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# Magnetic characteristics of the rock formations on Mount Kinabalu, Sabah

Woo Chaw Hong*, Chow Yor Chun, Teng King Kuen & Mazshurraiezal Nasir
Petroseis Sdn. Bhd.
Kota Kemuning, 40460 Shah Alam, Selangor, Malaysia
*Coresponding author: ch.woo@petroseis.asia

**Abstract:** Mount Kinabalu consists of granites at its core on the higher ground of the mountain, and is surrounded by sedimentary rocks of Trusmadi formations at its foot, with the occurrences of serpentinised ultrabasic rocks found between the granites and sedimentary rock at the elevation of 2000m to 2800m. The granite is sub-divided into hornblende granite, biotite granite and porphyritic granite. The porphyritic granite is found in a belt between serpentinite in the lower part and hornblende granite in the upper part of the mountain. A ground magnetic data acquisition was conducted in May 2013 along the tracks from Mesilau to the summit of Mount Kinabalu and from summit down at Timpohon gate. The processed magnetic data shows distinctive magnetic characteristics that correlate very well with three different rock formations of Mount Kinabalu. Large variations of total magnetic total field from 39400nT to 41700 nT (magnetic variation range of 2300nT) were observed within the serpentinised ultrabasic rocks. It is believed that this distinctive magnetic characteristic is due to occurrence of ferromagnetic minerals, which was formed as a result of serpentinisation of ultrabasic rock with the presence of water during deep seated hydrothermal activity. The total magnetic field within the granite zone decreased gradually from the edge of serpentinite to the hornblend granite near the summit with relatively smaller variations from 40900nT to 39990nT (magnetic variation range of 910nT), probably due to small percentage of magnetite in it. The Trusmadi sedimentary formation in lower altitudes was magnetically "stable", with the small magnetic variation from 40000nT to 40385 nT (magnetic variation range of 385nT).

**Keywords:** Mount Kinabalu, magnetic total field, ferromagnetic, serpentinite

## INTRODUCTION

Trekking up the highest peak in South East Asia, Mount Kinabalu, brought us through three distinctive geological variations, which are the deepwater deposition of Trusmadi Formation in the lower altitudes, serpentinised ultrabasic rocks at the elevation between 2000m - 2800m and granites in the higher grounds and towards the summit. Figure 1 shows the survey area in Mount Kinabalu, Sabah, Malaysia. A ground magnetic survey was conducted along the two existing tracks from Mesilau and Timpohon gate to the summit of Mount Kinabalu (Figure 2) with the objective to study the magnetic variations across these three rock formations.

The survey results show distinctive magnetic patterns which correlate very well with the boundaries of the three rock formations. Consistent magnetic readings with very little variations were recorded within the Trusmadi sedimentary formation, while high variations of magnetic intensity were observed in the serpentinised ultrabasic zone, and moderate magnetic variations were observed in the granites.

## GEOLOGICAL BACKGROUND

Many authors have produced similar geology maps for the Kinabalu region, among them are Collenette (1964), Kirk (1968) and Jacobson (1970). The map produced by Jacobson (1970) is used as comparison of magnetic data collected in this study (Figure 3).

The summit region of Mount Kinabalu comprises granites, which have intruded into the Tertiary sedimentary rock of Trusmadi Formation in the lower altitude (Jacobson, 1970). Jacobson has divided the granites into hornblende granite, biotite granite and porphyritic granite. Porphyritic granites form a narrow belt surrounding the west, southwest and south margin of the granite body, separating hornblende granite in higher altitudes from the ultrabasic rocks. The ultrabasic rocks which comprise peridotite, pyroxenite and dunite (Collenette, 1964) are found in a narrow belt of 430m – 1000m wide which stretch in east-west orientation from Mesilau check point to the north of Layang-layang shelter, which is located near the junction between two existing tracks. Ultrabasic rocks are also found in a larger extensive area in the west and NW of the summit. Trusmadi Formation which is found in the lower altitudes, consists of deep

