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Full Length Research Paper

Geophysical investigation of barite deposit in Tunga, Northeastern Nigeria

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Gravity and electromagnetic methods were combined to characterize known veins and possibly unveil other concealed veins in Tunga, Northeastern Nigeria. Barite occurs in the study area as vein deposits hosted in clean sandstone rocks. Laboratory analyses of samples show average specific gravity of the variety to vary between 3.16 and 4.24 while the host sandstone rock is 2.63. The study is focused on an area of 0.5 km^2 measuring 1.0 km in the strike and 0.5 km in the dip (designated X_1 to X_6 in northwest-southeast azimuth) which appears as the most promising terrain in barite prospectivity. Relatively high Bouguer anomalies were recorded over regions that are presumably underlain by barites. Barite mineralization potential varies from high with gravity values of between 177.507 and 181.072 mGals around western flanks of Traverses X_2 and X_3 to medium values (174.681 and 176.801 mGals) around central areas of Traverse X_3. Areas of low Bouguer anomaly were presumably barren (X_1, X_4, X_5, and X_6). The variations in the Bouguer anomaly values are presumably influenced by the density contrast between the barite and the host rocks. Areas of high gravity values exhibit very low conductivity values (< 10 mS/m) and are presumed underlain by dense materials of low conductivity to which barite mineralization can be associated. Thus, in this study, areas of high gravity values accompanied by low conductivities on the western/southwestern flank of the prospect around Traverses X_2 and X_3 are associated with barite mineralization. The trend of mineralization in the area is southwest-wards in the direction of River Benue. Thus, higher barite mineralization potential probably exists beneath River Benue and its southern flank in Tunga area.

Key words: Barite, vein, bouguer anomaly, conductivity, mineralization.

INTRODUCTION

Barite (barium sulphate, $BaSO_4$) owes its industrial value to its heaviness; with a specific gravity of 4.5. It is unusually heavy for a non-metallic mineral. The occurrence of barite in parts of the Middle Benue Valley was first reported by Tate (1959).

Three prominent known barite districts in Nigeria are Azara in Nasarawa State and Dumgel and Ibi both in Taraba State. Barite in all of these districts occurs in veins and each of these districts is multi-veined with most of the veins ranging between one and two metres in thickness and about a kilometre in length. Azara is the most prominent district. Other new discoveries are in the areas around, Alifokpa, Gabu and Osina in Ogoja area of Cross River State and Anka in Zamfara State.

GEOLOGY

The study area which is located in Nasarawa State, Nigeria is situated within the Lower Benue Trough (Figure 1) within latitudes N08° 00' 43" and N08° 01' 41" and longitudes E09° 23' 49" and E09° 24' 24". Benue Trough taken together with Abakaliki Trough is about 800 km long and varies from about 230 km wide at the southern end to about 120 km wide at the northern end in Lau area, where the Benue-Gongola-Yola troughs meet to form a trilete junction (Burke and Whiteman, 1973). Prominent occurrences of lead-zinc-barytes mineralization have been known (Farrington, 1952) in parts of the Benue Trough (Figure 2). There is no apparent mineral

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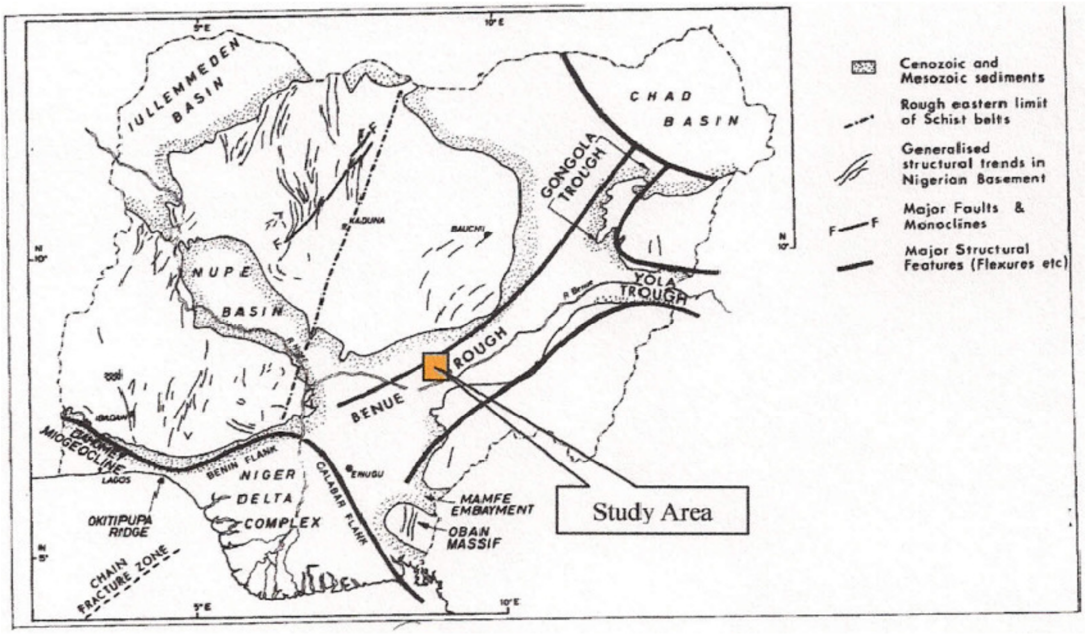

Figure 1. Structural map of Nigeria showing the project area; based on Oyawoye (1972).

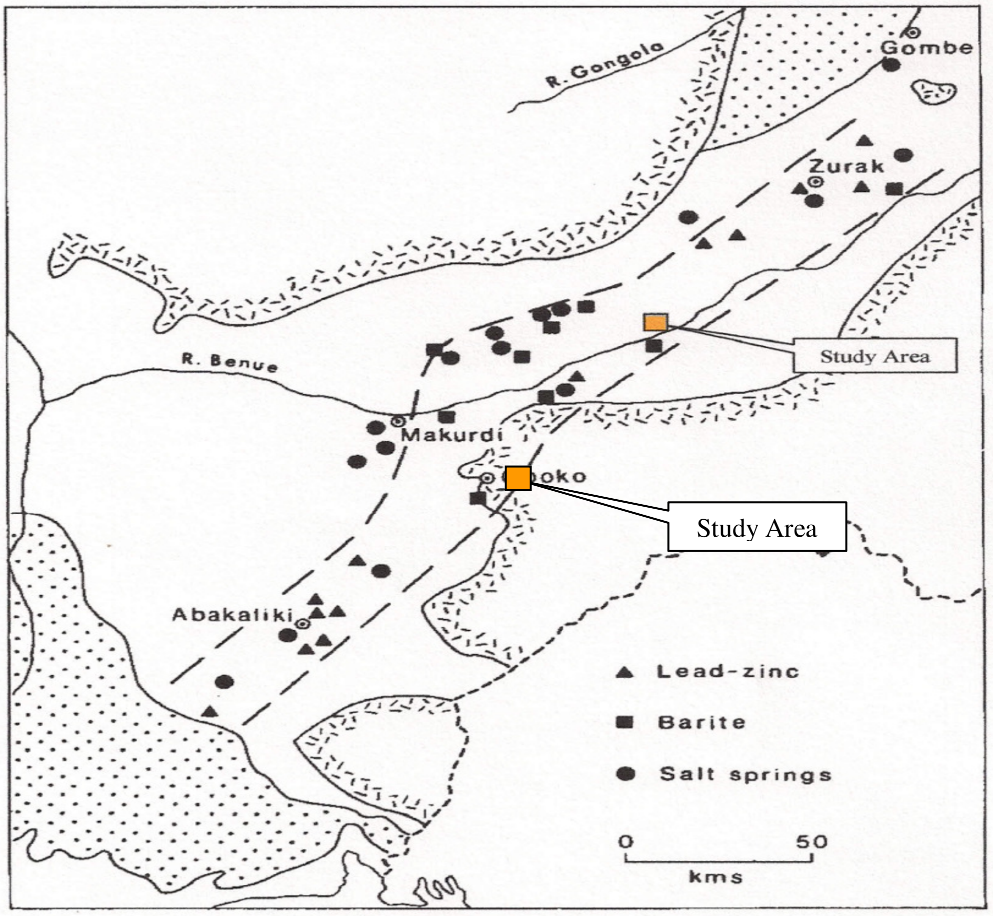

Figure 2. Map showing the general geology of the Nigerian lead and zinc field (Geological Survey of Nigeria based on Farrington (1952)).

zoning or gradation between the lead-zinc veins and the barites veins; or between barite and fluorite veins. The barite veins are hosted in clean sandstone.

