The new magnetic data set of Namibia: Its contributions to the understanding of crustal evolution and regional distribution of mineralization

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Within the framework of German - Namibian technical cooperation, a national magnetic data set was compiled from 41 different airborne magnetic surveys flown in Namibia during the past three decades. The magnetic data set is available as both coloured contour maps (scales 1 : 250 000 and 1 : 1 000 000) and digital grids with varying cell sizes (2 000 m, 500 m, 200 m). Shield areas, mobile belts and anorogenic intrusions dominate the magnetic anomaly pattern of Namibia. The mobile belts are characterized by parallel-running narrow (<100 km) magnetic and virtually non-magnetic zones. Shield areas, covered by a thick sequence of mostly non-magnetic Proterozoic and Paleozoic sediments, are distinguished by broad, mid-amplitude anomalies with low gradients. Modelling of two regional magnetic profiles crossing the Damaran fold belt has provided additional insights into its nature and structure. Evidence for the association of mostly epigenetic mineralization, occurring close to or immediately on magnetic lineations, with the general linear magnetic pattern is presented. This may prove to be a new successful tool to prospect the mineral wealth of Namibia.

Introduction

Despite regional airborne geophysical surveys having been conducted in Namibia since 1962 and that these surveys, together with reconnaissance magnetic surveys conducted over the inland basins during hydrocarbon prospecting, almost completely cover the entire country, very limited regional interpretation of these data has been undertaken. To the best of our knowledge, just one paper (Corner, 1983) has been published to date.

The reasons for this are varied, but were largely the result of the diverse nature of the data themselves and lack of compilation of individual data sets. In view of this, the German Federal Institute of Geosciences and Natural Resources (BGR) has been providing technical assistance to the Geological Survey of Namibia (GSN) in:

- Upgrading the existing Namibian airborne magnetic data.
- Evaluating airborne magnetic anomalies and structures, including ground truth control.
- Delineating areas with future mineral exploration potential

This paper highlights the importance of the airborne magnetic data set in the field of crustal research and mineral prospecting.

Magnetic field data, compilation, and presentation

The total field magnetic data derived from 41 different survey blocks (Fig. 1) were collected to varying specifications using different magnetometers, such as fluxgate, proton and caesium, with varying survey parameters (Table 1). They were presented as contour maps to varying standards, using different reference levels, with in most cases, the International Geomagnetic Reference Field (IGRF) not having been removed. These airborne magnetic data, though on open file for many years, were therefore not available as a single compatible data set and were thus not conducive to regional interpretation.

At the start of the project, Simon Petroleum Technology Ltd. (SPT) were contracted to merge the airborne magnetic data into a single uniform compatible data base. The following steps were undertaken to achieve this objective (Eberle *et al.*, 1994):

- Determination of the original absolute magnetic field values.
- Construction of a Digital Terrain Model.
- Calculation of the IGRF model (IAGA, 1985) for each survey block.
- Subtraction of the model field.
- Downward continuation of anomaly values to the nominal flight height of 100m above terrain.

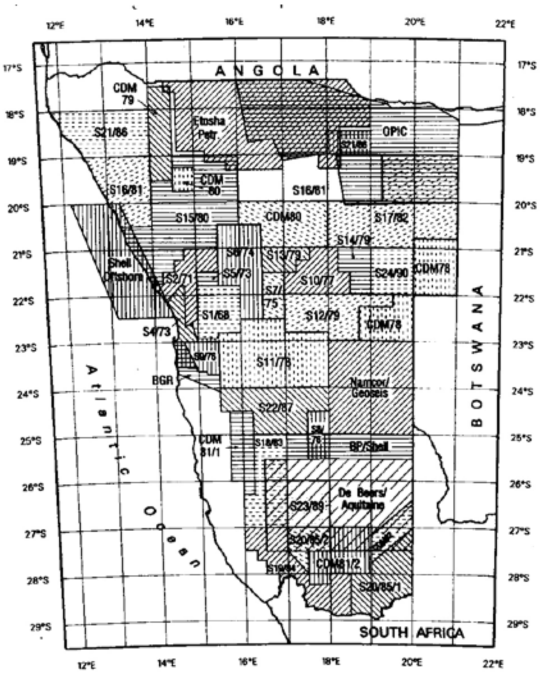


Figure 1: Survey location map. Survey nomenclature indicates funding agency and for S- and CDM- surveys year of execution. (Abbreviations: S - Government, CDM - Consolidated Diamond Mining Co., BGR - Federal Institute for Geosciences and Natural Resources, Germany; Etosha Petr. - Etosha Petroleum Co.; OPIC - Overseas Petroleum and Investment Corp.)

