RADIOMETRIC MAPS OF ISRAEL — PARTIAL CONTRIBUTION TO THE UNDERSTANDING OF POTENTIAL RADON EMANATIONS

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Abstract

An airborne radiometric survey over parts of Israel was carried out in 1981. The system was comprised from 10 NaI 4" × 4" × 16" detectors, arranged in 4,4 and 2 sensors, with total volume of 1560 inch^3, and one 4" × 4" × 16" uplooking NaI detector. All the data, including 2 full spectra (0–3 MeV), air temperature and pressure, time and altitude, were recorded by GAM-2001 (Scintrex) on tapes. Ground projections of the flight lines were obtained by video recording using Panasonic wide angle camera and VTR. Synchronized fiducial markings were generated at 1sec^{-1} frequency at both the radiometric data and video tapes. Flight nominal height was 400 feet, line distances were 1 km and line tie every 20 km. Data analysis took place using the eU, eTh and K region of interest, the data was corrected for cosmic radiation, Rn in the air, background and altitude, stripped and the terrestrial concentration of eU, eTh and K were calculated [1]. The radiometric concentrations were smoothed using 1/4; 1/2; 1/4 3 points moving average and every point was checked for statistical acceptance. he radiometric data was calculated on a grid using the minimum curvature method with SURFER for Windows (version 6) and presented on the maps using the 0, 25, 50, 75, 90, 95 and 100 percentiles. Statistical radiometric signature of all exposed rock formations was accomplished using a GIS system. It was found that the Mount Scopus Group (of Senonian origin) is the main source for high uranium — phosphoritic rocks of this group contain up to 150 ppm U. Comparing the eU radiometric map with a map of potential radon emanation from rock units [2], reveals a fair correlation — high radon emanations usually follow the distribution of the Mount Scopus Group in Israel. The correlation between the two maps is excellent over arid terrain where soil cover is missing, whereas over semi-arid — humid areas (western and northern Israel), where soil and cultivation covers are developed, the eU levels over Mount Scopus Group's outcrops are much lower due to absorption of the radiation, and do not depict the full radon potential. Detailed mapping of radon hazards usually exhibit poor correlation between airborne eU data and direct pore radon measurements, even in arid terrain. This phenomenon is attributed to the fact that a radon "source rock" (e.g. phosphorite) could be covered with a few up to some tenths of meters of uranium-barren rock. About 0.5 meter cover is enough to absorb all radiation, causing very low airborne eU readings, while the radon free way in this rock is about 10 meters, yielding high pore radon levels when directly measured.

1. THE RADIOMETRIC SURVEY

An airborne radiometric survey over parts of Israel was carried out in 1981. The system was comprised of 10 NaI(Tl) 4" × 4" × 16" detectors (4π), arranged in 4, 4 and 2 sensors, with total volume of 40 liters, and one 4" × 4" × 16" uplooking NaI(Tl) detector with 4 liters volume (2π). All the data, including 2 full spectra (0–3 MeV), air temperature and pressure, time and altitude, were recorded by GAM-2001 (Scintrex) on tapes. Ground projections of the flight lines were obtained by video recording using Panasonic wide angel camera and VTR. Synchronized fiducial marks were generated at 1 sec^{-1} frequency at both the radiometric data and video tapes. The flight was carried out using a Piper Navajo Chieptain on nominal height of 400 feet. Line spacing was 1 km and line tie was done every 20 km.

Calibration of the airborne system was done using calibration pads, specially built near the Soreq Nuclear Research Center. Background and cosmic rays contribution was calibrated by high altitude flights over the Mediterranean sea. Details of the calibration and fluctuation analysis for the airborne system can be found in Aviv and Vulkan [1].

Data analysis took place using the eU, eTh and K region of interest. Table I shows the windows for the Region of Interest in keV.

