JAHRBUCH DER GEOLOGISCHEN BUNDESANSTALT

Jb. Geol. B.-A. | ISSN 0016-7800 | Band 143 | Heft 4 | S. 581-604 | Wien, Dezember 2003

Airborne Geophysical Survey of the Lake Bosumtwi Meteorite Impact Structure (Southern Ghana) – Geophysical Maps with Descriptions

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24 Text-Figures

Ghana
Lake Bosumtwi
Meteorit
Impaktkrater
Aerogeophysik
Magnetik
Elektromagnetik
Gammastrahlenmessung

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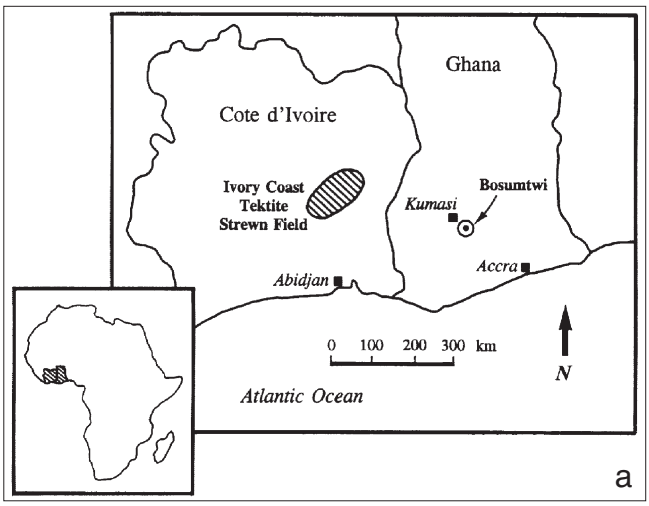
Aerogeophysikalische Untersuchungen der Lake-Bosumtwi-Impaktstruktur im südlichen Ghana – Geophysikalische Karten und Beschreibungen

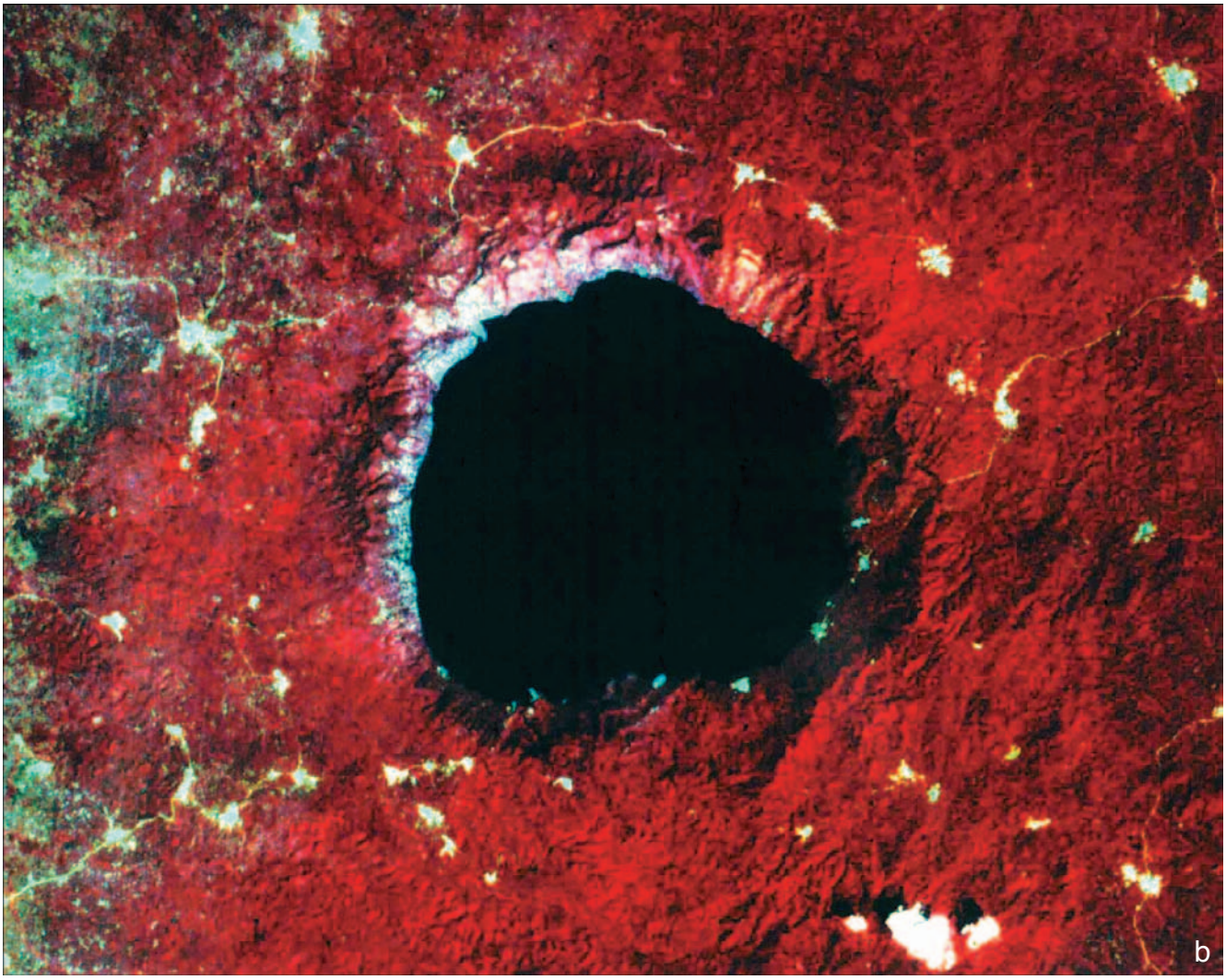
Zusammenfassung

Im Jahre 1997 wurde vom Finnischen Geologischen Dienst in Zusammenarbeit mit der Universität Wien und dem Geological Survey Department of Ghana eine hochauflösende aerogeophysikalische Untersuchung der Lake Bosumtwi-Impaktstruktur (Ghana) durchgeführt. Die technischen Parameter der Datengewinnung und die Resultate der Untersuchung werden in einer Serie von geophysikalischen (Magnetik, Elektromagnetik und Gamma-Strahlung) Karten im Maßstab 1 : 50 000 präsentiert. Kurzbeschreibungen jeder Karte sollen behilflich sein bei künftigen geophysikalischen Modellierungen der Struktur und bei der Auswahl von Bohrpunkten im Kraterboden; Bohrungen sind für Mitte 2004 im Rahmen eines internationalen und interdisziplinären Projektes vorgesehen.

Abstract

In 1997, a high-resolution airborne geophysical survey over the Lake Bosumtwi impact structure, Ghana, was carried out by the Geological Survey of Finland in collaboration with the University of Vienna, Austria, and the Geological Survey Department of Ghana. Here we present the technical part of the data acquisition, as well as the results of the survey in a series of geophysical (magnetic, electromagnetic, and gamma-ray radiation) maps at a scale of 1 : 50,000. We offer a short description of each map to promote future geophysical modeling of the structure and to help in choosing sites for deep drilling into the crater floor, which is anticipated for mid 2004 within the framework of an international and interdisciplinary drilling project.





Text-Fig. 1.
a) The location of the Bosumtwi impact structure in Ghana, as well as the location of the associated Ivory Cost tektites.
b) SPOT-satellite image of Bosumtwi.

1. Introduction

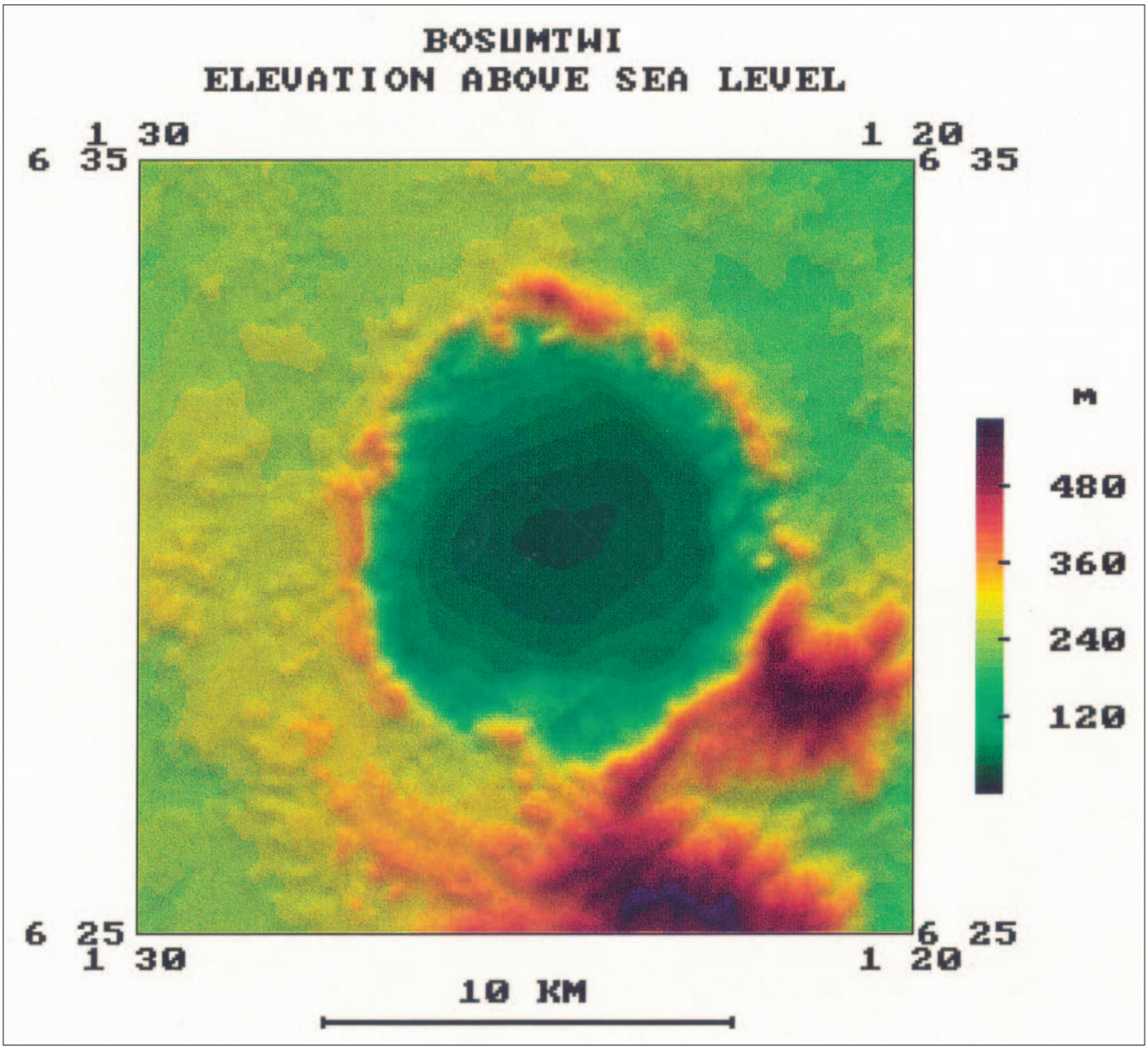
The Bosumtwi impact crater is located in the Ashanti Province of Ghana, near the town of Kumasi, centered at 06°32'N and 01°25'W (Text-Fig. 1). It is one of only about 18 impact structures in Africa (e.g., KOEBERL, 1994), and it is probably the youngest large impact crater known on Earth.

The structure, which has an age of 1.07 Million years, is almost completely filled by Lake Bosumtwi, and has a rim-to-rim diameter of about 10.5 km.

The first suggestions that the Bosumtwi crater is the source crater for the Ivory Coast tektites were made in the early 1960s. Ivory Coast tektites were first reported in 1934 from a geographically rather restricted area in the Ivory Coast (Côte d'Ivoire), West Africa. Microtektites have been reported from deep-sea sediments of corresponding age from the eastern equatorial Atlantic Ocean west of Africa. Ivory Coast tektites and the Bosumtwi crater have the same age (1.07 Ma [KOEBERL et al., 1997a]), and there are close similarities between the isotopic and chemical compositions of the tektites and crater rocks (for references and details, see KOEBERL et al. [1998]). These observations strongly support a connection between the crater and the tektites.

In spite of this, the subsurface structure of Bosumtwi is poorly known due to lack of drillings in the center of the structure (now occupied by Lake Bosumtwi) and lack of high-resolution geophysical data. The Geological Survey of Finland (GSF) and the Geological Survey Department of Ghana (GSDG) agreed in 1996 to carry out an airborne geophysical survey in Ghana, Africa, with a Finnish-owned Twin Otter aircraft.

The survey, conducted by Malmilento Co., was carried out in March of 1997 in collaboration with the Minerals Commission of Ghana and the Swedish Geological Survey. A smaller side-project was negotiated between the GSF and GSDG to carry out a low altitude airborne geophysical survey of the Lake Bosumtwi meteorite impact structure in southern Ghana, during the time when the aircraft was transported from Accra to the main survey area in north-western Ghana.



Text-Fig. 2.
Superimposed topography and bathymetry of the Lake Bosumtwi structure. Map prepared by Seppo Elo (GSF).

The project "Lake Bosumtwi Airborne Geophysical Survey" (OJAMO et al., 1997; PESONEN et al., 1997) was a collaboration between the Finnish Geological Survey and the University of Vienna, Austria, the Ghana Geological Survey Department, and the University of the Witwatersrand, Johannesburg, South Africa (W.U. REIMOLD); the latter three groups had already carried out geological field work in the Bosumtwi area, including sampling for paleomagnetic and petrophysical studies, in January of 1997 (e.g., KOEBERL et al., 1997b; PESONEN et al., 1997).