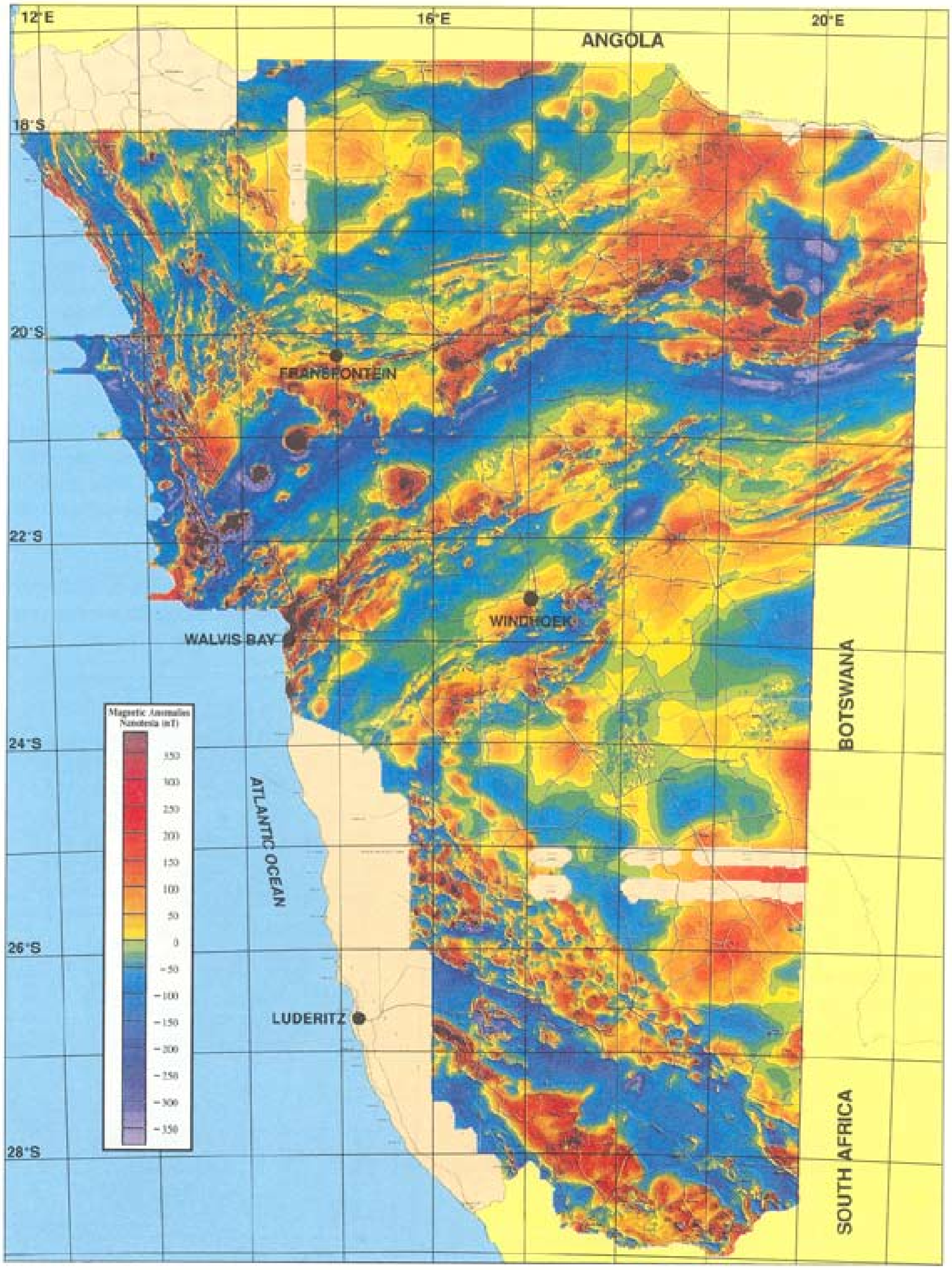


Figure 3: The airborne magnetic anomaly map of Namibia, in nT, with the International Geomagnetic Reference Field (IGRF) at time of data acquisition subtracted.

Surveys flown by	Stinger-mounted Magnetometer, Sample Rate	Flight Height a.g.l.	Flight / Tie Line Spacing	Navigation	Data Acquisition	Coordinate System
Government	Fluxgate,Proton; ≤1 sec	70 - 150 m	0.5 - 1 km / 10 km	mainly visual, aerial photo mosaics, rarely Doppler	early surveys only analogue charts, since mid 70's on analogue or digital tapes	Gauss Conformal Projection (Namibian Lo- System)
Precious stone prospecting companies	Fluxgate, Proton; ≤ 2 sec	80 - 120 m	0.5 - 1 km / 10 km			
Hydrocarbon prospecting companies	Fluxgate, Atom. Absorpt; ≤ 1 sec	500 - 800 m	2.5 - 12 km / 10 - 20 km	Doppler, flight path camera, gyrocompass		Gauss Conformal Projection (Namibian Lo-System), rarely UTM.

Total mileage: app. 600 000 km

Table 1: Survey parameters.

. Merging of all survey blocks.
. Creation of a uniform digital grid.

The resultant merged data are presented as either gridded data or contour maps and are on open file at the Geological Survey of Namibia. Maps are available at two scales, a 1:250 000 series comprising 39 sheets (Fig. 2) and a 1:1 000 000 map consisting of four sheets.

Both sets will be available as either coloured or black and white contours, and are identical in scale with the existing geological and topocadastral map series. The gridded data will be available at three scales, 1:1 000 000, 1:250 000, and 1:50 000 using cell sizes of 2 000 m, 500 m, and 200 m, respectively.

