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*-RESEARCH ARTICLE-*

# Subsurface Soil Evaluation using Seismic Refraction Tomography and Standard Penetration Test at Bukit Bunuh Impact Crater Area

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**Abstract**

Subsurface soil varies from place to place due to the rock type, its mineral constituents, the climate of the area, time and other geological activities such as meteorite impact. The process that leads to the formation of impact crater can cause great variation in the subsurface soil characteristics, which may have an effect on civil engineering structures. Hence, the need to evaluate the subsurface soil of the impacted area. In this study, Seismic refraction and borehole data were used to achieve the aim. The result revealed that the overburden layer inside the crater is dominated by low-velocity values (< 750 m/s) which correspond with low N-values. Moderate seismic velocity values (750 – 1400 m/s) with moderate to high N-values were predominant for overburden soil within the crater rim and outside the crater. Slightly, moderately and highly weathered granite was observed at all survey lines with velocity values ranging from 1200 - 3450 m/s. The low N-values with low-velocity values obtained inside the crater are indications that the subsurface soil inside the impact crater area has been deformed and weakened as evident by the presence of brecciation which occurred during the impact process.

**Keywords:**

Impact Crater, Subsurface Soil, Seismic Refraction, N-value

**Article history:**

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**Introduction**

Generally, subsurface soil distribution and occurrence vary from place to place. The variation of the soil depends on the climate of the area, rock type, its mineral constituent, vegetation, topography and time (Daniel, 2004; Roy & Bhalla, 2017). Subsurface soil information is of great importance, as most civil engineering structures such as building, bridge, dam, tower, highway, tunnel, etc are laid below or on the surface of the earth. Several studies (Arifin et al., 2010; Azwin et al., 2015; Nawawi et al., 2004; Nur Amalina et al., 2012; Rosli et al., 2012; Rosli et al., 2014) have been conducted at Bukit Bunuh Lenggong Perak, Malaysia with the aim of identifying the impact crater. Considering the event that led to the formation of impact crater, there is need to evaluate the subsurface soil of the area. Impact structure can be regarded as a geologic structure formed by intense collision between a planet Earth and a cosmic body (space projectile) such as comet or meteor. Its formation is a complex process which depends on size, type and velocity of the projectile, the impact angle and target materials such as crystalline, sediment, water or ice (Collins et al., 2012; Ernstson & Claudin, 2013; Melosh & Ivanov, 1999; Pati & Reimold, 2007; Selen, 2013). This paper is aimed at evaluating the subsurface soil within and outside the impact crater area using seismic refraction and SPT N-value. Researchers such as Awang et al. (2015), Azwin et al. (2013), Bery & Rosli (2012), Nordiana et al. (2012) have proven the effectiveness of the adopted methods in evaluating the subsurface soil. Bukit Bunuh is situated in Lenggong town of Perak, Malaysia. It lies between two mountain ranges, Titiwangsa Range and Bintang Hill with rugged topography. The entire Lenggong Valley of which the study area is a part, is underlain by granitic rock of Jurassic end to Carbonaceous low era, which has originated from Bintang Range at West of Lenggong (Saidin, 1993). Bukit Bunuh is made up of Quaternary sediment and small lithology unit of Tertiary tephra ash and metasediments. Nawawi et al. (2009) reported that the surrounding topography of Bukit Bunuh was formed due to meteorite impact, about 1.83 million years ago. Geological map of Lenggong Valley showing the location of Bukit Bunuh was depicted at Figure 1.

