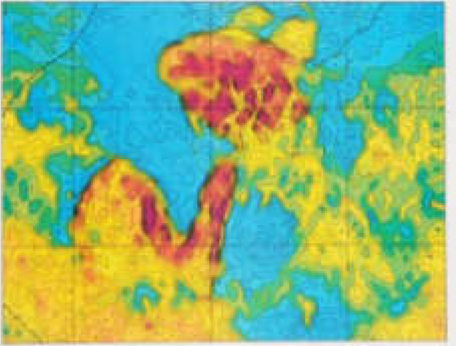
DIRECTORATE GEOLOGICAL SURVEY

MINISTRY OF MINES AND ENERGY

THE REGIONAL RADIOMETRIC DATA SET OF NAMIBIA: COMMENTS ON COMPILATION OF THE DATA FROM WEST CENTRAL AND SOUTHERN NAMIBIA AND ON ANOMALY PATTERNS THEREOF

by

Eberle, D., Hutchins, D. G. and Petzel V.



BULLETIN 3

1997

Cover: *Section of the 1 : 250 000 scale map sheet 2014 (Fransfontein) of the Regional Airborne Radiometric Map Series showing the potassium concentration in the area southeast of Khorixas. High values (yellow to reddish brown) are produced by the Naauwpoort volcanics of the Mitten Fold and Summas Mts., low values (blue) to the east indicate the Ugab and Okotjize Folds built up by extremely low radiating Damaran marbles.*

MINISTRY OF MINES AND ENERGY
GEOLOGICAL SURVEY OF NAMIBIA

Director: G. I. C. Schneider

in co-operation with the

GERMAN FEDERAL INSTITUTE FOR GEOSCIENCES AND NATURAL RESOURCES

BULLETIN 3

The Regional Radiometric Data Set of Namibia: Comments on Compilation of the Data from West Central and Southern Namibia and on Anomaly Patterns thereof

by

Eberle, D. [1)]**, Hutchins, D.G.** [2)] **and Petzel, V.** [2)]

1) Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) Federal Institute for Geosciences and Natural Resources, Germany;
at present: Geological Survey of Namibia, Windhoek

2) Geological Survey of Namibia (GSN)

Obtainable from the Geological Survey
P. O. Box 2168, Windhoek, Namibia

ISBN 0-86976-402-9

Cover: Section of the 1 : 250 000 scale map sheet 2014 (Fransfontein) of the Regional Airborne Radiometric Map Series showing the potassium concentration in the area southeast of Khorixas. High values (yellow to reddish brown) are produced by the Naauwpoort volcanics of the Mitten Fold and Summas Mts., low values (blue) to the east indicate the Okongue and Okotjize Folds built up by extremely low radiating Damaran marbles.

MINISTRY OF MINES AND ENERGY
GEOLOGICAL SURVEY OF NAMIBIA

Director: G. I. C. Schneider

in co-operation with the

GERMAN FEDERAL INSTITUTE FOR GEOSCIENCES AND NATURAL RESOURCES

BULLETIN 3

The Regional Radiometric Data Set of Namibia: Comments on Compilation of the Data from West Central and Southern Namibia and on Anomaly Patterns thereof

by

Eberle, D. [1], **Hutchins, D. G.** [2] **and Petzel, V.** [2]

1) Bundesanstalt für Geowissenschaften und Rohstoffe (BGR, Federal Institute for Geosciences and Natural Recources, Germany)
at present: Geological Survey of Namibia, Windhoek

2) Geological Survey of Namibia (GSN)

Obtainable from the Geological Survey
P. O. Box 2168, Windhoek, Namibia

ISBN 0-86976-402-0

CONTENTS

Introduction

A cooperation project between the Geological Survey of Namibia (GSN) and the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR, Federal Institute for Geosciences and Natural Resources, Germany) ran from 1992 to 1996 and covered the refinement, compilation and interpretation of existing open-file airborne geophysical data.

As part of this cooperation, the refinement and compilation of regional airborne gamma-ray data was undertaken over two selected areas.

From 1968 Namibia was gradually covered by government funded airborne geophysical surveys. Most of these surveys were always in conjunction with magnetic surveys. Typical traverse spacing was 1000 m with a survey height about 100 m above ground. Most of the gamma-ray data were processed immediately after surveying, but map production was of an inconsistant standard, and in some cases a few survey blocks were never processed.

The merging of the various survey blocks had never before been tackled, partly as a consequence of the various detector sizes used during the course of time. It was only in the early nineties when back-calibration and reprocessing of airborne gamma-ray data were made feasible. It soon became evident that merging and compiling the Namibian airborne gamma-ray data would be useful to support geological mapping, to contribute to environmental issues and to determine the general background radiation.

As the Namibian airborne gamma-ray data vary in quality, it was agreed by the GSN and the BGR not to compile all the existing airborne gamma-ray data, but rather to select an area to test methodology, cost effectiveness and quality of the final compilation products. The area selected covered four 1 : 250 000 scale map sheets, namely 2014 (Fransfontein), 2016 (Otjiwarongo), 2114 (Omaruru) and 2116 (Okahandja) in west central Namibia. This area comprised data collected from the earliest 1968 surveys (merely analogue charts) to more modern (tape records) surveys flown in 1980.

In this way it was possible to gain practical experience with the Namibian gamma-ray data and to see whether it would be worth compiling greater portions of the data in the future.

The aim was the compilation of a 1 : 250 000 scale map series consisting of individual map sheets showing the ground level exposure rate, the ground concentrations of potassium (K), thorium (Th) and uranium (U) as well as elemental ratios. This was to be achieved by comparing the airborne measurements with ground measurements using a calibrated portable gamma-ray spectrometer.

In fact, back-calibration and compilation of the west central Namibian data were succesful and stimulated to process and compile all the open-file airborne radiometric data of southern Namibia that was a priority target area of the cooperation project.

This bulletin gives detailed information on the data processing and compilation and provides interpretation summaries for each 1 : 250 000 scale map sheet. This is to support the user of the radiometric map series in his understanding of the radiometric patterns and their significance in terms of prospectivity for natural radio-elements, lithology, and soil chemistry.

2 Data Sources

2.1 History of Surveying

Regional airborne geophysical surveys have been conducted in blockwise fashion in Namibia on a more or less annual basis from 1968 onwards (Eberle and Hutchins, 1996). These surveys were carried out as combined airborne magnetic and radiometric surveys comprising 32 different blocks with a total of some 600 000 line km (Fig. 1).

Most of these airborne surveys were funded by the Government. To a minor extent, surveys were also performed by the private sector during base metal, uranium, precious stone, and groundwater exploration campaigns.

2.2 Survey Parameters

The technical specifications of the government-funded airborne geophysical surveys conducted between 1968 and 1990 typically used a 1 km traverse spacing, a 10 km tie line spacing with flight directions perpendicular to the general geological strike and a 100 m terrain clearance.

This configuration infers that large outcrops of regional geology were effectively surveyed; however, point or small area sources were only detected if the traverse passed quite close. At a 100 m terrain clearance, 90% of the detected radiation derives from a circular area (circle of investigation) with a diameter of about 550 m, and 50% of the radiation from a circular area with a diameter of about 200 m (cf. Kellog, 1971) assuming the point of observation is above an infinite plane radiating source. Taking the velocity of the plane and the distance covered during the integration time of the spectrometer (see ch. 2.3.1) into account the area sampled by an airborne survey system is rather an oval strip than a circle. The length of the oval is greater than the moving distance of the aircraft during the intergration time, as radiation is also collected from sources ahead and behind the plane (Fig. 2). Length and width of the strip increase with survey altitude, but are not proportional to the latter because of the greater attenuation of gamma rays with oblique angles of incidence (IAEA, 1979). Using a terrain clearance of about 100 m, 50 % of the counts in the thorium window can be ascribed to a strip of up to 240 m in width.

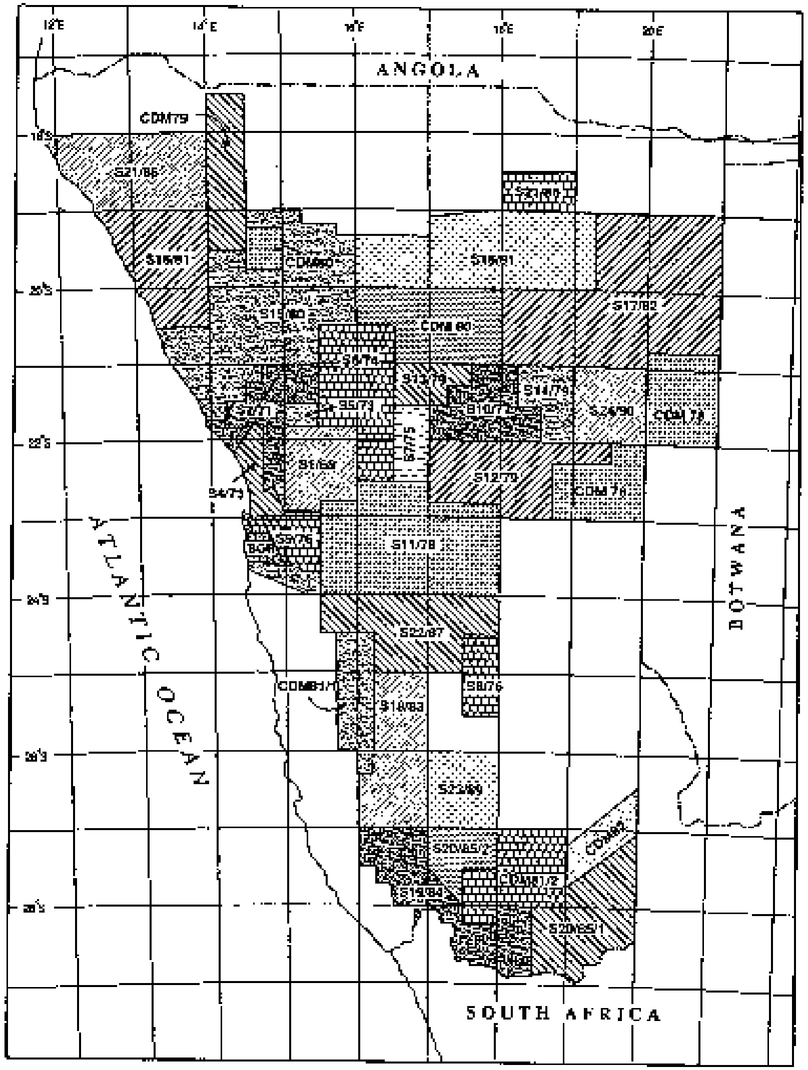


Fig. 1 Location map of individual surveys. Survey nomenclature indicates the funding agency and for the S- and CDM-surveys the year of execution. S-Government; CDM-Consolidated Diamond Mining Co.; BGR-Federal Institute for Geosciences and Natural Resources, Germany.

Even if a 90% circle of investigation is assumed for the regional Namibian airborne gamma-ray surveying, a strip between two adjacent flight lines of about 500 m width still results whose radiation did not produce any essential effect on the measured count rates. This means only 50% of the surface covered by the regional surveying contributed to the collected data. This should always be kept in mind when using the maps and coming to geological/lithological conclusions.

A few of the surveys, those funded by Consolidated Diamond Mines (CDM) and the BGR, used closer line spacings of 250 - 500 m and a terrain clearance of about 80 m. These surveys were conducted to support precious stone, base metal and groundwater exploration and were in some cases flown in combination with electromagnetic methods. The closer spacing of these surveys provided a nearly 100 % coverage of the survey areas assuming a 90% circle of investigation.

Adjacent survey blocks overlap only in a few cases, and this proved to be counter-productive when merging the individual survey blocks.

All the survey parameters relevant to the gamma-ray surveying are given in detail in Tables 1 and 2 (pp. 13-20).

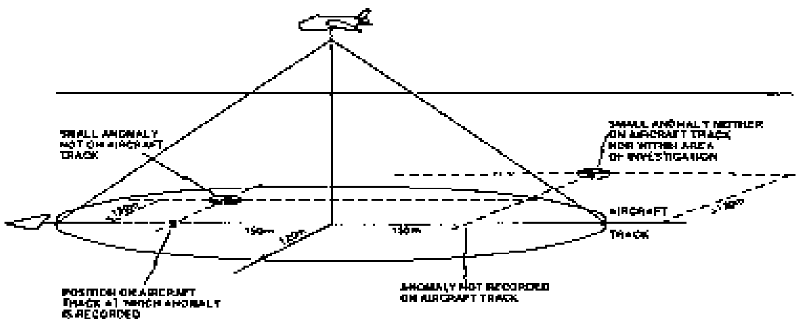


Fig. 2 Oval strip of investigation of an airborne gamma-ray spectrometer as achieved within the integration time of the spectrometer (modified after Richards, 1979).