The lead-zinc, barite and fluorite veins in the Benue Trough appear to have been formed in open spaces or in area of low pressure in fault zones where the proper physical and chemical conditions occur and where metallic minerals can precipitate (Farrington, 1952). Most of the recorded districts are multi-veined made up of a number of parallel or anostomosing veins generally occurring in an overlapping "en echelon" pattern. Many of the barite discoveries in the Benue Trough were made by prospectors who noted fragments of the mineralization in the heaps that farmers made for their crops.

The study area is situated within Benue River depression SSE of Awe town. The Awe formation in which the study area is situated succeeds the Asu River Group in the Lower Benue Trough and its age ranges from Late Albian to earliest Cenomanian (Offodile, 1976). Rock outcrops in the area are mainly shales, compact sandstones and eranaceous sediments. Barite mineralization occurs in the Tunga area as fracture, fissure and open space fillings in sandstone host rock. The barites colour is creamy white variety. The control of mineralization is structural, the trend of the mineralized veins being NW-SE with steep dips to the southwest. The host sandstone trends NNW-SSE.

Geomorphology

The topography of the study area presents a flat and gently undulating surface with little relief which is somewhat dissected by drainage. There is a gradual slope of the terrain upward from the Benue River flank northwards.

River Benue which flows in the southwest to join River Niger at Lokoja is the main drainage unit in the study area. Two perpendicular, southerly flowing tributary streams rising from the watershed of North Central Highland areas, join River Benue at near right angle in a succession of river captures.

MATERIALS AND METHODS

Laboratory analyses of samples from the study area show average specific gravity of the variety to vary between 3.16 and 4.24 while the host sandstone rock is 2.63. The contrast in specific gravity values between the host sandstone and the veined barite is the basis for the adoption of gravity method in the study.

The gravity and electromagnetic geophysical methods were adopted for the mineralized vein delineation. The combination of gravity and electromagnetic (EM) methods is expected to enable the determination of the length, width and depth persistence of the veins down to about 60 m below ground surface, and also enable identification of any additional veins that may be concealed in the prospect thereby increasing the chances of new barite discoveries.

Making use of the conceptual approach, the area marked in Figure 3, measuring 1,000 m in the general strike direction and 500 m in the dip direction, is delineated as a promising terrain in terms of barites prospectivity.

Instrumentation

Spring gravimeter of unstable classification which measures absolute gravity was utilized for field measurement. Worden Gravity meter Model III, manufactured by Texas Instruments with a calibration constant of 0948(4) was utilized. The equipment is an inclined zero-length fused quartz spring. The drift characteristics of the gravimeter are very low throughout the entire field survey with average drift rate of -0.000001014 mGal/s. Elevation within the study area range between 115 m (377 ft) and 130 m (426 ft) above mean sea level.

The results of the gravity survey are presented as anomaly profiles and maps. The gravity anomaly values are derived through corrections applied to field data to remove various effects of a defined earth model (Hinze et al., 2005; Nabighian et al., 2005). Corrections leading to the Bouguer anomaly (first approximation) are relatively independent of geology and are the standard reduction (LaFehr, 1991). The gravity elevations in the study area are referenced to the sea-level (geoid). The simple Bouguer correction is added to the theoretical gravity at the measurement location. The Bouguer correction accounts for the gravitational attraction of the layer of the earth between the vertical, that is, the ellipsoid and the station. This correction δg_{BC} in milligals is computed using the equation

$$\delta g_{BC} = 2\pi G\sigma h = 4.193\times10^{-5}\sigma h \tag{1}$$

where G, the gravitational constant is 6.673± 0.001* 10^{-11} $m^3/Kg/s^2$ (Mohr and Taylor, 2001), σ is density of the horizontal slab in kg/m^3 and h is the height of station in metres relative to the sea level.

Moving source-receiver GEONICS^{TM} EM34-3 Conductivity Meter was utilized for measuring terrain conductivity. Time-varying magnetic field arising from an alternating current in a transmitter coil induces very small currents in the earth. These currents generate a secondary magnetic field H_s which is sensed, together with the primary field, H_p, by a receiver coil. In general, the secondary magnetic field is a complicated function of the inter-coil spacing s, the operating frequency, f, and the ground conductivity (σ). Under certain constraints, technically defined as operation at low values of induction number, the secondary magnetic field is a very simple function of these variables. These constraints are incorporated in the design of the EM34-3 whence the secondary magnetic field is shown to be:

$$\frac{H_s}{H_p} \approx \frac{i\omega\mu_0\sigma s^2}{4} \tag{2}$$

where H_s = secondary magnetic field at the receiver coil; H_p = primary magnetic field at the receiver coil; $\omega = 2\pi f$; f = frequency (Hz); μ_0 = permeability of free space; σ = ground conductivity (mho/m); s = inter-coil spacing (m), and $i = \sqrt{-1}$

The ratio of the secondary to the primary magnetic field is linearly proportional to the terrain conductivity. Given H_s/H_p, the apparent conductivity indicated by the instrument is defined from Equation (2) as