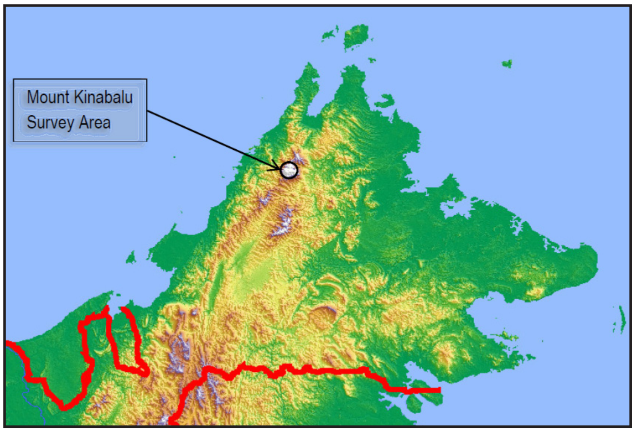

**Figure 1:** Map showing location of Mount Kinabalu in Sabah state, East Malaysia.

water deposition formed during early Tertiary (Collenette, 1964). Trusmadi Formation is characterized by dark colour argillaceous rocks, siltstone and thin-bedded turbidite in well-stratified sequence, which has undergone low grade metamorphism to form slate, phyllite and metarenite (Rodeano Roslee *et al*., 2010). The distribution of these three rock formations on Mount Kinabalu, together with collected magnetic data along the two existing tracks, is draped over the digital terrain model extracted from Google Earth in Figure 4.

The granitic body in the higher ground consists predominantly of hornblende granite (or hornblende adamellite). Biotite granites are found in an isolated patch within hornblende granite close to west of the summit. Porphyritic granites are found in a 1.0-1.5km belt between serpentinite in the lower portion and hornblende granite in the upper portion of the mountain. The granites were surrounded by metamorphosed ultrabasic rocks and closely folded and faulted sedimentary formations.

Kirk (1968) and James *et al*. (2010) reported the occurrences of serpentinite enclaves found in porphyritic granite. Jacobson (1970) also described the intensely deformed and metamorphosed crystalline basement rocks which are found as schist and gneiss in several small isolated patches in the northwest of the mountain and fault bounded patch in the southeast. Several small exposures of crystalline basement rocks was also reported by Reinhard & Wenk (1951) to occur as smaller isolated patches in the serpentinite.

## PREVIOUS MAGNETIC STUDIES ON SERPENTINITE

Serpentinite are well known for its unique magnetic characteristics. Many authors have studied the magnetic characteristic in ultrabasic rock and serpentinite from various parts of the world. The magnetic properties of serpentinised ultrabasic rocks were studied by Stokking *et al*. (1992) from Oceanic Drilling Program (ODP) drill hole samples taken from the seamounts in the Mariana and Izu-Bonin forearcs. Stokking's study revealed the occurrences of very fine grained and coarse grained (up to 0.3mm) magnetite in serpentine.

**Figure 2:** Google Earth image shows elevation of Mount Kinabalu. Red line indicates the existing trails from Mesilau and Timpohon gates.

Another study of rock magnetic properties of serpentines was carried out on the sample from Outokumpu Deep Drill Hole in Eastern Finland by Dietze and Kontny (2011). Their study revealed that magnetite and pyrrhotite minerals are the main carrier of magnetisation in the serpentinite. He also found that magnetic anomalies in aeromagnetic survey were limited to serpentinite units with strong degrees of serpentinisation, which carry stable remanent magnetisation.

Griscom (1964) carried out interpretation of aeromagnetic data of over serpentinite from Puerto Rico found that aeromagnetic readings across serpentinite area increased anomalously to more than 300nT. He also carried out a study on remanent magnetisation and magnetic susceptibility of the AMSOC drill core sample. It was believed that the magnetite, which was responsible for the anomalous magnetic field, was mostly formed during serpentinisation of the ultrabasic rocks.