2.3 Acquisition

As the surveys were flown over two decades, the data were collected using progressively more advanced instrumentation and calibration procedures.

2.3.1 Gamma-Ray Spectrometers

Although each survey recorded four radiometric channels (total count, potassium, uranium and thorium), the contractors, survey equipment, detector crystal volume, energy window, sensitivities and calibration procedures varied from year to year and from survey to survey. In addition to these documented variations, it became apparent that parameters were occasionally changed during the course of a single survey, for example survey aircraft, equipment, location of calibration sources, correction coefficients (Duffy *et al.*, 1994). Unfortunately, those deficiencies were compounded by incomplete records of survey procedures, particularly for some of the older surveys.

It can be seen from Tables 1 (pp. 13-16) that the detector volumes of the gamma-ray spectrometers vary from 5.25 ltr. in 1968 to 33.6 ltr. in the early 1980s. Current state of the art detectors are at least 33 ltr. of sodium iodide crystals for a fixed wing system, whereas 16 ltr. will be acceptable for a helicopter survey (Grasty and Minty, 1995). In most cases, 16 ltr. detector volumes were used for the Namibian regional airborne gamma-ray data at flight velocities of generally more than 200 km/h, which was satisfactory standard at the time of surveying. The early surveys flown with detector volumes smaller than 16 ltr. must at best be considered to be of poor quality.

Similarly, the sampling rate also varied between 0.7 and 2.0 sec. In most surveys, however, 1 sec was applied. This means that at a flight velocity of about 240 km/h and at a nominal flight height of 100 m a.g.l. about 90% of the counts originated from an oval strip of about 500 m width and about 600 m length.

Until the early 1980's, four channel differential gamma ray spectrometers followed later by multichannel (256) devices were in use, providing a summation of counts in windows centred on the potassium (K40), uranium (Bi 214), and thorium (Tl 208) peaks as well as two total count channels and the cosmic ray region from 3.0 - 6.0 MeV. Since the early 1980's window settings were usually chosen as recommended by the IAEA (1979). The K, U, and Th channels were usually corrected for Compton scattering (see ch. 2.3.2) by a microprocessor before the data were output to visual display or analogue charts.

2.3.2 Calibration Procedures

Calibration procedures applied before, during and after surveying are not easy to follow-up, in some cases it is no more possible due to missing or very poor reporting. Since the mid 1970's documentation has been more complete, and it has been a rule to perform castle calibrations each morning before take-off and again after landing. The castle calibration consisted of first recording the radiation background at usually more than 700 m above ground and then subjecting the system in turn to both a radium source and a thorium source. Furthermore, a background test line was established and flown before and after each sortie to obtain the average drift of the spectrum. In most cases, temperature stabilized and thermally insulated crystal packages were employed. Other devices provided self stabilization of the spectrum by monitoring the pulse height output of the more energetic photopeak of Caesium 137 at 0.622 MeV, which was doped into the crystals and adjusting according to the high voltage supply to the photomultiplier tubes.

The spectra of potassium (K), the uranium (U) series and the thorium (Th) series overlap. Each spectral window selected to detect one radioelement will therefore also contain some effect from the other two radioelements.

Correcting for this spectral overlap is called "stripping" (IAEA, 1991). Before commencement of the individual surveys, the spectrometer were therefore calibrated either at Lanseria Airport (R.S.A.) where calibration pads had been established by the South African Atomic Energy Board or using sources of known concentrations in the possession of the South African Geological Survey.

By use of concrete pads or pure sources containing known concentrations of the radio-elements the so-called stripping coefficients can be determined which describe the ratios of the counts detected in one window to those in another window. Stripping coefficients were determined for most of the surveys (see Tables 2, pp. 17-20). However, mainly due to missing standards, it must be assumed that stripping procedures applied might not have achieved its objective, especially for the early surveys.

2.3.3 Auxiliary Acquisition Parameters

As most of the surveys were flown with a constant ground clearance, use of a radar altimeter was compulsory. Furthermore, a radar altimeter constitutes an essential part of the equipment for gamma-ray surveying. Therefore specified accuracies were about ± 3% and radar altitude was continuously recorded on analogue chart and magnetic tape.

Gamma-rays are attenuated by air in an approximately exponential fashion for typical ranges of survey altitude (Grasty and Minty, 1995). Provision of a radar altimeter therefore enabled corrections for aircraft altitude which are clearly an important part of the processing procedures (cf. chap. 2.4).

Positioning control was provided by a tracking camera, either 35 mm mechanical or electronic (video). Exposure rates usually varied from 1 - 2 frames every two seconds whilst on traverse. Synchronization with both digital and analogue geophysical records was always provided.

Merely analogue surveys were conducted until the mid 1970's, thereafter survey data were collected both analogue and digital. Typical equipment parameters are described in Eberle and Hutchins (1996).

SURVEY	PERIOD FLOWN	TOTAL MILEAGE (km)	FLIGHT HEIGHT	TRAVERSE DIRECTION	TRAVERSE SEPARATION (km)	MAGNETOMETER, RESOLUTION, SAMPLE RATE	MAGNETIC REFERENCE	GAMMA-SPECTROMETER, DETECTOR VOLUME, SAMPLING INTERVAL	DATA ACQUISITION
S1/68 Rössing	03/12/68 - 01/02/68	24 000	120 m a.g.l.	NW-SE	1.0	Gulf Mark III Fluxgate, 1 nT, 0.125 sec	32 000 nT	Exploranium DGRS 1000, 5.25 ltr., 2 sec	Chart recorder
S2/71 Cape Cross	15/02 - 02/04/71	22 000	150 m a.g.l.	NW-SE	1.0	Gulf Mark III Fluxgate, 1 nT, 0.125 sec	29 500 nT	Exploranium DGRS 1000, 7 ltr., 2 sec	Chart recorder
S3/72 Hereroland	06/12 - 10/12/72	not documented	150 m a.g.l.	NW-SE	5.0	not documented	24 000 nT	not documented	Chart recorder
S4/73 + S5/73 Swakopmund	01/01 - 07/03/74	8 500 940	150 m a.g.l.	NW-SE N-S	1.0	Geometrics G803, 1 nT, 1 sec	28 500 nT	Exploranium DGRS 1 000, 8.3 ltr., 0.7 sec	Chart recorder
S8/74 Omaruru	28/10 - 30/11/74	38 880	125 m a.g.l.	E-W & N-S	1.0	GeometricsG803,1 nT, 1 sec	25 000 nT	Exploranium DIGRS 3001, 11.1 ltr, 1 sec	Geometrics G 704
S7/75 Okahandja	18/09 - 22/09/75	3 780	100 m a.g.l.	E-W & N-S	1.0	Geometrics G803, 1 nT, 1 sec	25 000 nT	Exploranium DIGRS 3001, 16.7 ltr, 1 sec	Geometrics G 704
S8/76 Walvis Bay, S9/76 Gibeon/ Mariental	10/12 - 21/12/76	6 829 1 174	100 m a.g.l.	E-W	1.0	Gulf Mark III Fluxgate, 1 nT, 0.125 sec	25 000 nT	Exploranium DIGRS 3001, 16.7 ltr, 1 sec	Kennedy 1101 tape recorder
S10/77 Okahandja	08/09 - 22/09/77	12 407	100 m a.g.l.	E-W	1.0	Digital Gulf Mark III Fluxgate, 1 nT, 0.125 sec	25 000 nT	Exploranium DIGRS 3001, 16.7 ltr., 1 sec	Kennedy 1101 tape recorder

Table 1.1

SURVEY	PERIOD FLOWN	TOTAL MILEAGE (km)	FLIGHT HEIGHT	TRAVERSE DIRECTION	TRAVERSE SEPARA-TION (km)	MAGNETO-METER, RESOLUTION, SAMPLE RATE	MAGNETIC REFERENCE	GAMMA-SPECTROMETER DETECTOR VOLUME, SAMPLING INTERVAL	DATA ACQUI-SITION
S11/78 Rehoboth	19/08 - 28/09/78	39 000	100 m a.g.l.	E-W	1.0	Digital Gulf Mark III Fluxgate, 1 nT, 0.125 sec	25 000 nT	Exploranium DIGRS 3001, 18.7 ltr, 1 sec	Kennedy 1101 tape recorder
S12/79 Windhoek, S13/79 Omatako S14/79 Summerdawn	03/07 - 17/08/79	34 669	100 m a.g.l.	E-W	1.0	Digital Gulf Mark III Fluxgate, 1 nT, 0.125 sec	25 000 nT	Exploranium DIGRS 3001, 18.7 ltr 1 sec	Geometrics G 704, Kennedy 1101 tape recorder
S15/80 Damaraland	30/10 - 04/11/80, 28/11/80-09/01/81	56 935	100 m a.g.l.	N-S & E-W	1.0	Geometrics G803, 1 nT, 1 sec	25 000 nT	McPhar Spectra II 256 ch., 16.8 ltr, 1 sec	Kennedy 9800 asynchronous 9-track tape recorder
S16/81 Tsumeb, Sesfontein	03/07 - 23/08/81	43 057	100 m a.g.l.	N-S & E-W	1.0	Geometrics G813, 1 nT, 1 sec	25 000 nT	Geometrics GR-800 (B) + GR 900 Detector Interface, 16.8 ltr, 1 sec	Geometrics G 714
S17/82 Tsumkwe	18/06 - 15/09/82	60 338	100 m a.g.l.	N-S	1.0	Geometrics G813, 1 nT, 0.8 sec	25 000 nT	Geometrics GR 800 (B) + GR 900 Detector Interface 16.8 ltr, 1 sec.	Geometrics G 714, Kennedy 9700 tape deck
S18/83 Helmeringhausen	29/07 - 06/08/83	22 678	100 m a.g.l.	NE-SW	1.0	Geometrics G813, 1 nT, 1 sec	25 000 nT	Geometrics GR 800 (B) + GR 900 Detector Interface, 16.8 ltr, 1 sec	Geometrics G 714, Kennedy 9700 tape deck
S19/84 A-Ais	09/08 - 28/09/84	25 867	100 m a.g.l	NE-SW & NW-SE & E-W	1.0	Geometrics G813, 1 nT, 1 sec	25 000 nT	Geometrics GR 800 (B) + GR 900 Detector Interface, 16.8 ltr, 1 sec	Geometrics G 714, Kennedy 9700 tape deck
S20/85 Karasburg	28/08 - 20/09/85	21 502 6 063	100 m a.g.l.	N-S E-W	1.0	Geometrics G813, 1 nT, 1 sec	25 000 nT	Geometrics GR 800 (B) + GR 900 Detector Interface, 16.8 ltr, 1 sec	Geometrics G 714 Kennedy 9700 tape deck