There were several objectives in the Bosumtwi aerogeophysical studies project:

1) A new airborne magnetic survey was needed to confirm the conclusions of the previous aeromagnetic study of Bosumtwi structure (JONES et al., 1981), i.e., that there are some hints in the magnetic data for the presence of a central uplift (C.U.) below the lake. In fact, this is to be expected in a structure of this size (e.g., GRIEVE & PESONEN, 1996; PILKINGTON & GRIEVE, 1991).
2) A more detailed 3-dimensional view of the Bosumtwi structure is warranted, not only to detect the central uplift, but also to study whether the structure is associated with one or several concentric rims (inner, middle and perhaps a third, outer rim) as seen in topographic maps of the structure (see Text-Fig. 2).
3) In order to decide the future drilling locations for the ICDP (**I**nternational **C**ontinental Scientific **D**rilling **P**rogram), in which the Bosumtwi structure is a site candidate (e.g., KOEBERL et al., 2002), a 3-dimensional image of the crater bottom and crater structure is necessary. The detailed magnetic structure is needed in order to integrate the old (JONES et al., 1981) and new gravity (POHL et al., in preparation) and seismic refraction and reflection data (KARP et al., 2002; SCHOLZ et al., 2002) into an integrated geophysical model of this unique impact structure.

2. Location and Size of the Structure

Figure 1a shows the location of the Bosumtwi impact structure in Ghana, Africa, and Text-Fig. 1b shows the structure in the SPOT-satellite image. The structure is located in southern Ghana, ca. 30 km southeast of the city of Kumasi (the second-largest city in Ghana).

The structure is almost completely filled by Lake Bosumtwi, with a present-day diameter of ca. 8.5 km and a maximum depth of ca. 80 m. As mentioned above, the crater has a rim-to-rim diameter of about 11 km as defined by the inner, steep topographic rim that is elevated ca. 300–400 m above the lake level (Text-Fig. 2).

2.1. Bathymetry

The lake has a diameter of 8.5 km (Text-Fig. 2). There are no islands in the lake and the bathymetric contours (Text-Fig. 2) are circular with a maximum present-day depth of 80 m at the lake center (see JONES et al., 1981).

The post-impact sediments, which reach thicknesses of up to ca. 300 m in the crater moat (KARP et al., 2002; SCHOLZ et al., 2002), and which have accumulated over the past million years since the formation of the crater, consist of lacustrine sediments. These sediments provide an important paleoclimatic record (e.g., TALBOT & DELIBRIAS, 1990; TALBOT & JOHANNESSEN, 1994; TALBOT et al., 1984). Bosumtwi is one of those rare lakes that has long sections of continuous, countable annual laminations (varves). Over 75 % of the last ca. 25,000 years of sediment record are varved, and it is likely that much of the longer record (i.e., at least several glacial cycles) will be varved as well.

The present lake sediment layer (i.e., the lake floor) does not show any evidence of a central uplift of the basement, but the interpretation of the previous (very coarse) aeromagnetic data, and the analogy with other impact structures of this size, led JONES et al. (1981) to suggest that a central uplift of the basement rocks should be present (see Text-Fig. 3). The lake has preserved the structure, however, against erosional processes. Based on the size criteria for terrestrial impact structures (e.g., GRIEVE & PESONEN, 1996), Bosumtwi should be a complex impact structure. The morphometric parameters of the structure are given in PLADO et al. (2000). And indeed, new seismic data (KARP et al., 2002; SCHOLZ et al., 2002) clearly indicate the presence of a central uplift, ca. 2 km in diameter, which is buried by up to 150 m of lake sediments.

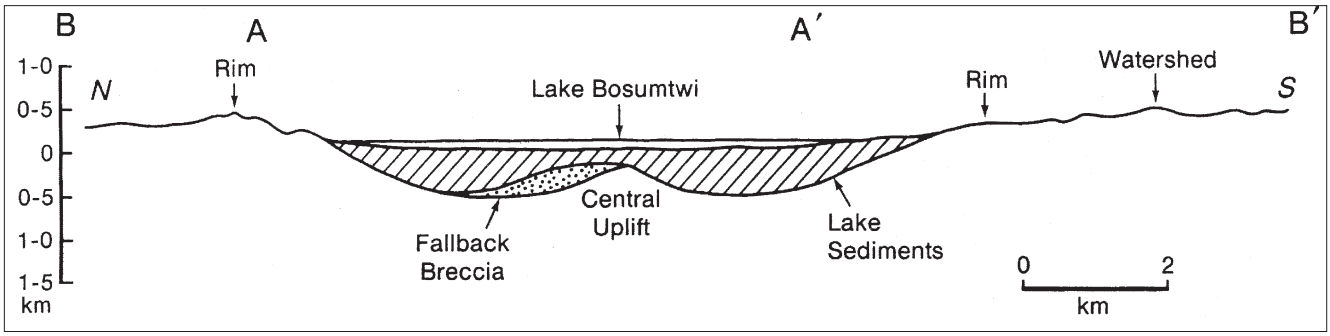
2.2. Topography

Text-Fig. 2 shows the topography of the Bosumtwi area, which distinguishes two ring structures: the actual crater rim (diameter of 10.5–11 km), and a weakly exposed outer arcuate structure with a diameter of about 18 km.

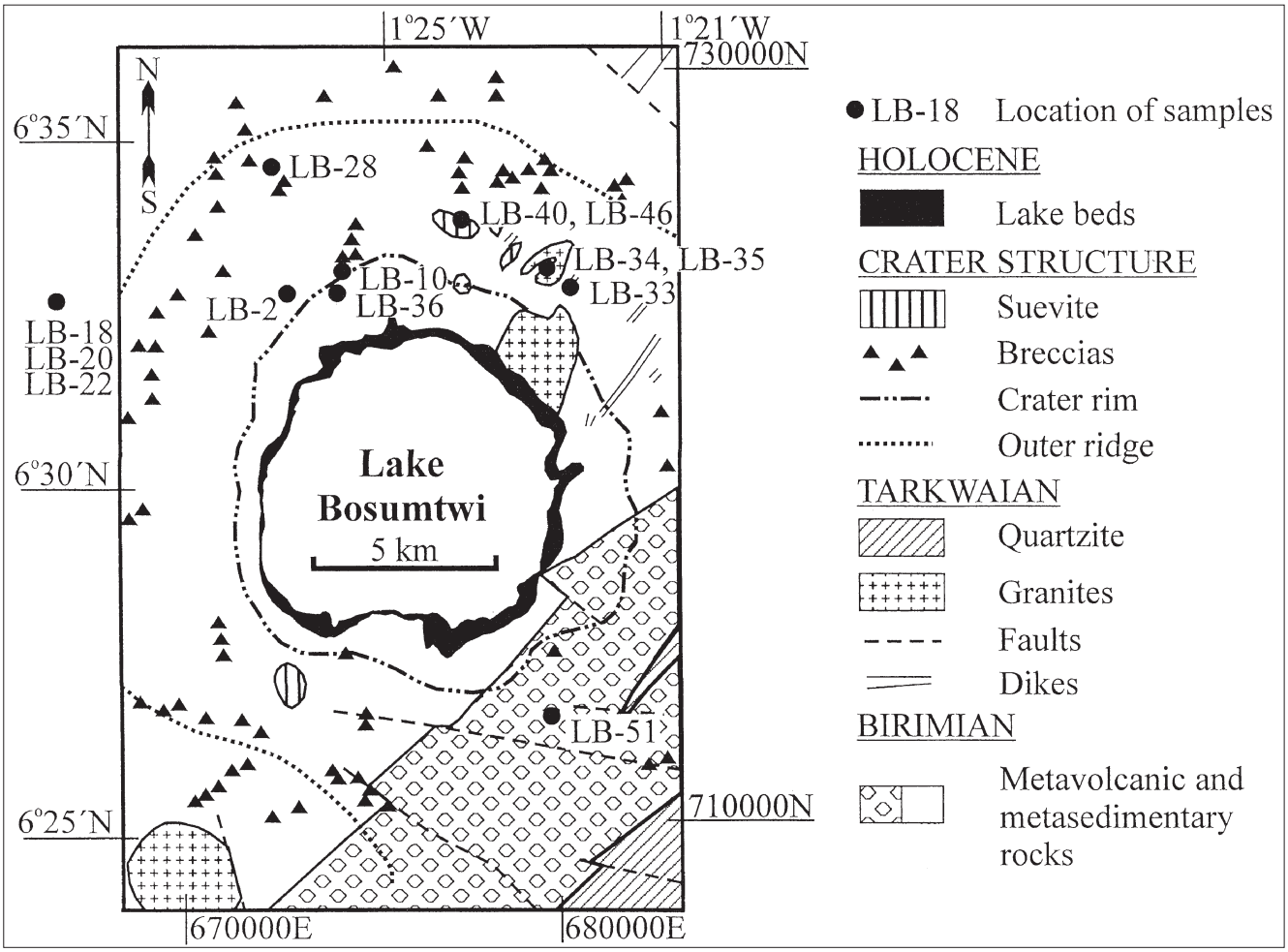
3. Geology

Ghana occupies a major part of the Precambrian West African Craton. The early Proterozoic (~2,100 Ma) basement in Ghana is subdivided into the Birimian and Tarkwaian Supergroups.

The Bosumtwi crater (Text-Fig. 4) was excavated in lower greenschist facies metasediments (mainly graywackes and sandstones) of the ~2.1–2.2 Ga old Birimian Supergroup (Text-Fig. 4). Several Proterozoic granite intrusions occur in the region around the lake. In terms of impactites,



Text-Fig. 3.
Hypothetical cross section (W–E) of the Bosumtwi impact structure, showing the water depth, lake sediment layer and the bottom topography. Note the inferred (from previous aeromagnetic data and comparison with other impact structures) central uplift.
After JONES et al. (1981).



Text-Fig. 4.
Simplified geological map of the Bosumtwi impact structure.
From PLADO et al. (2000.)

massive suevite deposits are located slightly outside the northern rim and also in the southern part of the lake.

In early 1999, a shallow drilling program was undertaken by the University of Vienna with the cooperation of the Geological Survey Department of Ghana (GSD).

Seven holes were drilled to the north of the crater, at a distance of 2.5 to 8 km from the lakeshore, to a maximum depth of about 30 m, and core samples of impact breccias, suevites, and other rock types were recovered. The drilling locations were chosen based on geophysical information obtained from an airborne radiometric map (see below). Two of the drill holes were sited not far from suevite outcrops, with the aim of recovering suevite and determining the thickness of the fallout suevite deposit.

Results show that a variety of impactite lithologies (different breccia types) are present. The suevite cores show that melt rock inclusions are present throughout the whole length of the cores, in the form of vesicular glasses, with no significant change of abundance with depth. Major and trace element analyses yielded compositions similar to the target rocks in the area (graywacke-phyllite, shale, and granite).

The shallow drill core data indicate that the thickness of the fallout suevite in the northern part of the Bosumtwi structure is ≤15 meters, and occupies an area of about 1.5 km^2 (see BOAMAH & KOEBERL, 1999; BOAMAH, 2001; BOAMAH & KOEBERL, 2002, 2003). For other recent studies see also KOEBERL et al. (1999, 2000a,b).

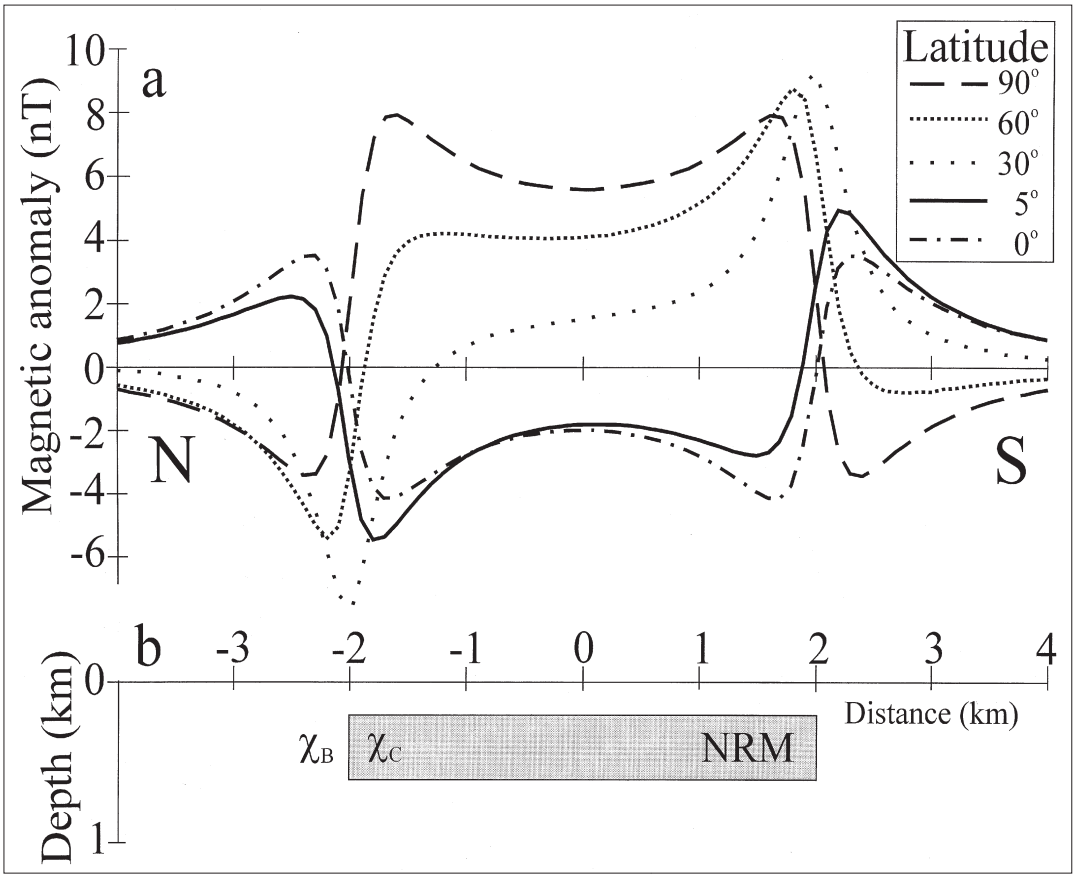
Radiometric age determinations on Ivory Coast tektites (derived from the Bosumtwi crater) and Bosumtwi impact glass, as well as stratigraphic studies of microtektite-bearing deep sea cores in the Atlantic Ocean have shown that the Bosumtwi impact occurred at ~1.07 Ma ago during the lower Jaramillo normal polarity magnetic chron. This age for the Bosumtwi impact event is also supported by ^{87}Rb-^{87}Sr, ^{39}Ar-^{40}Ar and fission track dating (e.g., KOLBE et al., 1967; KOEBERL et al., 1997a).

