White Paper - SkyTEM Multi Geophysical Airborne Surveys

(TDEM / Magnetic and Gamma-Ray Spectrometry)

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INTRODUCTION

SkyTEM is a helicopter-borne dual-moment time-domain electromagnetic (TDEM) system employed globally for resource exploration and environmental and geotechnical studies. Initially designed to acquire electromagnetic data the system was upgraded in 2008 to include an option for the acquisition of total field magnetic data. A further upgrade in 2010 allowed for the acquisition of gamma-ray spectrometry (GRS) data as well. All geophysical sensors (TDEM receiver coils, magnetometer and gamma-ray spectrometer) are mounted on the rigid carrier frame providing the unique capability to acquire simultaneously all geophysical data (EM+MAG+GRS) as close to the ground as safe flying allows. This paper, with a focus on the acquisition of GRS data, provides an overview of the technology as well as examples of surveys where multi geophysical data sets have been acquired.

TECHNOLOGY APPROACH

SkyTEM Surveys primarily utilizes Geometrics G-822A high-sensitivity cesium magnetometers and Medusa MS4000 Spectrometers. Magnetic and gamma-ray spectrometer (GRS) data are acquired with the SkyTEM data acquisitions system together with auxiliary data required for navigation and positioning accuracy (GPS, laser altimetry) and for correction of geophysical data (inclinometry, outside air temperature and pressure). Installation of the SkyTEM system is straightforward and no STC is required enabling quick installation in a variety of helicopters.

The magnetometer can be placed either:

- On the carrier frame of all SkyTEM TDEM Systems (SkyTEM^{101}, SkyTEM^{304}, SkyTEM^{508})
- Inside the SkyTEM MAG Bird – airfoil towed beneath the helicopter for single magnetometer surveys
- Boom attached to the helicopter

The GRS spectrometer can be placed either:

- Onboard of aircraft
- On any one of the SkyTEM system frame

This approach simplifies acquisition of single or multi geophysical data sets as required for each client and application. Acquisition of all geophysical data from a uniform sensor height greatly enhances the positioning accuracy of the data as well as the resolution obtained from flying all sensors close to the ground. Installation of the GRS on the carrier frame is made possible by utilizing the Medusa GRS system (Medusa BV Group, The Netherlands) as it is a lightweight robust spectrometer offering a novel full spectrum analysis (FSA).

BACKGROUND OF THE LIGHTWEIGHT GRS SYSTEM APPROACH

Airborne gamma-ray surveys (GRS) have been routinely applied for decades to map the earth's surface. Most of the standards, procedures and guidelines governing the acquisition and processing of GRS data originated in the 1980s (Grasty, Glynn et al. 1985). These guidelines prescribe the use of large volume crystal packs housing at least 16 liters of NaI and use a conventional ROI window processing method, still considered by some to be the best method for airborne GRS surveys (i.e. (IAEA 2003). However, recent advancements in computing power and detection technology have significantly improved and it is now possible for gamma-ray systems to be manufactured more compactly. Two developments paved the way for such lightweight GRS systems.

First, the utilization of new scintillation materials like CsI and BGO. These materials are more robust, water-resistant and have higher photo peak efficiency than NaI. For a 4x4x16 inch detector, the photo-peak efficiency as compared at the ^{232}Th peak (2560 keV) shows 30% higher efficiency for CsI and even 200% higher efficiency for BGO w.r.t. NaI.

Second is the increase of power of computers capable of running complex nuclear particle simulation codes in real time. These codes allow for rapid calibration of the detector's response against (virtually any) geometry source, which enables use of the full recorded gamma spectrum in the spectrum analysis (full spectrum analysis) as opposed to the classical method utilizing the counts received within defined photo-peak energy windows.

The combination of more effective crystal materials and full spectrum analysis allows for a considerable size/weight reduction of spectrometers as was suggested in 1980s (Grasty, Glynn et al. 1985) and subsequently shown by Hendriks et al (Hendriks 2001) and Limburg et al (Limburg 2010). The later papers show that a 16L standard NaI-based spectrometer can be replaced with a 4L CsI system without compromising data quality.

The key advantage of using lightweight spectrometers is in the system integration. The SkyTEM system is an excellent example showing how the size and weight of the 4L Medusa system permits seamless installation on the SkyTEM carrier frame that would be almost impossible with a heavy and fragile standard crystal pack. This installation brings the spectrometer 30-50 m closer to the ground during surveying as opposed to the conventional installation on board the helicopter.