Table 1.2

SURVEY	PERIOD FLOWN	TOTAL MILEAGE (km)	FLIGHT HEIGHT	TRAVERSE DIRECTION	TRAVERSE SEPARA-TION (km)	MAGNETO-METER, RESOLUTION, SAMPLE RATE	MAGNETIC REFERENCE	GAMMA-SPECTROMETER, DETECTOR VOLUME SAMPLING INTERVAL	DATA ACQUI-SITION
S21/86 Opuwa	11/86 - 01/87	6 527 24 678	100 m a.g.l., 150 m a.g.l.	E-W	1.0	Geometrics G 813, 1 nT, 1 sec	25 000 nT	Geometrics GR 800 (B) + GR 900 Detector Interface, 16.8 ltr, 1 sec	Geometrics G714, Kennedy 9700 tape deck
S22/87 Mariental	05/11 - 15/11/87, 08/01 - 20/01/88	23 898	100 m a.g.l.	E-W	1.0	G.S.M 11, Overhauser, 0.01 nT, 0.5 sec	DGRF 1985 removed	Exploranium DGRS 1002, 16.8 ltr., 1 sec	Geometrics G 714, Kennedy 9700 tape deck
S23/89 Bethanien	16/01 - 02/02/90	13 056	100 m a.g.l.	E-W	1.0	Scintrex H8 Caesium Vapour, 0.005 nT, 0.1 sec	DGRF 1985 removed	Geometrics GR 800 (B) + GR 900 Detector Interface, 16.8 ltr., 1 sec	RMS DGR - 33
S24/90 Epukiro	17/08 - 27/08/90	12 920	100 m a.g.l.	N-S	1.0	Scintrex H8 Caesium Vapour, 0.005 nT, 0.1 sec	DGRF 1985 removed	Geometrics GR 800 (B) + GR 900 Detector Interface 16.8 ltr, 1 sec	RMS DGR - 33
CDM 78/1 Gobabis N	19/05 - 30/06/78	15 231	60 m a.g.l.	N-S	1.0	Geometrics G 803, 1 nT, 1 sec	25 000 nT	McPhar - Spectra II, 256 ch, 16.8 ltr, 2 sec	Kennedy 9800, asynchronous 9-track magtape recorder, partially only analogue records existent
CDM 78/2 Hereroland S	10/08 - 16/09/78	12 746	60 m a.g.l.	N-S	1.0	Geometrics G803, 1 nT, 1sec	25 000 nT	McPhar Spectra II, 256 ch, 16.8 ltr, 2 sec	Kennedy 9800 asynchronous 9-track magtape recorder, partially only analogue records existent

Table 1.3

SURVEY	PERIOD FLOWN	TOTAL MILEAGE (km)	FLIGHT HEIGHT	TRAVERSE DIRECTION	TRAVERSE SEPARA-TION (km)	MAGNETO-METER, RESOLUTION, SAMPLE RATE	MAGNETIC REFERENCE	GAMMA-SPECTROMETER, DETECTOR VOLUME, SAMPLING INTERVAL	DATA ACQUI-SITION
CDM 79 Kaokoland	18/05 - 20/06/79	10 454	100 m a.g.l.	E-W	1.0	Digital Gulf Mark III Fluxgate 1 nT, 1 sec	25 000 nT	McPhar Spectra II, 256 ch 16.8 ltr, 1 sec	Kennedy 9800 asynchronous 9 - track tape recorder
CDM 80/1 Otjiwarongo	14/05 - 11/06/80	6 000	100 m a.g.l.	N-S	0.5	Geometrics G 803, 1 nT 2 sec	25 000 nT	McPhar Spectra II, 256 ch, 16.8 ltr 2 sec	Kennedy 9800 asynchronous 9 - track tape recorder
CDM 80/2 Outjo	23/08 - 03/09/80	22 140	100 m a.g.l.	N-S	0.5	Digital Gulf Mark III Fluxgate, 1 nT, 0.3 sec	25 000 nT	McPhar Spectra II, 256 ch, 16.8 ltr. 2 sec	Kennedy 9800 asynchronous 9 - track tape recorder
CDM 81/1 Sinclair	22/03 - 07/04/81	11 000	100 m a.g.l.	E-W	1.0	Geometrics G803, 1 nT, 1 sec	25 000 nT	McPhar Spectra III, 128 ch, 33.6 ltr, 1 sec	Kennedy 9800 asynchronous 9 - track tape recorder
CDM 81/2 Grünau	10/04 - 11/05/81	30 548	100 m a.g.l.	E-W	0.5	Geometrics G803, 1 nT, 1 sec	25 000 nT	McPhar Spectra III, 128 ch, 33.8 ltr, 1 sec	Kennedy 9800 asynchronous 9 - track tape recorder
CDM 82 Aroab	07/05 - 18/05/82	16 000	100 m a.g.l.	N 50°E	1.0	Digital Gulf Mark III Fluxgate, 1 nT, 0.4 sec	25 000 nT	McPhar Spectra III, 128 ch, 33 6 ltr, 1 sec	Kennedy 9800 asynchronous 9 - track tape recorder
BGR Kuiseb	15/05 - 16/11/92	12346	80 m a.g.l.	N-S	0.4 / 1.0	Scintrex MAC - C3 Caesium vapour, 0.01 nT, 0.25 sec	IGRF 1982 removed	Geometrics GR-800D, 16.8 ltr., 1 sec	RMS TCR - 12 magtape recorder, 6400 bpi GCR - formatted; RMS GR - 33 analogue recording

Table 1.4

SURVEY	RADIOMETRIC DATA ENHANCEMENT	NAVIGATION	ARCHIVE TAPE	COMPANY	REMARKS
S1/68 Rössing	not applied	visual, photo mosaics, flight path camera	not existent	Aircraft OperatingComp Ltd., Map Studio Productions Ltd.	analogue data only
S2/71 Cape Cross	stripping	visual, photo mosaics, flight path camera	not existent	Aircraft OperatingComp.Ltd., Map Studio Productions Ltd.	analogue data only
S3/72 Hereroland	not applied	not documented	not existent	Aircraft OperatingComp.Ltd., Map Studio Productions Ltd.	parameters are given for completeness, survey is of reconnaissance nature.
S4/73 + S5/73 Swakopmund	background removal, stripping	visual, photo mosaics, Doppler support, flight path camera	not existent	Preka - Scismos Hannover, Geomapping Ltd., Johannesburg	analogue data only
S6/74 Omaruru	background removal, stripping	visual, photo mosaics, Doppler support, flight path camera	9 track, 800 BPI, EBCDIC coded, unlabelled, 3 000 characters / block	Aircraft Operating Comp Ltd., Geomapping Ltd., Johannesburg	
S7/75 Okahandja	background removal, stripping	visual, photo mosaics, Doppler support, flight path camera	9 track, 800 BPI, EBCDIC coded, unlabelled, 3 000 characters / block	Aircraft Operating Comp. Ltd., Geomapping Ltd., Johannesburg	
S8/76 Walvis Bay, S9/76 Gibeon/Mariental	background removal, stripping	visual, photo mosaics, Doppler support flight path camera	9 track, 800 BPI, EBCDIC coded, unlabelled, 1980 characters / block	Aircraft Operating Comp. Ltd., Geomapping Ltd., Johannesburg	
S10/77 Okahandja	background removal, stripping	visual, photo mosaics, Doppler support, flight path camera	9 track, EBCDIC unlabeled, 1600 BPI, phase encoded	Aircraft Operating Comp. Ltd. Geomapping Ltd., Johannesburg	field tapes only and analogue

Table 2.1

SURVEY	RADIOMETRIC DATA ENHANCEMENT	NAVIGATION	ARCHIVE TAPE	COMPANY	REMARKS
S11/78 Rehoboth	background removal stripping	visual, photo mosaics, Doppler support, flight path camera	9 track, EBCDIC, unlabelled, 1600 BPI, phase encoded	Aircraft Operating Comp. Ltd. Geomapping Ltd., Johannesburg	field tapes only and analogue
S12/79 Windhoek, S13/79 Omatako, S14/79 Summerdown	background removal, stripping	visual, photo mosaics, flight path camera	created	Inter-Science Research and Development Services, Johannesburg	
S15/80 Damaraland	background removal, stripping, height correction	visual, photo mosaics, flight path camera	9 track, 1600 BPI, EBCDIC, variable block format	Avex Air (Pty) Ltd., Geomapping Services Ltd., Geodass S.A. (Pty) Ltd.	
S16/81 Tsumeb, Sasfontein	background removal, stripping, height correction	visual, photo mosaics, flight path camera	9 track, 1 600 BPI, ASCII character format, unlabelled	Avex Air (Pty) Ltd., Geomapping Services Ltd., Geodass S.A. (Pty) Ltd.	
S17/82 Tsumkwe	background removal, stripping	visual, photo mosaics, flight path camera	9 track, 1 600 BPI, ASCII character format, unlabelled	Avex Air (Pty) Ltd., Geomapping Services Ltd., Geodass S.A. (Pty) Ltd.	
S18/83 Helmeringhausen	background removal, stripping, height correction	visual, photo mosaics, flight path camera	9 track, 1600 BPI ASCII character format, unlabelled	Avex Air (Pty) Ltd., Geodass S.A. (Pty) Ltd	
S19/84 Ai-Ais	background removal, stripping, height correction	visual, photo mosaics, flight path camera	9 track, 1600 BPI, ASCII character format, unlabelled	Aircraft Operating Comp. Ltd., Geodass S.A. (Pty) Ltd.	
S20/85 Karasburg	background removal, stripping, height correction	visual, photo mosaics, flight path camera	9 track, 1600 BPI, ASCII character format, unlabelled	Aircraft Operating Comp. Ltd., Geodass S.A. (Pty) Ltd.	

Table 2.2

SURVEY	RADIOMETRIC DATA ENHANCEMENT	NAVIGATION	ARCHIVE TAPE	COMPANY	REMARKS
S21/86 Opuwa	background removal, stripping	visual, photo mosaics, Doppler support, flight path camera	9 track, 1 600 BPI, ASCII character format, unlabelled	Aircraft Operating Comp. Ltd., Geodass S.A. (Pty) Ltd.	
S22/87 Mariental	background removal stripping	visual, photo mosaics, flight path camera	created	Geosels (Pty) Ltd., Avex Air (Pty) Ltd.	
S23/89 Bethanien	background removal, stripping, height correction.	visual, photo mosaics, flight path camera	9 track, 1 600 BPI tapes in ASCII character format	Aircraft Operating Comp. (AOC), Geodass (Pty) Ltd.	
S24/90 Epukiro	background removed, stripping, no compilation requested	visual, photo mosaics, flight path camera	9 track 1 600 BPI tapes in ASCII character format	Aircraft Operating Comp. (AOC), Geodass (Pty) Ltd.	
CDM 78/1 Gobabis N	background removal, stripping	visual, photo mosaics, flight path camera	800 BPI, ASCII character format	Avex Air (Pty) Ltd., Geomapping Services; Johannesburg Consolidated Investment (JCI) - Geophysical Dptm.	
CDM 78/2 Hereroland S	background removal, stripping	visual, photo mosaics, flight path camera	not existent	Avex Air (Pty) Ltd., Geomapping Services, Anglo American Corp. (AAC) - Geophysical Dptm.	only contour maps existent

Table 2.3

SURVEY	RADIOMETRIC DATA ENHANCEMENT	NAVIGATION	ARCHIVE TAPE	COMPANY	REMARKS
CDM 79 Kaokoland	background removal, stripping	visual, photo mosaics, flight path camera	ASCII character format for standard data; spectrometer data in binary format	Avex Air (Pty) Ltd., Geomapping Services, Geodass S.A. Ltd., Anglo American Corp (A.A.C.) Geophys. Dptm	simultaneously flown with McPhar EM - system F - 400: 340 + 1070 Hz-out-of-phase EM-system
CDM 80/1 Otjiwarongo	background removal, stripping, height corrections	visual, photo mosaics, flight path camera	ASCII character format for standard data; spectrometer data in binary format	Aircraft OperatingComp Ltd., Map Computations (Pty) Ltd., Geodass S.A. Ltd., A.A.C. Geophys. Dptm	
CDM 81/1 Sinclair	background removal, stripping	visual, uncontrolled photo mosaics, Doppler support, flight path camera	ASCII character format for standard data, binary format for multichannel spectrometer data record length 120 bytes, 40 records/block	Aircraft OperatingComp.Ltd., Map Compilations (Pty) Ltd., A.A.C. - Geophys. Dptm. Geodass S.A. Ltd., Johannesburg. Data Plotting Services, Toronto, Canada	
CDM 81/2 Grünau	background removal, stripping	visual, uncontrolled photo mosaics, Doppler support, flight path camera	ASCII character format for standard data, binary format for multichannel spectrometer data, record length 120 bytes, 40 records / block	Aircraft OperatingComp.Ltd., Map Compilations (Pty) Ltd., A.A.C. - Geophys. Dptm., Geodass S.A. Ltd., Johannesburg. Data Plotting Services, Toronto, Canada	
CDM 82 Aroab	background removal, stripping	visual, uncontrolled photo mosaics, Doppler support, flight path camera	ASCII character format for standard data, binary format for multichannel spectrometer data, record length 120 bytes, 40 records / block	Aircraft OperatingComp.Ltd., Map Compilations (Pty) Ltd. A.A.C. - Geophys. Dptm., Geodass S.A. Ltd., Johannesburg, Data Plotting Services, Toronto, Canada	
BGR Kuiseb	background removal, stripping, height corrections	Doppler, GPS, flight path video	created, available from BGR	Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany	simultaneously flown with three-frequency DIGHEM III - EM-system

Table 2.4

2.4 Processing

During the course of time various procedures were applied to obtain and visualize gamma-ray data as free from interfering influences as possible.