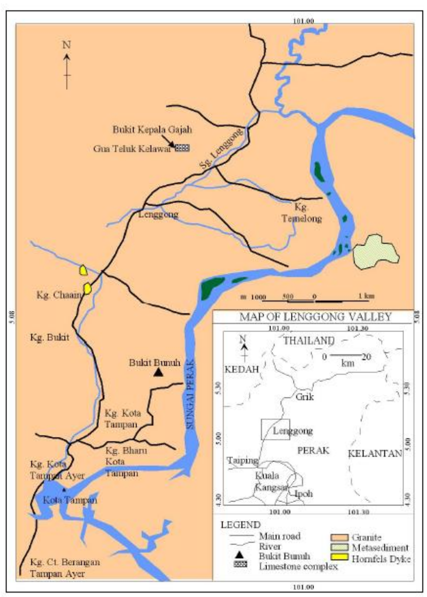



Figure 1. Geological map of Lenggong Valley showing location of Bukit Bunuh (Adopted from Ismail, 2015)

Seismic refraction is one of the geophysical methods of exploration based on measuring the travel time of seismic wave generated by an impulsive energy source (Rosli, 2018). The wave generated from the seismic source such as explosive, sledge hammer or weight drop, propagate downward through the subsurface and becomes critically refracted when it encounters medium of different velocity (Burger et al., 1996; Kearey et al., 2002; Lowrie, 2007; Reynolds, 1997; Telford et al., 1990) (Figure 2).

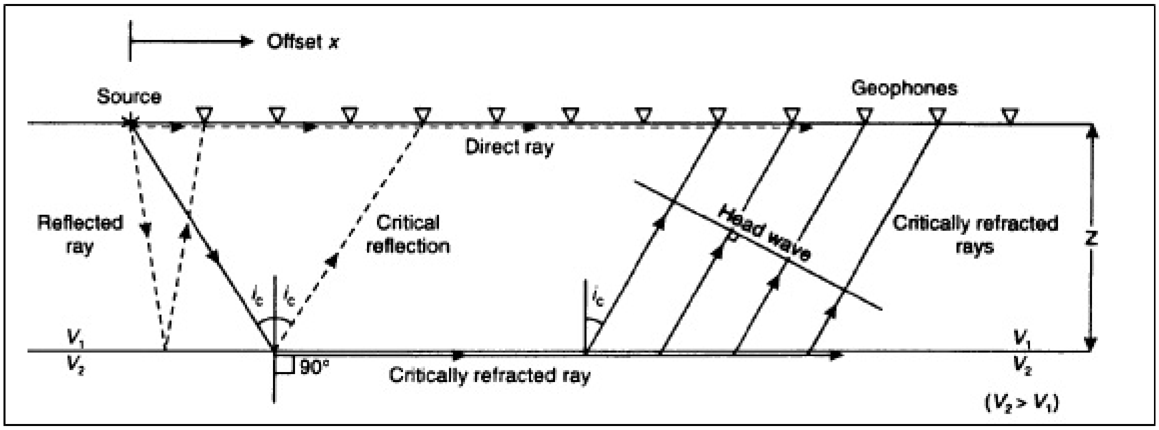



Figure 2. Raypath diagram showing the respective paths for direct, reflected and refracted rays (Reynolds, 1997).

The Standard Penetration Test (SPT) is one of the most commonly used testing methods designed to determine the geotechnical engineering properties of subsurface soils. It is a simple and inexpensive test which gives an indication of the compressibility and relative density of granular deposits such as sand and gravel. According to BS1377, SPT is a dynamic test used as the quantitative measure of the subsurface characteristics (Bery & Rosli, 2012; Mohamad et al., 2015). The test is carried out by driving a standard thick-walled sample tube (50 mm diameter) into the soil using repeated blows with 63.5 kg weight drop. The sample tube is driven 75 mm into the ground and then the number of blows required for the tube to penetrate each 75 mm (3 in.) up to a depth of 450 mm (18 in.) is recorded. The sum of the number of blows required for the third to sixth (3 in.) of penetration is reported as SPT blow count value, commonly termed "Standard Penetration Resistance/Test" or the "N-value".