This is also consistent with recent paleomagnetic data of the melt-suevites and fractured target rocks (PLADO et al., 2000), which show that the characteristic remanent magnetization component has a shallow northerly pointing magnetization of the Lower Jaramillo N-polarity chron.

We note here that this magnetization is close to the present Earth's magnetic field direction at a nearly equatorial site location. Thus, the expected total magnetic field anomalies in the north-south direction should have a wave-type pattern (high – low – high), as shown in a simple modeling example (Text-Fig. 5).

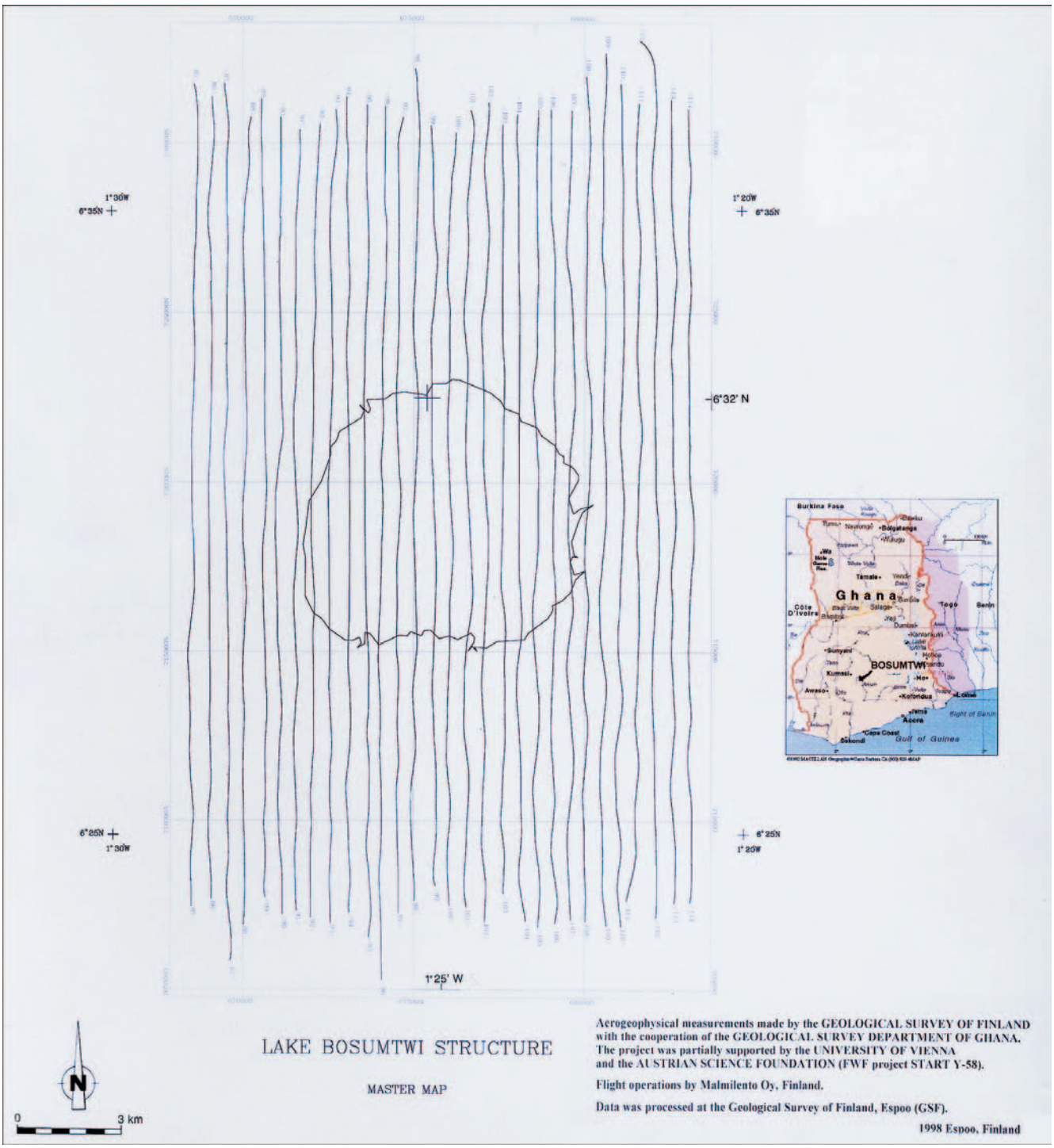
To understand and visualize the dependence of a magnetic anomaly on site latitude, we calculated the total magnetic field profiles (N–S) for an artificial model (prism with dimensions of 4×4×0.4 km) at various latitudes. It shows that a magnetized body at the Lake Bosumtwi latitude (~6°N) should cause a major negative anomaly occurring slightly northwards of its center and positive side anomalies on the northern and southern sides of the major low.

This type of anomaly is expected for Bosumtwi if there is a highly magnetic body underneath the lake sediments, and indeed, is observed.



Text-Fig. 5.
a) Magnetic profiles (N–S) across a hypothetical magnetic prism at different geographic latitudes.
b) Cross-section of the model (4 x 4 x 0.4 km), producing the calculated magnetic anomaly profiles in (a), has the following properties: χ_C (magnetic susceptibility of the prism) = 0.0005 SI units; NRM (intensity of the natural remanent magnetization) = 0.05 Am-1. χ_B (magnetic susceptibility of the background) = 0.00015 SI units; NRM of background is set to zero. The calculations were made with ModelVision software according to the geocentric axial dipole model.
Courtesy J. PLADO, Univ. Tartu.

Text-Fig. 6.
An aerial photograph of Lake Bosumtwi from the Twin Otter aircraft. A part of an aircraft wing with its electromagnetic receiver coil is visible.
Photo by Kai NYMAN (GSF).



Text-Fig. 7.
Outline of Lake Bosumtwi and flight paths for the 1997 aerogeophysical survey.

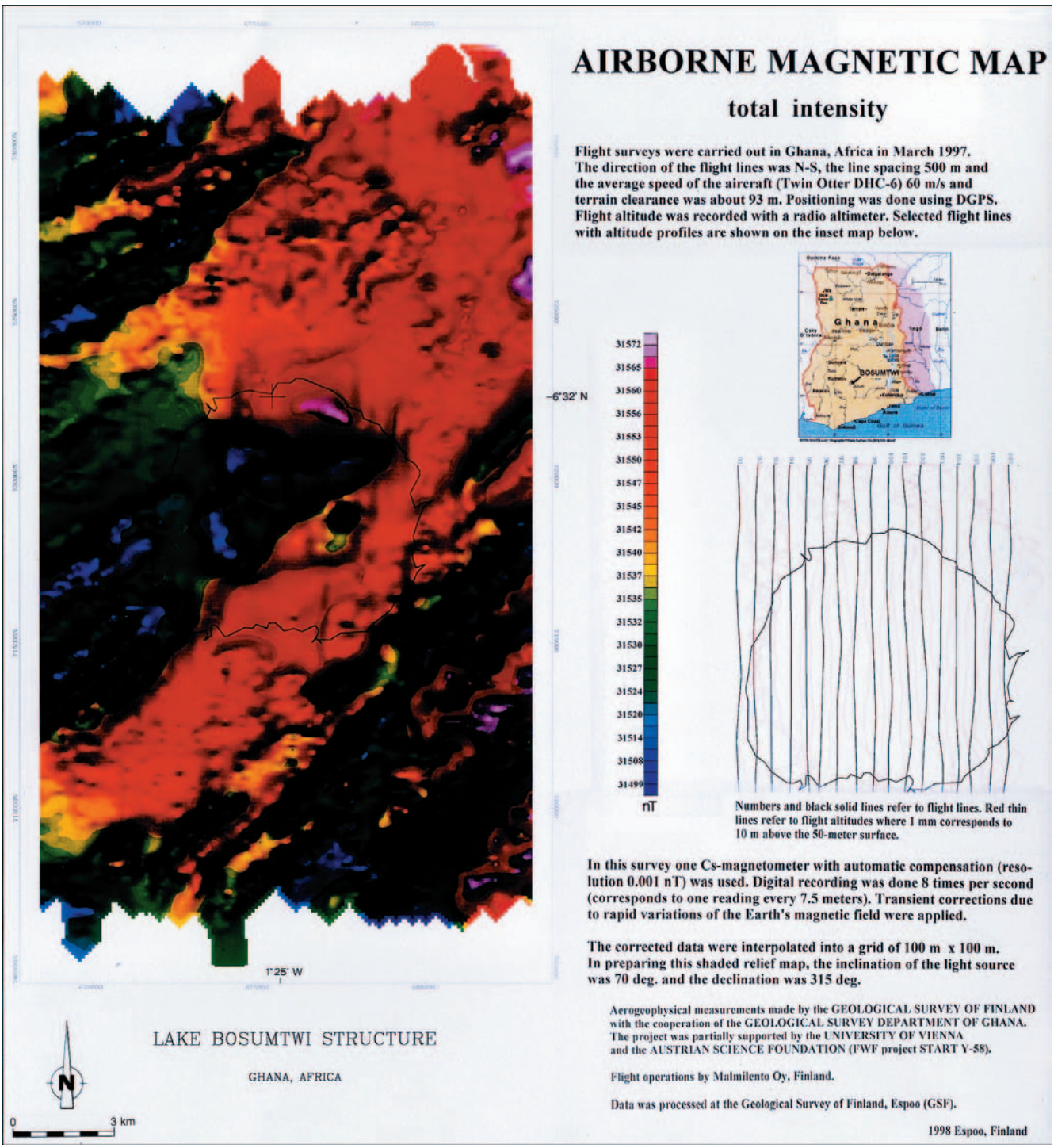
4. The New Airborne Geophysical Survey, and Equipment Used

4.1. Aircraft and Field Survey

In order to obtain a more detailed view of the subsurface structure below and beyond the lake, a high-resolution aerogeophysical survey across the structure was conducted by the GSF in March 1997.

The survey was done with a DeHaviland two engine Twin Otter DHC-6/300 aircraft owned by Finnair Co. and operated by Malmilento Co (Finland). This aircraft offers several advantages in terms of utility and cost, including excellent performance reserves, low speed handling characteristics and operational flexibility. The flight speed during the measurements is 160–220 km/h (44–61 m/s) with a rate of climb of 7.5 m/s.

The nominal flight altitude in Bosumtwi area was ~ 70 m, flight directions N–S and the line spacing 500 m. The outline of the lake and the flight paths are shown in Text-Fig. 7. The inset of each airborne geophysical map (e.g., Text-Fig. 8 ff) shows the survey lines over the Bosumtwi survey area. The average speed of the aircraft was 60 m/s and recordings were obtained at intervals of 7.5 m (magnetics), 15 m (EM) and 60 m (gamma radiation), respectively, along the N–S profiles.



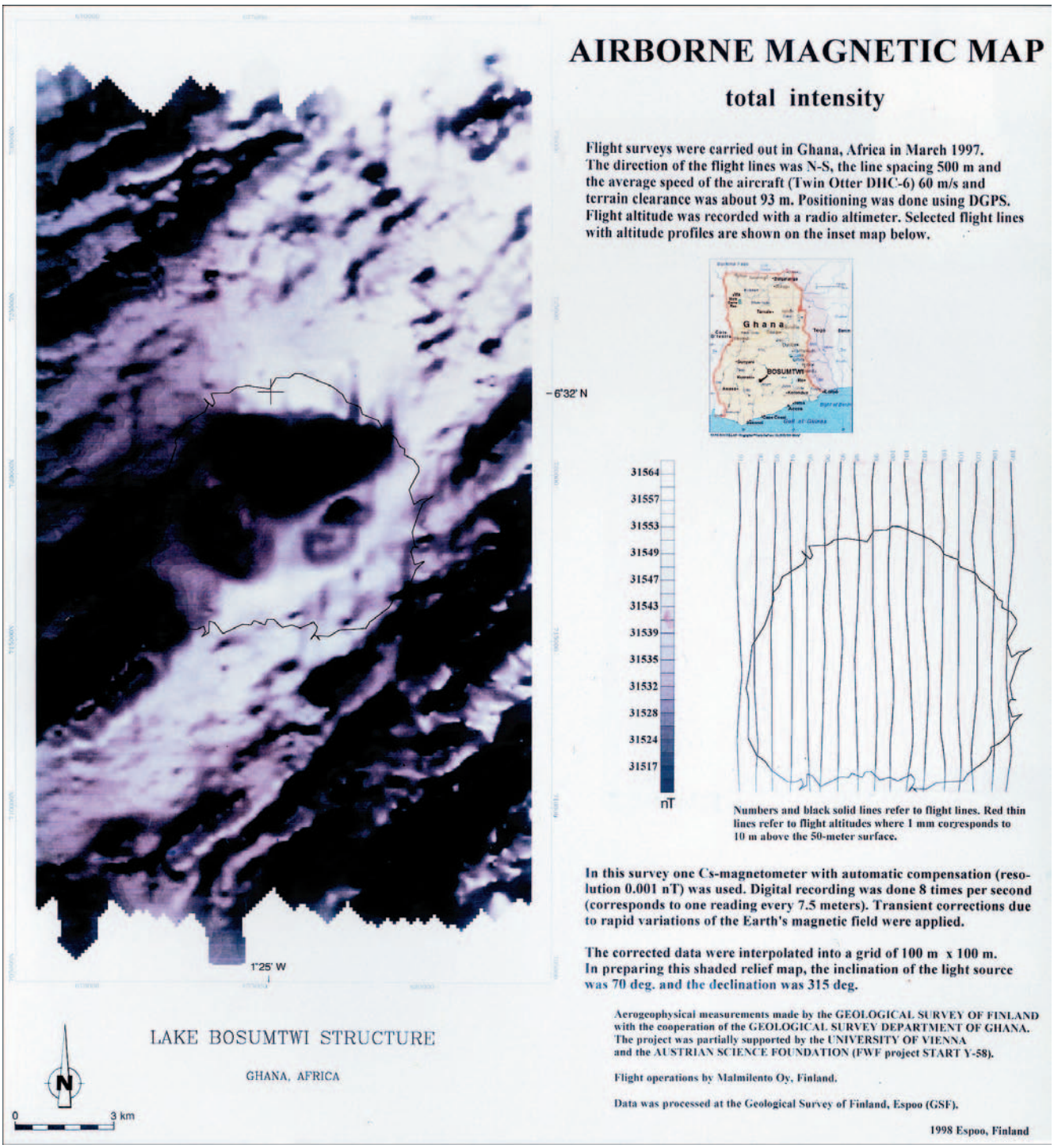
Text-Fig. 8.
Total magnetic field (nT) map of the Bosumtwi structure (see text for explanation).
The periphery of the lake is contoured on this map. We note that the overall magnetic map shows similar anomalies as the map by JONES et al. (1981), but is more detailed and has a better space resolution.
The basic anomaly pattern in this figure is as follows: the northern part of the lake has a maximum anomaly (pink),which is followed by the distinct central to northern negative anomaly (dark blue). The very center of the lake has a weaker anomaly. Two other negative anomalies are present: one in central west (bright blue) and one (nearly circular) central east. Finally the southern part is again occupied by a strong positive anomaly (red).