In some cases where processing was not even carried out either due to limited funds or possibly due to lack of interest in these data, the data when digitally recorded were dumped to archive tapes.

2.4.1 Corrections Applied

The counts recorded in any window have three background components. These background components originate from

(1) radon (Rn) decay products in the air,
(2) radioactivity of the aircraft and its equipment,
(3) high energy cosmic ray particles that interact with the air, the aircraft and the detector (Grasty and Minty, 1995).

Background removal procedures as described by the bulk of the operational reports only consider component (2), which was achieved by surveying a high altitude test line to obtain the most reliable estimate of the total count background. The procedure was applied for nearly all surveys with the exception of the early surveys conducted between 1968 and 1972 (cf. Tables 2). Flights over the South Atlantic ocean for measurement of background have not been reported.

Height corrections were applied only to a minor extent using a conventional exponential formula

$$N_h = N_o \exp(-\mu h)$$

where

N_h is the background corrected and stripped count rate,
N_o is the count rate at ground level,
μ is the attenuation coefficient,
and h is the height above ground level.

The values of the attenuation coefficients for each window were determined by testing various coefficients and selecting the optimum result, obviously ignoring the procedure of making a series of flights at different heights over an airborne (dynamic) calibration range as suggested and described by IAEA (1991). Therefore the accuracy of the height corrections applied must be considered with some reservations.

Although the gamma-ray window count rates depend on air temperature and pressure, corrections for a standard atmosphere have not been reported; nor allowances made for the increase of the three stripping ratios with altitude above the ground resulting from scattering of gamma-rays in the air layer between the detector and the ground surface.

Further corrections and calibrations, such as determination of the radon and cosmic backgrounds or of system sensitivities, were not pursued, presumably because they were not specified and required by the tender documents.

2.4.2 Line Archive Data

When digitally recorded, all data used in a survey - calibration lines, test lines and production data - were written to final archive tapes. The archive data were recorded on nine track, 800 or 1600 bpi tapes, EBCDIC code, and in ASCII character format applying various block lengths. The files are mainly unlabelled.

The line archive data together with the analogue charts of the early surveys (from 1968 to 1977) were the main source data for the compilation of the refined airborne radiometric data as digital grids and radiometric maps.

3. Standardization and Compilation

High-Sense Geophysics Ltd., Toronto, were contracted to standardize, compile and merge selected Namibian airborne gamma ray data into a master digital data set. Supervision was carried out jointly by the BGR and the GSN. These digital data could then be used to produce maps of

(1) exposure rate,
(2) ground concentrations of potassium, uranium and thorium,
(3) elemental ratios,
(4) ternary images.

Data were processed first from an area of west central Namibia, comprising four (4) 1 : 250 000 scale map sheets - namely 2014 (Fransfontein), 2016 (Otjiwarongo), 2114 (Omaruru) and 2116 (Okahandja) covering an area of almost 91 000 square kilometers. This radiometric data resource comprises ten different surveys flown between 1968 and 1980 with approximately 42 000 line kilometers of analogue chart records and about 49 000 line kilometers of

digital data. This area gives a representative sampling of the different types of radiometric data available in Namibia.

The success of the compilation of data from west central Namibia, especially of those surveys flown digitally, led BGR/GSN to contract High-Sense Geophysics Ltd. to compile data from southern Namibia covering further seven (7) 1 : 250 000 scale map sheets - namely 2514 (Spencer Bay), 2516 (Gibeon), 2616 (Bethanien), 2716 (Ai-Ais), 2718 (Grünau), 2816 (Alexander Bay) and 2818 (Warmbad). These data comprising seven different surveys with a total of about 140 000 line kilometers and a surface of about 110 000 square kilometers were to be processed to support an appraisal of the mineral potential of southern Namibia. These surveys are more homogeneous and consistent in quality than those from west central Namibia, and above all, they had the advantage that they were completely digital. Analogue data recovery was therefore not necessary.

3.1 Data Recovery

Analogue data recovery formed a major input. Approximately 46% of the total line kilometers of the west central area had to be digitized prior to the refinement of the data. Digitization was undertaken using a proprietary interactive trace recovery procedure (RE-TRACE) previously developed by the contractor. This interactive, semi-automated system scans and vectorizes each pen trace of an analogue chart, capturing a perfect digital reproduction of both high and low frequency components, thereby ensuring profile fidelity for all gamma-ray channels and altimeter records (Duffy *et al.*, 1994).

Raw digital data were recovered from either original field tapes or from line archive tapes. The degree of early data manipulation (stripping, background removal, height corrections) done by the initial contractors had to be found out and assessed. This varied from survey to survey for both analogue and digital data sets.

Once the data recovery was complete, it was verified. This verification consisted of

(1) the preparation of rough maps to ensure completeness,
(2) the identification of data errors,
(3) the adjustment for original survey failings,
(4) the selection of suitable back-calibration sites.

3.2 Back-Calibration

Back-calibration of radiometric data is based on the comparison of airborne count rates with ground concentrations measured beneath the flight path by a calibrated portable gamma-ray spectrometer (Grasty *et al.*, 1992). Aircraft sensitivity factors calculated by this technique can be used to correlate survey results obtained from radiometric systems with different detector crystal volumes and, to a lesser extent, different energy windows (Duffy *et al.*, 1994).

Systematic ground radiometric measurements in Namibia were made at about twenty (20) calibration "sites" within each of the airborne survey blocks. Preferred ground calibration sites were situated at the intersection of flight lines and roads, in areas of uniformly elevated radiometric signatures and subdued topography. By choosing calibration sites located at the same features used by the survey aircrews for navigation (fiducial markers recorded on flight records and manually transferred to navigation maps and photo mosaics) good data correlation was assured.

Each site, for example given by a flight line where it traverses a gravel road or a farm fence, was evaluated with respect to potential cultural disturbance or physiographic influences prior to taking ground concentration readings. Four (4) measurements were made at every calibration site; two (2) on either side of the road or fence and typically 25 m apart. A laptop computer was used to store the full digital site spectrum measured by the portable spectrometer. Preliminary databases for each survey area (generated during the data verification stage) were available on the same computer, allowing each day's ground data to be processed, evaluated and compared with the airborne results while the field crew was still in the area (Duffy *et al.*, 1994).

Navigation in the field was via published 1 : 50 000 scale topographic maps, assisted by satellite GPS (Global Positioning System). GPS readings were used to verify location at each calibration site, and provided positioning control in areas of featureless terrain. A typical series of ground calibration sites is shown in Fig. 3 (Duffy *et al.*, 1994).

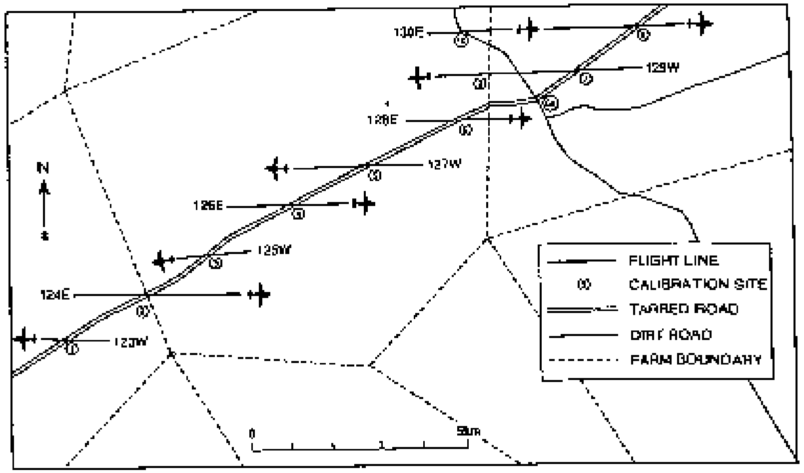


Fig. 3 Cluster of ten ground calibration sites, survey S 10/77 (cf. Fig. 1).

Airborne count rates at the different calibration sites showed variations in radioactivity. Airborne and ground measurements were therefore compared separately at each site to derive estimates of the airborne sensitivities. The uncertainties in these sensitivities were compiled from the calculated statistical error of the airborne signal in the vicinity of the ground measurements, i.e. along an approximately 500 - 600 m flight line section centred where it crosses the road, as well as from the variations in the four ground measurements, based on the mean value of the airborne count rates and the four ground measurements.

The total count channel was calibrated by comparing the airborne measurements with the calculated exposure rate derived from the ground concentrations of potassium, uranium and thorium using the following standard relationships (Grasty *et al.*, 1984).

$$1\%\ K = 1.505\ \mu R/h$$
$$1\ ppm\ U = 0.625\ \mu R/h$$
$$1\ ppm\ Th = 0.31\ \mu R/h$$

The elemental airborne channels were successively calibrated in a very similar manner by comparison with the measured ground concentrations of each natural element.

Table 3 provides an example of the total count sensitivites for survey block S 10/77. The final sensitivity was calculated from the individual sensitivities taking into consideration errors associated with calibrations at each ground measurement location. Fig. 4 compares the exposure rates (μR/h) at each of the calibration sites.

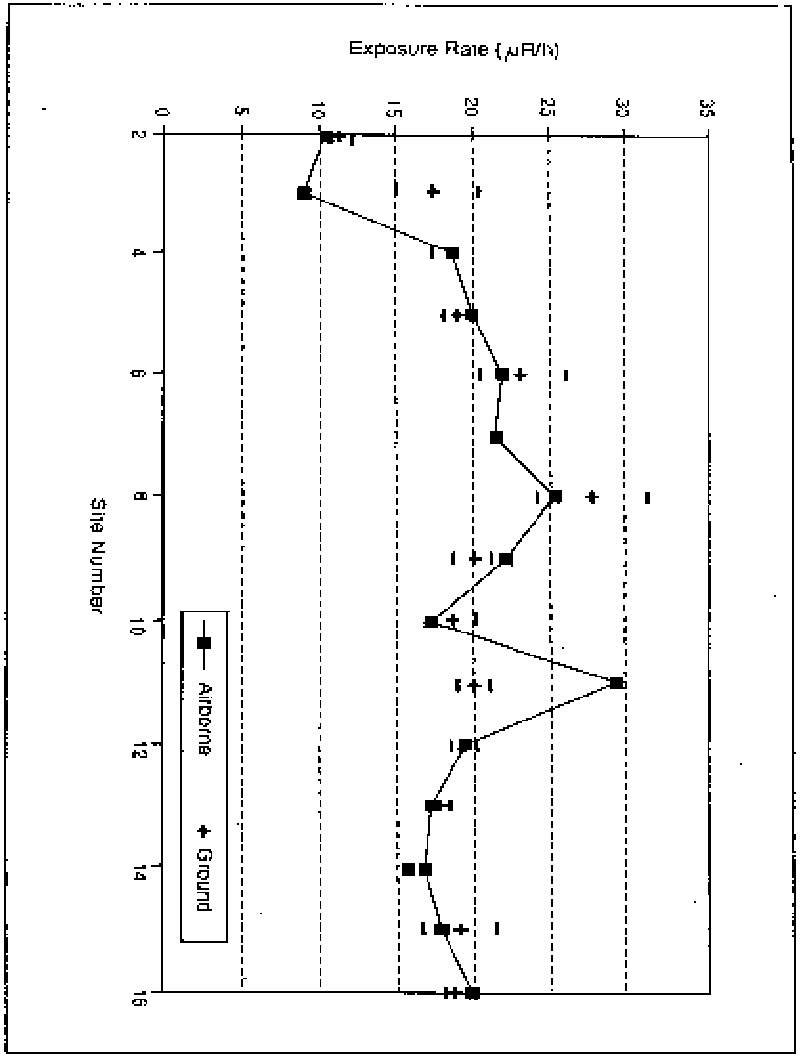


Fig. 4 Comparison of airborne and ground exposure rate measurements after back-calibration, survey S 10/77. Horizontal bars indicate ground data range (Duffy *et al.*, 1994).

Table 3. Calibrations for the total count channel (S 10/77).