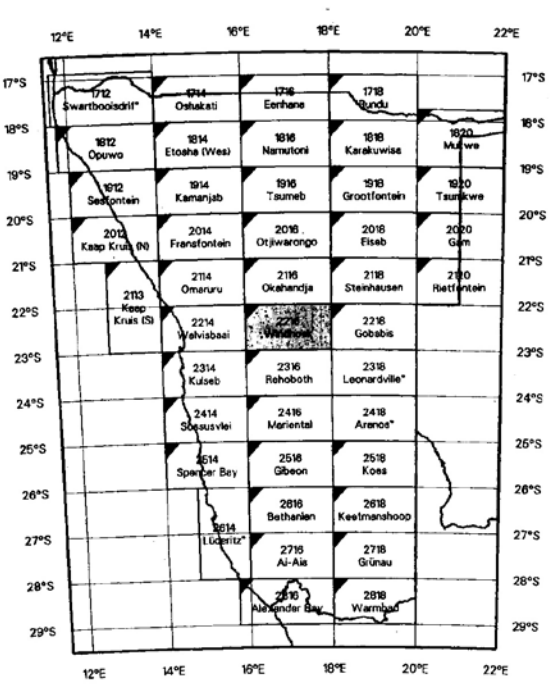


Figure 2: The sheet layout of the 1:250 000 scale airborne magnetic map series.

Major magnetic inventory

The regional magnetic anomaly map (Fig. 3) is largely dominated by elongated anomaly clusters which are associated with Proterozoic mobile belts and are peripheral to the Kalahari and Angola cratons in the south-east and in the north of the country. These cratons are characterized by extended moderate amplitude anomalies (Fig. 4) resulting from deep-seated sources, with depths of burial ranging from five to ten kilometres (Reeves, 1985; Zhou, 1988). These basinal areas are thus favourable for hydrocarbon exploration.

The Proterozoic mobile belts, such as the Kaoko belt along the northwestern coast, the Gordonia in the southwest and the Damara in the centre (Fig. 5) comprise alternating parallel zones of strongly magnetic and virtually non-magnetic units. A striking, subcontinental magnetic low extends from the Omaruru delta throughout Namibia to NW-Botswana, running approximately parallel to the northern graben of the Damaran mobile belt. The southern Central Zone of this belt contains many magnetic anomalies, whereas the Khomas trough is magnetically quiet. Further to the south the Marginal Zone regains a distinct magnetic anomaly pattern.

It is these mobile belts that have been most extensively prospected for base metals, particularly where outcropping. The magnetic map clearly indicates the continuation of the Damara Belt to the east of the country where it is largely concealed by Kalahari cover.

Plateau volcanics, such as the Etendeka basalts, Mesozoic anorogenic intrusions, such as the Brandberg, the Messum Crater, and the Erongoberg (Fig. 6), and sills and dykes of varying age complete the major magnetic inventory of the country.

Elucidating the configuration of the crust: Interpretation results from a few regional traverses

Contributions of a comprehensive magnetic data set to crustal investigations and mineral prospecting can be multiple. Modelling of selected traverses across the