Altogether 30 profiles with an average length of 22 km were recorded (Text-Fig. 7). Positioning was done using a differential global positioning system (DGPS) and flight elevations were measured with a radar altimeter. The survey consisted of airborne magnetic, electromagnetic, and gamma-ray radiation measurements. All recordings were done digitally and corrections due to aircraft have been performed.

4.2. Magnetics

The total magnetic field intensity (nT) was recorded with two single Scintrex MAC-3 cesium magnetometers with a CS-2 sensor and MEP-2111 processor modules.

The magnetometers were installed in the wing tips with an automatic compensation unit (to reduce aircraft magnetic disturbances); however, only the right wing magne-



Text-Fig. 9.
Total magnetic field (nT) map of the Bosumtwi structure, gray-shaded version.
See also PLADO et al. (2000).

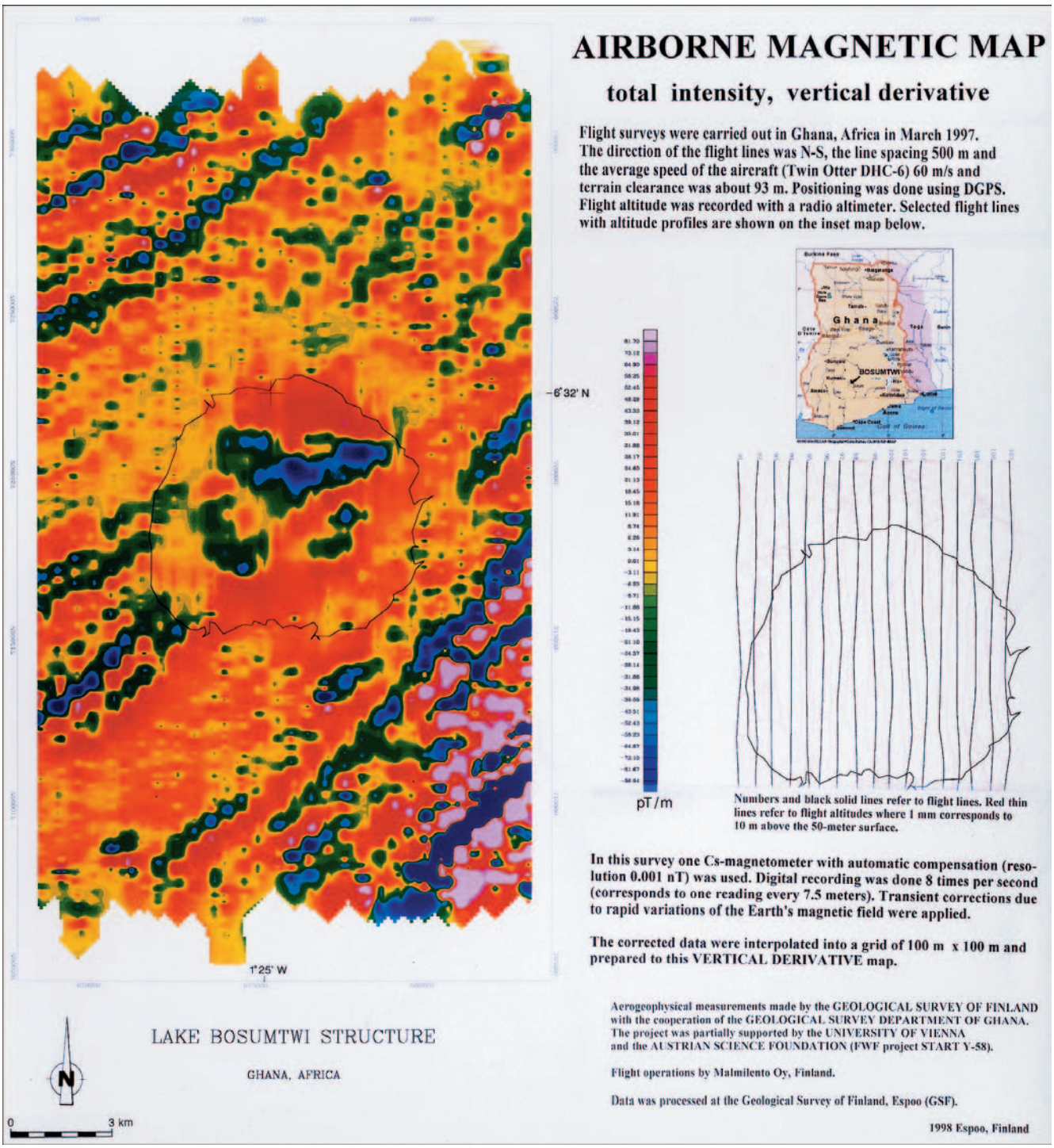
tometer was in operation for the Bosumtwi survey. This system has a resolution of 0.001 nT and a sensitivity of 0.005 nT. The average noise level is 0.0006 nT/sqrt (frequency). The registration took place 8 times/second (corresponding to an average reading at every 7.5 m).

To reduce the local magnetic variations, a magnetic reference station was installed close to lake Bosumtwi, at Kumasi airport, where the total field variations were recorded throughout the survey days using a Scintrex MAC-3 cesium magnetometer. No nearby observatory data were available, so the results are on the level of the measuring date and place.

4.3. Aero-Electromagnetic Data (AEM)

The aero-electromagnetic (AEM) data were recorded using a dual frequency, broadside, vertical, coplanar coil configuration (Model GSF-95), where the coils are installed at the wing tips and have a separation of 21.36 m.

The used frequencies are 3,125 Hz and 14,368 Hz, respectively. The in-phase (Real, Re-) and quadrature (Imaginary, Im-) components of the EM signal were measured. The recording sensitivity is 1 ppm and the noise levels are <6 ppm for both quadrature and in phase components when the frequency is 3,125 Hz. The corresponding



Text-Fig. 10.
Vertical derivative of the total magnetic field data over the Bosumtwi impact structure.

noise is <35 ppm for the 14,368 Hz data. The measurement range for both in-phase and quadrature components is 0–50,000 ppm.

The registration took place at every 15 m on average. There are several advantages of this AEM system over the commonly used Very Low Frequency (VLF) system.

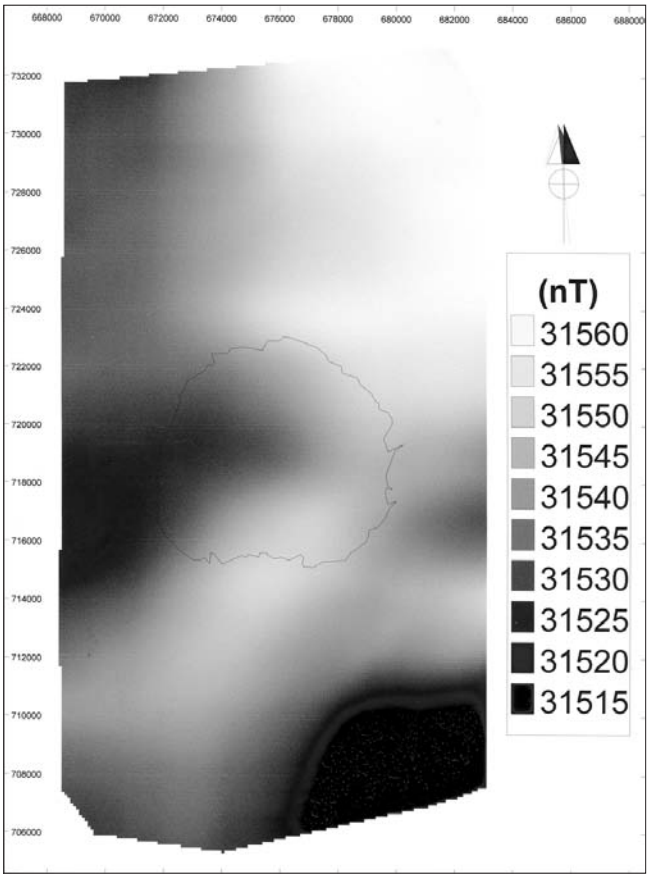
This system has a continuous transmitter signal and the two frequencies guarantee that a large conductivity range can be detected.

The system provides a possibility to calculate the apparent resistivity and apparent depth (see below) for a uniform half-space earth model. Moreover, this system is not as sensitive for topographic effects as the VLF system.

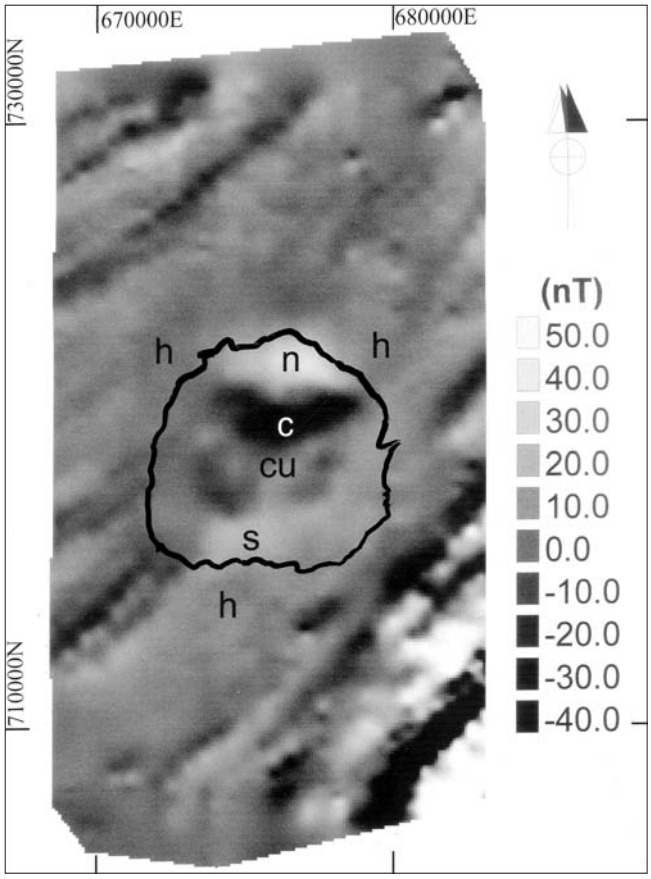
4.4. Gamma Ray Radiation

The gamma ray spectrometer used was an Exploranium GR-820/3. This unit has two NaI crystal sets, each containing four downward and one upward looking crystals, with a total volume of 41 liters (i.e., totally 33 l downwards, 8 l upwards). The system has a an energy range of 0.01–3 MeV, 256 channels each having 12 keV. The cosmic window is >3.0 MeV.

The spectra were converted to measurements of the U, Th, and K contents, as well as total radiation.



Text-Fig. 11.
The regional field map (total intensity, nT) of the Bosumtwi structure.
In order to remove the regional trends and to amplify the Bosumtwi related anomalies, we applied a 2D-smoothing window with an areal operator of 4 x 4 km in a grid of 100 x 100 m.
See PLADO et al. (2000) for details.



Text-Fig. 12.
The residual magnetic field (nT) map of the Bosumtwi structure.
The residual magnetic anomaly (Fig. 5) is obtained by subtracting the regional field from the original total field.
See PLADO et al. (2000) on how this map was prepared from Text-Figs. 9 and 11. Symbols are as follows: n = northern maximum; c = central minimum, cu = anomaly pattern possibly related to the central uplift; h = magnetic halo encircling the structure and roughly matching the inner rim.

4.5. Navigation and Other Instruments

The navigation was done with a real time DGPS with an accuracy of ±2 m after post-processing of the data. Visual navigation was also done with maps. The altitude was obtained, in addition to DGPS data, with the help of a radar altimeter (Collins-type), with a resolution of 0.1 m, accuracy 0.5 m, and a measurement density of 2 readings/s.

Other instruments employed in the survey were barometer, thermometer, accelerometer, and a spheres monitor. Moreover, the survey was video-taped for later cross-checking if necessary.