Saad (1969) who studied the magnetic properties of ultrabasic rocks from Red Mountain, California has shown that the degree of magnetism in ultrabasic rock depends on the degree of serpentinisation. Magnetisation of ultrabasic rocks occurred when iron atoms in the paramagnetic olivine

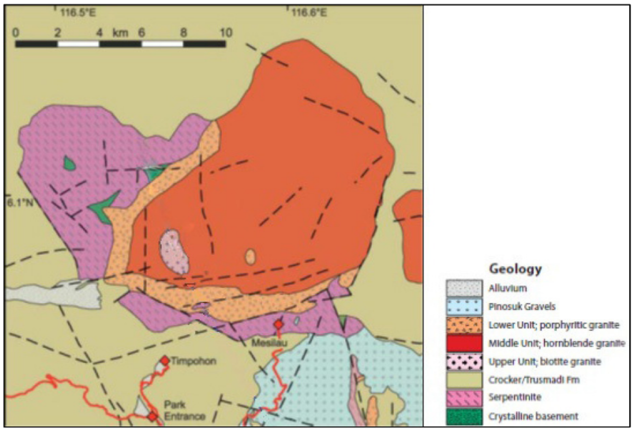

**Figure 3:** Simplified geological map extracted from Jacobson (1970).

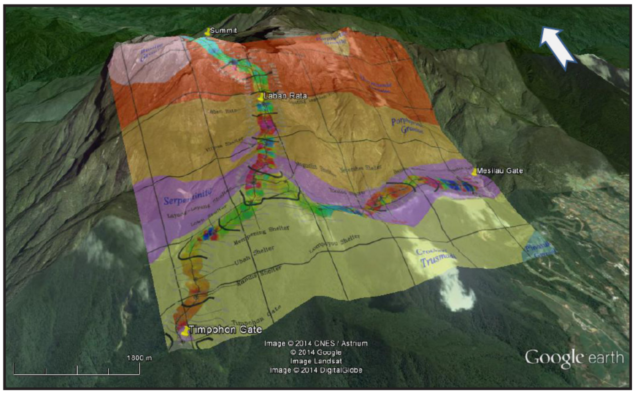

**Figure 4:** Digital terrain with geological map and magnetic survey data overlain. Arrow points to the north direction.

and pyroxene were released from the silicate structure, and oxidized to form ferromagnetic magnetite.

## MAGNETIC SURVEY METHODOLOGY

It is presumed that in the field, earth's dipole magnetic field is perturbed by relatively localised contrasts in magnetisation, which are normally caused by the presence of ferrous minerals in the rock formation or other magnetic anomalies.

Magnetic surveys measure the magnitude of total magnetic field ($F_t = F_e + F_a$) as a function of GPS (Global Positioning System) positions, which is the sum of Earth's magnetic field and anomalous magnetic readings. Earth's dipole magnetic field is produced by its internal iron core dynamo effect, this Earth's magnetic field is normally represented by vector $F_{e.}$ Magnetic anomaly is typically caused by magnetic induction or remanent magnetisation of crustal rocks, and this is represented by the vector $F_a$. All materials with natural magnetic property such as ore bodies, igneous bodies and objects made of iron are detected as magnetic anomalies.

This magnetic survey intends to record variations in magnetic field along the two existing (Mesilau and Timpohon) tracks that go up to the summit of the mountain, as the tracks travel across the meta-sedimentary Trusmadi Formation, serpentinite/ultrabasic rocks and granites.