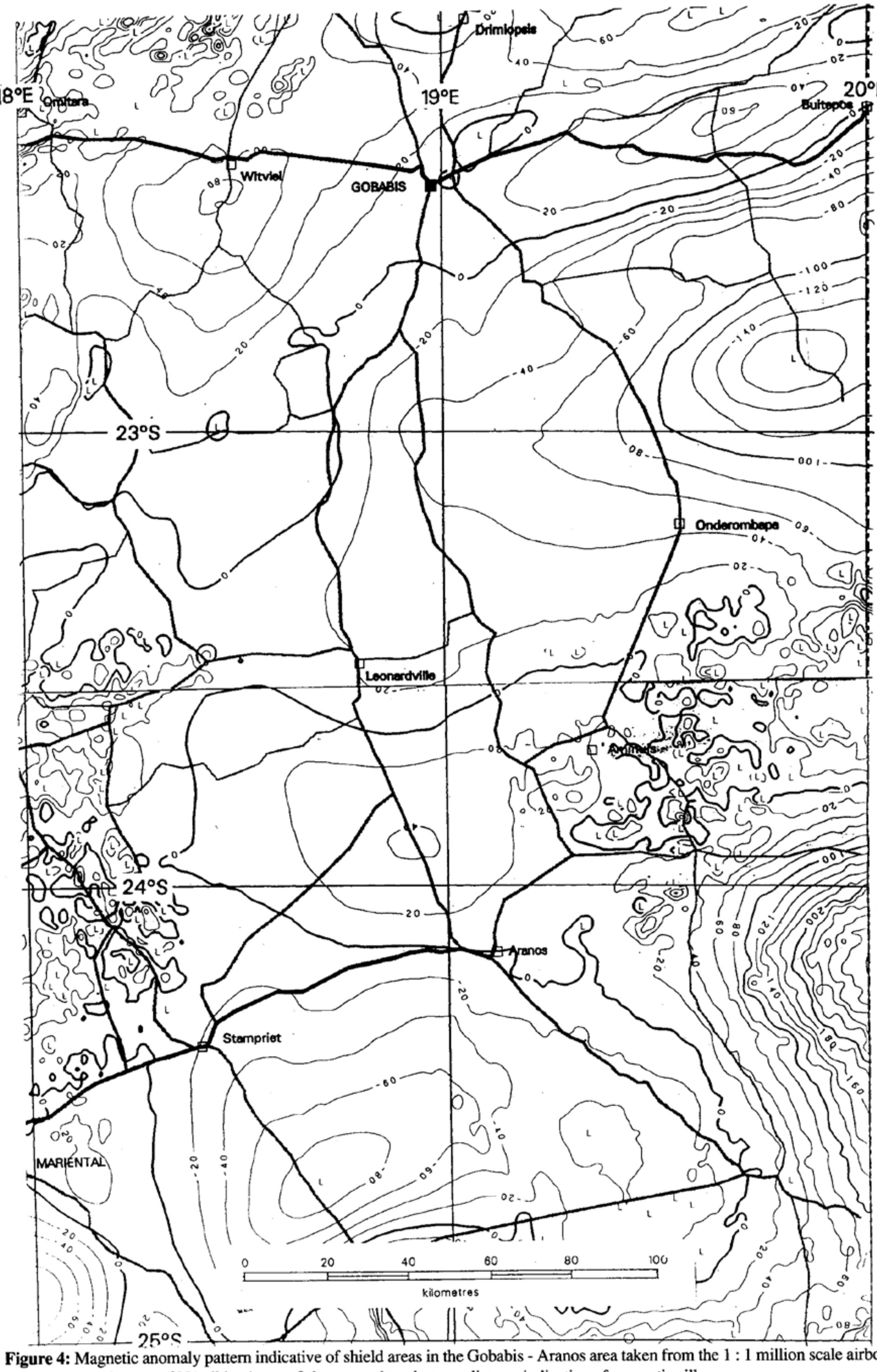


Figure 4: Magnetic anomaly pattern indicative of shield areas in the Gobabis - Aranos area taken from the 1 : 1 million scale airborne magnetic map of Namibia. Areas of short wavelength anomalies are indicative of magnetic sills.