TABLE I. THE WINDOWS SETTING

Name of region	Isotope	Photopeak Energy (MeV)	Energy interval (KeV)	Energy width (keV)
Total count (4π)			398 - 2984	2586
K (4π)	^{40}K	1.461	1357 - 1569	211
U (4π)	^{214}Bi	1.764	1661 - 1860	199
Th (4π)	^{208}Tl	2.615	2410 - 2820	410
Total count (2π)			1661 - 2984	1323
U (2π)	^{214}Bi	1.764	1661- 1860	199
Th (2π)	^{208}Tl	2.615	2410 - 2820	410

The data was corrected in this order:

1. Background and cosmic radiation subtraction.
2. Radon in the air subtraction.
3. Stripping of the mutual contribution the elements.
4. Altitude correction, taking into account the air temperature and pressure.
5. Terrestrial concentration of eU, eTh and K calculation [1].
6. Statistical test for "acceptance/not acceptance" detection level, based on net count being higher than 1.5 the square root of the background (raw counts — net counts).

The radiometric concentrations were smoothed using 1/4; 1/2; 1/4 3 points moving average, to exclude irregularity of data points. The radiometric data was calculated on a grid using the minimum curvature method with SURFER for Windows (version 6) and presented on the maps using the 0, 25, 50, 75, 90, 95, and 100 percentiles [3].

2. GEOLOGICAL SETTING

The outcropping rock sequence in Israel is built mainly of sedimentary rocks, ranging from Paleozoic sandstones up to recent soils. Precambrian igneous and metamorphic rocks can be found only in the southern part, at the vicinity of the Gulf of Eilat. Young basalts are covering quite large areas in the northern part of Israel. The prominent rock formations that cover over 70% of the area belong to three groups:

Judea Group: The Judea Group is built of Cenomanian carbonate rocks — limestones, dolomites, chalks and marls — usually without any clastic components. As a result of magmatic activity during the Cenomanian, some tuffs and basalts can be found in the Mount Carmel area.

Mount Scopus Group: The Senonian-Paleocene Mount Scopus Group is characterized by a wide transgression of a nutrient-rich sea which deposited chalks with a high content of phosphate. Under shallow conditions, a sequence of alternating chalks and cherts was deposited, in many places including economic phosphorite layers. The Mount Scopus Group is divided into three formations (described from bottom to top):

Menuha Formation — massive chalk, usually covered by a calice crust;

Mishash Formation — alternating chalks, cherts and phosphorites. The Mishash Formation attains its maximal thickness in synclinal basins in the northern Negev, where the economic phosphorite layers are most developed and utilized for the fertilizers industry. The P_2O_5 content in these layers is usually 24–35%;

Ghareb Formation - chalk, marly chalk and marl; a metamorphosed analogue of this formation is the Hatrurim Fm.

Avedat Group: Comprised of a thick sequence of chalks, limestones and marls of Eocene time, with chert lenses in some places.

Since the Mount Scopus Group contains high content of phosphate with appreciable amounts of uranium (90–150 ppm [4]), this group's outcrop was a target for a more detailed study concerning radon emanations.

3. CONSTRUCTING A RADON "RISK" MAP

As part of the on-going effort of producing baseline data maps for Israel, a map of potential radon emanation from rock units was accomplished by the Soreq Nuclear Research Center and the Geological Survey of Israel. The map (on a 1:500 000 scale) is based on direct measurements of radon within the rock/soil pore space, coupled with the known local stratigraphy and sub-surface geology [2].

A modified alpha-track detection system was implemented for direct measurements of radon in soil/rock pore gas, as described in [5 and 6]. The instrumental assemblage is installed in a PVC pipe which makes it easy and convenient to insert the system in shallow (~50 cm) drillholes. The measurements were conducted in 70 sites, representing all outcropping rock formations in Israel. In each site, 15 to 35 films were buried, usually on a 20 × 20 m grid, for up to 28 days (according to the expected radon level). After removal, the foils were electrochemically etched and track densities measured. Calibration of the track density versus absolute activity was accomplished by a special designed calibration cell with a known radon source.