$$\sigma_a = \frac{4}{\omega\mu_0 s^2}\left(\frac{H_s}{H_p}\right) \tag{3}$$

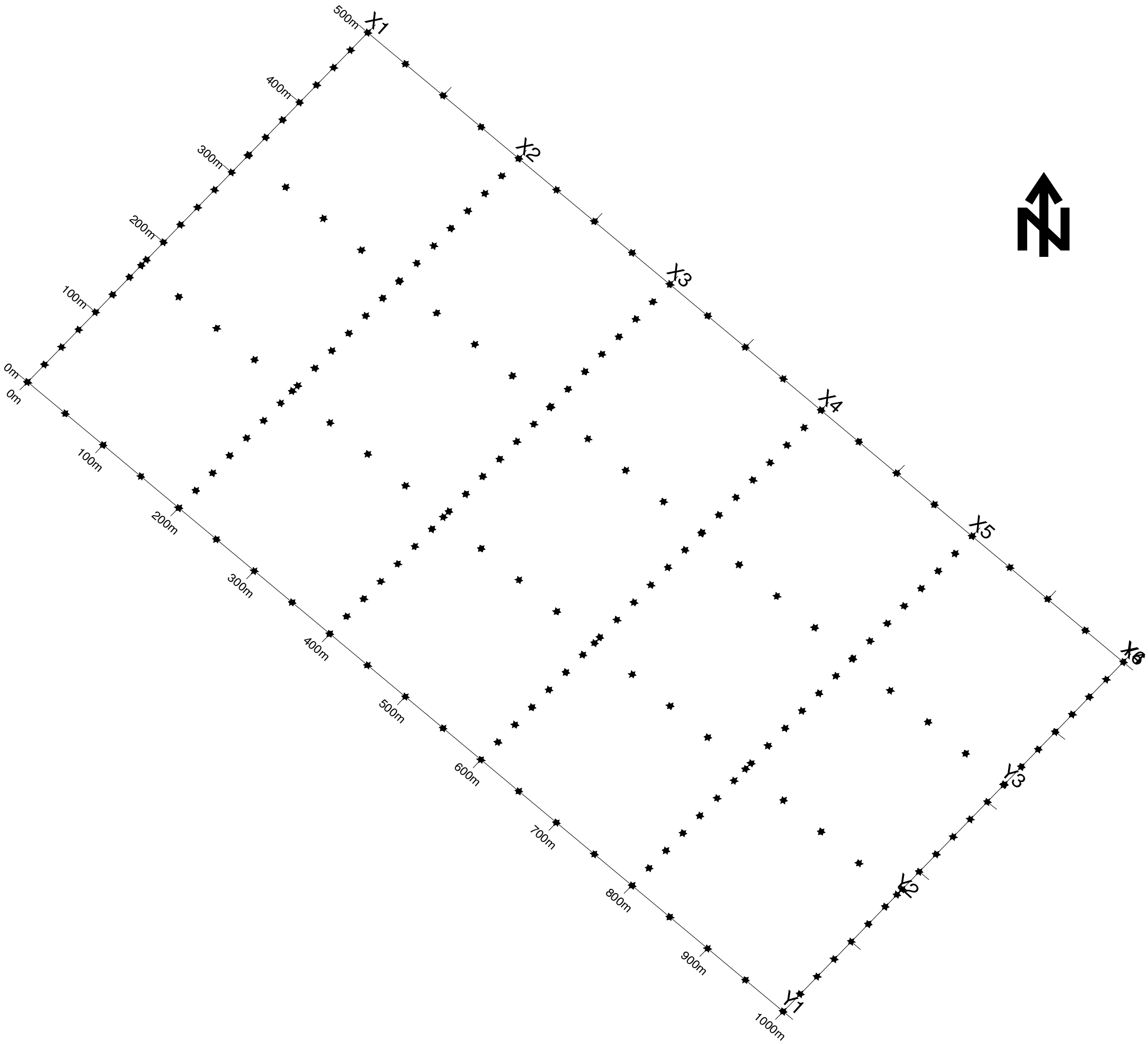

Figure 3. Grid layout of the study area.

The coils were carried with their planes vertical for horizontal dipole mode and horizontal for vertical dipole mode since in this configuration, the measurement is relatively insensitive to misalignment of the coils. EM34 instrument is calibrated to read terrain conductivity in millimhos per meter.

RESULTS AND DISCUSSION

The gravity survey results are presented as corrected drift and bouguer anomaly profiles (Figure 4) and maps (Figures 7 and 12). The interpretation of the gravity data in this study assumes that the barite mineralization zones are characterized by relatively high Bouguer anomaly values.

The electromagnetic survey data are presented as profiles (Figures 5 and 6) and maps (Figures 8, 9, 10, 11 and 13). The profiles are presentations of horizontal and vertical dipole measurements at coil separations of 20 and 40 m. Interpretation of the electromagnetic data assumes very low conductivity values in the region of barite mineralization.

Combination of high Bouguer anomaly and very low conductivity is presumably diagnostic of barite

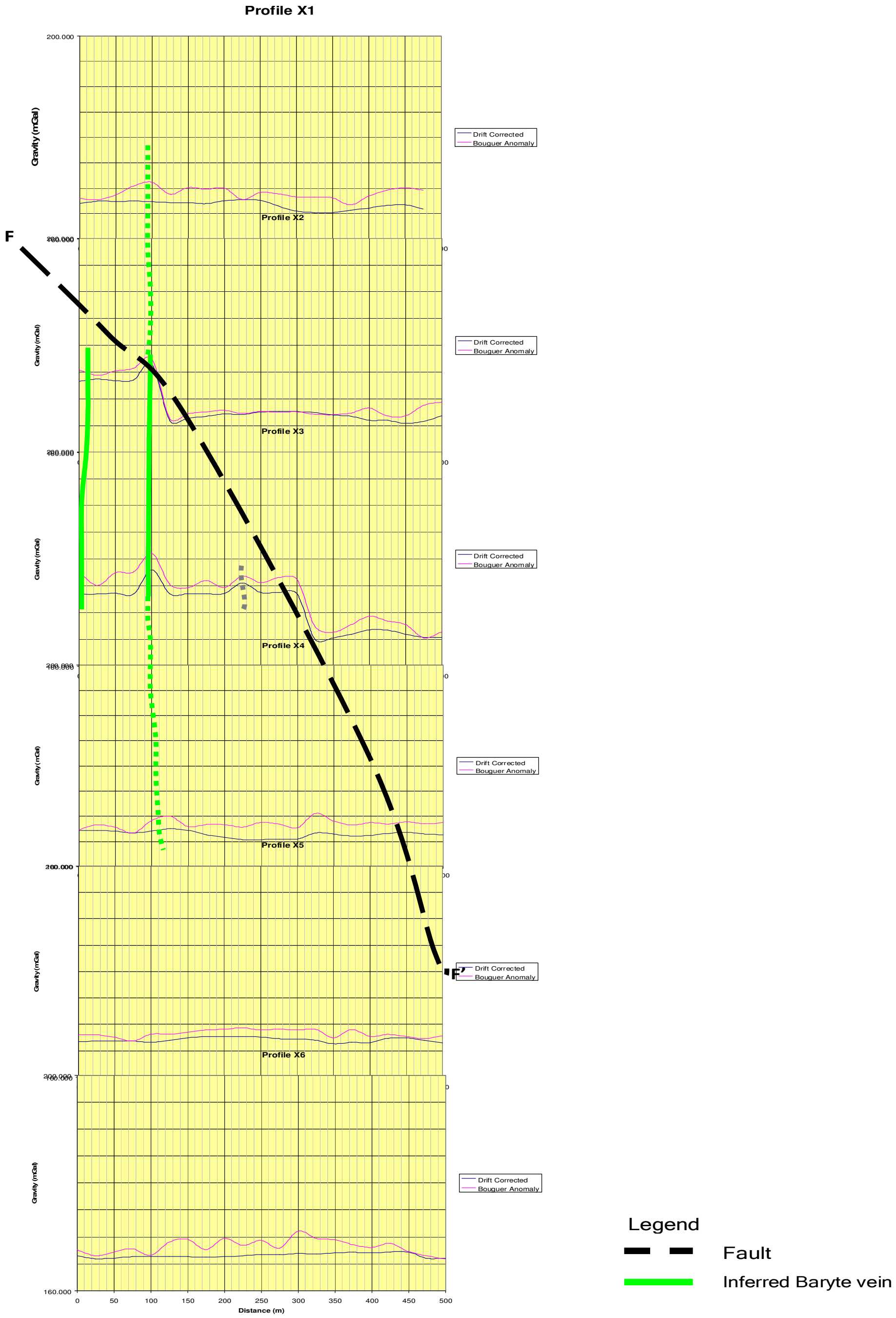

Figure 4. EM profiles (20 m coil separation) showing inferred barite veins.

mineralization. Areas exhibiting relatively low Bouguer anomaly combined with high conductivity values are presumably barren.

Profiles

The gravity dip profiles in Figure 4 show lateral variation of drift corrected and bouguer anomaly values. The gravity readings and bouguer anomaly values on Traverse X_1 are slightly high at values ranging between 165.209 and 167.723 mGals for drift corrected values and between 167.756 and 171 mGals for bouguer anomaly. Anomalously high gravity values that may be attributable to mineralization are not discernible on the entire profile; High conductivity values characterize the southwestern half of the traverse length at both shallow and deep depths of 15 to 60 m (Figures 5 and 6). Low