## Materials and Methods

Seismic refraction data was acquired using 24 channel ABEM Terraloc MK8 seismograph and 28Hz geophones. Five seismic refraction survey lines (SL1 – SL5) with length of 115 m each were conducted (Figure 3), the breakdown is as follows: two survey lines (SL1 and SL2) located inside the crater, SL3 and SL4 crossing the expected crater and SL5 located outside the crater. Geophone spacing of 5 m was used in acquiring all the seismic refraction survey data. Software such as IXRefrac, FIRSTPIX v4.21, GREMIX-15 v2.58, SeisOptPicker and SeisOpt2D were used for the data processing to obtain the seismic velocity. Five boreholes (BH1 – BH5) were considered along the survey lines. The distribution of the boreholes is as in the seismic refraction survey breakdown (i.e BH1 and BH2 located inside the crater, BH3 and BH4 crossing the expected crater and BH5 situated outside the crater). The seismic velocities at a given depth and distance along the survey lines where the boreholes are located were extracted and correlated with the borehole data (N value lithology and Rock Quality Designation (RQD)).

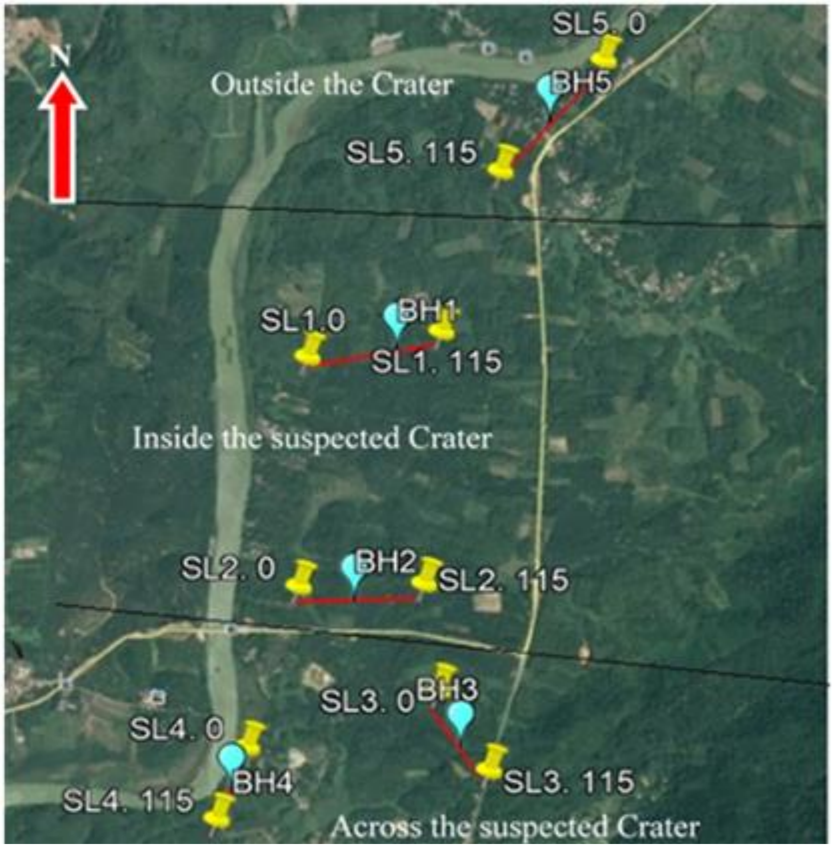



Figure 3. Location of seismic refraction survey lines (red) and boreholes (light blue)

**Results and Discussion**

The results obtained are presented based on the methodology adopted which involved considering seismic refraction survey and borehole data inside or center of the crater, on the crater rim and outside the crater. Generally, the velocity values obtained ranges from 375 – 3345 m/s of which they are classified as low (< 750 m/s), moderate (750 – 1500 m/s) and high (> 1500 m/s). The N-values ranges from 0-50 which is also classified as low (< 16), moderate (16 - 30) and high (30 - 50).