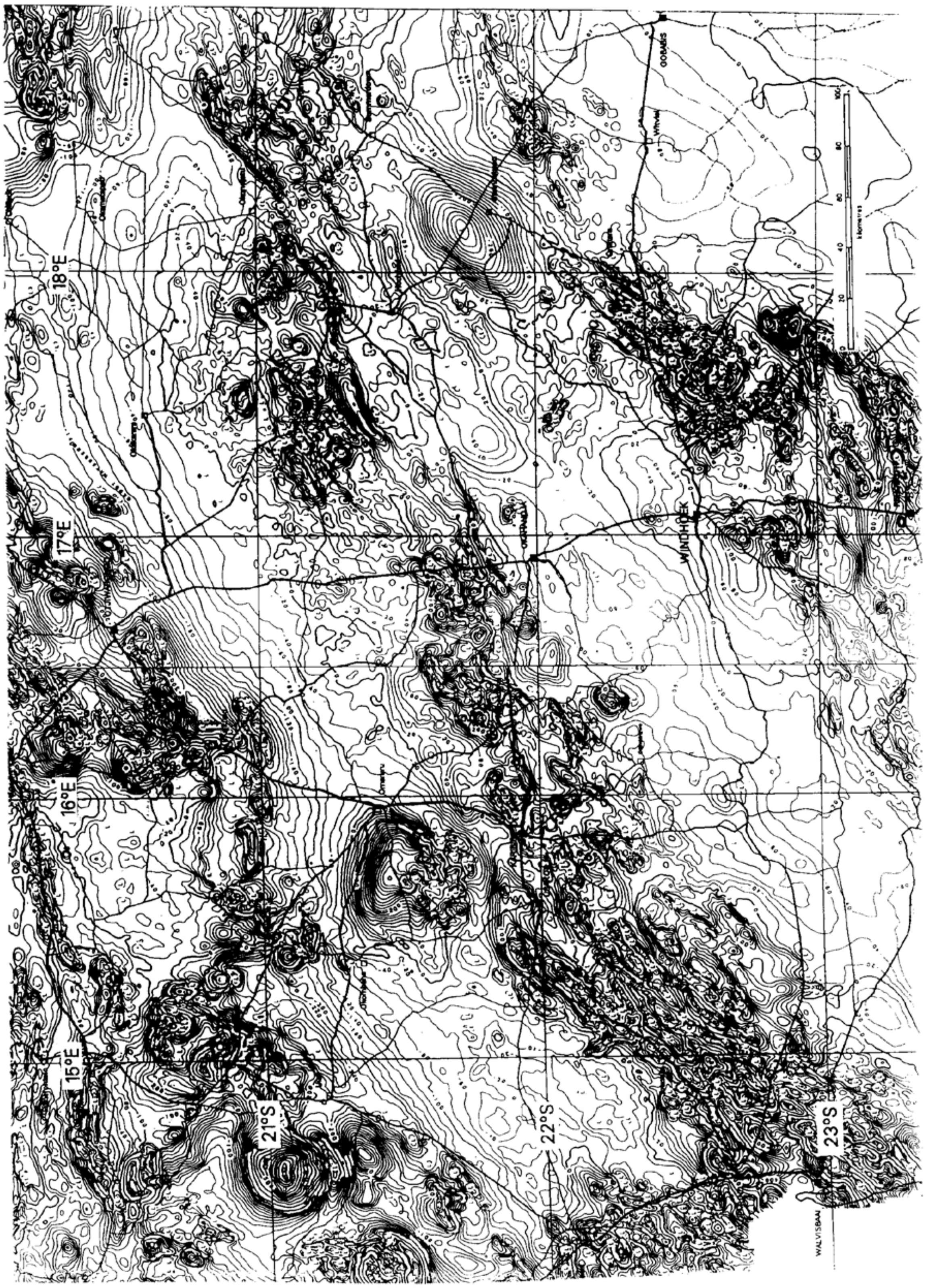


Figure 5: Magnetic anomaly pattern of the Damara fold belt between the Atlantic coast and longitude 19 E, as taken from the 1 : 1million scale airborne magnetic map of Namibia.

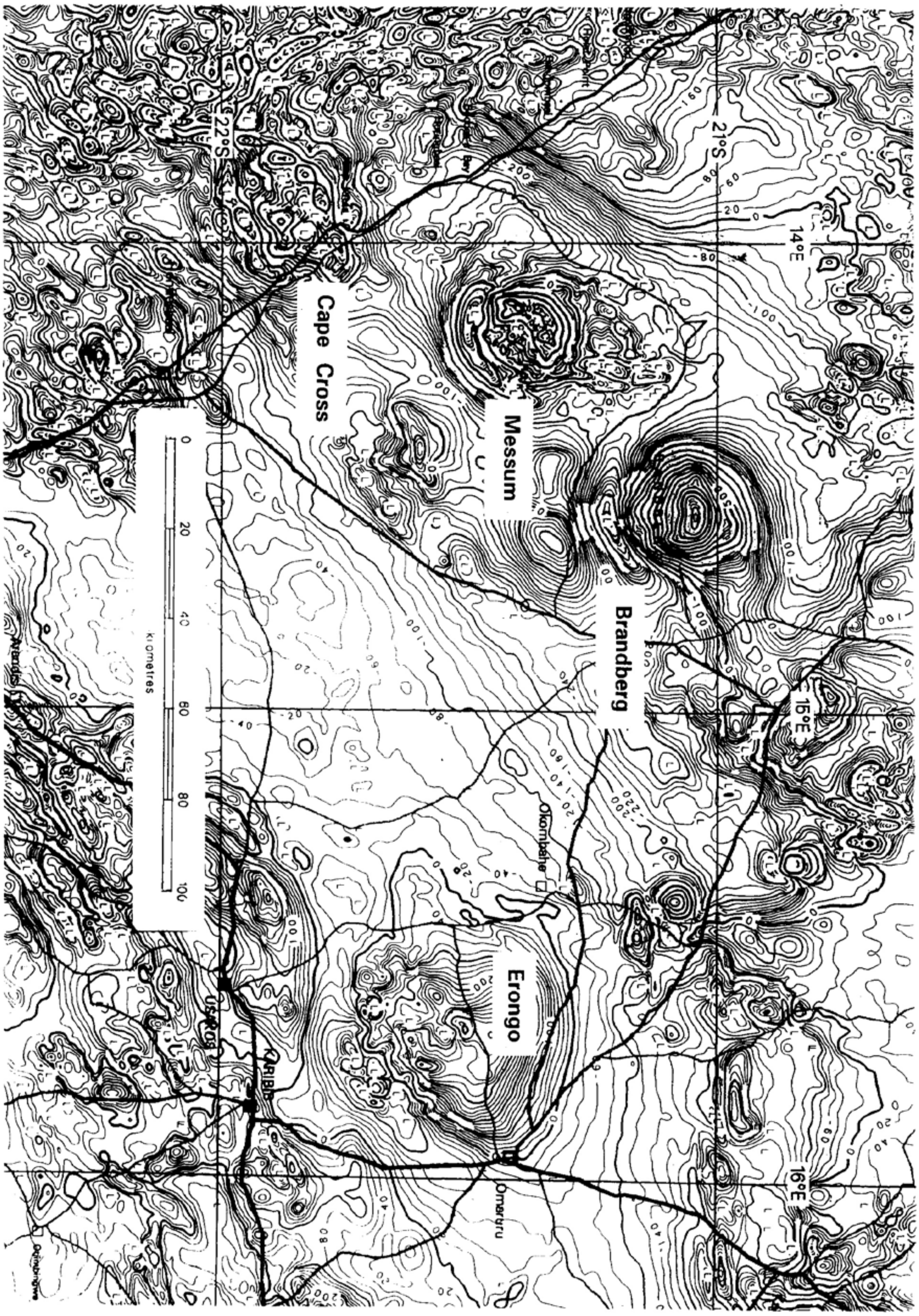


Figure 6: Prominent circular - shaped anomalies associated with the anorogenic Cape Cross, Messum, Brandberg and Erongo massifs, as taken from the 1 : 1 million scale airborne magnetic map of Namibia.

mobile belts will yield valuable information about depth of burial, thickness, layering, dip and magnetization of the rock units producing the magnetic anomalies. Six traverses have been selected for regional modelling (Fig. 7), and the results from two are presented here.