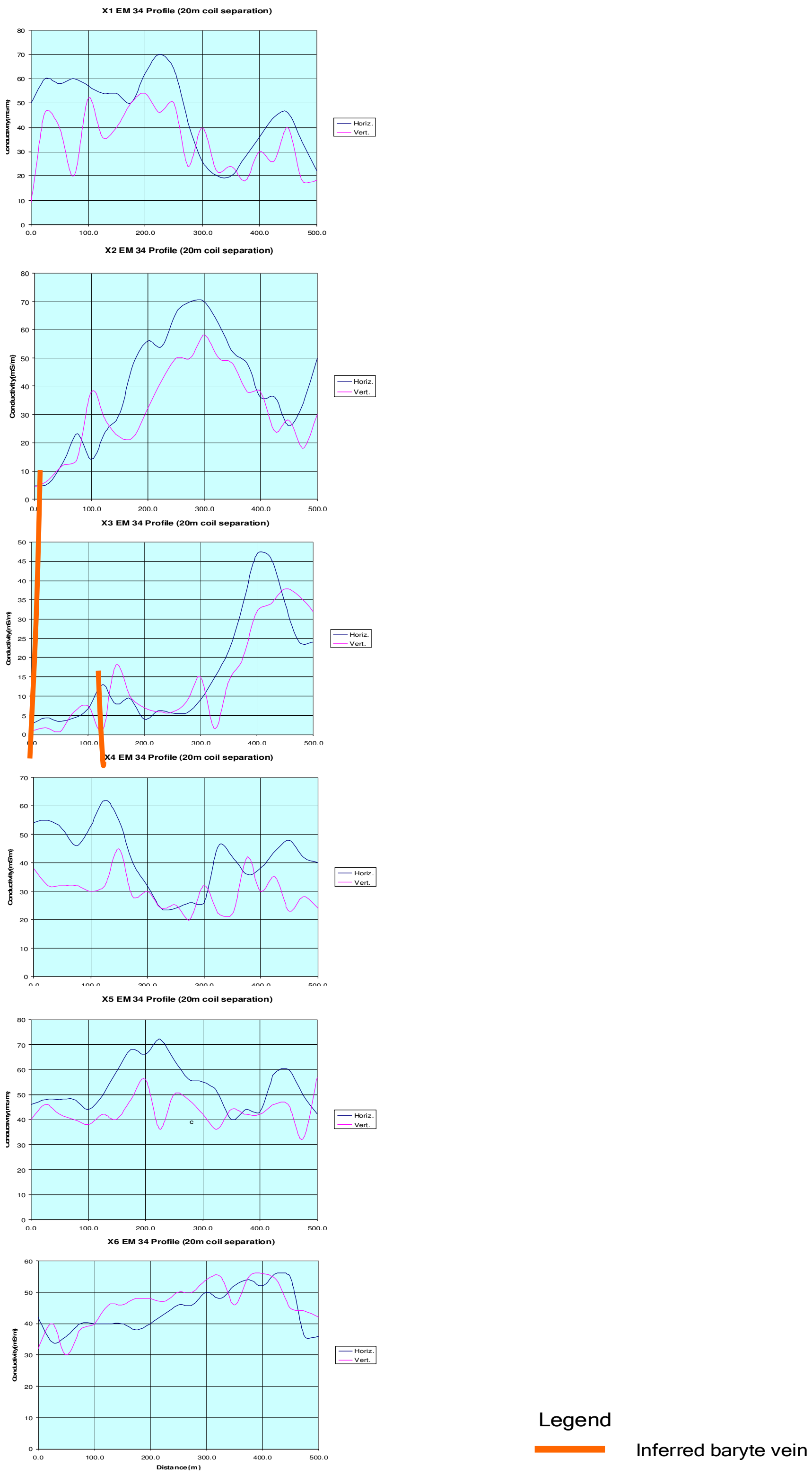

Figure 5. EM profiles (20 m coil separation) showing inferred barite veins.

conductivity values characterizing the eastern flank cannot be associated with barite because the values are greater than 10 mS/m at shallow depths and less than 10 mS/m at deep depths where surface mining method is

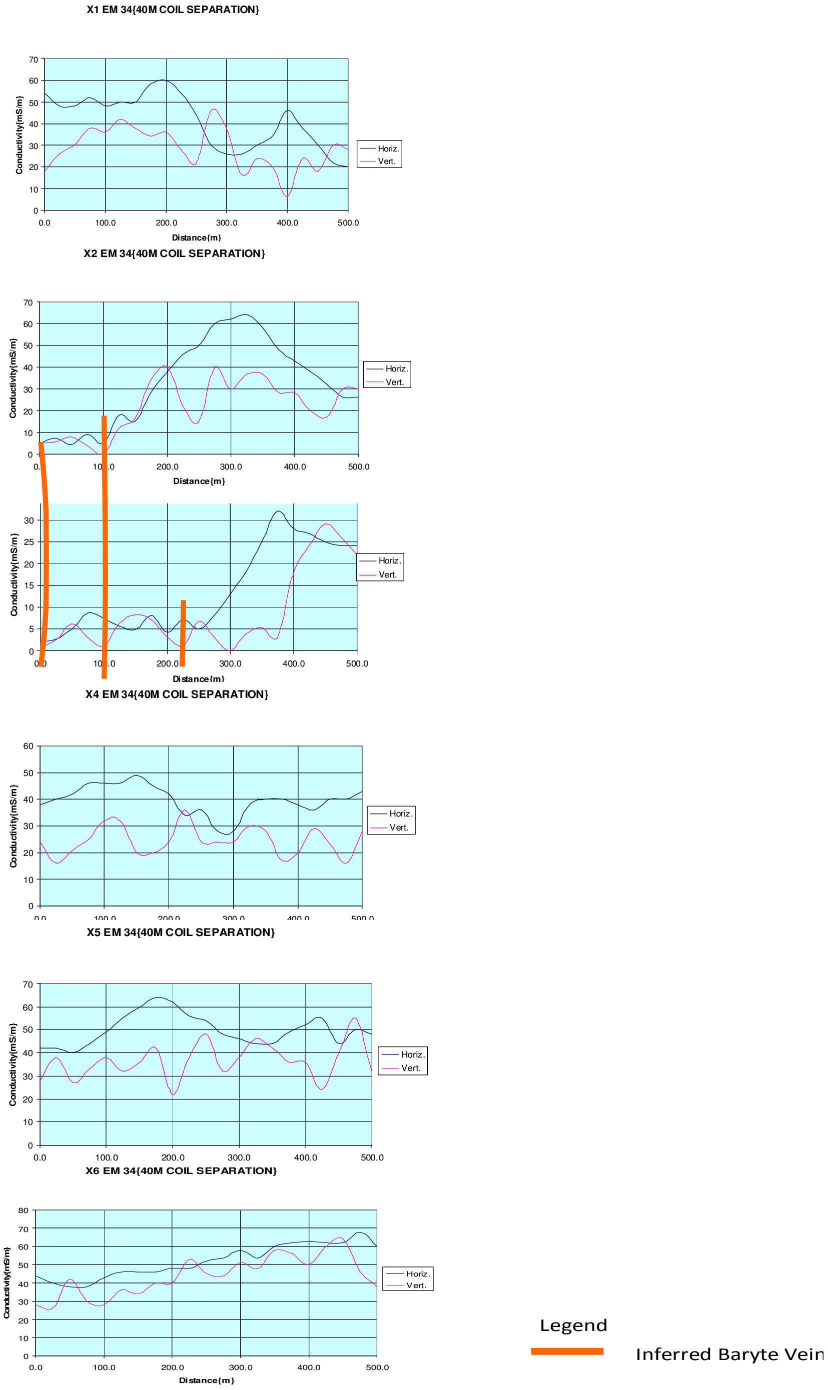

Figure 6. EM profiles (40 m coil separation) showing inferred barite vein.

apparently not feasible. The entire X_1 traverse is presumably barren (Figures 7 to 11).