4.6. Data Recording and Processing

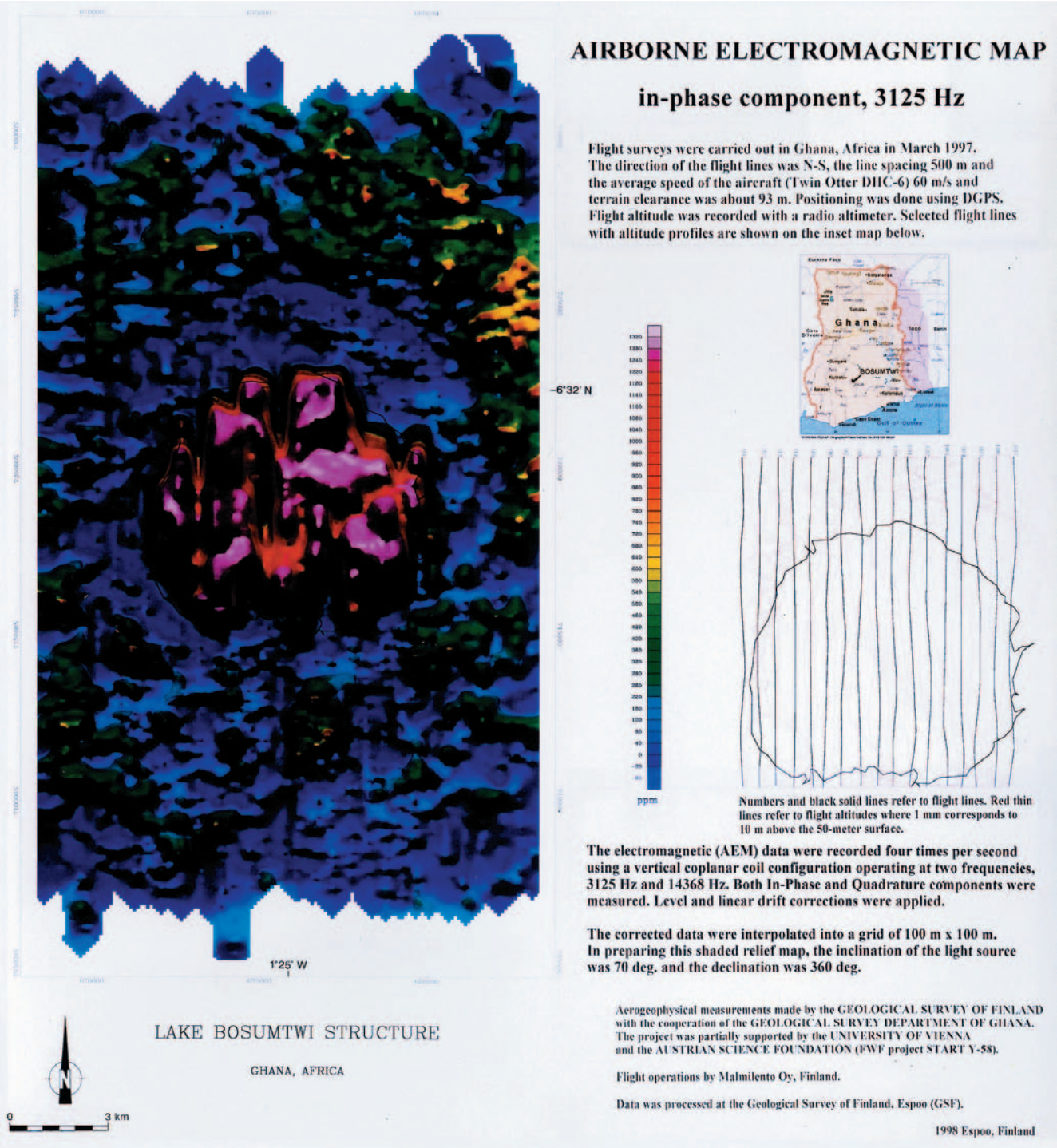
The recordings were done during the flight to PC hard disk and then copied to a PC-compatible Iomega Zip disk. The analog displays were also used to monitor the operational conditions of the geophysical instruments during the flights.

All the initial data processing was done at the GSF in Espoo, Finland (OJAMO et al., 1997). All original data (corrected for aircraft disturbances, transients and for variations in elevation) were transformed into a grid of 100 m x 100 m. From this gridding, several sets of contoured, colored, gray, or shaded relief maps were drawn with applying various filters, smoothing and shading directions. All magnetic maps shown here represent the total magnetic field intensity values without removing the regional magnetic trends (which are quite distinct in the area; see Text-Fig. 8 and PLADO et al., 2000). Here we show examples which are all smoothed contour maps, where the anomaly intensities are shown as colors, with red generally pointing to enhanced intensity of the anomaly or content of a measured quantity (e.g., in-phase component), and green to blue pointing to a negative intensity value or content of a quantity.

The data of the survey are available in a series of 1 : 50,000 maps and are reproduced in this paper. The data are also, upon request (contact H. HAUTANIEMI, GSF) available as paper copies from the GSF and can include color, gray, or shaded-relief versions.

The original flight-line recordings of these geophysical data are available from the GSF on request, and arrangements can be made for the maps shown in this paper to be available on CD-ROM from the GSF (contact H. HAUTANIEMI for information). The preliminary interpretations of the geophysical data were done at the Geophysics Department of the GSF (PESONEN et al., 1997; see also PLADO et al., 2000, PESONEN et al., 2001).

In order to compare the new results with those of the previous high-altitude aerogeophysical survey by JONES et al. (1981), we have digitized the previous maps and diagrams of JONES et al. (op cit.) in the same scale (1 : 50,000) as the new data. The previous data include aeromagnetic, some scarce gravity data (only outside of the lake), and topographic and bathymetric data (see below).



Text-Fig. 13.
In-phase component map of the electromagnetic field of the Bosumtwi structure (f = 3,125 Hz).
See map and text for explanation.

5. Geophysical Maps

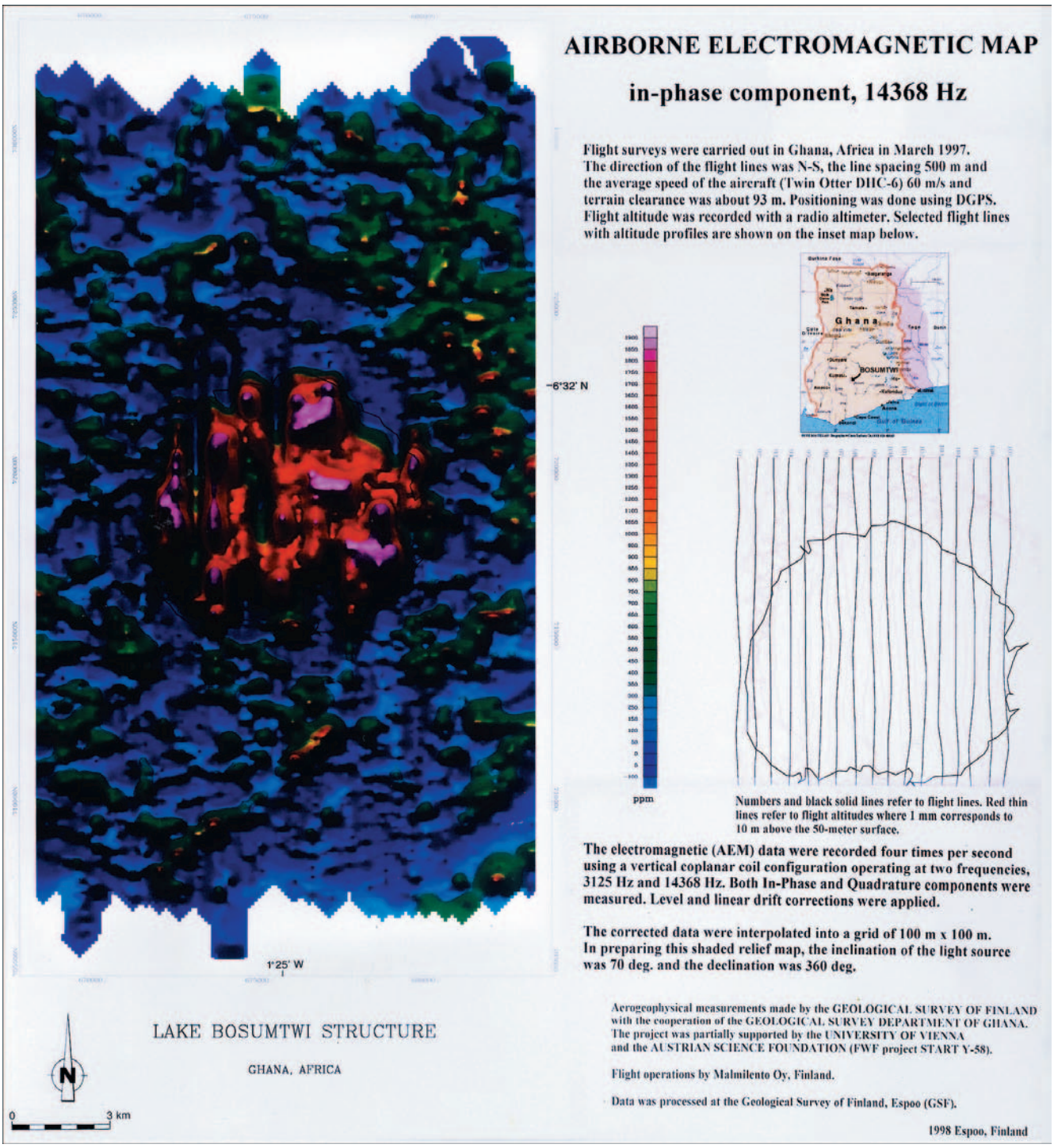
We have prepared a set of 16 new geophysical maps in 1 : 50,000 of the Bosumtwi survey. They are:

❶ Three magnetic maps (colored and gray tone total field)
- – Total intensity, colored
- – Total intensity, shaded relief
- – 2nd vertical derivative, colored

❷ Eight electromagnetic maps
- – in-phase and quadrature component maps f = 3,125 Hz
- – in-phase and quadrature component maps f = 14,386 Hz
- – apparent resistivity maps for both frequencies
- – apparent depth maps for both frequencies

❸ Four gamma radiation maps: the U, Th, K and total radiation content maps.

We note here that other maps were also prepared (and can be ordered from GSF), but these turned out to be very complex and were, thus, not used in the follow-up studies. These include magnetic maps in which the data were reduced to the pole using the Euler transformation techniques.



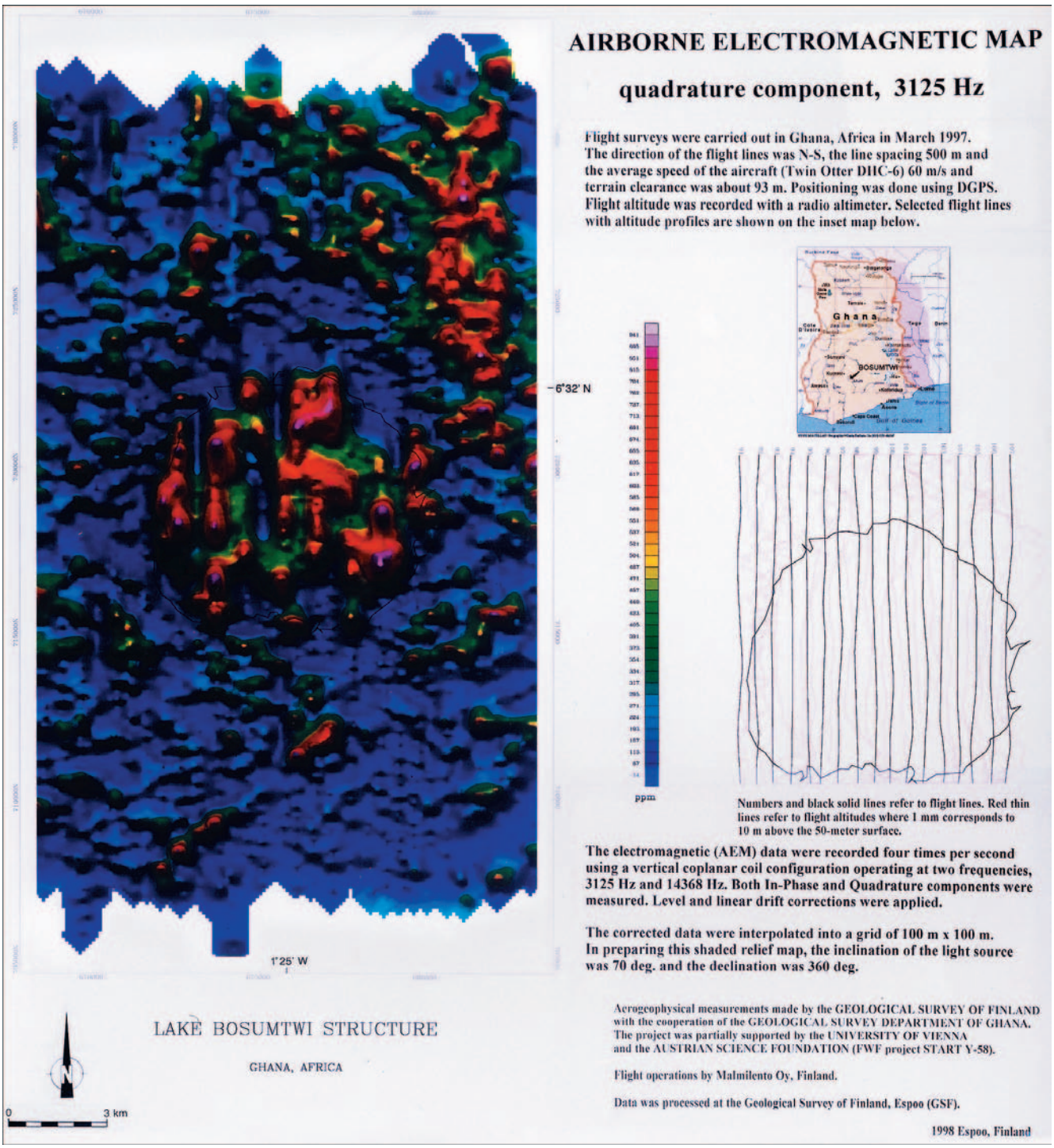
Text-Fig. 14.
In-phase component map of the electromagnetic field of the Bosumtwi structure (f = 14,368 Hz).
See map and text for explanation.

5.1. Magnetic Maps

Several types of magnetic maps have been prepared (Text-Figs. 8 and 9). All magnetic maps are total magnetic field values (nT) as reduced to the level of the field in Ghana (which is typically 31,000±1,000 nT). They are thus not IGRF-values.

Text-Fig. 8 serves as an example of the map display from this survey. On the upper right corner the location of the Bosumtwi in Ghana is shown. The inset in middle right shows the flight lines as black solid lines. The red lines denote the flight altitudes along these flight lines (with a scale of 1 mm corresponding to 10 m above the 50 m flight elevation). In the left is map, in this case the total field intensity, where the data have been filtered to get smoothed charts. In this example the scale bar varies from 31,572 nT (pink) to 31,500 nT (blue). The scaling varies from map to map.

Text-Fig. 9 is the corresponding gray shaded relief map; Text-Fig. 10 is the vertical derivative map of the same data as Figs. 8 and 9. Text-Fig. 11 shows the regional field, and Text-Fig. 12 shows the residual magnetic field at Bosumtwi (see figure caption and PLADO et al. [2000] for details).