Site Number	Calculated Exposure Rate (μR/h)	Airborne Total Counts (cps)	Sensitivity (cps/μR/h)
2	11.6 +/- 0.8	301 +/- 24	26.0 +/- 2.7
3	17.9 +/- 2.9	258 +/- 30	14.4 +/- 2.9
4	18.3 +/- 0.7	536 +/- 33	29.3 +/- 2.1
5	18.6 +/- 0.7	574 +/- 35	30.9 +/- 2.2
.	...	...	...
.	...	...	...
16	17.8 +/- 1.2	566 +/- 44	31.8 +/- 3.3

3.3 Data Enhancement and Merging

During the final stage of data processing, the individual surveys were "fine"-levelled using a variation of microlevelling adapted for radiometrics. Each survey was processed independently following standard radiometric correction procedures consisting of background determination and removal, Compton stripping (where required, some analogues had already been stripped) and height correction (see IAEA, 1991; Grasty and Minty, 1995).

All surveys were continued to a common flight height of 100 m above terrain. Filters optimally adapted to the nature of radiometric data were applied to reduce noise effects. Intermediate grids of each survey block were prepared throughout the process and checked for internal consistency with an imaging program.

Airborne sensitivities were then re-calculated for each survey block and applied to generate equal area ground concentration grids for each component. Individual survey areas were merged together on central meridians of 15°E, 17°E and 19°E at a 250 m grid cell size. The data were decorrugated (Urquhart, 1988) and contoured, with any potential damages mitigated by the earlier application of fine levelling (Duffy *et al.*, 1994). Remaining concentration differences between survey blocks are attributed to incompatible spectral windows.

In areas of rugged terrain, exaggerated highs and lows may be introduced by the height correction, particularly where the survey aircraft exceeded nominal terrain clearance.

3.4 Data Presentation

The back-calibration and enhancement processes facilitated merging of the individual surveys to provide a master digital grid, for each of the components (potassium, uranium, thorium and exposure rate). The merged data are available as either contour maps or as gridded data.

3.4.1 Map Products

Both monochrome and colour 1 : 250 000 scale contour maps for each of the components were produced from the final and standardized 250 m gridded data in the Namibian Lo Projection using central meridians of 15°E, 17°E, and 19°E. Fig. 5 shows the layout and naming of the sheets so far compiled. They are conform in scale and coordinate system with the existing topocadastral, geological and regional airborne magnetic map series.

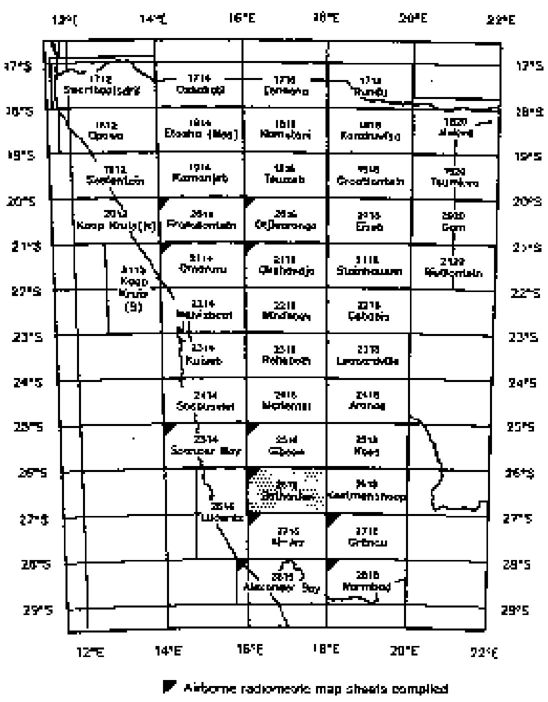


Fig. 5 Sheet layout of the 1 : 250 000 scale regional airborne radiometric map series.

Radiometric ratios were calculated from the corrected ground concentration data. Elemental ratios are particularly useful because they are less affected by source geometry and surface variability than individual element data (Darnley and Ford, 1989). Elemental data were pre-conditioned by having set negative radio-element concentrations due to statistical noise and non-optimum stripping, resp., to zero. To further minimize the influence of statistical noise in low activity areas, data for each element were accumulated over a limited radius to attain a minimum threshold level prior to ratio calculation. Ratios were not applied if these minimums were not reached.

The confidence level of the calculated radio-elements ratio is immediately related to local activity. As active areas tend to produce more reliable ratios, users are recommended to consult the corresponding exposure rate maps.

No uranium (U)/thorium (Th) and uranium (U)/potassium (K) ratio maps were produced due to the generally fairly noisy character of the uranium data. Thorium (Th)/potassium (K) ratios were produced only for two west central map sheets, namely 2014 (Fransfontein) and 2016 (Otjiwarongo), and the southern Namibia map sheets. The Th/K ratio significantly increases from ultrabasic to acid igneous rocks thus being a useful indicator of the composition of igneous rocks.

Three-component compilations commonly referred to as ternary maps were prepared for all map sheets so far processed. The ternary display is formed by calculating the relative concentration of the three radio-elements (K, U, Th) at each data point. The subtractive primary colours, yellow, magenta, and cyan, are used to represent the three radio-elements thorium, potassium and uranium. Individual colours are set to provide the greatest variation in colour within the range of most frequently observed concentrations. Total radioactivity information is added by varying the colour saturation at each point according to the total count level. Colours resulting from the combination of the concentration images reflect variations in relative content of the three elemental radio sources, with statistical certainty increasing with colour density.

Some residual effects from errors and deficiencies inherent in the original data from the west central areas can be seen in the final products. However, the resultant radiometric grid and map products enable correlation between surveys, and across the selected area. Products from the southern areas hardly show anyone of these imperfections reflecting the technical progress made in radiometric surveying within a single decade.

All maps contain geographic information (roads, coastline, towns), which was supplied in digital format by the Geological Survey of Namibia (GSN) from 1 : 250 000 scale topographic maps. The film masters of the monochrome contour maps are in the archives of the GSN.

3.4.2 Digital Data Products

The final digital gridded data were archived as ASCII compressed characters in the Geosoft GXF File format onto 3.5" floppy discs, at a grid cell size of 250 m. The gridded data sets consist of a header containing all necessary information, such as origin, cell size, storing sense, followed by the data stored row after row. Each grid point is described by the

- (1) easting coordinate (m),
- (2) northing coordinate (m),
- (3) final radiometric value,
- (4) elevation (m) of topography from the Digital Terrain Model (DTM).

The GXF files can be converted to common ASCII XYZ or to *Geosoft* files using the *Geosoft* programs GXF.EXE and GRIDXYZ.EXE.

4. Comment on Interpretation

Airborne radiometrics are widely considered as a surficial mapping technique since approximately 95 % of the collected radiation is emitted from the upper 50 cm of the ground (cf. Nielson *et al.*, 1990). A minor thickness of overburden absorbs already most of the radiation emitted by camouflaged bedrock. This, however, does not constrain the use of the method to areas with extensive outcrops. Thick residual soil cover, except for alluvial plains or aeolian sands, reasonably reflects the composition of the immediately underlying bedrock source. Therefore airborne radiometrics have proven a valuable tool in mapping lithologies.

Distinguishing lithologies is possible due to the varying content of natural radio-elements. As a rule of thumb it can be said that acid igneous rocks show a stronger gamma radiation than ultrabasic to basic intrusives and effusives. Sediments radiate the more intensively the more they contain clayish and graphitic particles, i.e. schists, silts, shales and other pelitic sediments generally exhibit stronger radiation than carbonates and quartzites.

5. Radiometric Patterns and Major Geological Units in West Central Namibia

West central Namibia is largely covered by rocks of the late Proterozoic (Pan-African) Damara orogen, hosting a couple of prominent Mesozoic anorogenic intrusions (Fig. 6). The airborne radiometric maps and ternary displays (BGR/GSN 1994a, 1994b) comprise the 1 : 250 000 scale sheets 2014 (Fransfontein), 2016 (Otjiwarongo), 2114 (Omaruru) and 2116 (Okahandja) covering the Central and Northern Zones of the Damara orogen (Miller, 1983). Prevalent lithologies are metasedimentary, granitic, and gneissic.

5.1 Map Sheet 2014 (Fransfontein)

In terms of natural gamma radiation, this map sheet is one of the most outstanding from the central west area.

Several high radiation clusters can be observed in its central, southern and western portions. In the centre area potassium radiation is predominant, whereas radiation in the south and west is mainly due to high thorium contents. The radiation highs are produced by the K-rich volcanics (ignimbrites) of the Mitten Fold and Summas Mountains as well as by Salem-type, and to a minor extent, by post-tectonic Sorris-Sorris granites to the west and southwest of the U-shaped Mitten

Fold. The large, oval-shaped high radiation complex of the Omangambo pluton (traversed by district road D 2612, which leads to Twyfelfontein) to the west of the Mitten Fold neatly contrasts with its weak radiation vicinity.

In the southeast of the sheet, the Otjohorongo thrust fault is clearly marked by a steep gradient produced by the immediate contact of high radiating Salem-type granites in the south with poor radiating metasedimentary units (Kuiseb and Karibib Fms.) in the north.

A more or less circular prominent radiation high was observed over the syenite complex about 5 km to the west of the village of Otjohorongo. Increased ground concentrations of uranium (> 10 ppm) and thorium (app. 70 ppm) are indicated by this anomaly. The Okenyenya igneous complex situated 15 km further to the west fails to produce a radiation anomaly, as one would have not iniatially expected. The complex, however, consists of gabbroic rock types (Watkins and le Roex, 1994), which fully explains its poor radiation pattern.

The central east part of the sheet is quite low in radiation indicating that the metasedimentary units of the Northern Zone (Kuiseb, Karibib, Okonguarri Fms. of the Swakop Group and Ugab Subgroup) and Karoo cover sediments produce only weak radiometric signals. A thick sequence of carbonates exposed in the Okotjize and Okongue Folds situated to the east of the Mitten Fold is characterized by distinct radiation lows.

The southern boundary of the Kamanjab inlier is clearly marked by another conspicuous gradient feature with radiometric intensities changing over a short horizontal distance from low average exposure rates of 3 $\mu R/h$ over pelitic to dolomitic metasediments of the Otavi and Mulden Groups in the south to about 10 $\mu R/h$ in the mean over pre-Damaran gneisses and granites in the north.

About 25 km to the west of the town of Khorixas a sickle-shaped sequence of singular radiation highs can be observed running in a more or less SSW/NNE-direction. They may be attributed to volcanics of the Nosib Group deposited during the rifting stage of the Damara orogen. Potassium concentrations are on a lower level, but thorium concentrations are largely increased against background. A swarm of carbonatite dykes reported from the farms Lofdal and Bergville by Diehl (1992) is supposed to produce this interesting radiation pattern. In one case, a local, but distinct uranium anomaly (> 10 ppm) was detected. This anomaly is likely to be associated with the Oas/Lofdal syenite stock (see Diehl, 1992).