Inside the crater, BH1 and BH2 were correlated with seismic refraction survey line SL1 and SL2 at distance 58 m and 60 m respectively along the survey lines (Figure 4). The results revealed that the overburden consist of clay, silt, sand and gravel with predominantly low velocity (< 750 m/s). Based on the borehole data BH1 along SL1, slightly and highly weathered granite was found at depth of 15 m with velocity of 1290 - 2160 m/s; moderately and highly weathered granitic rock was encountered at depth of 12 m with velocity of 1200 - 1540 m/s for BH2 along SL2. The overburden for BH1 which is made up of medium dense sand to very stiff silt was observed to have moderate N-values of 16 - 24 while stiff silt and very soft clay has 0 – 13 N-values. The SPT N value in the overburden layer for BH2 varies from 10 - 21. The low N-values of inside the crater which corresponds with low seismic velocity (Bery & Rosli, 2012) is an indication that the subsurface soil inside the impact crater area has been deformed due to brecciation during the impact process. Tables 1 & 2 show the correlation of velocity, N value, RQD and Lithology for BH1 & BH2 at the given depth.

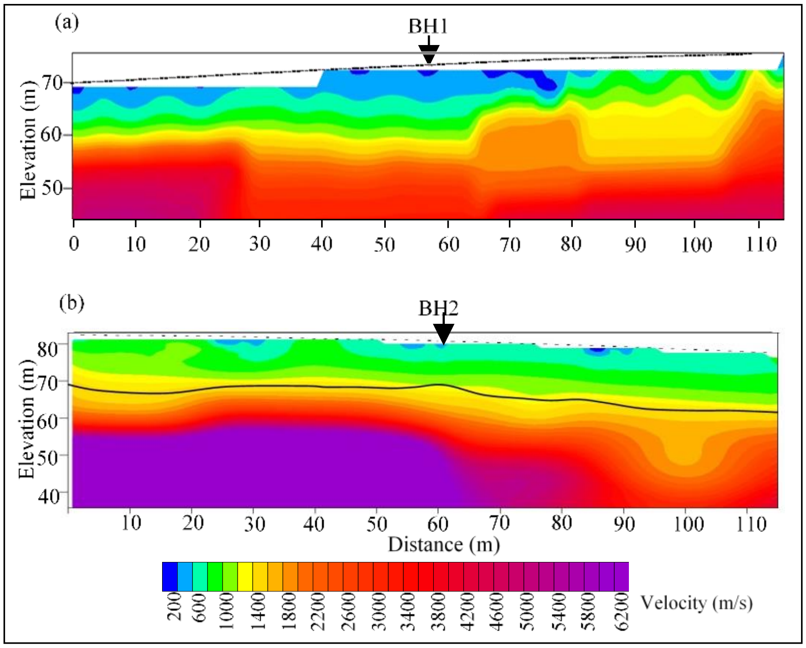



Figure 4. Seismic refraction tomography of (a) SL1 and BH1 (b) SL2 and BH2

Table 1. Correlation of velocities, N-values and lithology record (soil description) of BH1 & SL1

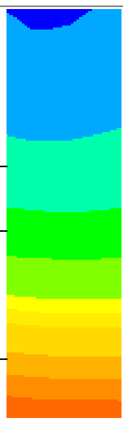
| **Depth (m)** | **Velocity Contour Section** | **Velocity (m/s)** | **N value** | **Lithology** |
|---|---|---|---|---|
| 1.50 |  | 375.4790 | 2 | No Recovery |
| 3.00 | | 421.4202 | 4 | Very soft, grey SILT |
| 4.50 | | 479.0673 | 0 | Very soft, dark grey CLAY |
| 6.00 | | 537.5970 | 9 | Stiff, grey dark brown sandy CLAY |
| 7.50 | | 607.8326 | 13 | Stiff, grey sandy SILT |
| 9.00 | | 709.4028 | 19 | Medium dense, grey SAND |
| 10.50 | | 798.2767 | 16 | |
| 12.00 | | 942.0948 | 20 | Stiff, light grey to dark grey SILT with some gravel. |
| 13.50 | | 1090.6996 | 24 | Very stiff, reddish light grey SILT |
| 15.00 | | 1292.4271 | RQD= 50 | Light grey slightly weathered GRANITE. |
| 16.50 | | 1542.5697 | RQD= 0 | Yellowish light grey moderately weathered GRANITE |
| 18.00 | | 1851.0531 | RQD= 69.23 | Yellowish light grey slightly weathered GRANITE |
| 19.50 | | 2151.1898 | RQD= 100 | |

