east), but the true depth of the phosphate mineralization is not known.

The Finish geologist Kiukkola carried out a preliminary assessment of the agricultural suitability of the Kurun phosphates in 1988-1989 (Mageed 1998). Surface samples, analysed by Kemira Oy of Finland, contain 26.2% P_2O_5, 28% CaO, 14% SiO_2, 12% Al_2O_3, 4% Fe_2O_3, 1.4% F and small amounts of Zn, Mn, Cu, and Ni. The main minerals of these samples were apatite, silica, crandallite and phlogopite (Mageed 1998). Calcination tests indicate that the citric acid-soluble P_2O_5 only slightly increases from 4.5% P_2O_5 to 6.5% P_2O_5 for uncalcined phosphates, making this modification technique unattractive. Fine grinding (80% finer than 66 microns - 230 mesh), however, increased the citric acid phosphate solubility from 4.5% to 9.6% P_2O_5 (or 37% of the total P_2O_5). The energy requirement for grinding these phosphatic rocks was 25 kWh per short ton (Mageed 1998).

Sam and Holm (1995) and Sam *et al.* (1999) carried out radiological assessments of the Uro and Kurun phosphates. They concluded that the application of 300 kg phosphate rock containing 336 mg kg^{-1} eU (equivalent mass concentration of uranium) for Uro phosphates and 31.9 mg kg^{-1} eU for the Kurun phosphates per hectare would not contribute to the mean terrestrial radiation exposure of the farming population. The radionuclide contribution of the Kurun phosphate rocks to the natural radionuclide content of arable land is considered 'comparatively insignificant' (Sam *et al.* 1999).

Other phosphates

Another potential prospect for further phosphate exploration is the area at Jebel Dumbeir near Er Rahad (12^o31' N; 30^o45'E) where small carbonatite plugs and dykes close to a nepheline-syenite are reported by Mageed (1998). The area is strongly affected by potassic metasomatism and is fractured. Anomalous values of F, U, Ba, Sr are reported, but no phosphates have been described so far.

The occurrences of apatite in pegmatites in the Baiyuda Desert, 130 km north-northwest of Atbarah, are of no practical and economic importance.

Other agrominerals

Limestone/dolomite/travertine

There are considerable limestone and dolomite resources in Sudan. The Red Sea coastal area is endowed with extensive Mesozoic and younger sedimentary limestone resources. In addition, extensive coral reef deposits of Pleistocene age rise up to 16 m above the sea level of the Red Sea. Many of these limestone deposits have been characterized by geologists for their suitability as raw material for the cement industry.

Precambrian marble and dolomitic marble beds are numerous in Sudan. In the compilation by Gwosdz (1996), 36 limestone and dolomite resources, mainly Precambrian, are described. Mageed (1998) provides a detailed inventory including reserves, chemical composition and utilization of many more marble and dolomitic marble deposits of Sudan. The marble deposits of Wadi Kurmut, west of Atbarah, and the El Jebelien marble deposits, form the raw material base for the cement factories of Atbarah and Rabak (near Kosti) respectively. Only limited use is made of these extensive resources for decoration purposes, for lime burning or whitewash.

Gypsum

Gypsum is produced as a by-product from salt-production and from the major Bir Eit gypsum deposit approximately 77 km north of Port Sudan, some 8 km from the Red Sea coast.

The well studied Bir Eit gypsum beds, of Miocene age, are 2.5 km in length, 300-700 m in width and have a drill-proven depth of more than 120 m. The reserves of this deposit, to a depth of 50 m, are 190 million tonnes (Mageed 1998). Other gypsum deposits close to Bir Eit include the Tabonam deposit and the Jebel Saghum gypsum deposit. The estimated reserves of the Jebel Saghum deposit, some 19 km north of Bir Eit, are about 34 million tonnes. However, if the reserves of this deposit are extrapolated to a depth of 50 m, about 124 million tonnes are available (Mageed 1998).

Approximately 20,000 tonnes of gypsum are sold annually to the domestic cement works at Atbarah and Rabak on the River Nile. A limited amount of gypsum is produced for the chalk industry in Port Sudan.

Agromineral potential

The potential of developing agrominerals in Sudan is difficult to assess due to the relative scarcity of published industrial mineral resource information and soils data.

The phosphates of the Hailab area need more detailed geological investigations and the small but important phosphate mineralization at Kurun needs additional exploration to establish the depth extent and provide a more accurate estimate of the resource base. Further agronomic testing is needed, including direct application of Kurun phosphate rock to acid soils, as well as testing various phosphate modification techniques to make the phosphates more plant available and to reduce the potentially detrimental metal and radionuclide contents.

The potential use of liming materials using existing limestone/marble and dolomitic limestone resources for agricultural needs should be assessed in view of potential needs for liming materials on acid soils.

Unfortunately, the large gypsum resources along the Red Sea coast are far from potential areas of application, for instance to ameliorate saline-alkaline soils and as a nutritional source for groundnuts.

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