Traverse “Damara 2” (Fig. 8, Table 2) starts in the southeast over the Kalahari craton, crosses the Damara Belt, ends over the carbonate platform in the northwest, and has a length of about 500 km. Distinct magnetic anomalies occur within the Central Zone and, with still stronger amplitude; over the Otavi Mts. which are part of the carbonate platform.

The bulk of these anomalies are modelled by prism-shaped source bodies with predominant normal magnetization. Keeping in mind that depth determination from magnetic anomalies tends to yield maximum depths, their depths of burial are indicated to vary between 1 - 5 kms. The magnetization values of the source bodies vary between 0.2 A/m in the south to about 2.5 A/m beneath the carbonate platform. The interpreted dip of the source bodies are in dicative of antiformal or domal structures corroborating the geological observations and deductions of Martin (1983) for the Central Zone of the Damaran mobile belt.

Traverse “Damara 3” (Fig. 9, Table 3) runs from the south to the north about 200 km to the east of traverse “Damara 2”, crossing vast areas covered by Kalahari sands. All source bodies determined from this traverse are buried at depths shallower than five kilometres. The configuration of the prism-shaped source bodies again seems to indicate two antiformal structures, the northern one situated within the transition zone from the Damaran mobile belt to the Congo craton.

Both profiles show similar magnetic features in the north, where a series of strong anomalies are bounded by a broad magnetic negative zone to the south. Simplifying this magnetic signature, and in a very general sense, a magnetic plate flatly dipping to the north will produce this type of anomaly configuration. Is this feature indicative of a subcontinental suture? Alternatively the low magnetic zone may represent non-magnetic units deposited within Porada’s (1983) northern graben, assumed to be the most active during the Damaran cycle.

Source	Apparent Susceptibility [SI]	Total Magnetization [A/m]	Dip [deg]	Depth to top below surface [km]	Remanence assumed Yes/No
1	0.0075	0.18	---	7.3	No
2	0.1395	3.27	110	4.5	Yes*)
3	0.0063	0.13	50	0.6	No
4	0.0251	0.59	112	2.7	No
5	0.0113	0.25	106	0.9	No
6	0.0276	0.64	81	2.4	No
7	0.0126	0.29	19	6.9	No
8	0.0088	0.20	96	0.7	No
9	0.0138	0.32	142	2.4	No
10	0.0905	2.14	159	3.8	No
11	0.2048	4.78	127	3.7	No
12	0.0804	1.89	70	1.8	No
13	0.0440	1.05	81	2.5	No
14	0.0226	0.53	39	0.6	No
15	0.1043	2.46	33	5.1	No
16	0.0314	0.74	100	3.3	No
17	0.0202	0.47	130	3.5	No
18	0.0214	0.49	135	2.3	No
19	0.0251	0.59	125	1.3	No

Profile Direction 328°

Inducing Field Strength 29500 nT
Geomagnetic Inclination -64°
Declination 344°

*) Remanence Inclination 110°
Remanence Declination 344°

Table 2: Parameters of modelled magnetic source bodies, on traverse “Damara 2".

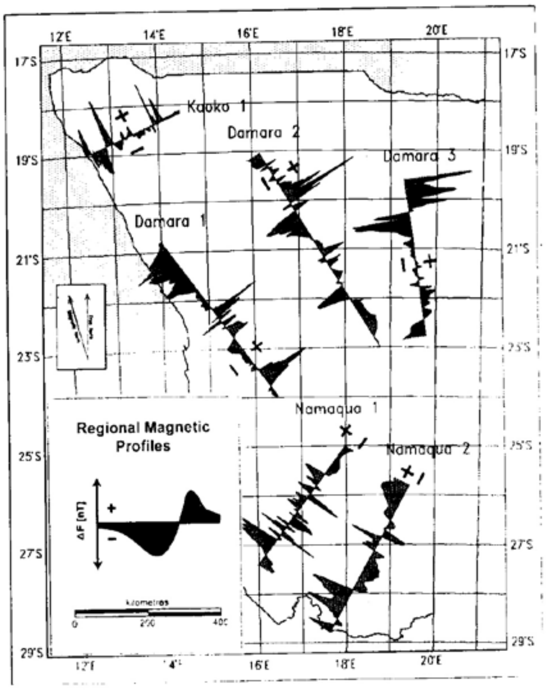


Figure 7: Location of six regional magnetic profiles interpolated from the airborne magnetic gridded data (cell size 2 000 m).

Magnetic lineament pattern

Magnetic lineament recognition is a subjective but integral part of the interpretation of airborne magnetic contour maps.

Two sets of orthogonal magnetic lineations are evident from the magnetic anomaly map indicating a tectonic stress pattern in which a predominantly E-W/N -S lineation set can be distinguished from a more or less SW-NE/NW-SE oriented system (Fig. 10). The magnetic lineations indicate geological faults, shear zones, and magnetic and non-magnetic dykes.

