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3D MODELING AND PRODUCTION SCHEDULING OF KHEWRA SALT MINES

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ABSTRACT

In this study, AutoCAD based 3D Modelling of production scheduling, visualization of mining, and geological features in Khewra Salt Mines are showing. Unmanned Aerial Vehicle (UAV), photogrammetry and GIS Softwares are used to generate 3D surface modelling of Khewra Salt Mining Area. Khewra Salt Mines is the oldest and largest mine of sub-continent in the Salt Range with huge salt reserves from industrial quality to piece grade. Being a state-of-the-art mine consisting of 17 levels, 70 chambers with hundreds of tunnels, a layman pattern of development and manual mining procedure is followed with handy-made planes and maps. Hundreds of levels and cross-section maps were unified to a single 3D Model, presenting all mining features like tunnels, chambers, levels, inclines, and geological deposition of different salt seams with their thickness and qualities, overburden, and surface feature. The quantity of salt excavated since the beginning of mining is calculated for corroboration, and the remaining amounts of different qualities of salt are determined from the model. 3D topographic Modelling can also be used for area, volume calculations, and planning of remedial actions for rainwater inundations inside the mine.

KEYWORDS: 3D Modelling, UAV, Photogrammetry, GIS, Salt Range

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1. INTRODUCTION

Khewra Salt Mines, operating by Pakistan Mineral Development Corporation, is the oldest in the subcontinent in the mineral-rich mountain range called the Salt Range [1], as shown in figure 1. The lithology of this region belongs to the Pre-Cambrian age, comprising of Sahwal Marl Member, Bhandar Kas Gypsum Member, and Billianwala Salt Member [2]. The Sahwal Marl Member's lithology consists of bright and red marl beds with asymmetrical gypsum, 3-100 meter thick beds of dolomite, dull red marl beds with some salt layers, and gypsum 10 meters thick above the top. The Bhandar Kas Gypsum Member is made up of massive gypsum with few clay and dolomite beds (approximately 80 m). Similarly, red marl with a ferruginous content and thick layers of salt (approx. 650 m) comprises the Billianwala Salt Member [3]. The leased area covers 2789.29 acres of land [4]. Salt occurs in the form of an irregular dome-like structure. There are seven thick beautiful alternate bands of red and white color salt seams with a cumulative thickness of about 150

meters . At places, rock salt is 99% pure. Salt is transparent, white, pink, reddish to beef-color red [5]. In specific horizons, it is crystalline. Estimated reserves of salt range from 82 - 600 million tons [6]. Khewra salt mines produce approximately 400,000 tonnes of salt per annum [7] through the room and pillar mining method, mining only half of the salt and leaving the remaining half to support tunnel and chamber roofs. The main tunnel extends about 730 meters (2550 ft.) into the mountains from the tunnel mouth [8]. The accumulative length of tunnels is about 40 km covering 144 sq. km, with a total depth of 748 feet [4].

Based on the available survey data and geological knowledge, resource estimates have been made. Iftikhar A. Malik first measured the salt resources of the entire leased Khewra Main Mine area, as given in table 1 [9]. Asrarullah in his Report measured salt reserves by considering each salt seam separately in each chamber [10]. Table 2 describes his reserves calculations up to Chamber-62 and the pillars in between.

Seven different qualities and color salt seams exist at different levels in Khewra Main Mine, namely South Pharwala, Middle Pharwala (Upper Pharwala), North Pharwala, Thin Seams, Sujjowal, Buggy, and NLLT as sown in figure 2. The salt seams strike N-E and the dip varies from 10 ° to more than 70 ° and usually dips northward [9]. Mining begins with drilling inclined holes 3 or 4 ft (1.21 m) in length and 50-58 mm in diameter holes with auger drills. The gun powder charged with cape and fuse is used in the blasting method for initiation purposes [11]. Main Mine is made up of 17 stages. Five levels are higher than ground level, and 11 levels are lower than ground level. The height of each level is 7.62 m, according to available data from 17 levels of the main mine. Rock salt is being extracted through room and pillar mining technique in which 35 to 50 feet width of each room and 35 to 50 feet width of each pillar is developed during exploitation of rock salt and upto 70 chambers are developed in different levels. Out of 90 functioning chambers, 55 are industrial grade salt chambers and 35 are food grade salt chambers. Out of 10 inclines namely Inclines number 02, 22, 23, 26, 28, 38, 40, 43, 47, 52 only 04 inclines are safe and operational [4].