Text-Fig. 15.
The quadrature component map of the aero-electromagnetic field map of the Bosumtwi structure (f = 3,125 Hz).
See text for explanation.

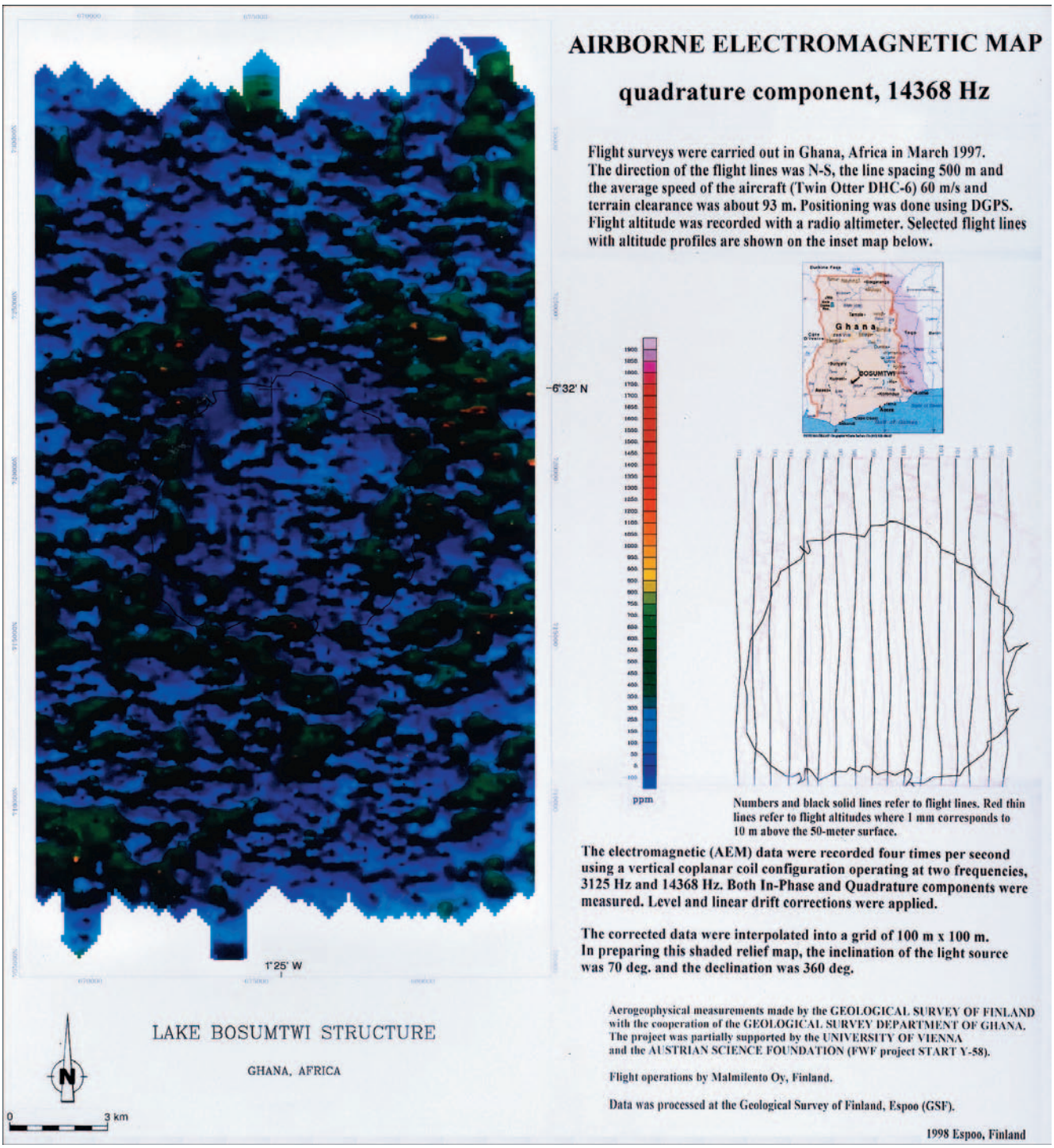
5.1.1. Magnetic Structure: Example of Interpretations

The magnetic data show a circumferential magnetic halo (h) outside the lakeshore, ~12 km in diameter. The central-north part of the lake reveals a central negative magnetic anomaly (c) with smaller positive side-anomalies N and S of it (n and s, respectively), which is typical for magnetized bodies at shallow latitudes (cf. Text-Fig. 5; see also JONES et al. (1978).

A few weaker negative magnetic anomalies exist in the eastern and western part of the lake. Together with the northern one they seem to encircle a central uplift (cu). Our model shows that the magnetic anomaly of the structure is presumably produced by one or several relatively strongly remanently magnetized impact melt rocks or melt-rich suevite bodies.

The new magnetic maps therefore give further support for the existence of a central uplift below the lake sediments (see also KARP et al. [2002] and SCHOLZ et al. [2002] for new seismic data that indicate the presence of a central uplift; also, preliminary gravity data in POHL et al. [in preparation] support this view).

The southern part of the structure lacks prominent magnetic anomalies. This could be due to landslides or col-



Text-Fig. 16.
The quadrature component map of the aero-electromagnetic field map of the Bosumtwi structure (f = 14,368 Hz).
See text for explanation.

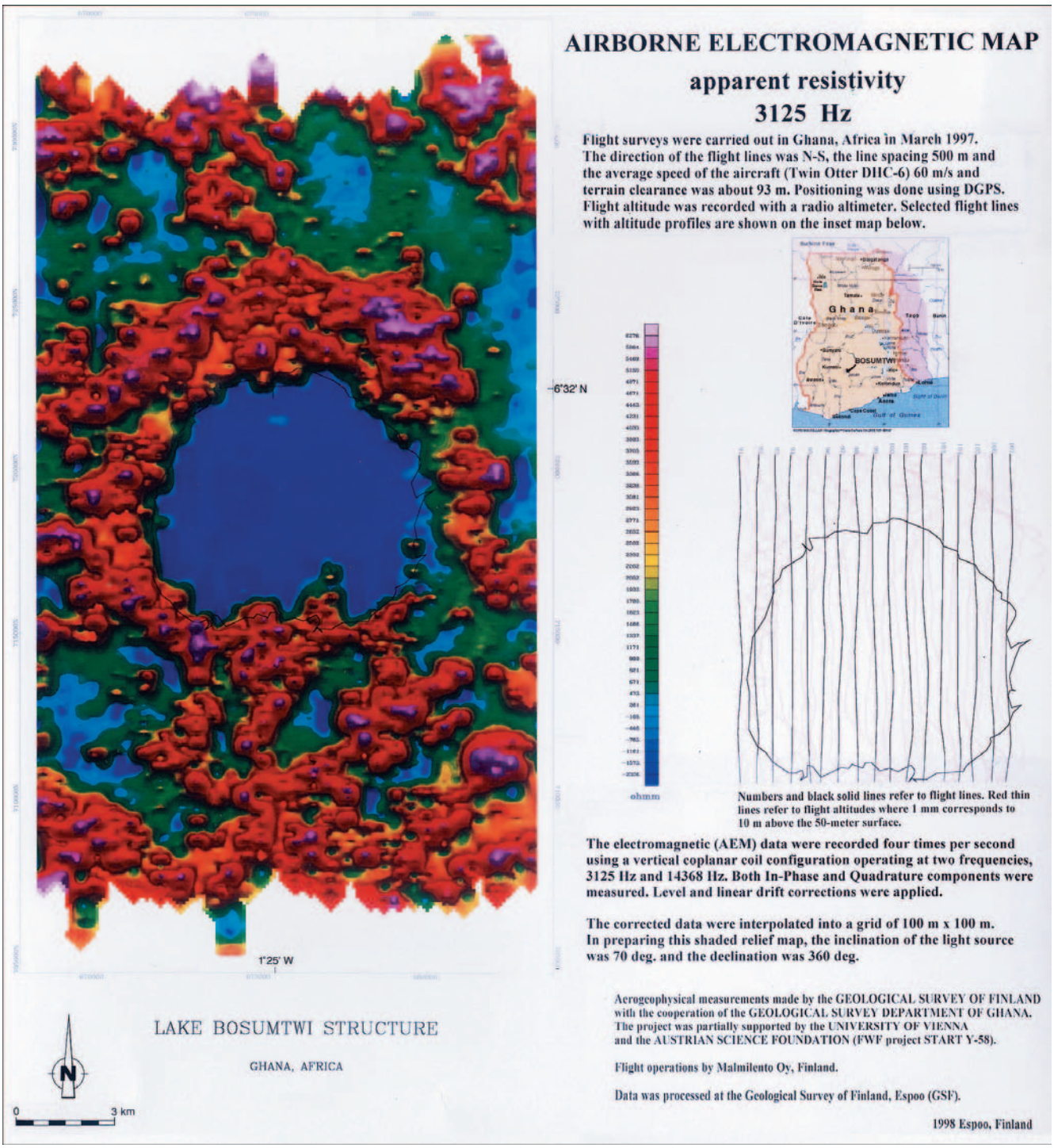
lapse of weakly magnetic rocks from the mountain chain (Obuom Range) southeast of the structure into the fresh crater.

5.2. Electromagnetic Maps

Various airborne electromagnetic maps are now available for the survey area. Test-Figs. 13 and 14 show the in-phase component of the AEM anomaly maps at a frequency of 3,125 Hz and 14,368 Hz, respecively, and Text-Figs. 15 and 16 show the quadrature component maps at the same frequencies. The scale has been adjusted artificially into colors where red denotes high and blue low in-phase EM values, respectively. The zero value is artificial and is taken to represent a typical (average) value of the in-phase component in the area outside the Bosumtwi structure (which appears in dark blue).

We note that the lake area has several positive in-phase EM anomalies (pink to red "blocks").

However, due to the screening effect of the highly conductive lake water (cf. TURNER et al., 1996, for water analyses) on the measured AEM signal, the interpretation of these observed EM-anomalies in the lake is dubious and very difficult to do in terms of possible structures or impactite bodies below the water.



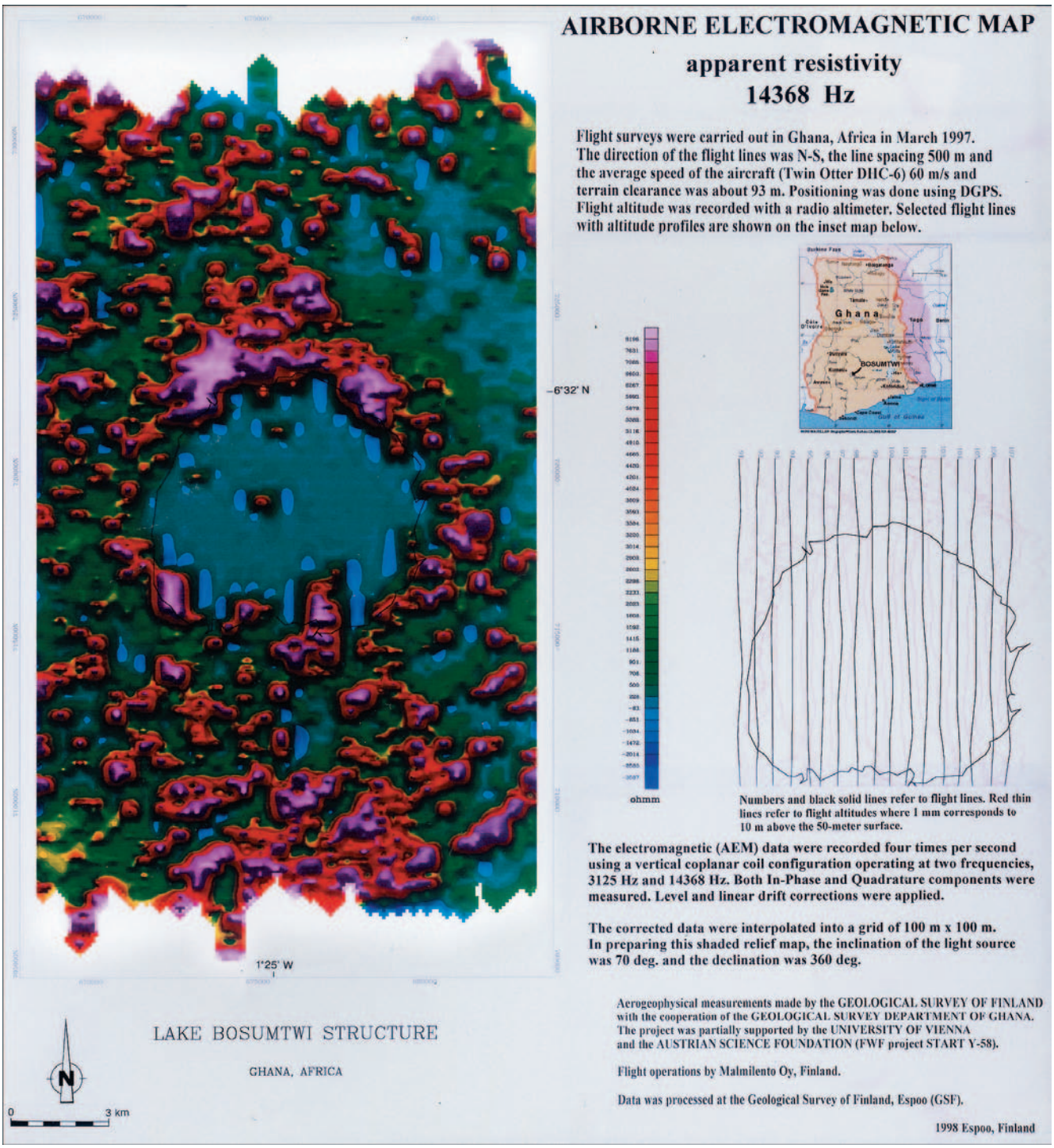
Text-Fig. 17.
The apparent resistivity map (f = 3,125 Hz) of the Bosumtwi structure.
See text for explanation.

Some of the anomalies may indicate real "conductive" bodies in the subsurface strata (lake sediments, buried impact melt rocks, or fractured uplifted basement), but to verify this requires detailed 3-dimensional electromagnetic modeling, which has to be done in the future. We note that two of these lake anomalies appear to be systematic in these AEM maps (including the apparent resistivity maps), which may indicate that they are real. These are the northern pink anomaly (ca. 2 km in size and slightly elongated in the NNE–SSW direction) and the small central anomaly.