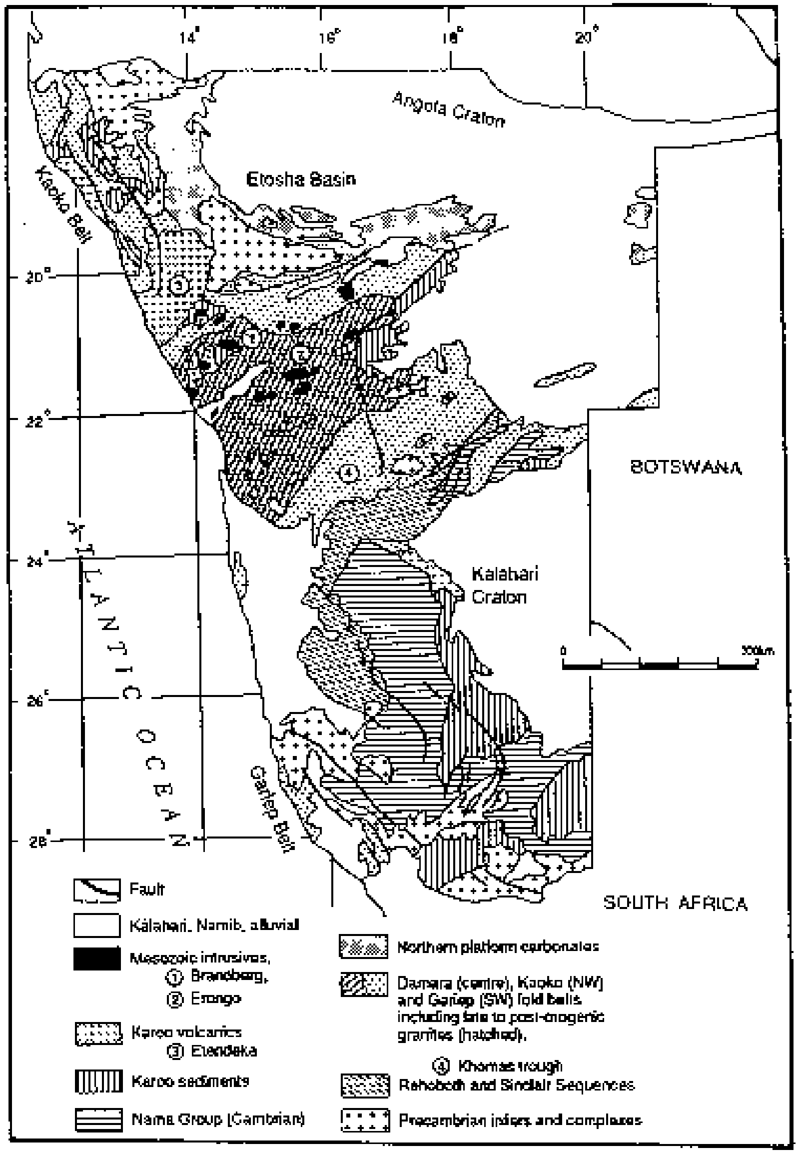


Fig. 6 Generalized geological map of Namibia (modified after Schneider, 1990).

5.2 Map Sheet 2016 (Otjiwarongo)

Natural gamma radiation gradually decreases from west to east due to the increasing occurrence of Karoo and Kalahari cover sediments towards the east.

There are several more or less circular high radiation patterns in the area between longitudes 16°E and 17°E. An approximately 50 km wide, SW/NE running high radiation cluster extends from Kalkveld in the most southwestern corner to approximately 50 km E and SE of Otjiwarongo in the centre of the map sheet. It is produced by various granitic rocks of Damaran age bearing thorium in abundance (see respective yellow pattern in ternary map).

Extremely low radiation can be observed over the whole of the Waterberg plateau built up by Karoo-aged aeolian Etjo sandstones that must be assumed to be very poor in clay minerals due to their negligible potassium concentrations. The whole of the Omaheke region as far as covered by this map sheet is also very low in radiation. A slight increase in radiation can only be observed along the two Omatako river beds since uraniferous minerals are fairly leachable. Information from beneath the Kalahari sand cover is not obtainable as the thickness of the sands is obviously too great to be penetrated by radiation from underlying bedrock.

The circular high radiation patterns are associated with carbonatites of Mesozoic ages. The radiation high at 20°S/16°45'E is produced by the Okurusu Alkaline Complex where increased thorium concentrations are the major source of radiation (see ternary map, yellow circular pattern).

Further to the southwest, at about 20°22'S/16°15'E, the Paresis anorogenic per-alkaline complex is responsible for the strongest individual radiation high of the map sheet area. From the ternary map it can be deduced that thorium and uranium concentrations are greatest in its northwestern part (Th: 100 ppm, U: 15 ppm) and potassium concentration is predominant in its southeastern extremity.

Smaller circular radiation features occur some ten kilometers northwest of Kalkveld. They are due to various smaller Mesozoic alkaline and carbonatite plugs which form the Kalkveld, Ondumakorume and Osongombe complexes. They are rich in thorium (about 100 ppm) and uranium (about 12 ppm).

Post-Karoo alkaline complexes situated about thirty kilometers to the east of Kalkveld on farms Okonjati, Kubusie and Okaue close to the Waterberg thrust fault are distinguished by increased potassium, thorium (>130 ppm) and uranium (12 ppm) concentrations in an area of generally increased radioactive background.

A SW/NE runnning belt of slightly increased total radiation (average exposure rate of 10μR/h) linking the Paresis and the Okorusu alkaline intrusives correlates well with pre-Damaran Huab paragneisses (Miller and Schalk, 1980). Natural radiation is due to their increased potassium concentrations (see potassium and ternary maps).

5.3 Map Sheet 2114 (Omaruru)

Average natural gamma radiation gradually increases from west to east in the map sheet area. The coastal plains including the Messum crater, the Gobobosebberge and even the Brandberg are extremely low in gamma radiation. Data collected in the Brandberg area should, however, be considered with some reservations due to very steep surface gradients and terrain clearances for reasons of flight safety probably greater than the nominal flight height. Only east of the Henties Bay - Uis gravel road radiation attains more increased average background values of about 10 to 15μR/h.

Local strong radiation highs are observed in the coastal plains over scattered outcrops of Salem-type granites, undifferentiated rocks of the Nosib Fm. and turbiditic metasediments of the Swakop Group. Interestingly, some peaks show non-average U/Th-ratios of about 1. They occur in the former Mile 72, Henties Bay, Cape Cross and Namib Rock grants (cf. Müller-Kahle and Roesener, 1996) and are produced by secondary enrichments of uranium in calcretes and gypcretes frequently bound to drainage systems.

In some portions of the Omaruru plains radiation is fairly increased due to higher thorium concentrations occurring parallel to the actual river bed (see yellow patch close to 22°S/14°15'E on ternary display). From there, a band of increased radiation with an average width of approximately 25 km develops to the east and northeast extending via Okombahe and the northernmost outskirts of the Erongo massif to the area just north of the town of Omaruru. In its southwestern section, from the coastal plains to about the Usakos - Uis gravel road, uranium is the prevalent radio-element. Former uranium prospects, such as Marenica, Kleine Spitzkoppe and Ootmoed (cf. Müller-Kahle and Roesener, 1996), are contained by this section of the radiation belt which draws attention by its promising U/Th ratios of 0.3 to about 1. However, the more the belt proceeds to the east, the more the abundance of thorium becomes evident with U/Th ratios getting smaller.

Scattered low radiation features within this belt are largely due to the Arises River Marble Member and other carbonates of the Karibib Fm. (cf. Miller and Grote, 1988). Lows in the Uis Berge and northeast of them are produced by Karoo sills and dykes (cf. Miller and Schalk, 1980). A prominent radiation low some twenty kilometers NNW of Omaruru extending over the Elefantenberge is also produced by carbonates of the Karibib Fm.

The outcropping granites of the Große and Kleine Spitzkoppe show increased ground concentrations of uranium in the order of 10 ppm possibly indicating that these late Mesozoic intrusives are the source of the various surficial (secondary) uranium deposits occurring in the surroundings. High thorium concentrations which are wide-spread in the north and northeast of the map sheet area can be related with mostly late to post-tectonic leucogranites. Wide-spread late tectonic biotitic granites of this region are, however, inconspicuous (cf. Miller and Grote, 1988).

The circular shape of the Erongo massif is best reflected by the uranium and thorium concentrations. Highs delineate the outer parts predominantly consisting of granites, whereas lows spread into the inner zone consisting of basaltic lava flows. The most prominent high situated in the northwest of the Erongo on farm Omandumba West 137 can be associated with anorogenic late Mesozoic granites intruded into syn- to post-tectonic Salem-type granites. It is described by a uranium/thorium ratio of about 0.4. Further peak ratio values of up to 0.3 are observed on farms Brabant 68 and Etiromund 51 along the southern slopes of the Erongo.

5.4 Map Sheet 2116 (Okahandja)

Similarly to geological conditions existing in the area of the adjacent map sheet 2016, natural radiation gradually decreases from west to east as Karoo and Kalahari cover sediments increasingly occur east of longitude 15°E. The central northern part of the map sheet area is widely covered by Omingonde silt-, mud- and sandstones (Miller and Schalk, 1980) of Karoo age, which results in generally low radiation mainly originating from accessory uraniferous minerals (see blue pattern in ternary display). Outstandingly low radiation was observed over the Ombotuzo mountains some forty kilometers north of Okahandja (farm Matador) as well as over the Etjo Mountains in the northwest of the map sheet area. These lows are attributed to Karoo (aeolian) sandstones.

Increased radiation concentrates on the western and central southern parts of the map sheet area. In the northwest corner, an extensive pattern of

increased radiation indicates various Damaran granites that most probably outcrop to a much larger extent than mapped by Miller and Grote (1988). Immediately south of the Mount Etjo radiation low, a pattern of high radiation extends over Salem-type granites of Damaran age. The major contribution of the gamma radiation originates from high thorium ground concentrations (average value 70 ppm). Uranium ground concentrations are in the order of up to 12 ppm.

Further to the south, radiation originating from potassium becomes more prevalent (see pink pattern of ternary display). In the area confined approximately by the Wilhelmstal-Okahandja and Wilhelmstal-Omaruru main roads and by district roads 2108, 2121 and 2328, the radiation pattern is described by isolated highs rather than by extensive high-level radiation indicating the highly heterogeneous composition of the Salem-type granites as far as the natural radio-elements are concerned. Radiation mainly originates from abundant potassium (see pink pattern in ternary display) of the Salem-type granites which are locally altered by post-tectonic metamorphism (Miller and Grote, 1988).

An isolated high on farm Omapyu South 77 is worth mentioning as it surprisingly occurs over marbles of the Swakop Group and metasediments of the Kuiseb Fm. Peak concentrations of thorium and uranium are about 60 ppm and 6 ppm, respectively. The radiation low situated in the extreme southwest corner of the map sheet area (south of the main road Wilhelmstal - Karibib) indeed correlates with outcrops of marbles of the Karibib Fm.

The local radiation high at about 21°58'S/16°40'E can be attributed to the Ozombanda granite exposed in the Waldau dome structure. This post-tectonic granite variety is poor in potassium and natural radiation originates almost entirely from thorium (< 60 ppm) and uranium (< 8 ppm) sources (see green pattern on ternary display).

A cluster of WSW/ENE running radiation highs situated some twenty kilometers north and northeast of Okahandja has various geological sources: In the western portion of this anomaly belt radiation mainly originates from various Damaran granites, while in the east the anomalies can be ascribed to pre-Damaran Abbabis and Hohewarte paragneisses (Miller and Schalk, 1980). Major contributors to radiation are thorium and uranium sources, with uranium becoming prevalent towards the east (see change from yellow to green of the ternary display).

Another remarkable high was observed on farm Otjisazu 20 km ENE of

Okahandja. It can easily be explained by the carbonatitic igneous complex described by Gunthorpe and Buerger (1986) as consisting of alkali pyroxenite and gabbro, syenite and syenite pegmatite. Peak ground concentrations of thorium and uranium are <40 ppm and 6 ppm, resp.

The Hohewarte paragneisses as mapped by Miller and Grote (1988) in the extreme southeast corner of the map sheet are inconspicuous in terms of their radiometric characteristics. Quite similarly, the Otjosondu manganese mineralization does not show any radiometric pattern.

6. Radiometric Patterns and Major Geological Units in Southern Namibia

As far as regional airborne radiometric data had been collected over southern Namibia, they were fully used for the compilation of a set of 1 : 250 000 scale maps (BGR/GSN 1996a, 1996b). These cover the following sheet areas as a whole or partially: 2514 (Spencer Bay), 2516 (Gibeon), 2616 (Bethanien), 2716 (Ai-Ais), 2718 (Grünau), 2816 (Alexander Bay) and 2818 (Warmbad) (see Fig. 5).

These areas are largely covered by Proterozoic rocks of the Sinclair Sequence, the Namaqualand Metamorphic Belt and the Orange River Group. To a minor extent late Proterozoic rocks of the Nama Group, Paleozoic sediments of the Karoo Sequence and dune sands of the Namib occur within the above sheet areas (Fig. 6; Miller and Schalk, 1980).

6.1 Map Sheets 2514 (Spencer Bay) and 2516 (Gibeon)

These two map sheets are jointly discussed, since on map sheet 2514 was surveyed only a quarter degree by one degree area immediately adjacent to the western border of the neighbouring map sheet 2516.

On a regional scale, natural gamma radiation is low. Outstandingly low radiation is observed over sandstones and shales of the lower Fish River Subgroup of the Nama Group extending along the escarpment of the Schwarzrand. To the west of the Schwarzrand further radiation lows are associated with outcropping rocks (shales, limestone, sandstone) of the Kuibis Subgroup. Slightly increased radiation is, however, observed over shales, sandstones and limestones of the Schwarzrand Subgroup.