Gravity values are generally higher (up to 177.507 mGals at station 100 m) on Traverse X_2 (Figure 4) on the southwestern flank of the traverse. The gravity characteristics are generally high on the southwestern flank with a sudden fall of gravity profile (from 177.507 to 166.311 mGals) between stations 100 and 125 m indicating the possibility of fault. Low conductivity values (< 10 mS/m) are equally observed from Station 0.00 m and with a steady rise in conductivity profile from Station 100 m eastwards (Figures 5 and 6). The higher conductivity materials of the Traverse X_2 assume the highest values between stations 275 and 325 m. The areas defined by high gravity and very low conductivity are considered to be of possible barite mineralization

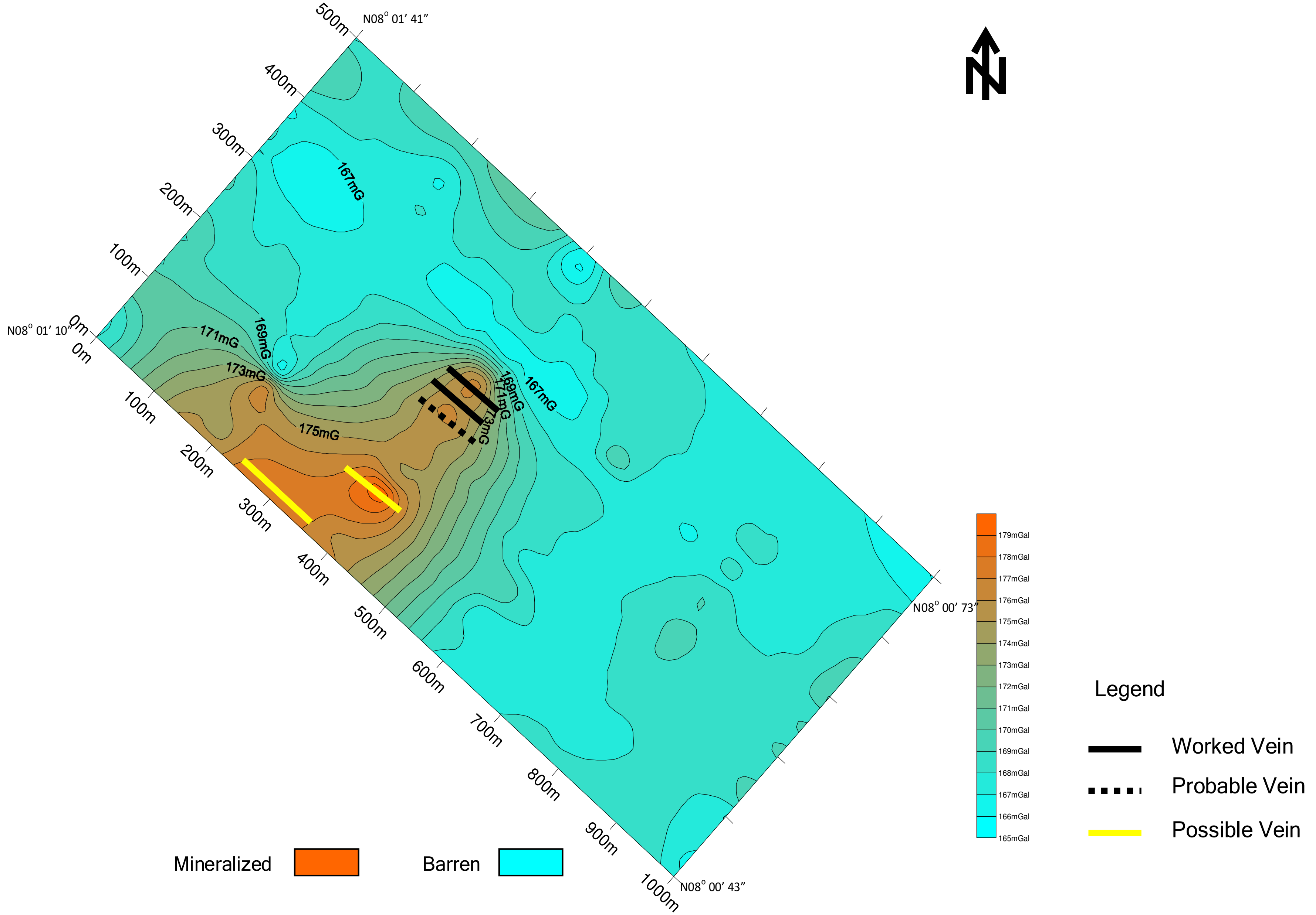

Figure 7. Bouguer anomaly contour map obtained from the study area.

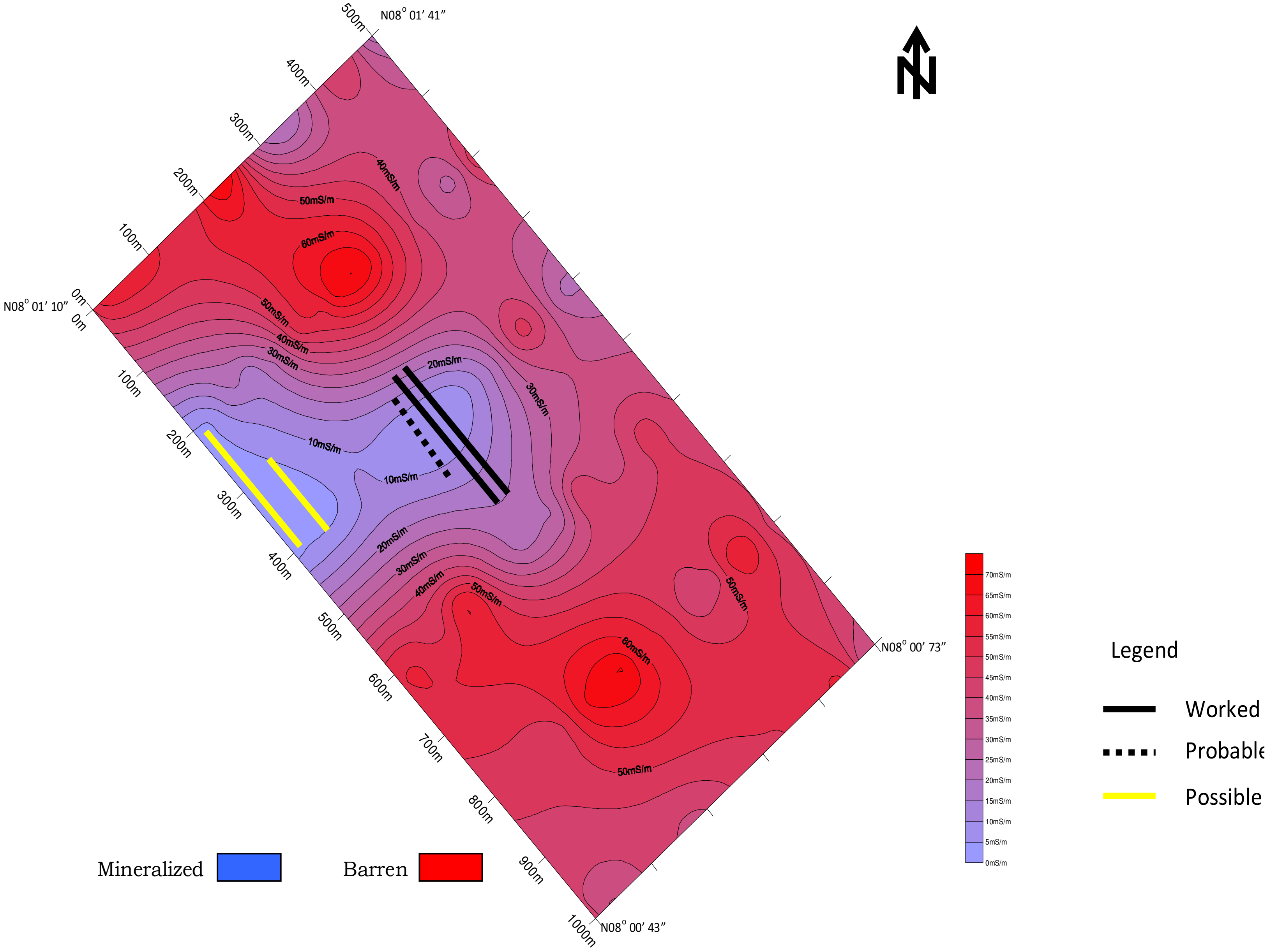

Figure 8. (Hd) Conductivity contour map at 20 m coil separation (15 m depth).