Apparent resistivity (ohmm) and apparent depth (m) maps have been prepared from original in-phase and quadrature maps by using an inversion algorithm in which the earth below is treated as a conductive half space (Text-Figs. 17 and 18 for apparent resistivity, and Figs. 19 and 20 for the depth maps).

This is a very simple approach and must be taken with caution, because the Birimian strata in general, and the Bosumtwi structure in particular, are far from a half space model.

However, more complex, 3-dimensional modeling would require sophisticated inversion tools, which are not currently available. The advantage of the apparent resistivity and apparent depth treatments are that the effect of flight alti-



Text-Fig. 18.
The apparent resistivity map (f = 3,125 Hz) of the Bosumtwi structure.
See text for explanation.

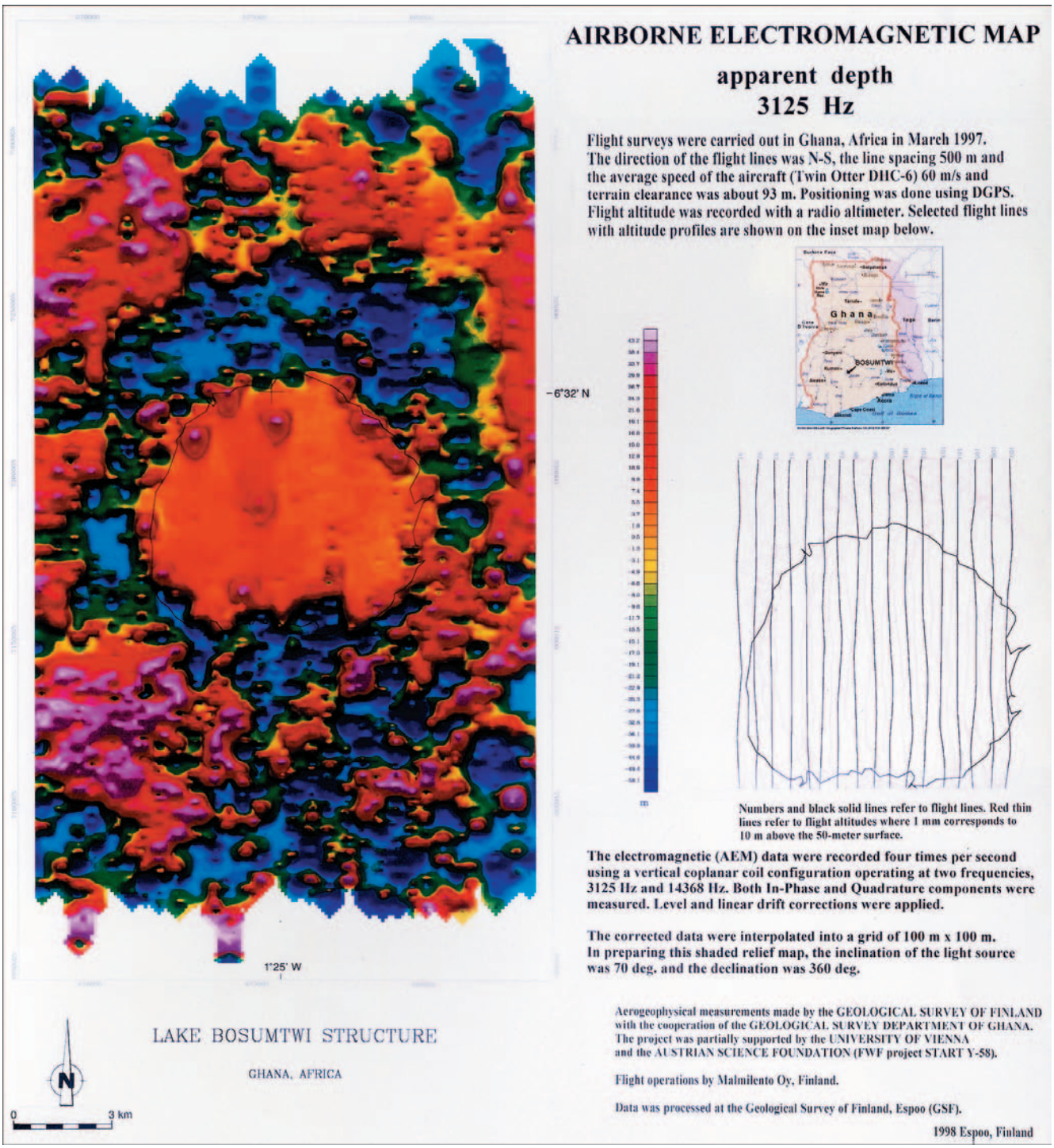
tude (and thus topography) variations on the EM signal are mostly eliminated. Therefore, these maps may provide the first more detailed insight of the conductive structure below the lake than the original in-phase and quadrature maps, but should nevertheless considered with caution.

5.3. Radiometric Maps

The gamma-radiation maps (the U-, Th- K- and the total contents) provide interesting information on the structure of the crater outside of the lake. Text-Fig. 21 shows the total gamma radiation map, and Figs. 22–24 show the K, Th, and U distribution maps, respectively.

The most interesting distribution is shown in Text-Fig. 22, the K distribution map. This map clearly shows two rings of enhanced potassium content: one more or less overlapping with the crater rim diameter of ca. 10 to 12 km, and the other one is further away from the lake, with a diameter of ca. 18 km.

Several models have been proposed (Reimold et al., 1998; Pesonen et al., 2001; Boamah & Koeberl, 2002, 2003; Wagner et al., 2002) to explain these features. It is interesting to note that these rings do not appear as promi-



Text-Fig. 19.
The apparent depth map (f = 3,125 Hz) of the Bosumtwi structure.
The depth values in meters are from the ground surface so that the flight altitude has been subtracted. See text for explanation.

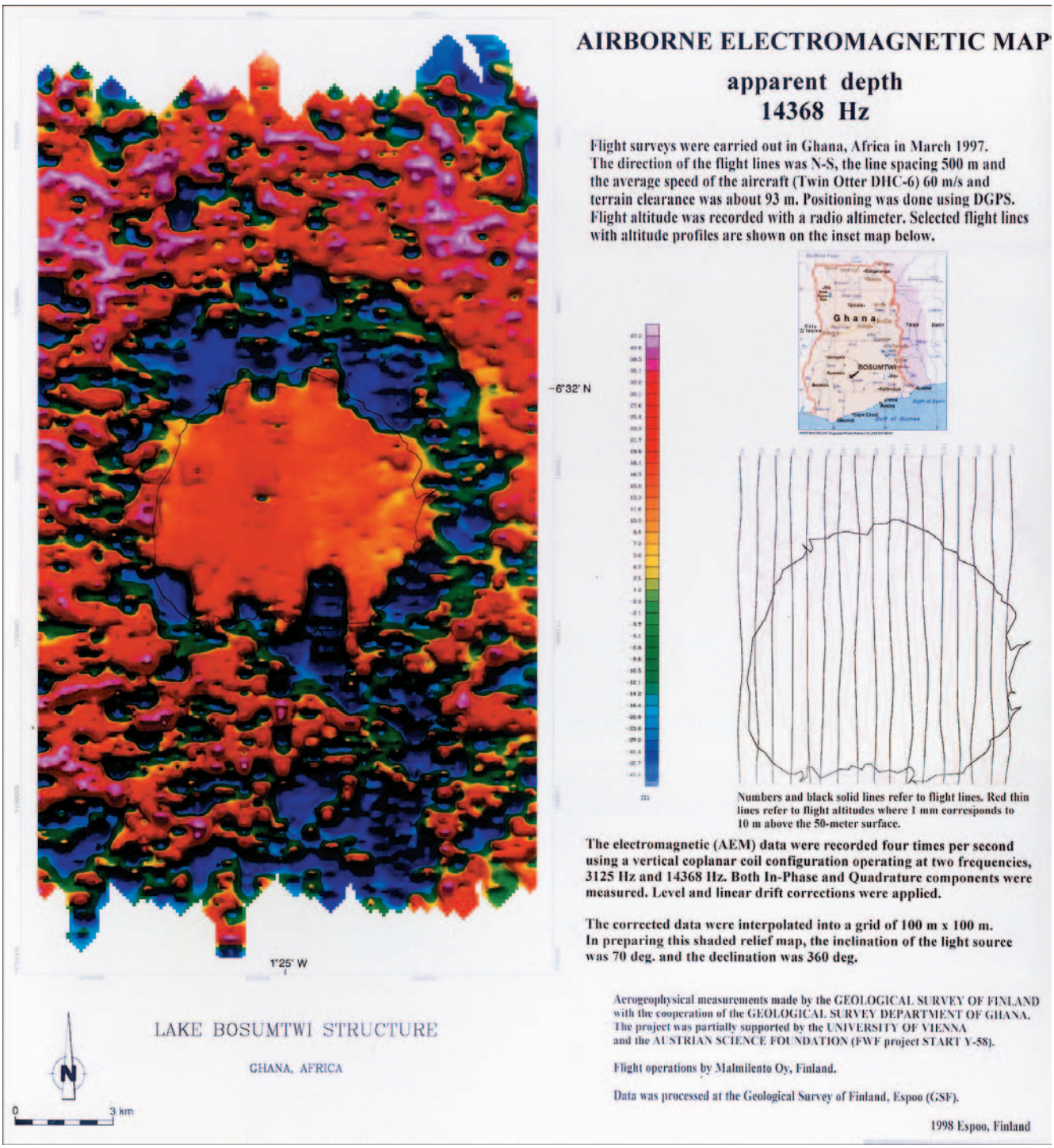
nent in the Th and U maps, indicating a K-dominated effect. One distinct possibility would be that this has to do with K-metasomatism due to alteration of impactites, which has been observed at a number of impact structures. BOAMAH (2001) and BOAMAH & KOEBERL (2002, 2003) reported on a shallow drilling project outside the N part of the crater rim to ground-truth the aero-radiometry data by analyzing soil and rock samples from the high-K and low-K regions.

6. Discussion and Conclusions

This paper presents a set of new high-resolution geophysical maps over the Bosumtwi meteorite impact structure, south Ghana. These maps are the product of a high-resolution airborne geophysical survey carried out in 1997 over the Bosumtwi meteorite impact structure. The new maps provide new insights into the structure both below the lake and also beyond the lake.

The magnetic data have yielded a new model of the structure by showing several magnetic rims and by providing hints for the existence of a central uplift.

The electromagnetic data delineate also several circular features around the structure. Due to conductivity of the lake water, the electromagnetic data are severely screened, but may show some evidence of hidden conductive



Text-Fig. 20.
The apparent depth map (f = 14,368 Hz) of the Bosumtwi structure.
The depth values in meters are from the ground surface so that the flight altitude has been subtracted. See text for explanation.

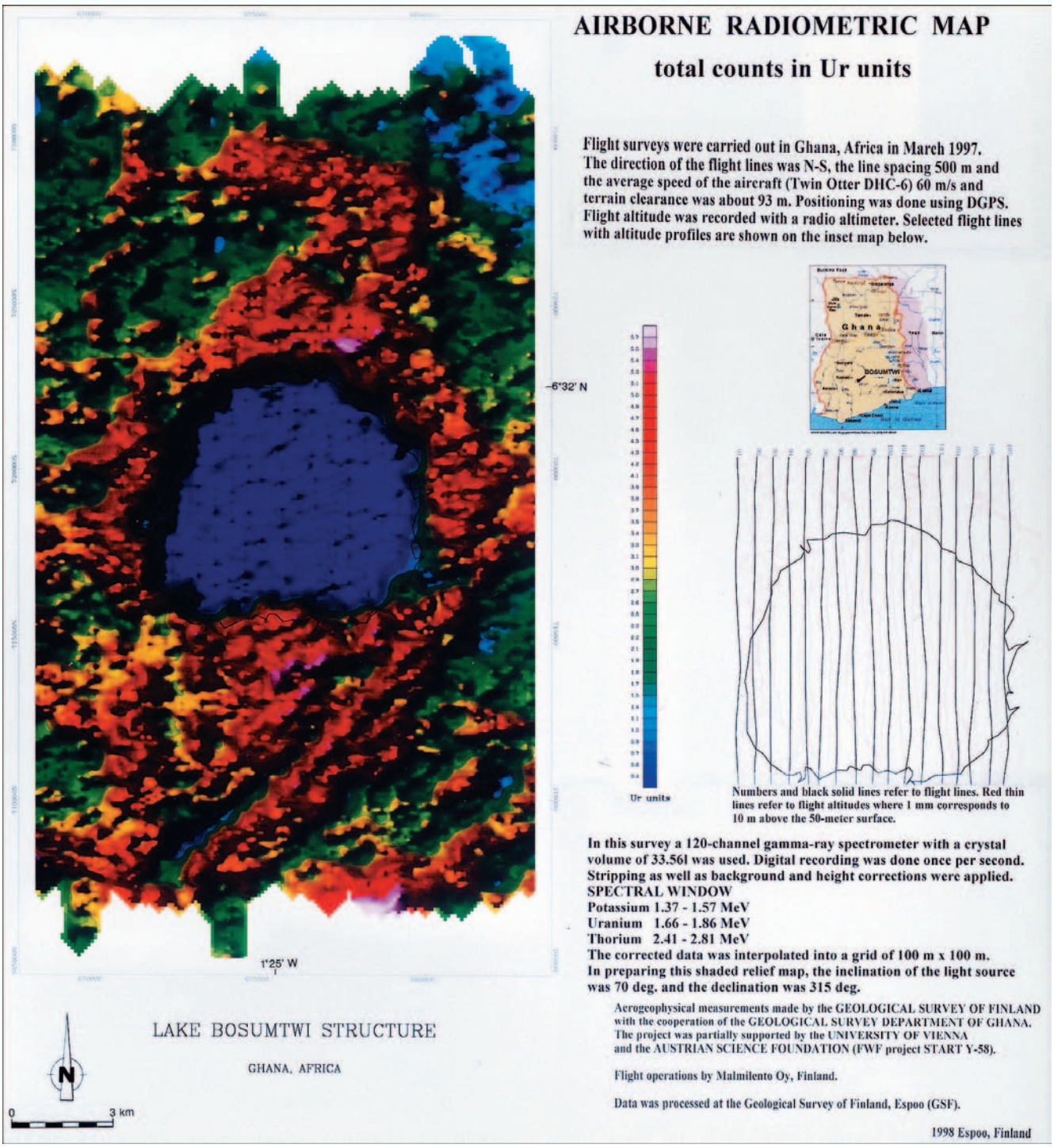
bodies within the structure. The gamma radiation data turned out to be surprisingly valuable and clearly pinpoint two ring features, one coinciding with the actual crater rim (ca. 11 km diameter), and the other one marking an outer ring feature (ca. 18 km diameter), the origin of which is not yet well understood.