Radiation lows to the west and northwest of Helmeringhausen and around the abandoned Sinclair mine are produced by mafics of the Sinclair Sequence,

namely basalts and andesites of the Barby Fm. Similarly, rocks of the Kunjas Fm. of the Sinclair Sequence occurring in a sickle-shaped area centered at about 16°10'E/25°40'S produce extensive radiation lows. Sand dunes come out as oval-shaped radiation lows increasingly occurring towards the west of sheet 2516 and on sheet 2514.

Along the southern edge of map sheet 2516 patterns of increased radiation can be attributed to metavolcanics of the Nagatis Fm., which is the lowermost unit of the Sinclair Sequence, and to the Tumuab granites of mid-Proterozoic age. Another high radiation pattern extending in a NW/SE direction from Nubib via Duwisib to Osis is produced by (Nubib) granites of about the same Proterozoic age. Patterns of slightly increased radiation extending approximately along latitude 25°30'S are either due to metavolcanics of the Guperas Fm. (Sinclair Sequence) or to individual occurrences of early Proterozoic paragneisses and metasediments of the Neuhof Fm. (Geological Survey, 1970).

The total count (exposure rate) contours run generally NW/SE, turning into a N/S direction only when approaching the Schwarzrand escarpment. The uranium concentrations hardly contribute to the dicrimination of lithologies. Only local peaks - generally less than 10 ppm - occur in the Nubib granites and in metavolcanics of the Nagatis Fm. and related Tumuab granites. Thorium and potassium are largely enriched in the above-cited three lithologies, thus being more discriminatory than the uranium. The ternary display nicely shows that thorium is the prevalent radio-element in the south, whereas uranium and potassium are the major contributors to radiation in the centre and in the north of the map sheet areas.

6.2 Map Sheet 2616 (Bethanien)

Low natural gamma radiation is wide-spread over this map sheet. Strong radiation only occurs in the west of the map sheet area, where a variety of gneisses of the Namaqualand Metamorphic Belt largely outcrop.

In the northwest, the Khoichab depression can be identified on behalf of a prominent radiation low trending NW/SE and having a width of approximately 20 km. To the northeast of the Khoichab low, increased radiation can be observed over various granites of the Sinclair Sequence. Contours are mainly oriented NW/SE in this part of the map sheet, which is also the direction of the Excelsior shear zone. This fault - best developed close to the T-junction of district road 707 with the western carrier C 13 - seems to be associated with a narrow ridge of increased radiation that can be followed from there in south-easterly direction to the Bethanien area.

Moving further to the east, vast areas with low natural gamma-ray intensity extend coinciding with wide-spread occurrences of carbonatic sediments of the Kuibis Subgroup. Individual narrow radiation highs within this low intensity area trend from N/S to NW/SE and are due to outcrops of the gneisses of the Namaqualand Metamorphic Belt. In the area between longitudes 17°E and 17°30'E a NNW/SSE trending belt of slightly increased radiation can be noticed correlating well with shales and sandstones of the Schwarzrand Subgroup.

Proceeding eastwards approximately as far as to the Seeheim and Berseba areas shales and sandstones of the Fish River Subgroup largely extend with no significant contribution to the natural gamma radiation. Locally red sandstones of the Nababis Fm. produce slightly increased radiation.

Parallel to the eastern border of this map sheet Karoo age clastics, mudstones and shales of the Prince Albert and Dwyka Fms. are associated with a distinctively increased radiation pattern. Individual lows occurring within this pattern are due to Karoo sills and dykes of dolerite.

Clarification of the local radiation peaks occurring in the area east of 17°E (within survey block S23/89) could not yet be obtained. It cannot be fully excluded that they are artefacts due to malfunctions occurred during surveying or data processing. A ground truth check will be necessary to definitively recognize the source of these peaks.

The ternary display nicely shows that thorium is the main contributing radioelement in the west where gneisses of the Namaqualand Metamorphic Belt largely outcrop. Low potassium and uranium concentrations produce the radiation patterns in the central and eastern parts of map sheet 2616. Contours of the exposure rate (total count) run generally NW/SE in the western part of the map sheet area superimposed by local W/E oriented anomalies. Approaching the central and eastern part the contours shift more and more into a N/S direction which is the strike direction of the Nama sediments covering the NW/SE trend of the Namaqualand Metamorphic Belt.

6.3 Map Sheet 2716 (Ai-Ais)

This is another map sheet area where natural radiation is remarkably low on a regional scale. In spite of a large variety of lithologies with ages covering a wide time span from the early Proterozoic to the Mesozoic (Geological Survey, 1979) there is little discrimination in the radiometric pattern.

High radiation can, however, be observed in the southeast corner of the map sheet. Syenites and granites of the Kuboos - Bremen line of intrusives are highly likely to be the major contributors to this high radiation pattern. In addition, coarse (syntectonic) granites and gneisses of the Namaqualand Metamorphic Belt largely occurring in this area are supposed to produce a high background radiation. Immediately west of the Ai-Ais resort a drastic change to low radiation can be observed. This indicates that the Ai-Ais gabbros, the grey (pre-tectonic) gneisses of the Namaqualand Metamorphic Belt and the metavolcanics and granodiorites of the Vioolsdrif Suite (Orange River Group) which extend in the area between Ai-Ais and Rosh Pinah are poor in natural radio-elements.

Some twenty kilometers north of Rosh Pinah a more or less circular high radiation pattern having a diameter of about 15 km has been located. This feature might be attributed to a late granitic intrusive of the Namaqualand Metamorphic Belt. From its shape and in conjunction with the mapping result (Geological Survey, 1979) an up-doming intrusive body with a large cover of autochthonous detritus must be suggested. Further occurrences of these late granites must be assumed in the northwest corner of the map sheet, since wide-spread increased average radiation was recorded there.

A twin chain of narrow individual radiation highs passes closely to the southwest of the above circular radiation high trending NW/SE from the Sperrgebiet to the area just north of Rosh Pinah. It should be noted that its southern member bends southward at its most southeastern extremity thus meeting the Rosh Pinah mine area. The change in strike direction occurs closely to a SSW/NNE oriented linear radiation feature that runs parallel to road C 13 between Witsputs and Spitskop. Furthermore, in the area between the Sperrgebiet and road C 13 a set of cross-cutting linear radiation features is indicated with strike directions SW/NE and SE/NW. This is easy to be recognized just west of the circular radiation high situated north of Rosh Pinah. In addition it is interesting to note that these gamma-ray linears are hardly visible on the regional airborne magnetic map (BGR/GSN, 1993).

The central and northern parts of the map sheet area are covered by rocks of the Nama Group. These are mostly composed of sandstones and carbonates and consequently nothing but an outstandingly low radiation can be expected in these areas. Only those members of the Fish River Subgroup produce slightly increased radiation that are built up by shales. In the northeast corner of the map sheet area increased radiation is wide-spread where Karoo shales and tillites extend.

The ternary display reveals that thorium and potassium are the prevalent radioelements in the high radiation areas except the extreme southeast of this map sheet where radiation is mainly produced by uranium and potassium. In all low intensity areas, i.e. in areas covered by Nama sediments or igneous rocks of the Vioolsdrif Suite (Orange River Group), radiation mainly originates from poor uranium concentrations.

The contour pattern is irregular. However, in a local scale NW/SE and SW/NE trends are more frequent than others.

6.4 Map Sheet 2718 (Grünau)

This map sheet stands out for its closer than standard flight line spacing of 1000 m. About two thirds of the map sheet area have been covered by traverses only 500 m apart. Natural radiation is high in the west, average in the centre and low in the east of the map sheet area.

Most intensive radiation occurs to both sides of the Grünau - Seeheim gravel road over syntectonic coarse-grained granites and gneisses of the Namaqualand Metamorphic Complex. These host lots of alkali-rich dikes and plugs of the Haruchas Intrusion (Geological Survey, 1977), thus esssentially contributing to the overall high natural radiation of this section of the map sheet. A narrow radiation low amidst this high radiation pattern is likely not to originate from geology, but is supposed to be produced by increased flight elevation in close vicinity of a steep mountain ridge.

Radiation is also increased along the Grünau - Keetmanshoop tar road due to syntectonic granitoids of the Namaqualand Metamorphic Complex largely building up the Grünau Horst. The high radiation pattern of the Horst, however, abruptly ceases in the Schroffenstein - Lord Hill area where a major shear zone has been suggested to run in a WNW/ESE direction. To the north of this zone, pretectonic granitoids and schists of the Namaqualand Metamorphic Complex extend and are associated with a low radiation pattern, thus indicating the shear as a strong radiometric gradient zone. In the regional airborne magnetics (BGR/GSN, 1993), a steep magnetic gradient coincides with this tectonic zone separating a wavy magnetic field in the north from quite a smooth pattern in the south that are the Sinclair and Karas domains postulated by Andritzky *et al.* (1996). Along its eastern border, the Grünau

Horst clearly contrasts with low radiating sandstones, shales and limestones of the Nama Group, the contact thus given by a sharp radiometric gradient.

In the east, natural gamma radiation is low on a regional scale. This area is covered by either dune sands or Karoo mudstones. The E/W running dune pattern is indicated by a very slight change in radiation intensity. In the dune valleys where the Karoo mudstone crops out radition tends to be slightly stronger than over the dunes where aeolian sands have been accumulated and absorb radiation coming from beneath.

The direction of the contours reflects the dune pattern in the east of the map sheet area, in the northern and southern central areas the SE/NW direction is prevalent and in the centre the contour pattern may be described as irregular. In the west, contours tend to be parallel to either the SW/NE or to the SE/NW directions, the latter being the strike of the Namaqualand Metamorphic Complex.

Thorium ground concentrations contrast well with the various lithologies occurring in the map sheet area. Uranium concentrations, however, discriminate less due to their greater statistical error. Peak concentrations are observed some 20 km west of Grünau in the area of the syntectonic Namaqualand granitoids and at about 19°30'E/27°10'S over a dried pan, which is a common feature in the Kalahari environs. Potassium concentrations are remarkably increased in the west of Grünau and in the Grünau Horst. Otherwise extremely low potassium ground concentrations values have been obtained.

The ternary display clearly reveals that thorium is the prevalent radioelement in the areas around and west of Grünau as well as in the southern section of the Grünau Horst. Potassium and uranium, however, largely contribute to natural radiation in the northern section of the Grünau Horst and immediately north of Grünau. Uranium is indicated as a main contributor to gamma radiation over sediments of the lower Nama Group. Radiation over Karoo sediments mainly originates from potassium and thorium.

6.5 Map Sheet 2816 (Alexander Bay)

This map sheet exhibits data collected only north of the Orange River, which forms the border line with the Republic of South Africa, and east of the Sperrgebiet fence (Diamond Area). This map section is covered by igneous rocks of the Orange River Group, by sediments of the Damara age Gariep Belt and to a greater extent by Karoo sediments and sills (Miller and Schalk, 1980).

In the Sendelingsdrif area Gariep age sediments of the Numees Fm. and Hilda Fm. consist of glacial diamictites, intercalated carbonates and clastic sediments, resp. Due to this composition the overall low radiation pattern of this area is not surprising. Further upstream to approximately where the Gamkab River joins the Orange River igneous rocks of the Vioolsdrif Suite extend and are associated with overall low radiation. A radiation high extends parallel to the Gamkab River in SW/NE direction close to the Marinkas Quellen. This high can easily be attributed to granites and bostonites of the Kuboos - Bremen line.

A large high radiation pattern in the northeastern section of the map sheet originates from mainly shales and mudstones of the Karoo Group. Karoo dolerite sills are indicated by individual radiation lows embedded in the high radiation pattern of the Karoo sediments.

Syenites and granites of the Richtersveld Complex, which outcrop in the Rooiberge about 25 km west of Noordoewer, produce another radiation high running in a N/S direction to both sides of the Orange River. High radiation areas southeast of the Nordoewer - Grünau tar road are produced by igneous rocks of the Vioolsdrif Suite. It should be noted that igneous rocks of the Vioolsdrif Suite are elsewhere known to be associated with low radiation. The Haib Prospect is situated within the high radiation pattern, but in transition to a local radiation low.