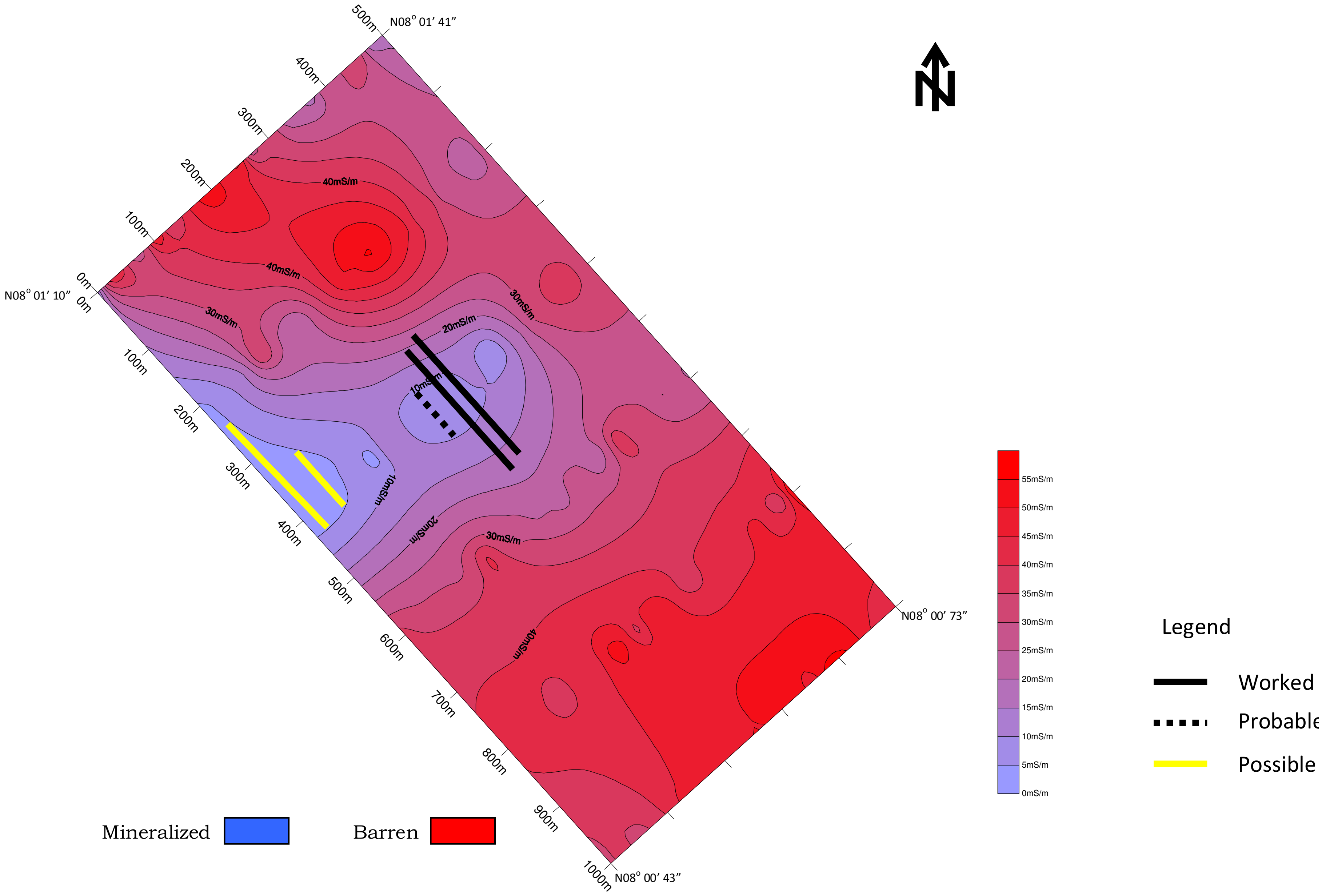

Figure 9. (Vd) Conductivity contour map at 20 m coil separation (30 m depth).

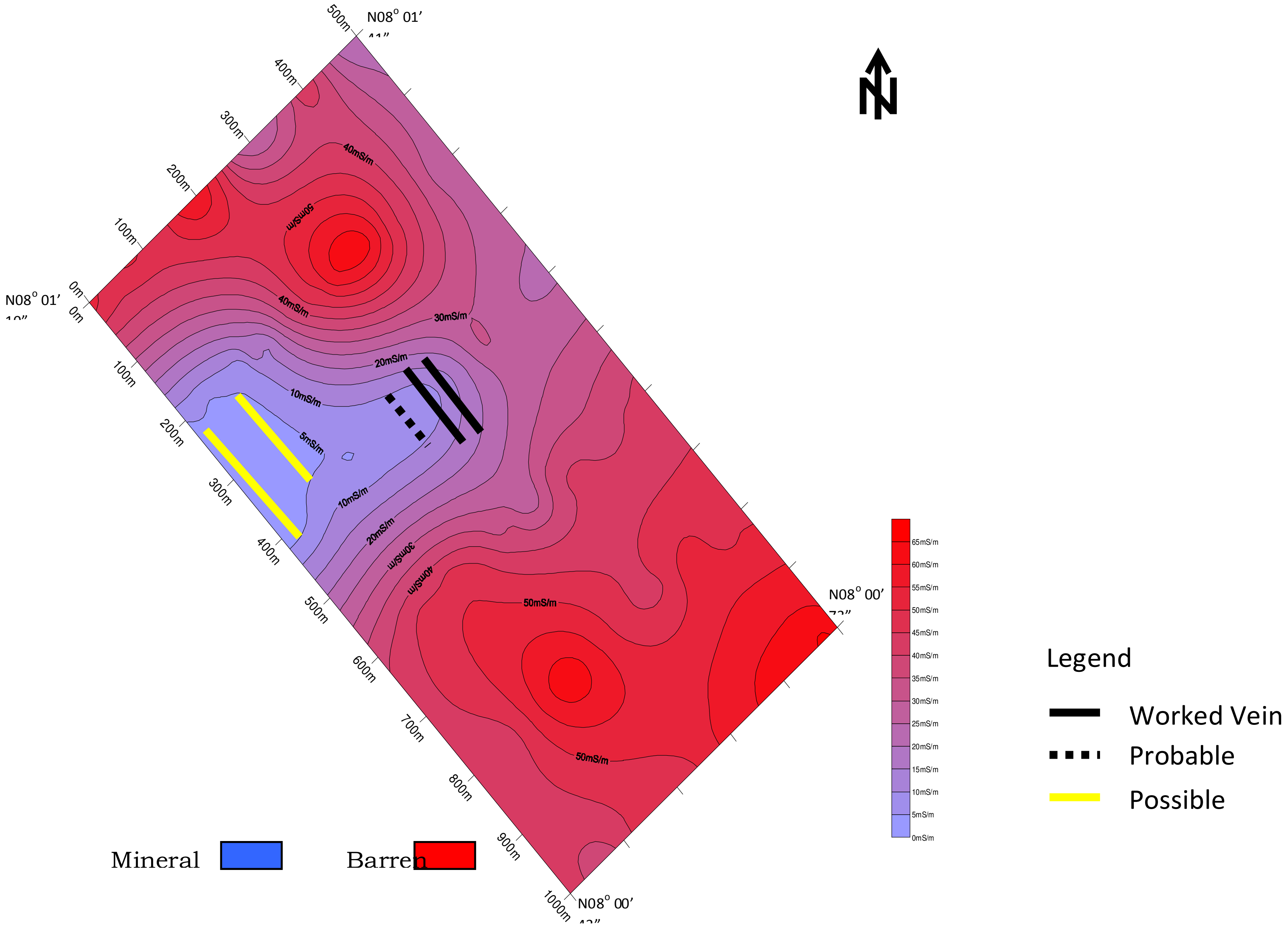

Figure 10. (Hd) Conductivity contour map at 40 m coil separation (30 m depth).