## FIELD DATA ACQUISITION

A ground magnetic survey was conducted along the 2 existing tracks of Mount Kinabalu on the 7th and 8th May 2013 by a few Petroseis employees. The magnetic data was acquired using an Overhauser "Walking" magnetometer (GEM GSM-19 GF) which was carried on a backpack. The Overhausser magnetometer allowed accurate measurement with virtually no dependence of upon sensor orientation, temperature or location. Positions of the survey track was recorded by a hand held Trimble Juno GPS, in WGS84 coordinate system. Magnetic data was continuously recorded when tracking up and down the mountain, with GPS data being recorded in a GPS carried by another person.

Another unit of G-856-AX magnetometer was installed at UMS campus as base station for monitoring and recording of the Earth's diurnal magnetic field variation. The base station magnetometer in UMS, walking magnetometer on the backpack and hand-held GPS were all time synchronized prior to the survey.

The data acquisition started on 7th May 2013 at Mesilau gate along the track up to the Laban Rata, where the survey team put up a night before continuing data recording on the way up to the summit in the next morning. Magnetic data was also recorded when the survey team travel from the summit down to the Timpohon gate on 8th May 2013. Hence, this survey has covered both tracks via Mesilau gate and Timpohon gate, with overlapping data along the section between Layang-layang Shelter near the junction of these two tracks and the summit. Figure 5 shows the raw magnetic data acquired along both the tracks.

## MAGNETIC BASE STATION DATA ANALYSIS

A magnetically stable location with minimal disruption within University Malaysia Sabah campus (WGS84 Datum Lat 6.0406, Long 116.1175) was chosen for the installation of magnetic base station. The magnetic base station recorded variations due to daily solar activities (diurnal variations). The data was later used for data correction to the field recorded data along the mountain tracks.

Magnetic diurnal variations from 6th to 9th May 2013 due to solar activities are presented in Figure 6 below. The base station data shows that magnetic readings climb sharply in the morning until exceeding 40500nT before reaching the peaks at around 1100 hrs. In the afternoon, magnetic readings decreased rapidly until sunsets at 1800 hrs. During daylight hours, magnetic variations of 120nT were observed. During the night, small variations of 16nT or less were observed with magnetic readings typically range from 40420nT to 40436nT. The collected magnetic data also shows a period of anomalous higher solar activity in the morning of 7th May from 0840 hrs to 1020 hrs.

## DATA PROCESSING

Data was stored digitally in the Overhausser "Walking" magnetometer recording unit, and later downloaded to computer for post-survey processing. The data processing flow is as shown in the Figure 7 below. The regional magnetic

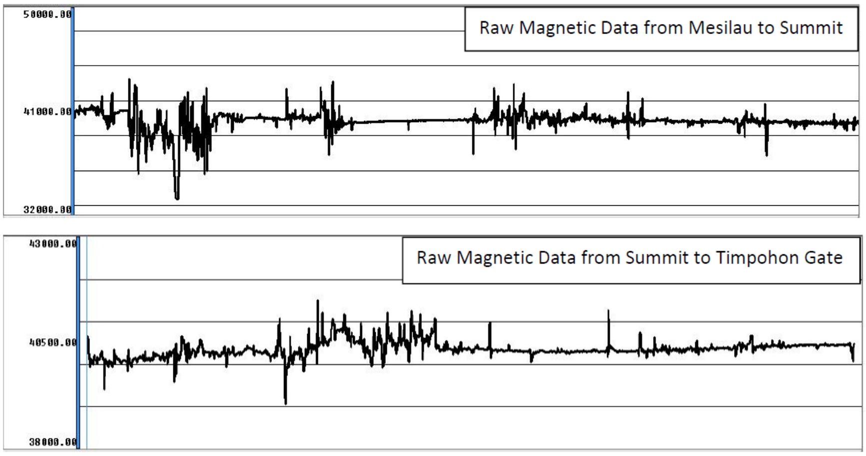

**Figure 5:** Raw magnetic data along the track from Mesilau to summit and from summit to Timpohon gate.

field intensity of 40408nT, declination 0.03˚E and inclination -2.74˚ values at Mount Kinabalu were determined by using International Geomagnetic Reference Field (IGRF) 2010 model. This value was later used in data correction.