Located much closer to the earth's surface, the frame-mounted GRS system absorbs much more energy from the ground and does not suffer from the gamma-rays being absorbed in the air. This effect is shown in the Figure 1 below that shows the evolution of the ^{232}Th spectrum with elevation (data obtained using nuclear particle modeling of the detector response). As can be seen in the figure, lowering the terrain clearance of the spectrometer by 30m increases the count rate about 40%.

Considering the low terrain clearance together with higher effectiveness of CsI scintillation crystal and FSA processing method the resolution of the GRS surveys using 4L CsI spectrometer installed on the SkyTEM frame is much higher (minimum factor of 1.7) than for a 16 L NaI crystal installed on board the helicopter and using conventional ROI windows processing method.

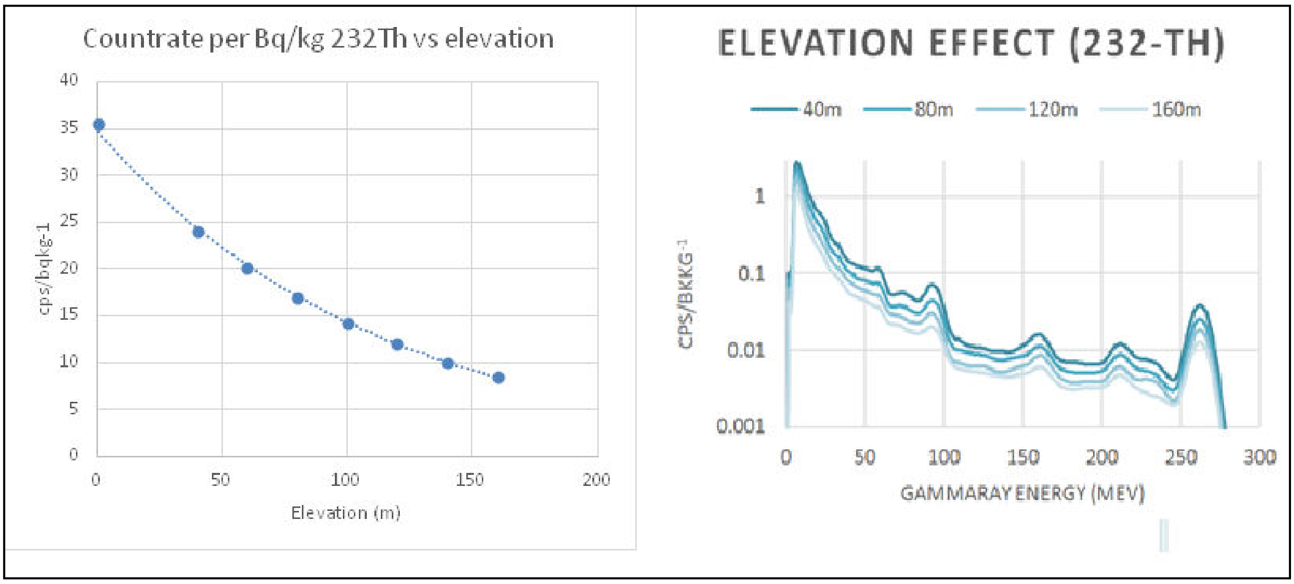

Figure 1: Evolution of ^{232}Th count rate and spectrum with elevation

SURVEY EXAMPLES

Case 1:

Magnetic and Gamma Ray Spectrometry (MAG-GRS) Survey - Mineral Exploration

This exploration survey was flown in 2011 over an area with investigation permits that are granted to Lundin Mining Corporation. The survey comprises a total of 2,000 line km. Data was acquired along survey lines with nominal spacing of

200 m using a helicopter flying at speed of 90 km/h. The mean terrain clearance for spectrometer was 60 m above the ground and 40 m for magnetometer sensor. The objectives of the survey were to provide insight into the geologic settings and distinguish geological units and alterations associated with mineralizing systems and it was expected the acquisition of high-resolution magnetic and gamma-ray spectrometry data would achieve these goals.

The Standard SkyTEM Bird MAG-GRS system shown in Fig. 1 was used for the survey comprising of:

- Geometrics G-822A high-sensitivity cesium magnetometer placed together with GPS, inclinometer and laser altimeter in airfoil towed beneath the helicopter.
- Dual Medusa Spectrometer MS4000 (8 liter CsI crystal, 1024 channels) placed onboard of the helicopter together with second GPS and laser altimeter.