Table 2. Correlation of velocities, N-values and lithology record (soil description) of BH2 & SL2

| Depth (m) | Velocity Contour Section | Velocity (m/s) | N value | Lithology |
|---|---|---|---|---|
| 1.50 |  | 490.5932 | 10 | Loose sandy gravel |
| 3.00 | | 630.5768 | 13 | Very stiff silt with some gravel. |
| 4.50 | | 688.3418 | 14 | |
| 6.00 | | 732.2085 | 17 | |
| 7.50 | | 911.5853 | 17 | Medium dense sand with some gravel. |
| 9.00 | | 1001.851 | 16 | |
| 10.50 | | 1110.924 | 21 | |
| 12.00 | | 1236.827 | RQD= 35.29 | Moderately weathered GRANITE. |
| 13.50 | | 1308.357 | RQD= 0 | Highly weathered GRANITE. |
| 15.00 | | 1460.405 | RQD = 81.82 | Slightly weathered GRANITE. |
| 16.50 | | 1540.922 | RQD = 0 | Highly weathered GRANITE. |

On the crater rim, the same approach was adopted for the inside crater by correlating BH3, BH4 and SL3, SL4 at distances of 80 m and 26 m respectively (Figure 5). The overburden as obtained from the result shows that it consists of medium dense to hard silty sand, silty sand with little gravel and very stiff sandy silt. It has velocity in the ranges of 580 - 1800 m/s for SL3 and 600 - 1450 m/s for SL4. Highly weathered granite was observed from the depth of 13.6 m with velocity ranging from 1800 -3300 m/s and N value of 22-50 for BH3 along SL3. For BH4 along SL4, slightly weathered granite was found at depth of 10.5 m with velocity of 1700 - 3200 m/s. It was observed that the N-value in BH4 along SL4 increased with depth and directly proportional to the velocity. Low N-values of 2 - 7 were detected at depth ≤ 6 m and increased to 19 and 50 as it approached very stiff silt and very dense silty sand. The correlation of velocities, N-value, RQD and Lithology for BH3 & BH4 at the given depth are shown in Tables 3 & 4.