With the exception of the magnetic dykes which are quite distinct features on the magnetic anomaly map, the other lineations are more subtly indicated by indirect parameters such as lateral offsets of anomalies extended in strike, changes in the separation of the magnetic lows and highs, variations in the maximum/minimum ratio of anomalies, and changes in strike direction.

Lineations exceeding 100 km in length are typically in the N-S direction (Fig. 11). Dextral strike-slip move-

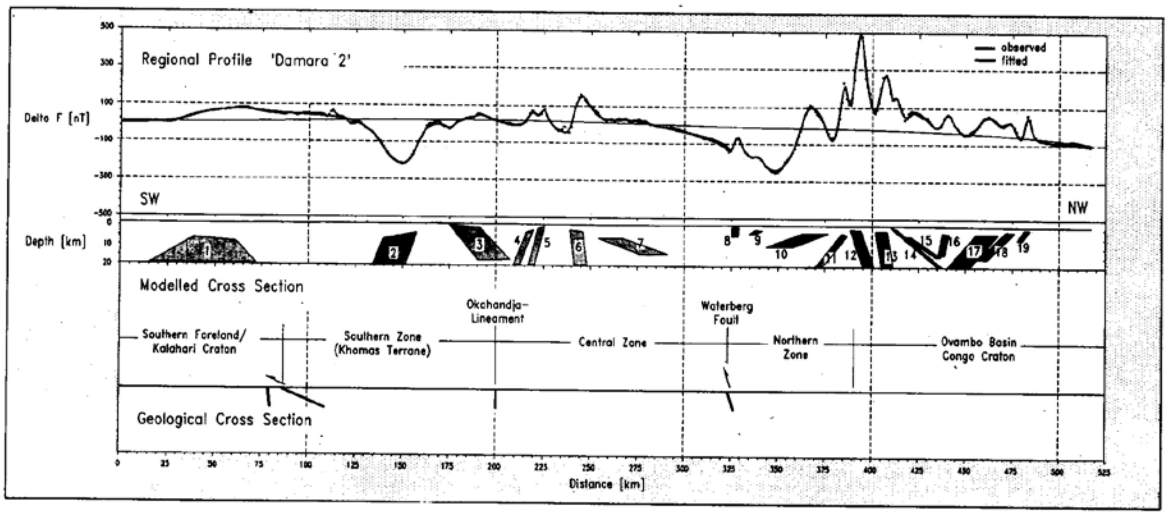


Figure 8: Regional magnetic profile 'Damara 2' extending from the Gobabis area in the southeast to the Etosha Pan in the northwest, with simplified geological cross section. The parameters of the modelled source bodies are given in Table 2.

ments are indicated along lineations trending in the W-E direction, whilst some sinistral movements are observed along N-S oriented linear features.

For various reasons, only a minority of these linear features will be reflected by the morphology and the known geology, i.e. a major portion of the country is covered by overburden, in many cases the lineaments are at depth and often are represented by the juxtaposition of similar geology. It must be stressed, however, that not all lineaments have a strong magnetic signature - some dykes may have no magnetic response, some flight line directions are unfavourable for the location of linear magnetic trends, and some linears are too narrow to produce a distinct signature at the sensor height (Stettler *et al.*, 1989).

Unlike in Tanzania where certain lineament directions are confined to the shield areas, in Namibia several of the major lineations can be traced from the surrounding fold belts into the shield areas. This suggests that they have been intermittently active throughout geological time. Furthermore the occurrence of similar lineament directions in different lithologies of varying age supports this hypothesis. In selected areas however such as the Khomas trough, the Etosha basin and the Kalahari craton these magnetic lineations become weak and in some cases disappear altogether. This can be explained by the suppression of the magnetic lineations by younger non-magnetic sedimentary cover.

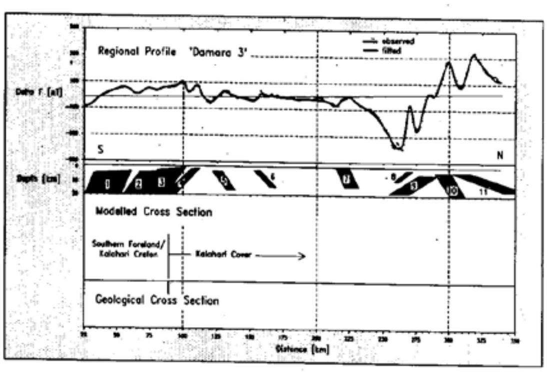


Figure 9: Regional magnetic profile 'Damara 3' extending from the Aroams area in the south to the Grootfontein area in the north, with simplified geological cross section. The parameters of the modelled source bodies are given in Table 3.