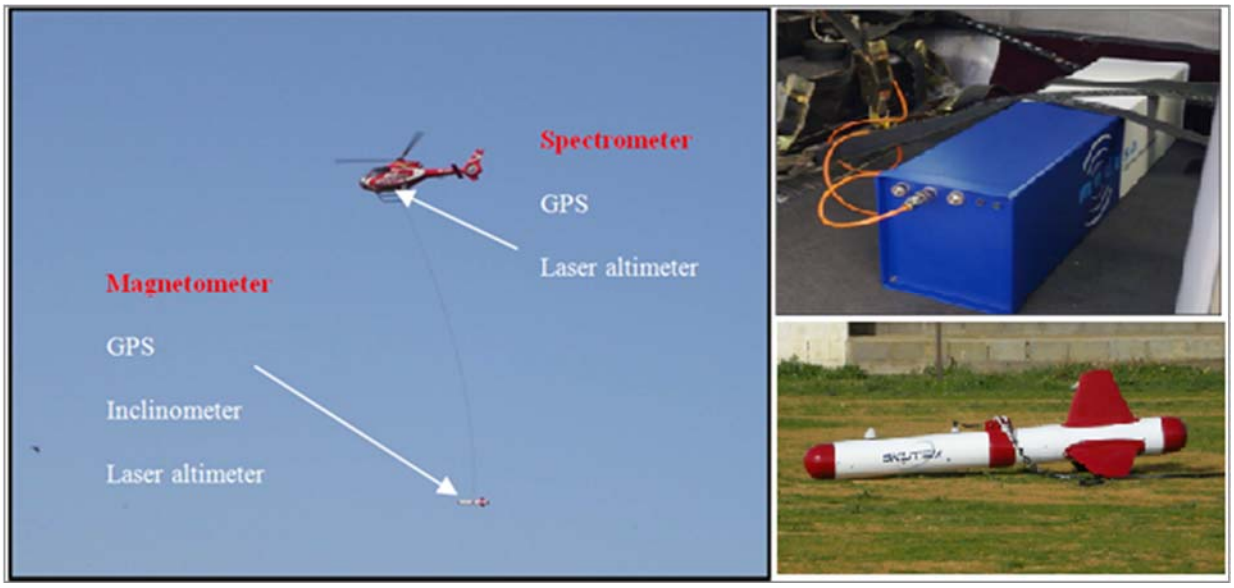

Figure 2: SkyTEM Bird MAG-GRS system ; Medusa Spectrometer MS4000 placed on board of aircraft; MAG Bird system

The GPS antenna is placed directly on the bird. The heading error stayed below 1 nT and the aerodynamic stability was adjustable according to actual flying conditions and monitored by the inclinometer placed inside the bird. Acquired magnetic data required minim filtering and corrections.

Gamma ray spectrum (20 keV – 3 MeV) recorded at 1024 channels was acquired together with cosmic ray, outside air temperature, pressure, GPS and laser altimetry in order to provide data required for corrections of GRS data.

Medusa full spectrum analysis (FSA) was used for GRS data processing where the entire spectrum was utilized to determine the apparent radio-elemental concentrations (% K, ppm eU, ppm eTh). Airborne data corrections such as carrier, cosmic and radon background removal and attenuation reduction were applied based on system tests and calibrations undertaken at ground based reference sites and during onsite calibration flights. The “conventional windows” method for GRS data processing as defined by IAEA technical documents can be applied as an option.