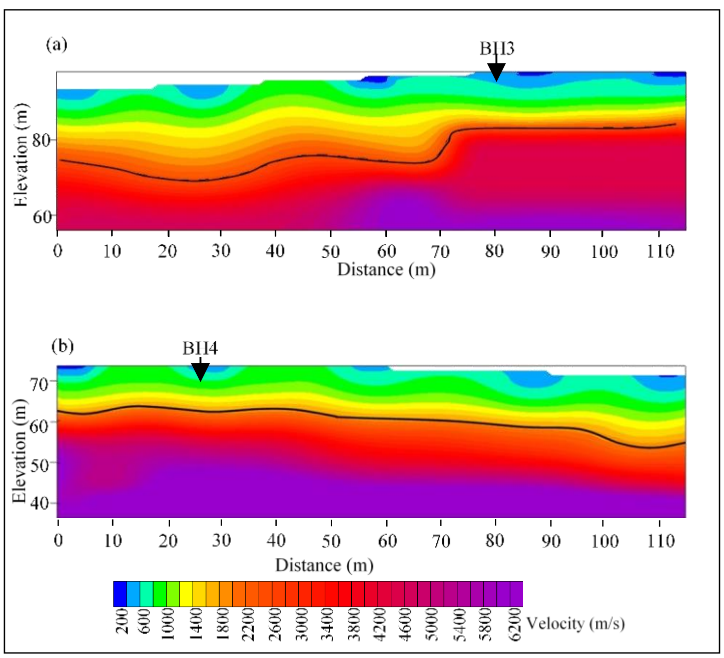



Figure 5. Seismic refraction tomography of (a) SL3 and BH3 (b) SL4 and BH4

Table 3. Correlation of velocities, N-values and lithology record (soil description) of BH3 and SL3

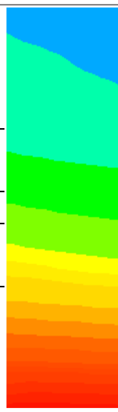
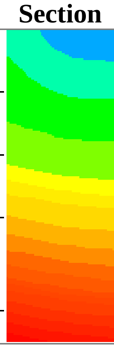
| Depth (m) | Velocity Contour Section | Velocity (m/s) | N value | Lithology |
|---|---|---|---|---|
| 1.50 |  | 580.7502 | 30 | Hard sandy SILT of high plasticity with a little gravel |
| 3.00 | | 602.6694 | 22 | Very stiff sandy SILT of high plasticity |
| 4.50 | | 754.6644 | 23 | Medium dense silty SAND of low plasticity |
| 6.00 | | 788.9838 | 25 | Medium dense silty SAND of low plasticity with a little gravel |
| 7.50 | | 828.4264 | 50 | Hard dense silty SAND of low plasticity with a little gravel |
| 9.00 | | 981.8570 | 50 | |
| 10.50 | | 1172.5530 | 50 | No recovery |
| 12.00 | | 1433.4995 | 50 | Hard dense silty SAND of low plasticity with a little gravel |
| 13.50 | | 1804.8656 | 50 | |
| 13.60 | | 1858.2631 | RQD 0 | Highly weathered GRANITE |
| 14.10 | | 2000.6564 | RQD 0 | |
| 15.60 | | 2550.3939 | RQD 0 | |
| 17.10 | | 3341.1732 | RQD 0 | |

Table 4. Correlation of velocities, N-values and lithology record (soil description) of BH4 & SL4

| Depth (m) | Velocity Contour Section | P-Wave Velocity ($ms^{-1}$) | N value | Lithology |
|---|---|---|---|---|
| 1.50 |  | 598.5082 | 2 | Very soft SILT of very high plasticity with a little sand |
| 3.00 | | 763.3621 | 7 | Medium stiff SILT of high plasticity with some sand |
| 4.50 | | 909.9052 | 6 | Medium stiff SILT of high to very high plasticity with some sand |
| 6.00 | | 1053.4572 | 6 | |
| 7.50 | | 1217.6644 | 19 | Very stiff SILT of very high plasticity with a little sand |
| 9.00 | | 1447.0846 | 50 | Very dense silty SAND of low plasticity with a little gravel |
| 10.50 | | 1738.7207 | RQD 63.6 | Slightly weathered GRANITE |
| 12.00 | | 2163.0471 | RQD 86.7 | |
| 13.50 | | 2630.1479 | RQD 56.0 | |
| 15.00 | | 3150.5459 | RQD 0 | Highly weathered GRANITE |

Outside the impact crater, only one dataset from borehole (BH5) and one seismic refraction survey line (SL5) were considered. BH5 was correlated with survey line SL5 at distance 61 m (Figure 6). Slightly weathered granite was detected at depth of 13.5 m with velocity of 1200 - 2100 m/s. The overburden is sandy silt, sand and gravel with predominantly moderate velocity and N-values ranging from 16 - 50. The moderate to high N-values, (16 - 50) of the overburden layer are due to very stiff sandy silt and dense to very dense sand and gravel. Table 5 shows the correlation of velocities, N-values, RQD and Lithology for BH1 & BH2 at the given depth.