The intention of the present paper is to present the new maps to the community; however, a detailed evaluation of the data is beyond the scope of this report.

The Bosumtwi project is a good example of how the GSF airborne geophysical system can be used in international projects which now include surveys of meteorite impact structures. We hope that this project will launch other new opportunities for GSF airborne geophysical surveys in the near future.

Acknowledgements

We are grateful to the Airborne Geophysics Group of the Geological Survey of Finland (Heli OJAMO, Jukka MULTALA, Jouko VIRONMÄKI, Maija KURIMO, Kai NYMAN and the late Risto PURANEN). We thank Malmilento Co., Finland, for performing the aerogeophysical flights in Bosumtwi, and to the Geological Survey Department of Ghana for logistic support. We thank Seppo ELO and Jüri PLADO for providing some of the geophysical maps. This project has been supported by the Austrian "Fonds zur Förderung der Wissenschaftlichen Forschung (FWF)" project Y-58 (to CK).



Text-Fig. 21.
The total gamma radiation map for the Bosumtwi impact structure.
High gamma radiation values appear on the crater rim, along the Obuom mountain range in the SE part of the crater, and in an arcuate structure to the N and the SW of the crater rim.

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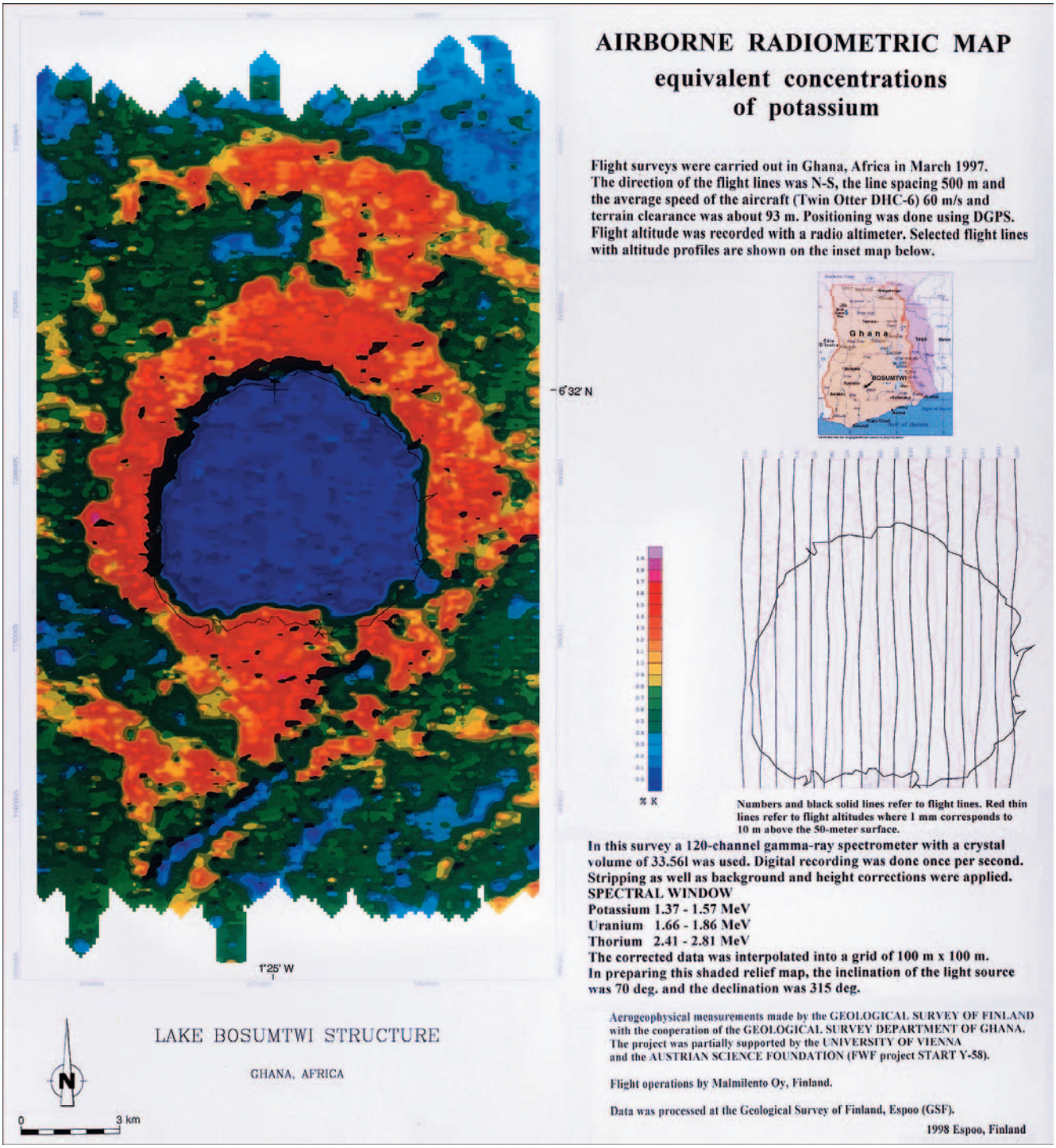

Text-Fig. 22.
The gamma radiation map of the K-content (in %) for the Bosumtwi impact structure.
In this map two almost concentric K-anomalies are clearly visible. The inner one coincides with the crater rim, and the other one coincides with a minor topographic feature. This outer ring is of so far unknown origin (but see also BOAMAH & KOEBERL [2002, 2003] and WAGNER et al. [2002]).

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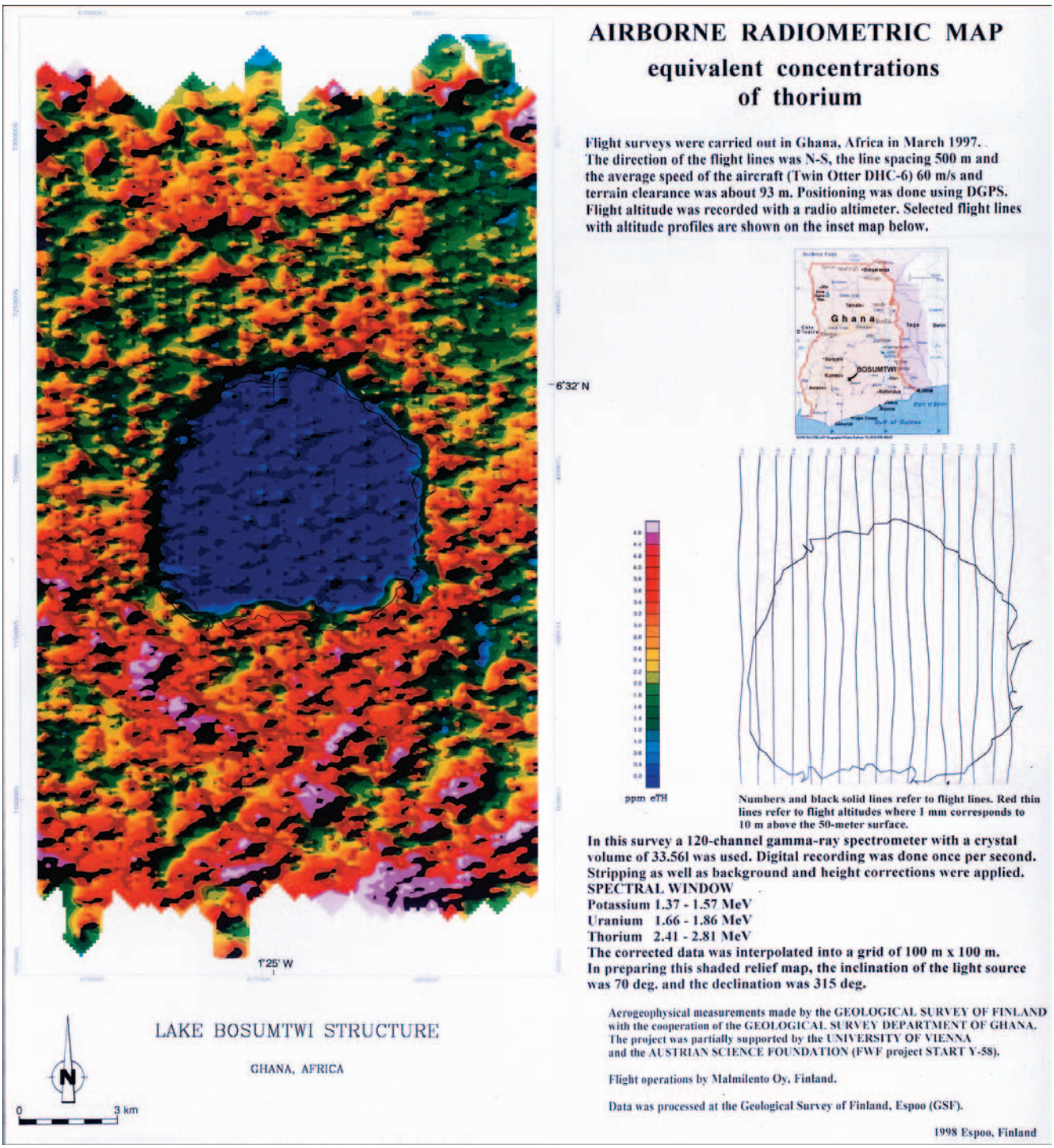

Text-Fig. 23.
The gamma radiation map of the Th content (in ppm) for the Bosumtwi structure.
A circular pattern is visible but not as clearly defined as in the potassium distribution map.

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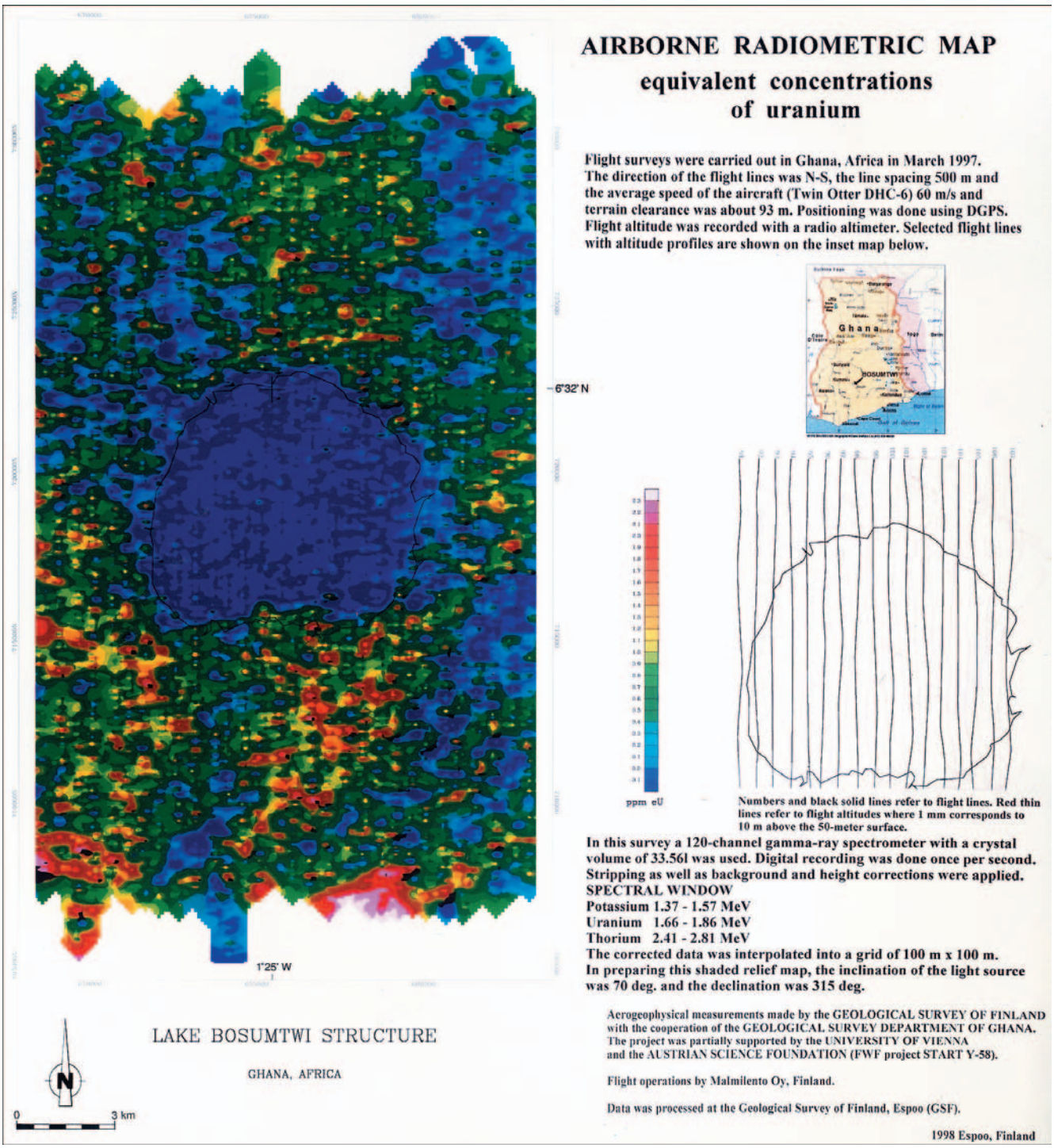

Text-Fig. 24.
The gamma-radiation map of the U content (in ppm) for the Bosumtwi structure.
The concentric patterns that are clear in the K distribution map are not as well pronounced here, although there are high U regions to the N and in the S part of the structure.

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Manuskript bei der Schriftleitung eingelangt am 6. November 2003