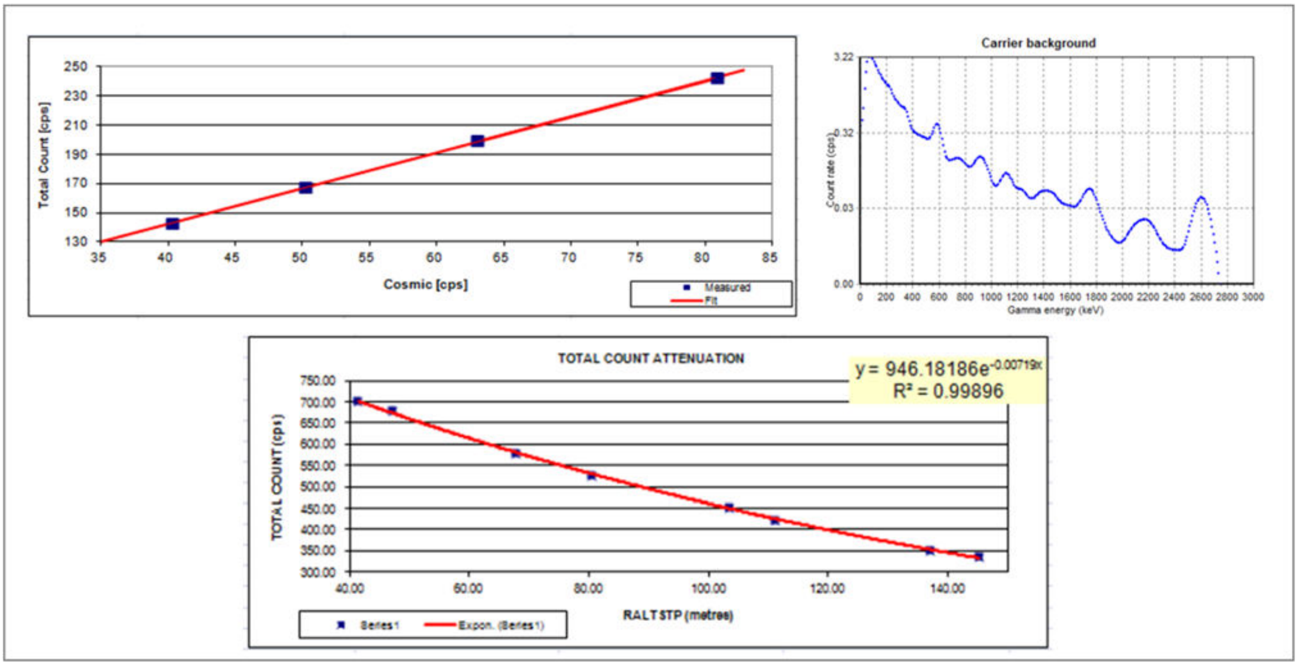

Figure 3: Typical calibration results: a) Aircraft and Cosmic Calibration – Total Count ; b) Entire Carrier Background Spectra c) Attenuation Test – Total Count

Figure 4 shows the magnetic and GRS data acquired over part of the Lundin Mining survey block. The survey met the objectives and shows that the quality of the results (radio elemental mapping) received from GRS data acquired with lightweight spectrometers (4-8 liters CsI) utilizing the effectiveness of FSA processing method is equal or comparable to data acquired with conventional systems (16-32 l NaI) using the “classic windows” processing method.

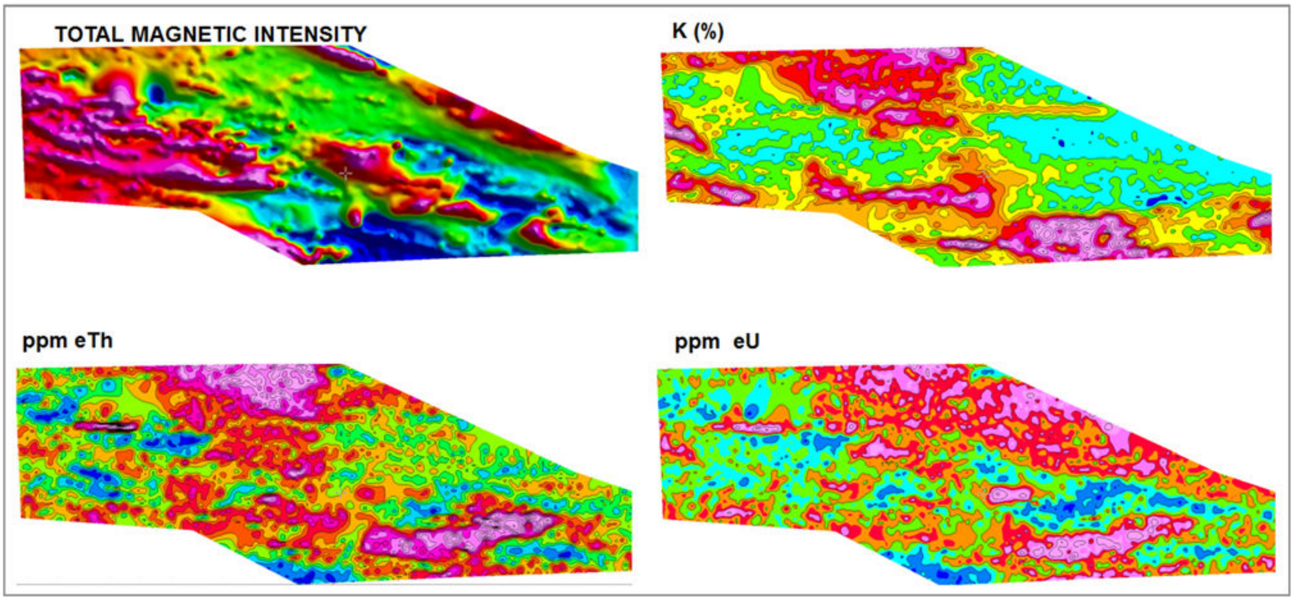

Figure 4: Mineral Exploration Survey Magnetic and GRS data

Case 2:

TDEM and Gamma Ray Spectrometry Survey - Groundwater Exploration

This electromagnetic TDEM airborne survey was flown over an exploration area in southern part of Denmark near Padborg as part of a national ground water mapping program for Danish authorities in September 2011. The entire survey comprised 4,000 line km. Data was acquired along survey lines with nominal spacing of 100 m using a helicopter flying at a speed of 45 km/h. The mean terrain clearance for the TDEM receiver coil and spectrometer was 25 m agl. GRS data acquisition was utilized as an internal add-on test survey in order to test the effectiveness for soil mapping.

Standard SkyTEM^{304} system was employed as shown in Fig. 5.

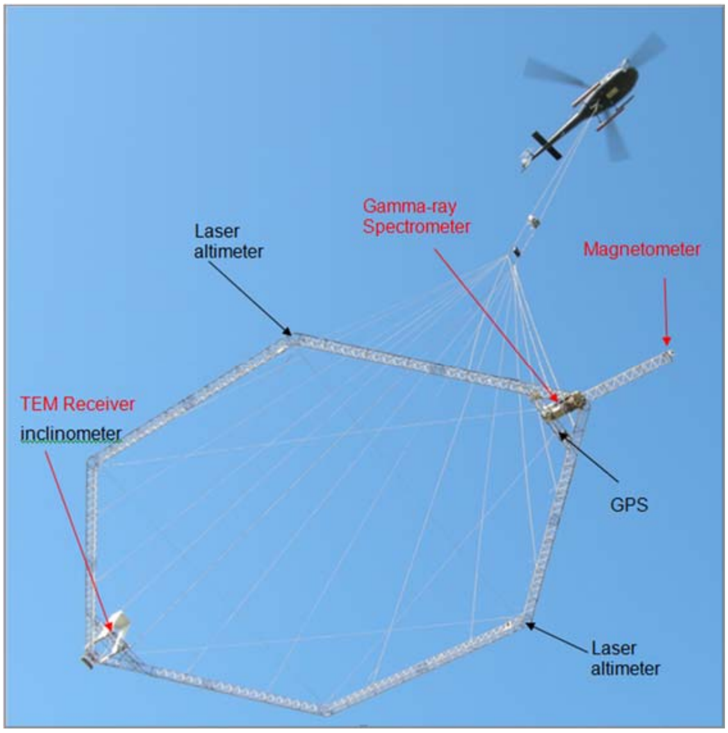

Figure 5: SkyTEM^{304} system with installed magnetometer and gamma-ray spectrometer;

The system is capable of acquiring TDEM and magnetic data in standard setup. Spectrometer MS4000 (4 liter CsI crystal, 1024 channels) can be placed on the carrier frame in the front section near the magnetometer sensor for data acquisition at the same low altitude terrain clearance. The carrier background is negligible for this setup compared to installation of systems on board the aircraft.

Medusa full spectrum analysis (FSA) was used for GRS data processing to determine the ground radio-elemental concentrations compared with existing soil and land use maps.

The TDEM data was processed in the standard way to receive subsurface 3D resistivity model used for groundwater mapping.

Figure 6 shows electromagnetic and GRS data acquired over the test area north of Skodsbøl. The results of GRS portion of the survey confirmed the ability of the system to map the distribution of different types of soils (clays, sands, humus) and their transitive variety including biomass distribution. The results showed much greater detail than what was available on existing regional scale soil maps and can be considered a good method for mapping the grade and type of fertilization process for agricultural land use.