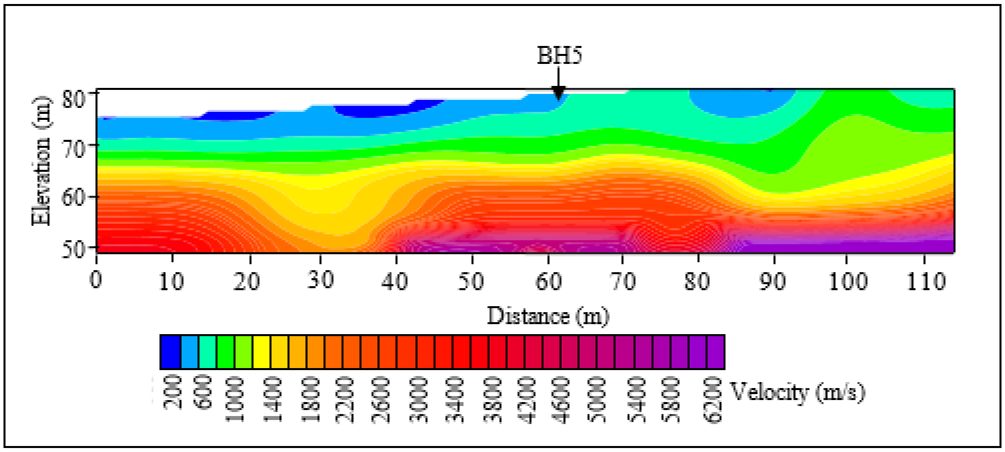
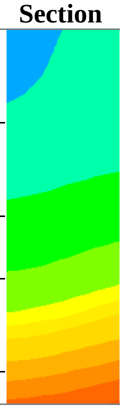



Figure 6. Seismic refraction tomography of (SL5 and BH5)

Table 5. Correlation of velocities, N-values and lithology record (soil description) of BH5 and SL5

| Depth (m) | Velocity Contour Section | P-Wave Velocity (m/s) | N value | Lithology |
|---|---|---|---|---|
| 1.50 |  | 668.4509 | 17 | |
| 3.00 | | 673.2590 | 19 | Very stiff sandy SILT of intermediate plasticity with a little gravel |
| 4.50 | | 762.1989 | 16 | |
| 6.00 | | 795.5185 | 17 | Very stiff silty SAND of intermediate plasticity |
| 7.50 | | 800.2868 | 27 | Medium dense GRAVEL with some sand and a little fine soil |
| 9.00 | | 859.5728 | 46 | Dense silty SAND of low plasticity with a little gravel |
| 10.50 | | 978.8439 | 50 | Very dense SAND and gravel with a little fine soil |
| 12.00 | | 1098.9426 | 50 | |
| 13.50 | | 1263.9139 | RQD 91.67 | |
| 15.00 | | 1471.8242 | RQD 66.67 | Slightly weathered GRANITE |
| 16.50 | | 1820.9230 | RQD 76.67 | |
| 18.00 | | 2121.4727 | RQD 0 | Highly weathered GRANITE |

## Conclusion

Seismic refraction results show that the overburden layer are made up of alluvium which predominantly consists of clay, silt, sand with existence of little gravel. Based on the borehole data obtained (N value, RQD and lithology) which were correlated with the p-wave velocities extracted from the seismic tomograms, the overburden layer inside the crater is dominated with low velocity values (< 750 m/s) which correspond with low N-values. Moderate seismic velocity values (750 – 1400 m/s) with moderate to high N-values were predominant for overburden soil within the crater rim and outside the crater. Slightly, moderately and highly weathered granite were observed at all survey lines with velocity values ranging from 1200 - 3450 m/s. The low N-values with low-velocity values obtained inside the crater are indications that the subsurface soil inside the impact crater area have been deformed due to brecciation which occurred during the impact process.

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