Data recording at UMS base station and along the mountain tracks were both synchronised in time. The recorded data from the walking magnetometer was merged with GPS data according to time. The data was corrected for diurnal effect by using the base station data before spike filtering process. The corrected dataset was gridded at 2 metres interval and reduced to magnetic equator before being used to produce a Total Magnetic Field map. The processed Total Magnetic Field map was then overlaid onto Jacobson's geology map of Mount Kinabalu as presented in Figure 8.

## RESULTS AND DISCUSSIONS

The processed magnetic total field is plotted against distance along the tracks for analytical purposes. The results are presented as color graph along the survey tracks and overlaid on the simplified geological map to analyse the magnetic variations across different rock formations along the track (Figure 8). Magnetic anomalies caused by man-made structures along the tracks have been identified and labeled on the map. The magnetic field data are found to correlate well to the geology on Mount Kinabalu, the results are discussed in details in the following section.

### Magnetic influence from man-made structures

The barren granitic surface in the upper altitudes above Laban Rata allowed direct measurement of magnetic total field of the granites. There were not many buildings or man-made structures along the survey tracks that could significantly influenced the magnetic readings. Structures such as bridges, shelters and accommodation quarters can be identified as small spikes in the processed data (Figures 9 and 10). The RTM Station and Kamborongoh Telecoms Station were located too far from the survey path to cause significant influence to the magnetic data. However, the power cable by the roadside near Lowli shelter has caused small anomalous readings to the magnetic data. Leaving out the small influence from mand-made structures, the processed data can be considered a direct representative of the nature magnetic characteristic of the rock formations, and this will allow correlation of magnetic data to the different rock formations on Mount Kinabalu.

### Correlation of magnetic data to geology

Magnetic total field along the trail from Mesilau to the summit is presented in Figure 9, while data from the summit to Timpohon gate is presented in Figure 10. In general, magnetic total field readings in the Trusmadi sedimentary