With the exception of the Rooiberge area where a distinct N/S trend of the contours can be observed the contour pattern is quite irregular. Supposingly uneconomic local thorium and uranium ground concentrations peaks were detected close to Marinkas Quellen and in the Rooiberge of the Orange River valley. Potassium ground concentrations are low all over the Namibian portion of the map sheet. From the ternary display it can be learnt that uranium is the main source of natural radiation in the map sheet area under discussion.

6.6 Map Sheet 2818 (Warmbad)

This map sheet presents data collected north of the Orange River which forms the border line with the Republic of South Africa.

High radiation patterns extend over most of the map sheet area. The area is covered by igneous rocks of the Orange River Group and of the Namaqualand Metamorphic Belt, by Karoo sills and sediments and to a minor extent by sediments of the Nama Group and by alluvial deposits (Miller and Schalk, 1980).

Low radiation patterns in the northwest and central northern parts of the map sheet area are definitely produced by Karoo dolerite sills. Quite a linear, narrow low radiation feature runs parallel to the Noordoewer - Grünau tar road that is related with outcrops of Karoo sills. Extensive low radiation patterns in the northeastern section of the map sheet are associated with Nama age shales, sandstone and limestone of the Kuibis and Schwarzrand Subgroups building up the Blydeverwacht Plateau. The escarpment is nicely indicated by a steep radiometric gradient that fairly abruptly changes from low gamma intensity in the north to high intensity in the south.

Most of the extended high radiation pattern is covered by pretectonic granitoids of the Namaqualand Metamorphic Complex. In its southeastern part igneous rocks of the Vioolsdrif Suite are intercalated among metavolcanics of the Orange River Group. From the intensity pattern it may be concluded that radiation of the Vioolsdrif Suite members (mainly leucogranites) is slightly stronger than average radiation emitted by the metavolcanics of the Orange River Group.

The centre of this high radiation pattern is at about 25 km north of the Orange River valley where it extends on both sides of the Onseepkans - Karasburg gravel road. Quite a uniform character and shallow gradients are characteristic of this area, which is not surprising, since it is covered by alluvial sediments. The high radiation level, however, indicates autochthonous weathering and Namaqualand granitoids beneath the weathering cover.

Distinctive local radiation lows occurring some ten kilometres north of the Orange River valley can be attributed to mafic intrusives of the Namaqualand Metamorphic Complex. They are aligned along the outstanding Tantalite valley shear zone. The most prominent lows are observed over the Tantalite and Kumkum complexes. To the east and northeast of these complexes lots of local radiation lows indicate further occurrences of mafic Namaqualand intrusives.

The contours reflect not only the stratigraphic pattern, but also elucidate the complicated tectonic inventory. NW/SE running features are most prominent. Several cross-cutting tectonic elements are obvious in a more or less SW/NE orientation. The strike of the Namaqualand granitoids swings from NW/SE to SSW/ENE trends in the Pelladrif area, which is clearly reflected by the contours. This is just an example to encourage the use of gamma-ray data to support geological mapping.

As could already be concluded from the adjacent map sheets thorium ground concentrations prove to be suitable for discriminating lithologies. Peak values of more than 30 ppm were recorded in the vicinity of Warmbad, to the south of the Tantalite valley shear zone and due south of the Blydeverwacht Plateau. Uranium concentrations have a less pronounced capacity to discriminate lithologies. Peak values of more than 10 ppm were observed south of Warmbad, south of the Tantalite Valley shear zone and along a SW/NE running narrow corridor on farm Sandfontein 131. This corridor is delineated by anomalous uranium values and supposed to be fault-controlled.

The ternary display nicely reveals that the Tantalite Valley shear zone separates areas with different radiometric characteristics. Thorium and potassium contribute most to natural radiation in the areas north and northeast of the Tantalite Valley shear zone, whereas uranium and potassium are the essential radio-elements in the areas to the south and southwest of the Tantalite Valley. Highest potassium concentrations were recorded within the uniform centre of the extended high radiation area, where alluvial covers extend on both sides of the Onseepkans - Karasburg gravel road at about 25 km to the north of Onseepkans (see above).

7. Conclusions

For the first time natural gamma-ray data of portions of Namibia are presented as a regional radiometric map series and as a digital data set.

The compilation of a refined and homogeneous radiometric data set from survey data collected with poorly calibrated detector devices and varying crystal volumes has turned out to be feasible.

Major obstacles overcome were

(1) data recovery from analogue charts,
(2) the back-calibration of the raw airborne data using a calibrated ground-borne gamma-ray spectrometer on selected sections of traverses crossing areas of homogeneous radiation,
(3) missing or incomplete data referring to calibrations and corrections previously applied,
(4) the merging of non-overlapping survey blocks.

The refined data and maps, though compiled from raw data collected on traverses 1000 m, or 500 m resp., apart, prove to be useful

(1) to facilitate decision making of environmental issues, such as appraisal of the average natural radiation background and assessment of soil quality to enable sustainable provision of land for agricultural and resettlement purposes by the government,
(2) to support geological mapping of both lithologies and tectonic features,
(3) to guide prospecting of uranium and heavy minerals.

It is hoped that these newly refined map and data sets will give valuable contributions to the environmental, geological and mining sectors and result in frequent consultation thereof.

Acknowledgements

The authors extend their sincere thanks to the Permanent Secretary of the Ministry of Mines and Energy and the Director of the Geological Survey of Namaibia (GSN) for authorization to work on the regional airborne radiometric data. The project was commissioned by the German Ministry of Economic Cooperation and Development (BMZ) and was carried out by the Federal Institute for Geosciences and Natural Resources (BGR) in cooperation with the GSN. High-Sense Geophysics, Canada, proved to be a competent contractor and the authors are thankful for sound cooperation. Thanks are also due to the personnel of the GSN who provided technical support whenever requested.

Bibliography

Andritzky, G., Eberle, D., Ostwald, J. and Wackerle, R. 1996. Synopsis of geological and geophysical data as a guide to new mineral exploration areas in southern Namaibia. *Open File Report*, German-Namibian Mineral Prospecting Promotion Project, Windhoek, 31 pp., 2 maps.

BGR/GSN. 1993. Airborne Magnetic Map Series, scale 1 : 250 000, sheets 2716 (Ai-Ais) and 2718 (Grünau). *Geological Survey of Namibia.*

BGR/GSN. 1994a. Airborne Radiometric Map Series, scale 1 : 250 000, sheets 2014 (Fransfontein), 2016 (Otjiwarongo), 2114 (Omaruru) and 2116 (Okahandja). *Geological Survey of Namibia.*

BGR/GSN. 1994b. Airborne Radiometric Ternary Series, scale 1 : 250 000, sheets 2014 (Fransfontein) and 2016 (Otjiwarongo). *Geological Survey of Namibia.*

BGR/GSN. 1996a. Airborne Radiometric Map Series, scale 1 : 250 000, sheets 2514 (Spencer Bay), 2516 (Gibeon), 2616 (Bethanien), 2716 (Ai-Ais), 2718 (Grünau), 2816 (Alexander Bay) and 2818 (Warmbad). *Geological Survey of Namibia.*

BGR/GSN. 1996b. Airborne Radiometric Ternary Series, scale 1 : 250 000, sheets 2514 (Spencer Bay), 2516 (Gibeon), 2616 (Bethanien), 2716 (Ai-Ais), 2718 (Grünau), 2816 (Alexander Bay) and 2818 (Warmbad). *Geological Survey of Namibia.*

Darnley, A.G. and Ford, K.L. 1989. Regional Airborne Gamma-Ray Surveys: A Review. *In:* Exploration '87 Proceedings. *Ontario Geological Survey Spec. Publ.* 3, 229-240.

Diehl, B.J.M.1992. The Mineral Resources of Namibia - REE-Yttrium-Thorium (Section 6.20). *Geological Survey of Namibia*, 5 pp.

Duffy, A., Eberle, D., Grasty, R.L., Hutchins, D.G. and Urquhart,W.E.S.1994. Recovery, compilation, back-calibration, and standardization of existing radiometry survey data: Namibia, southern Africa. *Expanded Abstract PP7.6*, 834-836, Technical Program 64th Annual SEG Meeting,Los Angeles.

Eberle, D. and Hutchins, D.G. 1996. The Regional Airborne Magnetic Data Set of Namibia: Comments on Compilation and Geological Overview. *Bulletin 2, Geological Survey of Namibia*, 40 pp.

Grasty, R.L., Carson, J.M., Charbonneau, B.W. and Holman, P.B. 1984. Natural Background Radiation in Canada. *Bulletin 360, Geological Survey of Canada*, 39 pp.

Grasty, R.L., Whitton, R.M. and Duffy, A. 1992. Back Calibration and Reprocessing of an Airborne Gamma-Ray Survey, Malaysia. *Expanded Abstract GM2.3*, 550-551, Technical Program 62nd Annual SEG Meeting, New Orleans.

Grasty, R.L. and Minty, B.R.S. 1995. A Guide to the Technical Specifications for Airborne Gamma-Ray Surveys. *Record 1995/60, Australian Geological Survey Organization*, Canberra, 89pp.

Geological Survey, 1970. Geological Map 1 : 250 000 , sheet 2516 (Gibeon), unpubl., *Geological Survey of Namibia.*

Geological Survey, 1977, Geological Map 1 : 250 000 , sheet 2718 (Grünau), unpubl., *Geological Survey of Namibia.*

Geological Survey, 1979. Geological Map 1 : 250 000 , sheet 2716 (Ai-Ais), unpubl., *Geological Survey of Namibia.*

Gunthorpe, R.J. and Buerger, A.D. 1986. Geology and Economic Evaluation of the Otjisazu Alkaline Igneous Complex, Central South West Africa/Namibia, 2255-2260. *In:* Anhaeusser, C.R.and Maske, S.(Eds.), *Mineral Deposits of Southern Africa*, II, Geol. Soc.S.Afr., 2376 pp.

Kellog, W.C.1971. *Calculation of Airborne Radioactivity Survey Responses: Theory, Method, and Field Test.* Paper presented at Annual A.I.M.E. Meeting, New York.

IAEA. 1979. Gamma-Ray Surveys in Uranium Exploration. *Technical Report Series 186*, Wien, 89 pp.

IAEA. 1991. Airborne Gamma-Ray Spectrometer Surveying. *Technical Report Series 323*, Wien, 96 pp.

Miller, R. McG. 1983. The Pan-African Damara Orogen of South West Africa/Namibia. *Special Publication of the Geological Society of South Africa*, 11, 431-515.

Miller, R.McG. and Grote, W. 1988. 1:500 000 Geological Map of the Damara Orogen in two sheets. *Special Publication of the Geological Society of South Africa*, **11**.

Miller, R.McG., and Schalk, K.E.L. 1980. 1:1 000 000 Geological Map of Namibia. *Geological Survey Namibia.*

Müller-Kahle, E. and Roesener, H. 1996. Report on Present and Past Uranium Exploration Activities, Uranium Deposits and Resources in Namibia and the Computerized Data Base URANAMIB. *Technical Report.* I.A.E.A. Technical Co-operation Project NAM/3/002/-01 Uranium Databank, 101 pp.

Nielson, D.L., Linpei, C. and Ward, S.H. 1990. Gamma-Ray Spectrometry and Radon Emanometry in Environmental Geophysics, 219-250. *In:* Ward, S.H.(Ed.),*Geotechnical and Environmental Geophysics*, vol. I, Soc.Explor.Geophysicists, Tulsa, 1050 pp.

Richards, D.J. 1979. *Technical Manual on Radiometrics*. Geophysical Field Manual for Technicians, No. 2, S.Afr.Geophys.Assoc.

Schneider, M.B. 1990. *Bewässerungslandwirtschaft in Namibia und ihre Grundlagen in der Kolonialzeit.* Inaugural-Dissertation, Fachbereich Geographie, J.W. Goethe-Universität, Frankfurt/Main.

Urquhart, W.E.S. 1988. Decorrugation of Enhanced Magnetic Field Maps. *Expanded Abstract G/M1*, 371-372, Technical Program 58th Annual SEG Meeting, Tulsa.

Watkins, R.T. and le Roex, A.P. 1994. A reinvestigation of the Okenyenya igneous complex: a new geological map, structural interpretation and model of emplacement. *Communs.geol.Survey Namibia*, **9**, 13-21.