Nearly all stratigraphic units which were studied exhibit low average radon levels (3,000–8000 Bq/m^3). On the other hand, the Mount Scopus Group yielded high average radon levels (10 000 -140 000 Bq/m^3), with the Mishash Formation showing very high levels (up to 300 000 Bq/m^3) due to its high phosphorite content.

The outcropping rock units were divided into three categories and accordingly mapped:

Category III — high radon

average ^{222}Rn concentrations higher than 50 000 Bq/m^3. This category includes the Mishash Formation in the Judea Desert and southern Israel, where phosphate-rich layers are mostly developed. It was observed that a chalky overburden of up to 20 m above a phosphorite layer yields radon concentrations which fall into this category. Hence, the relevant areas were mapped accordingly.

Category II — moderate radon

average radon concentrations between 10 000 to 50 000 Bq/m^3 are attributed to the Mount Scopus Group in central and northern Israel, Menuha and Ghareb Formations in southern

Israel. Areas in which a thin layer of alluvial material or soil cover rocks of the Mount Scopus Group were classified into this category.

Category I — low radon

average radon concentrations lower than 10 000 Bq/m^3. This category includes all other rock units and alluvial soils.

The area along the Dead Sea Rift was separately mapped due to high radon emanations from sediments [7] and water sources in the area [8], and the presence of alluvial fans of large wadis (ephemeral streams) which drain outcrops of phosphate-rich Mount Scopus Group rocks.

4. COMPARISON BETWEEN THE RADIOMETRIC AND RADON MAPS

Statistical radiometric signature of all exposed rock formations was accomplished using the data gathered during the radiometric survey and the GIS system of the Geological Survey of Israel, in which all exposed rock units are coded. It was found that the Mount Scopus Group is the main source for high uranium — the average eU levels ranges between 5-10 ppm for this group, while for other rock units the range is 1.3-4 ppm (Fig. 1). Based on these data, a "cut-off" value of 4 ppm was used for a comparison between the radiometric and radon maps.

Comparing parts of the eU radiometric map with that of potential radon emanation from rock units (both on a regional scale of 1:500 000), reveals a fair correlation. The radiometric map in Fig. 2 represents data above 4 ppm eU which usually follow the distribution of the Mount Scopus Group in Israel, depicting the outline of the radon map which is based on the known geology of the region. The correlation between the two maps is high over arid terrain where soil cover is missing, whereas over semi arid — humid areas (western and northern Israel), where soil and cultivation covers are developed, the eU levels over Mount Scopus Group's outcrops are much lower due to absorption of the radiation, and do not depict the full radon potential.