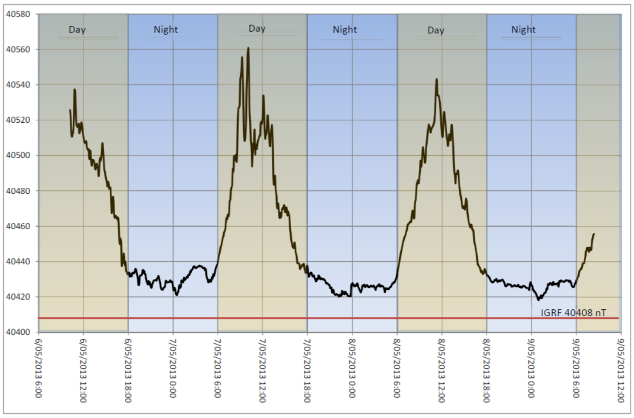

**Figure 6:** Magnetic diurnal readings recorded at UMS base station from 6th to 9th May 2013.

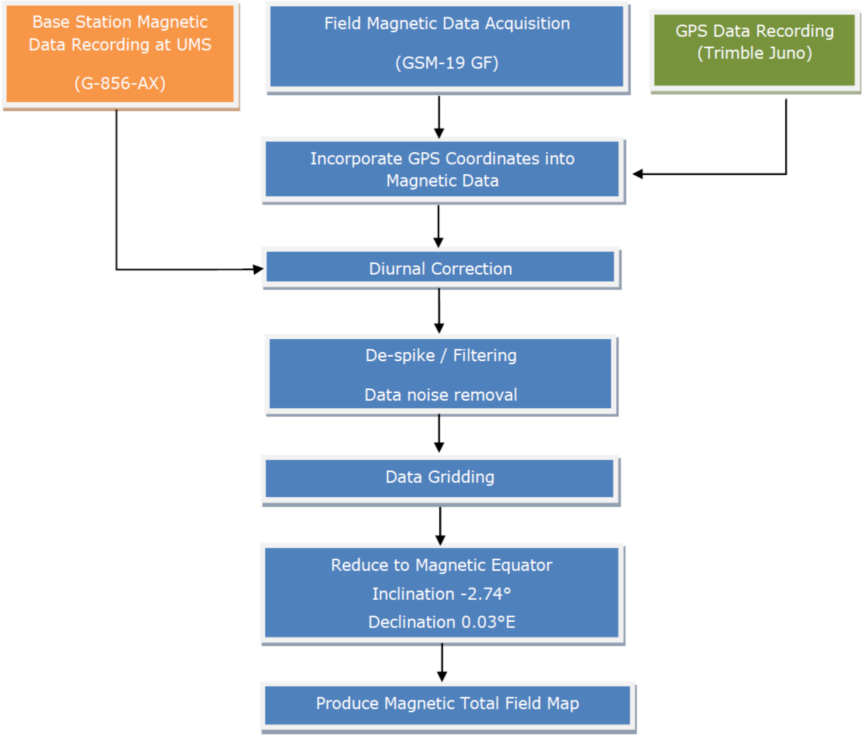

**Figure 7:** Magnetic data processing flow chart.

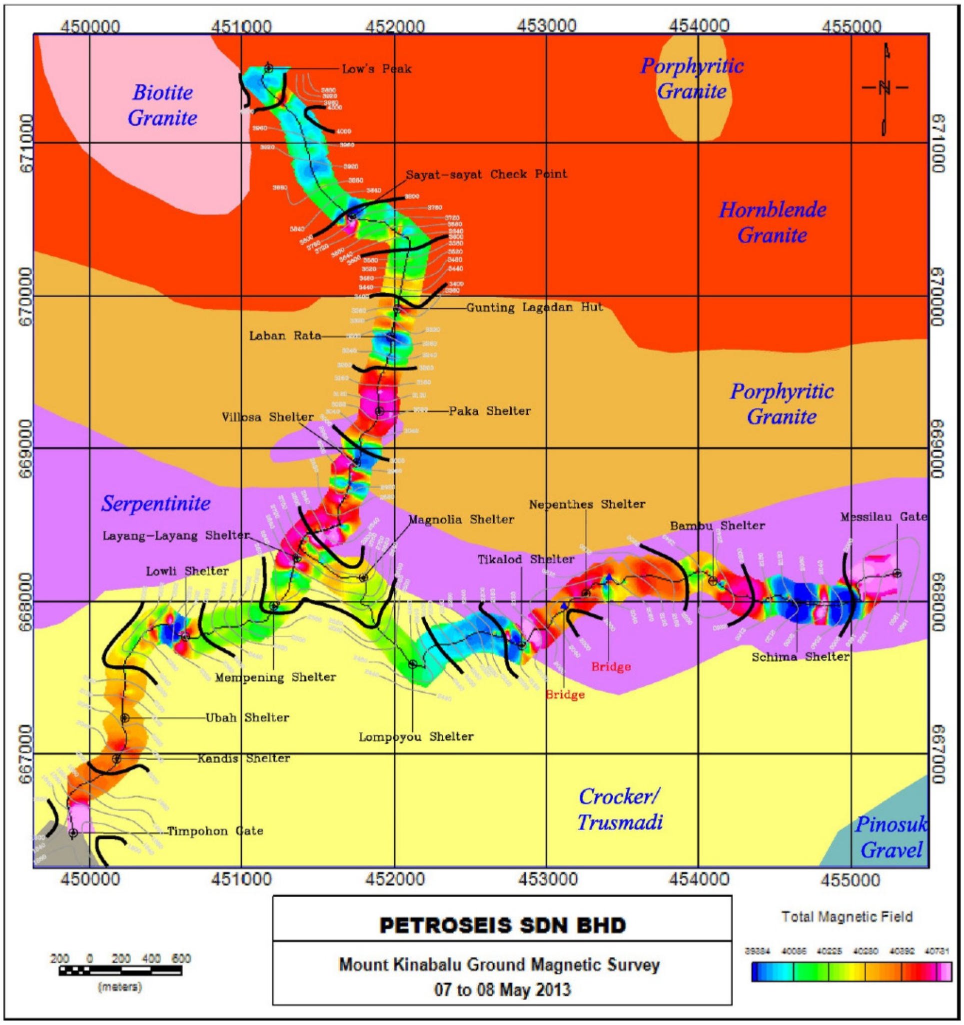

**Figure 8:** Magnetic data in total field presented in color graph along the trails of Mount Kinabalu with geology map overlaid (modified from Jacobson, 1970). All coordinates are in WGS84.

rocks show very little variations. The sedimentary rock is magnetically stable with magnetic field ranges from 40000nT to 40385nT, except for the few localities close to shelters where small spikes are observed. This is due to lack of iron minerals in the sedimentary formation. Moderate magnetic variations are observed within the granite zones, while the serpentinite zones are characterized by distinctive high magnetic variations (39400nT to 41700 nT).

As mentioned earlier, Kinabalu granites are divided into three types, porphyritic granite, hornblende granite and biotite granite. This survey did not reach the biotite granite area. The porphyritic granite and hornblende granite are distinguishable from the magnetic patterns. Hutchison (2005) has compiled detail information about the petrography of granitoid from Mount Kinabalu. He reported a small percentage of magnetite found in the porphyritic granite and hornblende granite. In the porphyritic granite, magnetic total field is observed to decrease in a wavy step-like curve from 40900nT at the serpentinite edge in lower altitude to 40080nT in upper altitude. Magnetic total field readings in the hornblende granite vary within a narrower range between 39990nT and 40450nT.

## Magnetic properties in serpentinite and ultrabasic rock

Jacobson (1970) has mapped a belt of serpentinised ultrabasic rock at the elevation of 2000m to 2800m above the sedimentary Trusmadi Formation, and below the granitic rock of Mount Kinabalu. The ultrabasic rocks were reported to be closely fractured and undergone serpentinisation. The magnetic data recorded when traversing through the serpentinised ultrabasic zone portrayed series of short wavelength and high amplitudes readings associated with large magnetic anomalies (Figures 9 and 10).