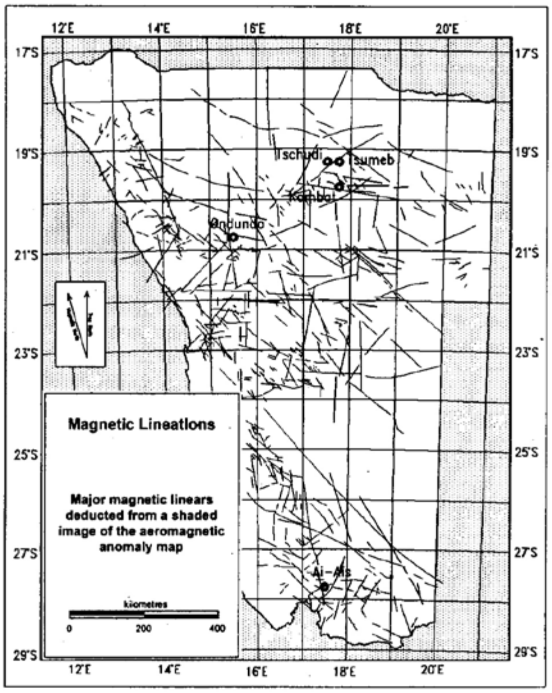
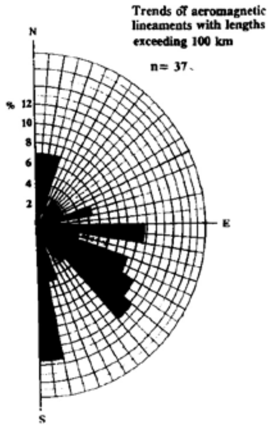
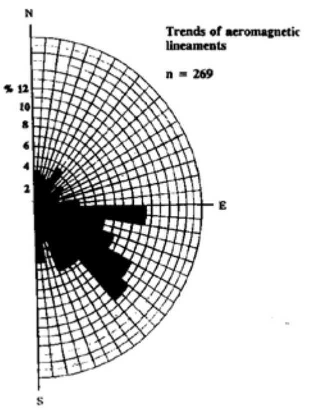


Figure 10: Pattern of magnetic linears of Namibia as derived from a shaded image of the 1 : 1 000 000 scale airborne magnetic anomaly map.





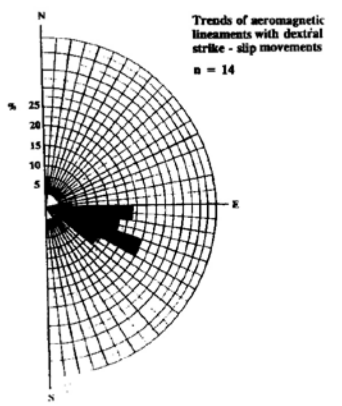


Figure 11: Trend statistics of the pattern of magnetic linears of Namibia

Setting of mineral occurrences in relation to the linear pattern

In Australia major magnetic and gravity linears are playing an important role in the direction of exploration activities with respect to control and distribution of mineral occurrences (O'Driscoll, 1985, 1989). If magnetic lineaments are interpreted as reflecting zones of fundamental crustal weakness where mineralizing fluids could ascend, the recognition and follow-up of these lineaments may likewise prove a versatile tool for directing prospecting in Namibia.

A systematic analysis of the structural signature of known mineral occurrences indicates that out of 62 known, mostly epigenetic mineral occurrences, about two thirds are located close to intersections and zones of confluence of magnetic lineaments. As an example, three such occurrences from different geographical and geological locations are given (see Fig. 10):

(1) Epigenetic base metal sulphide occurrences of the Otavi Mts. are possibly controlled by magnetic lineations having SW-NE and WNW-ESE strike.

(2)The Ai-Ais Pb-Ag vein occurrences and the Ai-Ais basic intrusive complex are located in an area where SW-NE running lineaments intersect the prominent Tantalite Valley shear zone which is characterized by a linear magnetic signature running SE-NW.

(3) The turbidite-hosted vein-type gold mineralization of Ondundu (Omaruru District) is located in a N-S running magnetic lineament corridor. Furthermore where the northern extension of this lineament traverses the carbonate lithologies the southern flank of the Kamanjab inlier, extensive metasomatic replacements as well as, to some extent, vein and breccia-type base metal mineralization have been observed.

Source No	Apparent Susceptibility [SI]	Total Magnetization [A/m]	Dip [deg]	Depth to top below surface [km]	Remanence assumed Yes/No
1	0.0176	0.42	115	3.7	No
2	0.0188	0.43	126	4.5	No
3	0.0138	0.31	126	0.9	No
4	0.0163	0.38	132	1.3	No
5	0.0138	0.31	132	3.7	No
6	0.0113	0.28	46	2.5	No
7	0.0050	0.11	65	0.7	No
8	0.0867	2.04	140	2.3	No
9	0.0239	0.55	129	5.3	No
10	0.0791	1.86	58	3.5	No
11	0.1307	3.06	18	3.3	No

Profile Direction 353°

Inducing Field Strength 29500 nT
Geomagnetic Inclination -64°
Declination 344°

Table 3: Parameters of modelled magnetic source bodies on traverse "Damara 3"

Conclusions

Forty-one airborne magnetic surveys flown over different portions of Namibia during the past three decades have been used to compile a national airborne magnetic data set. This has provided a complete overview of the various magnetic anomaly and lineament patterns of the major geological and tectonic units of the country.

Modelling of regional airborne magnetic profiles has shown that essential support to the elucidation of the structure of the crust can be achieved from this comprehensive data set.

Examples have been provided where linear magnetic features, often observed as breaks in the magnetic fabric, control the distribution and frequency of mineral occurrences. Recognition of these magnetic lineaments may lead to new approaches in prospecting the mineral wealth of Namibia.

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