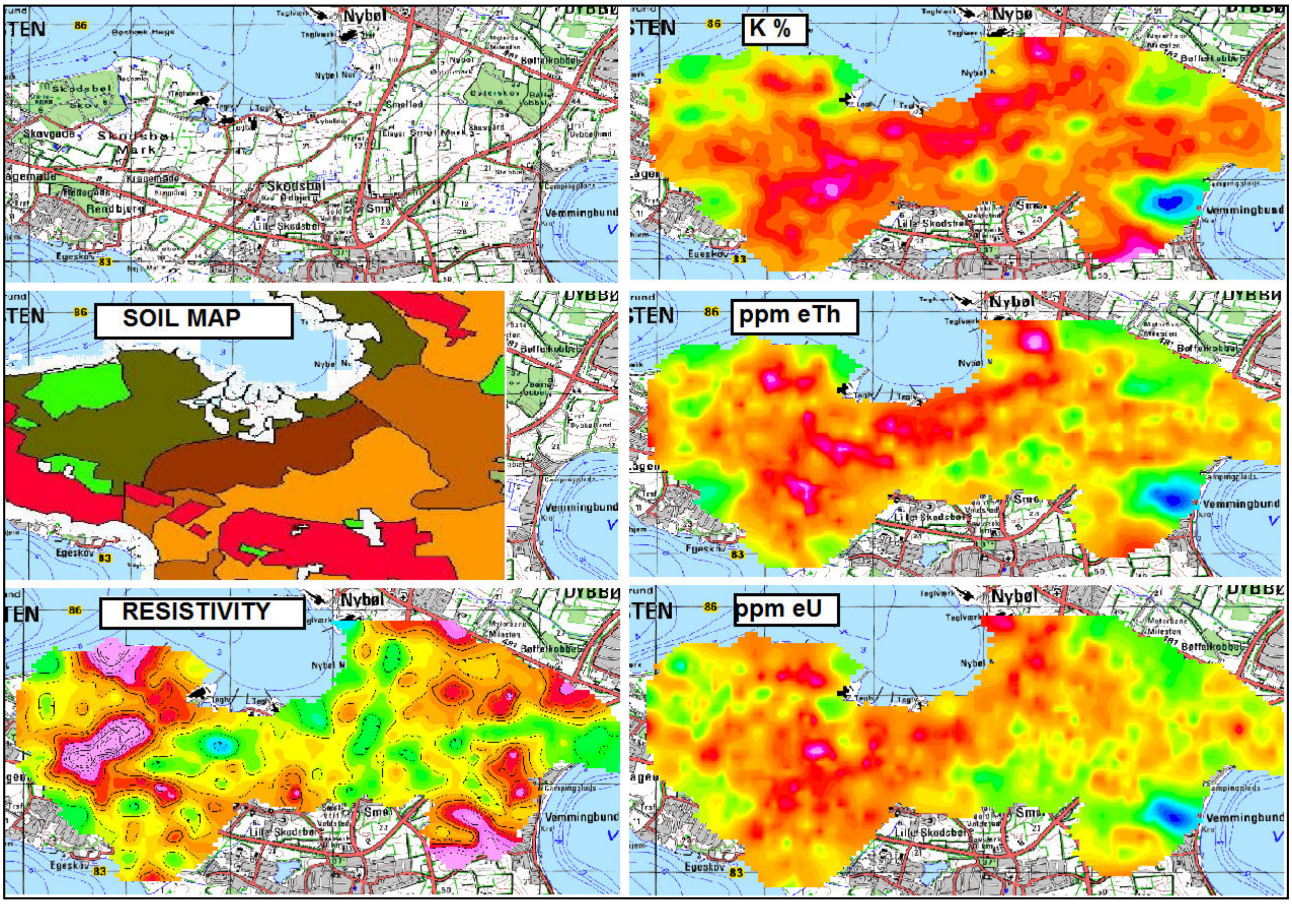

Figure 6: Zoomed view of GRS and TDEM data together with topography and soil map

CONCLUSION

The latest developments of lightweight spectrometers using robust and effective CsI scintillation crystals combined with the development of novel full spectrum analysis processing method of gamma ray spectrometry data now make it possible to install the spectrometer directly on the carrier frame of airborne electromagnetic systems such as SkyTEM^{101}, SkyTEM^{304}, and SkyTEM^{508}.

This approach allows for the acquisition of multi geophysical data sets (TDEM + MAG +GRS) at a uniform altitude. This is particularly significant for gamma-ray spectrometry as data can now be acquired closer to the ground resulting in higher resolution than previously available with conventional systems.

This paper supports the capability of this approach as high-resolution GRS data acquired for ground water application made it possible to utilize the data for detailed soil mapping.

This paper also shows that the lightweight GRS systems employed in combination with full spectrum analysis can be utilized for conventional types of surveys (i.e. helicopter borne MAG+GRS) for mineral exploration.

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