The ultrabasic rocks of Mount Kinabalu were reported as peridotite, pyroxenite and dunite which consist primarily of olivine and pyroxene, and no free quartz. The olivine and pyroxene in ultrabasic rocks were said to have undergone serpentinisation during deep seated hydrothermal activity (Collenette, 1958).

Serpentine minerals are hydrous magnesium silicates with typical chemical formulas of the form $Mg_3Si_2O_5(OH)_4$, they are formed when ultrabasic rock undergone hydrothermal metamorphism with the presence of water. A simplified chemical reaction that describes low temperature serpentinisation (Oufi *et al*. 2002) is as follow:

Olivine + $H_2O$ = serpentine ± brucite ± magnetite

Magnetite mineral was known to form during the serpentinisation of ultrabasic rocks on the sea floor or during subduction-related processes (Dietze & Kontny, 2011) Magnetite incorporates excess iron, which was released from the altered ferromagnesian minerals (olivine and pyroxenes). The anomalous and highly variable magnetic readings across the ultrabasic zone are thought due to the occurrences of magnetite in it.

## CONCLUSIONS

The recorded Total Magnetic Field readings along the two existing tracks on Mount Kinabalu portray three distinctive magnetic patterns which can be correlated to the three different rock formations of Mount Kinabalu.

The high variations and anomalous magnetic total readings observed in the serpentinite zone are due to occurrences of ferromagnetic minerals (magnetite and pyrrhotite) which were formed during serpentinisation of ultrabasic rock. Moderate magnetic fluctuations observed in the granite region are probably due to small amount of ferromagnetic minerals which occurs as accessory minerals in it. Very small magnetic variation observed in the Trusmadi deep water sedimentary formation suggests no ferromagnetic mineral in the formation.