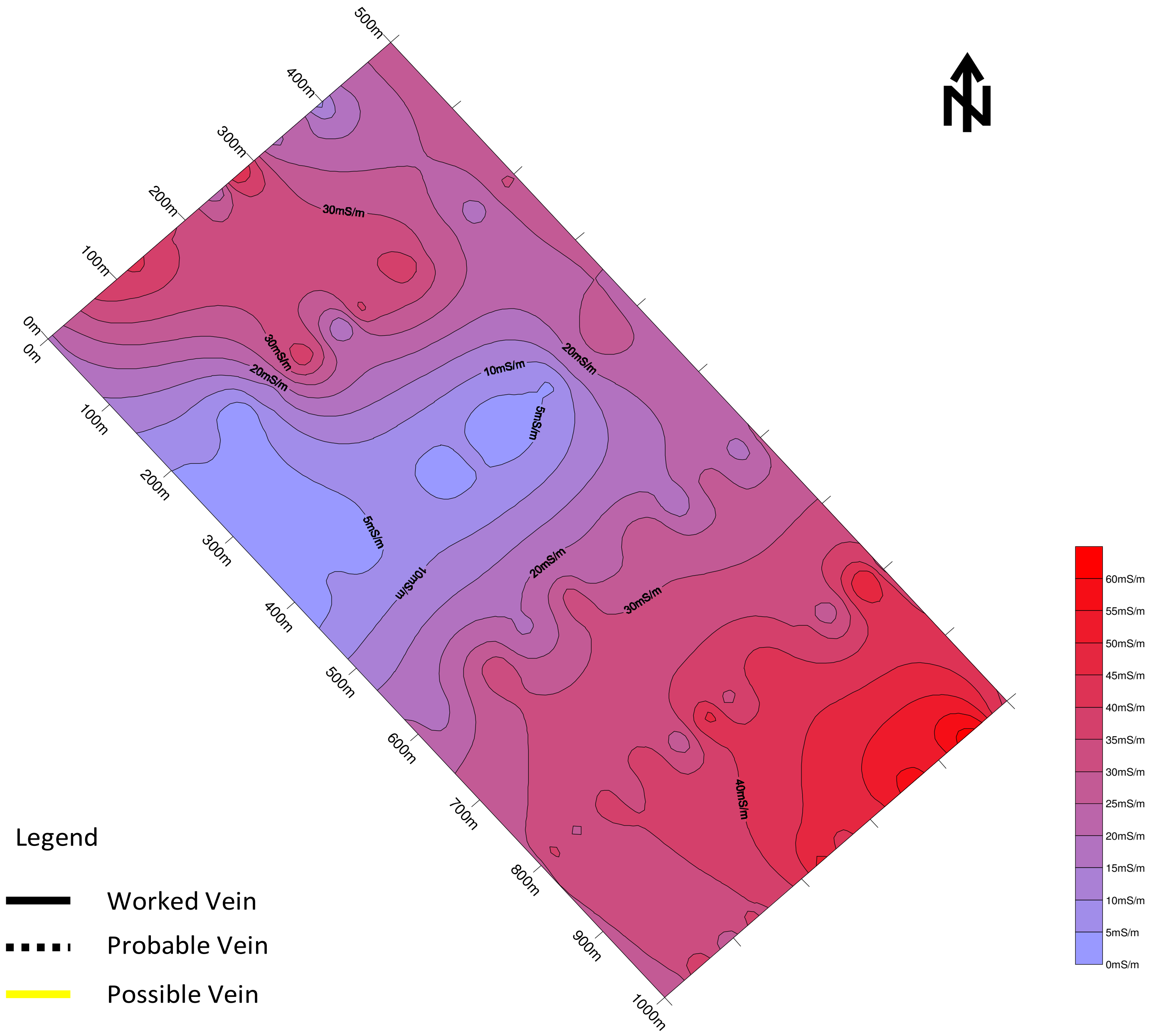

Figure 11. (Vd) Conductivity contour map at 40 m coil separation (60 m depth).

(Figures 7 to 11).

The Bouguer anomaly profile is generally higher (maximum of 181.072 mGals) on the southwestern limit (Figure 4) of Traverse X_3. The higher Bouguer anomaly obtained at the southwestern limit is presumably due to the presence of high density constituents of the underlying soil materials. The highest value of 181.072 mGals is indicative of barites vein mineralization. The southwestern limit of the traverse is also characterized by low conductivity values (0.6 to 2.8 mS/m). Very low conductivity values were recorded on the 100 m southwestern limit of the traverse. Area of barite mineralization is defined by the high gravity profile accompanied by low conductivity profile between stations 0 and 100 m (Figures 7 to 11).

Gravity profiles (drift corrected and Bouguer anomaly profile) assume a generally flat profile on Traverse X_4 (Figure 4) with low amplitude peaks demonstrating deeply buried vein mineralization. The Bouguer anomaly values vary from 166.709 mGals at station 75 m to 170.605 mGals at station 325 m. Moderately, high conductivity materials (16 to 49 mS/m) underlie the entire traverse (Figures 5 and 6). Thus, the combination of moderately low profile gravity values and fairly high conductivity values present a low potential barite mineralization (Figures 7 to 11).

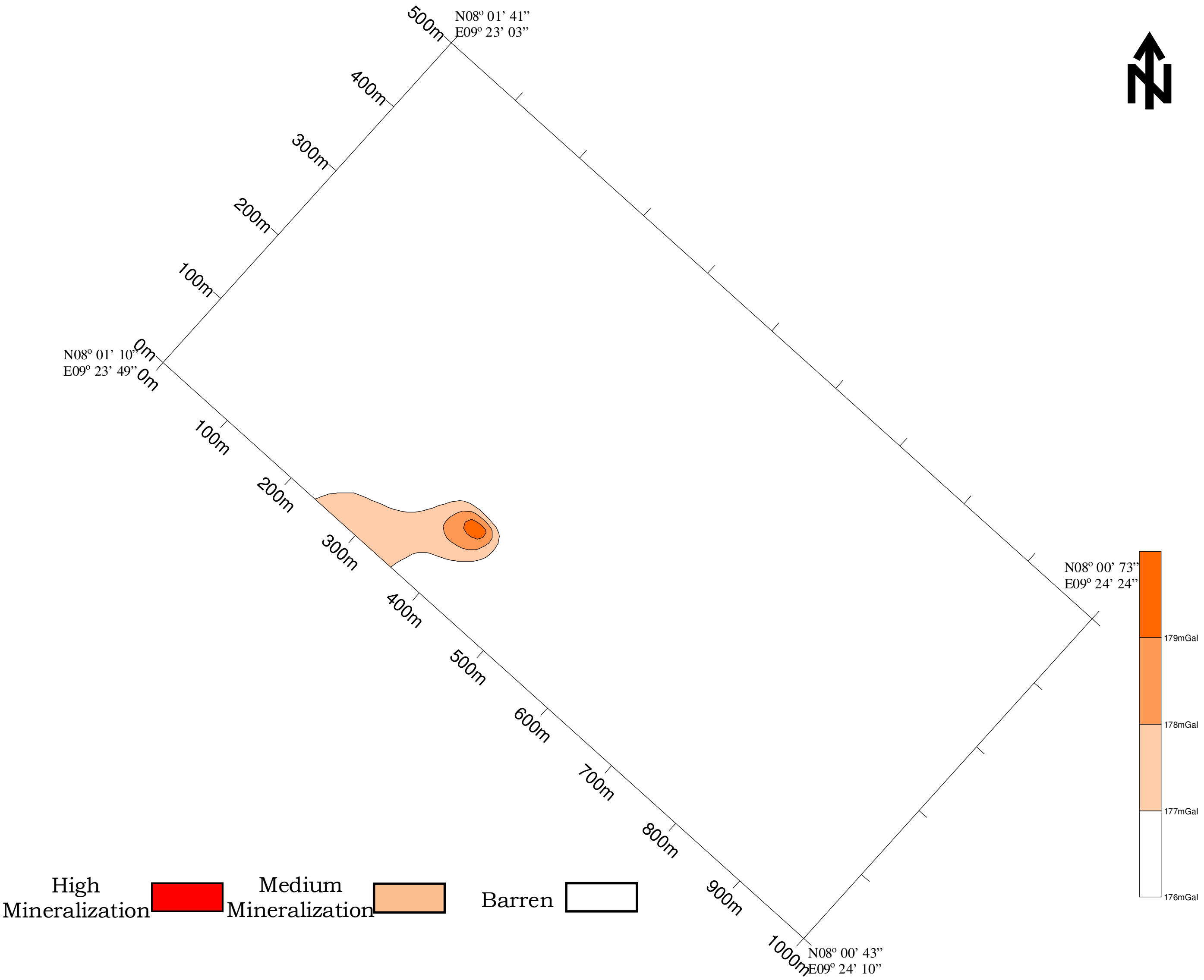

Figure 12. Bouguer anomaly map showing isolated possible mineralized zone.