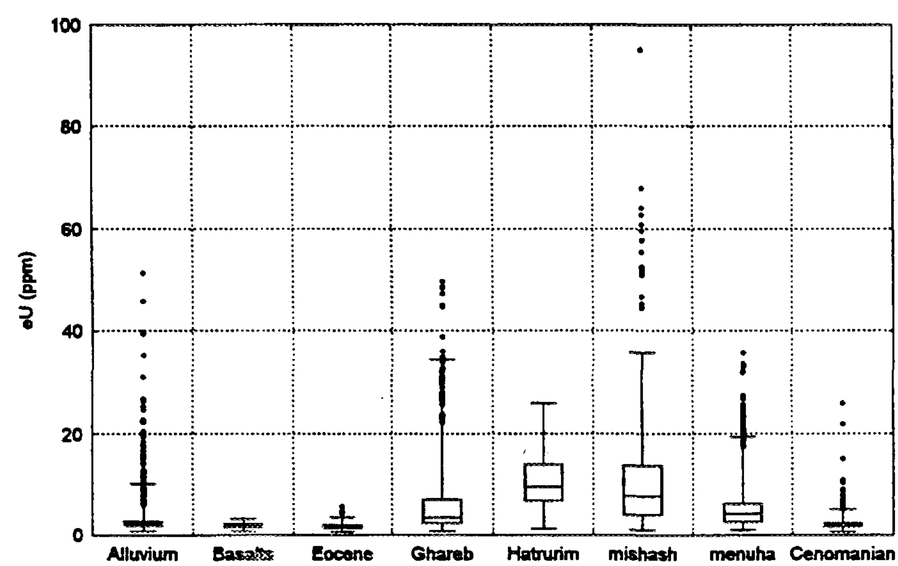

FIG. 1. Box plots indicating eU concentrations in main rock formations in Israel. The horizontal spread of each box represents 50% of the data, between the 25th and 75th percentiles; the vertical line in each box is the median. Horizontal lines extending from the boxes are bound at the 1st and 99th percentiles. Dots are extremes.

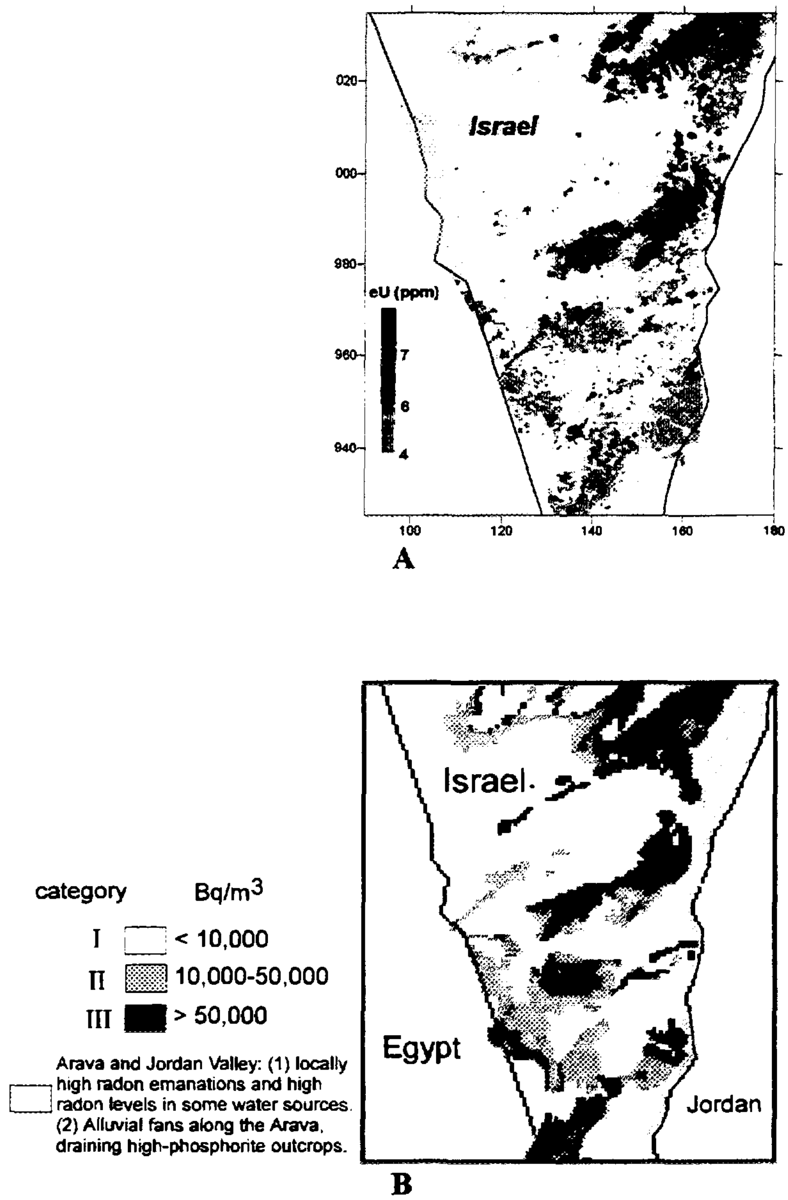

FIG. 2. Comparison between eU radiometric map (A) and a radon map (B) over part of the Negev Desert, Israel. The original scale is 1:500 000.