The 3D digitalization of resources using different software makes it easy of understanding the underground geological and mining features [12]. The surface modeling generation through different techniques like UAV and GIS [13] are being used for optimized production scheduling [14]. Similarly, rehabilitation and reopening of abandoned underground mines can be done using a 3D digital mine inventory model [15].

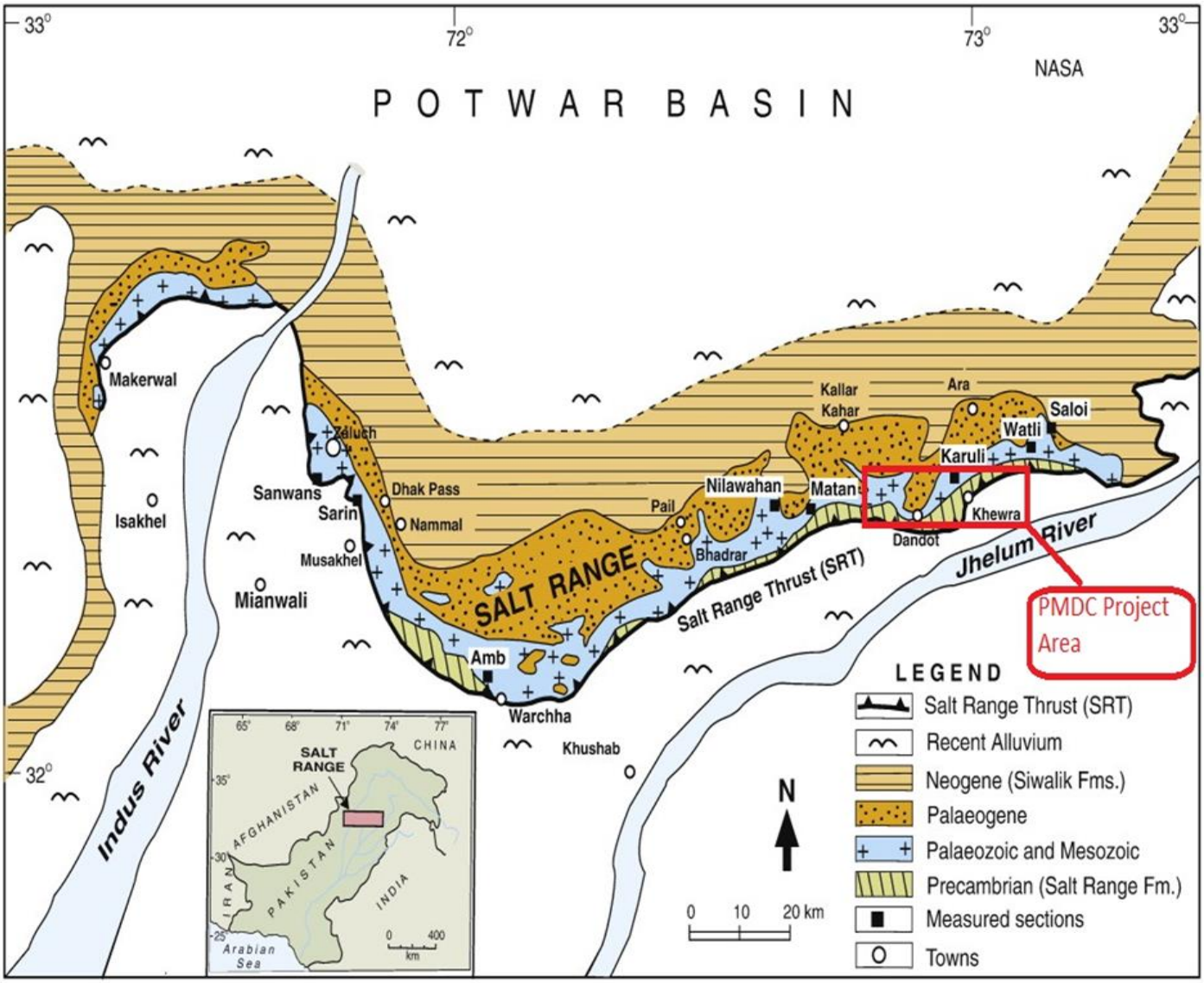


Figure 1: Geological and location map shows Salt Range from River Jhelum to River Indus (modifiied after Ghazi and Mountney, 2009).

Table 1: Rock salt resources of Main Mine in a million tons (Salt Resources of Khewra Salt Mines by Iftikhar A. Malik, PMDC, 2001).