## ACKNOWLEDGEMENT

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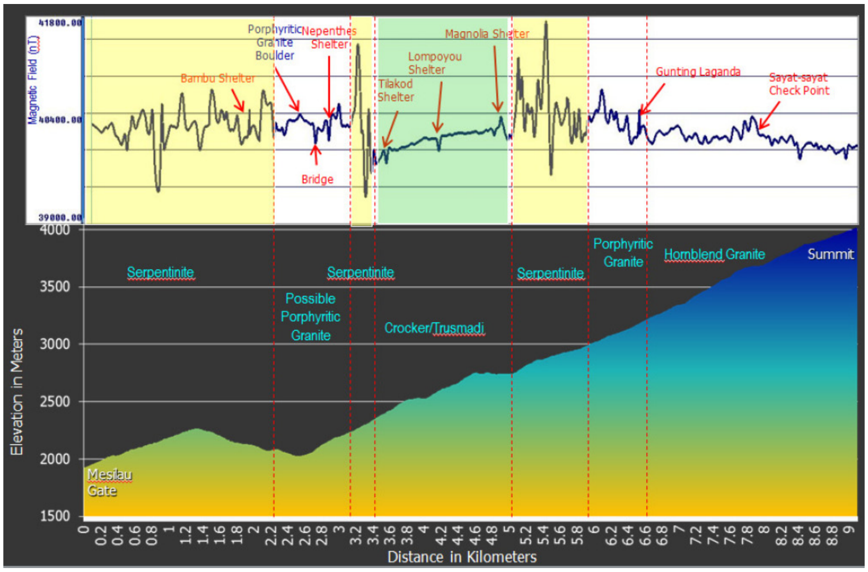

**Figure 9:** Total Magnetic Field recorded from Mesilau gate to the summit of Mount Kinabalu, with interpretation to correlate the magnetic readings to geology formations along the trail.

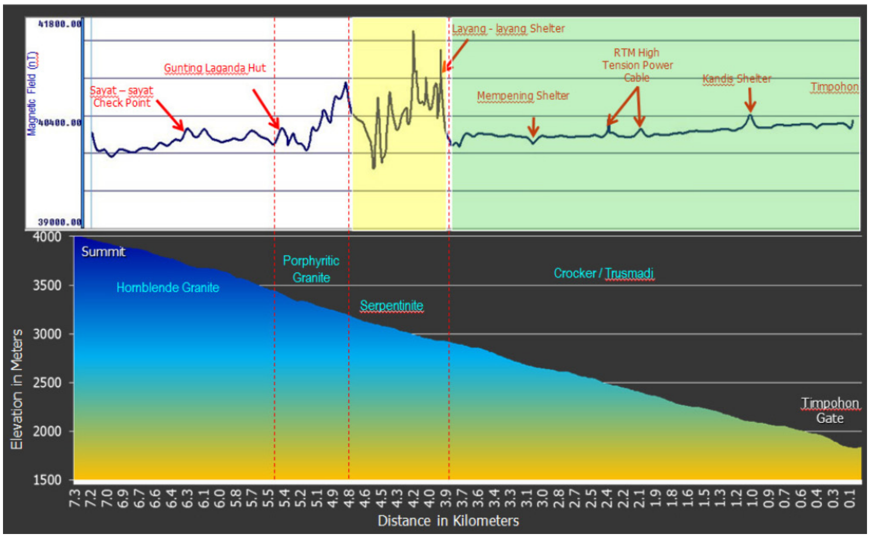

**Figure 10:** Total Magnetic Field recorded from the summit of Mount Kinabalu to Timpohon gate, with interpretation to correlate the magnetic readings to geology formations along the trail.

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