The Bouguer anomaly data (166.808 to 169.341 mGals) observed on Traverse X_5 generally present falling profile southwards when compared with that of adjoining X_4 Traverse (Figure 4). The electromagnetic readings on the traverse present generally high conductivity values (22 to 72 mS/m). Occurrence of high conductivity materials is more pronounced thus confirming very poor barite mineralization potential on the traverse (Figures 5 and 6).

The gravity values obtained on Traverse X_6 on the southeastern flank of the prospect remain relatively low (Figure 4). The X_6 traverse is characterized by high conductivity values suggesting poor barite mineralization potential (Figures 5 and 6).

In Figure 4, two high amplitude gravity profiles are traceable across two traverses (X_2 and X_3) only. These two traces are presumably barites veins. The two veins are delineated on the western end of traverses X_2 and X_3 and by extension the western flank of the prospect. The FF' mark in broken line is presumably a fault.

In Figure 5, mineral vein traceable to low amplitude conductivity (Horizontal and Vertical dipoles) profiles was delineated on X_2 (Station 0.00 m) while two low amplitude conductivity profiles (Horizontal and Vertical dipoles) were delineated on traverse X_3 (Station 50 and 125 m). However, in Figure 6, the two low amplitude conductivity profiles were traceable to X_2 and X_3. A third low amplitude conductivity profile was delineated on traverse X_3 around station 225 m. The low conductivity amplitudes delineated have values below 5 mS/m.

Higher Bouguer anomaly contours were obtained on the western flank of the study area as observed on the map as isolated in Figure 12. This is indicative of the presence of high density materials (presumably barites

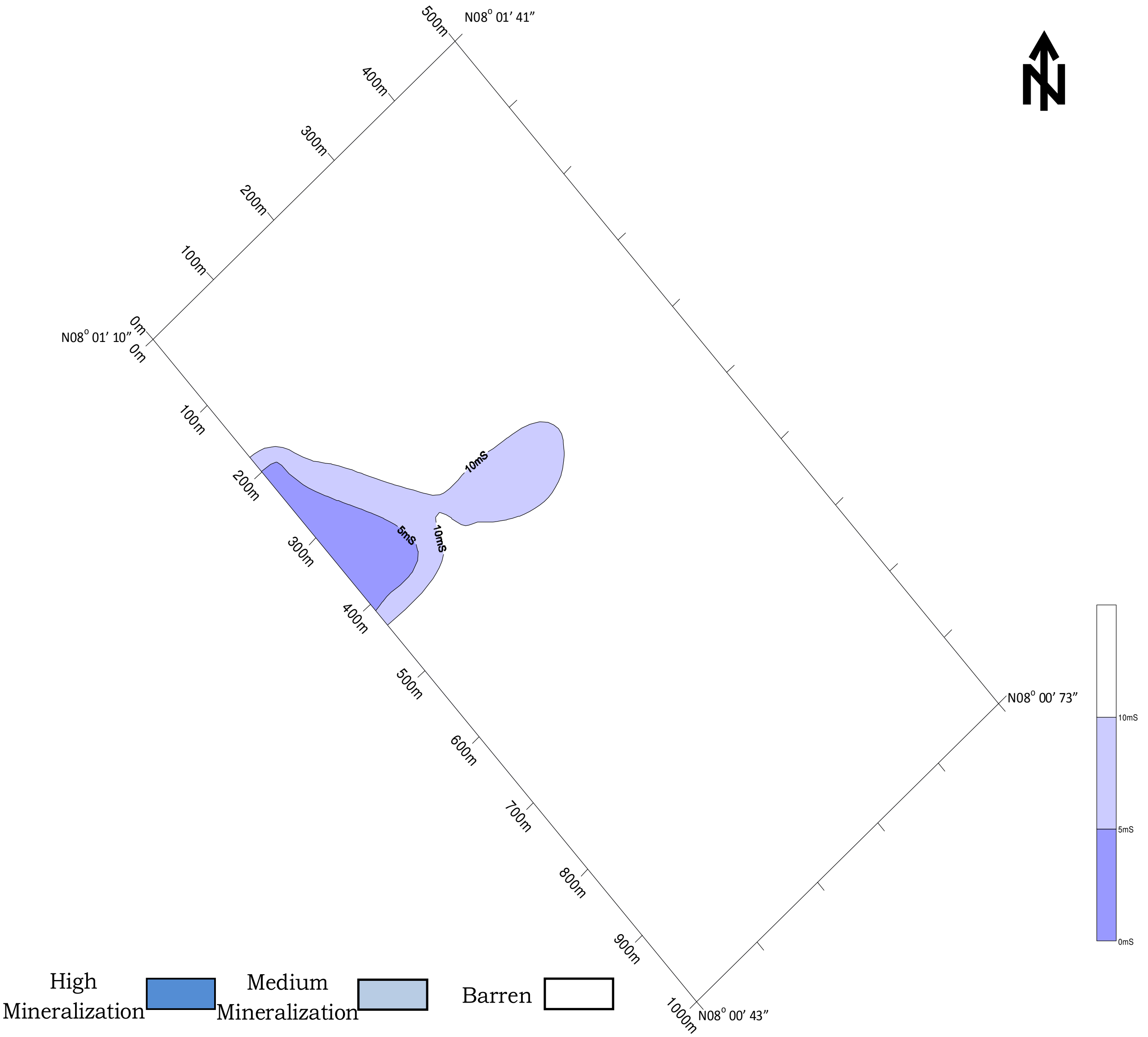

Figure 13. (Hd) Conductivity contour map at 20 m coil separation showing isolated possible mineralized zone (15 m depth)

mineralization) in the area. However, the presence of some dense, gangue minerals (galena) cannot be ruled out. Fairly high gravity contour closures (Bouguer anomaly > 177 mGals) obtained at the central area of the prospect may be remnants of the worked trenches. The possibility of concealed barite still exists in the central area close to the western mined vein. The attitude of the contours shows that the mineralization potential is highest on the western flank and increases in the direction of River Benue.

The conductivity maps presented in Figures 8, 9, 10 and 11 show similar trend and continuity of the resistive materials to the depth of 60 m (and possibly beyond) on the western flank of the study area. The area enclosed by 5 mS/m contour on the western limit of the prospect and isolated in Figure 13 presents the highest mineralization.

Conclusions

The variations in the Bouguer anomaly values are presumably influenced by the density contrast existing between the heavier minerals in the area and the host rocks. High Bouguer anomaly signatures were recorded over regions that are presumably underlain by barites. Such areas are located on the western end of the study area. Barites mineralization potential varies from moderately high on the western area around Traverses X_2 and X_3 (western end) to medium around central of Traverses X_3, (centre of prospect) and low at traverses X_1, X_4, X_5 and X_6 (northern and southern areas). Areas of low Bouguer anomaly are presumed to be barren of barites mineralization.

The conductivity profiles and maps further enhanced the interpretation of the gravity data. Areas of high gravity values accompanied by high conductivity that may be associated with other dense materials such as lead sulphide is not discernible on the traverses and maps. Thus, areas of high gravity values accompanied by low conductivities are associated with barites mineralization only in this investigation.

Manual trenching within azimuths varying between 312° WCB to 132° WCB and 324° WCB to 144° WCB of the delineated areas on the western parts of the prospect may increase the accuracy of mining in the area. It is observed that the trend of mineralization in the area is southwest-wards in the direction of River Benue. Thus higher barite mineralization potential most probably exists beneath River Benue and its southern flank in Tunga area.

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