Detailed mapping of radon hazards usually exhibit poor correlation between airborne eU data and direct pore radon measurements, even in arid terrain. This phenomenon is attributed to the fact that a radon "source rock" (e.g. phosphorite) could be covered with a few up to some tenths of meters of uranium-barren rock. About 0.5 meter cover is enough to absorb all radiation, causing very low airborne eU readings, while the radon free way in this rock is about 10 meters, yielding high pore radon levels when directly measured. The example displayed in Fig. 3 is taken from the vicinity of the town of Arad, northern Negev Desert. A detailed radon mapping for this area was carried out by Vulkan and others [9], based on numerous radon measurements and geological mapping in a 1:20 000 scale (Fig. 3A). The eU radiometric map for the same area (Fig. 3B), can only partly be correlated with the radon map, due, as mentioned, to local geological considerations (overburden above an uranium source) and the resolution between rock units which can not be achieved in a radiometric survey, compared with a very detailed geological map.

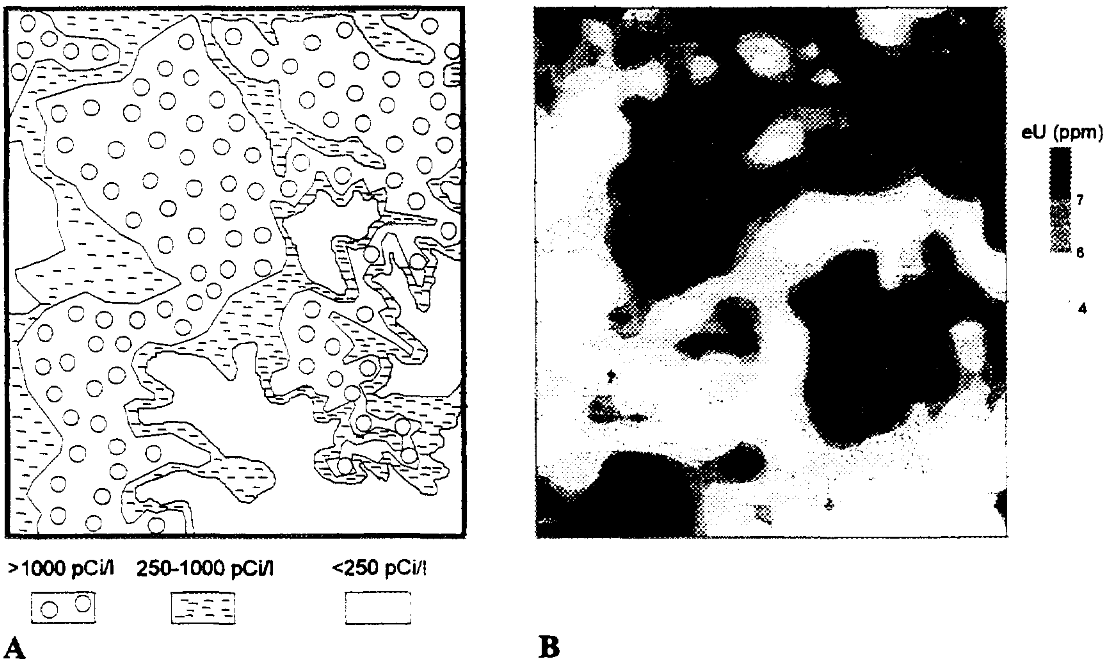

FIG. 3. Comparison between a detailed radon mapping in the vicinity of Arad, northern Negev Desert, Israel (A), and a radiometric map of the same area (B). The covered area is 8 × 9 km and the original mapping scale is 1:20 000.

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