Mine	Measured	Indicated	Inferred	Total
Main Mine	264.428	128.137	3144.920	3537.485

Table 2: Rock salt reserves of Khewra Main Mine leased area (Report on the Khewra Mines by Mr. Asrarullah, 1962).

Lease No	Area (acres)	Available as Pillars (MMT)	Probable reserves (MMT)	Proven reserves (MMT)
M.L- JLM-R-SALT (1), Khewra Main Mine	2789.2	49.361	3.464	37.324

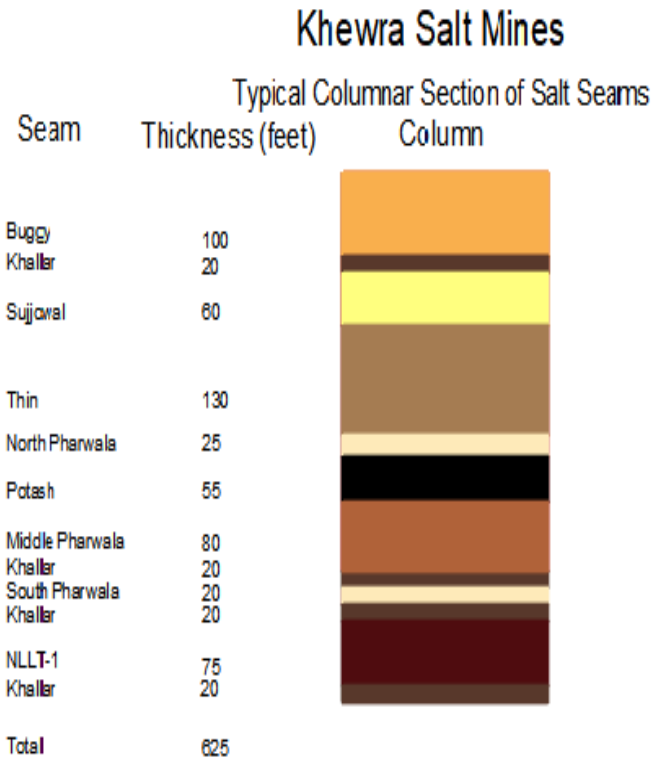


Figure 2: Columnar section of salt seams in Khewra Main Mine (Prepared by site management in 1971).

2. OBJECTIVES

The objective of the research study is to digitalize the resources through AutoCAD software, develop geological Model from existing maps and generate 3D object file of Khewra Salt Mining area using Unmanned Aerial Vehicle (UAV), photogrammetry and GIS Software for production scheduling as per market demands.

3. COLLECTION OF DATA

Maps of levels, the cross-section of chambers, and inclines were collected from the site to gather required features like the height of chambers and working, tunnels, seams, deposition and dipping, level, and surfaces drawn on it are shown in figure 3. Tunnels of Khewra Salt Mines are driven in the West-East direction while chambers are driven in the North-South direction. All these features are shown by their center line in the chambers of the respective cross-section. The extension of chambers in the North-South direction has been divided into blocks of 100 meter having 0 meters Northing in the extreme South of the Mines that increases gradually towards the north.

4. DIGITIZATION OF 2D MAPS AND CONVERSION INTO 3D

Cross-sections (E-A and 1-65) scanned and then imported in AutoCAD for digitization. Datum lines at an RL of 274.39m, Northing blocks of 100m, Tunnels in all pillars, excavations in the chambers, seams layers, inclines, and surface line were digitized as shown in figure 4. All 2D maps were converted into 3D in SE Coordinates by the following steps and shown in figure 5.

i. Datum lines, level lines, and Northing blocks lines remained unchanged in 3D.

ii. In the first 42 chambers (E-A and 1-37), the excavations and openings were Extruded/lofted on both sides of the centerline to 5.334m to a total width of 10.668m.

iii. Seams lines of the first 42 chambers (E-A and 1-37) were also extruded/lofted to 5.334m on both sides of the centerline.

iv. Inclines tunnels were lofted obliquely to a horizontal distance of 5.334m on both sides of the centerline of the incline in every chamber.

v. Surface lines of the first 42 chambers were also lofted in the same way.

vi. In the remaining 28 (38-65) chambers of 15.24m, the centerline of chambers, tunnels, seams, and surfaces were extruded to 7.62m on both sides of the centerline to a total of 15.24m.

vii. Inclines tunnels in the remaining chambers were also lofted obliquely to a horizontal distance of 7.62m on both sides of the centerline in each chamber.

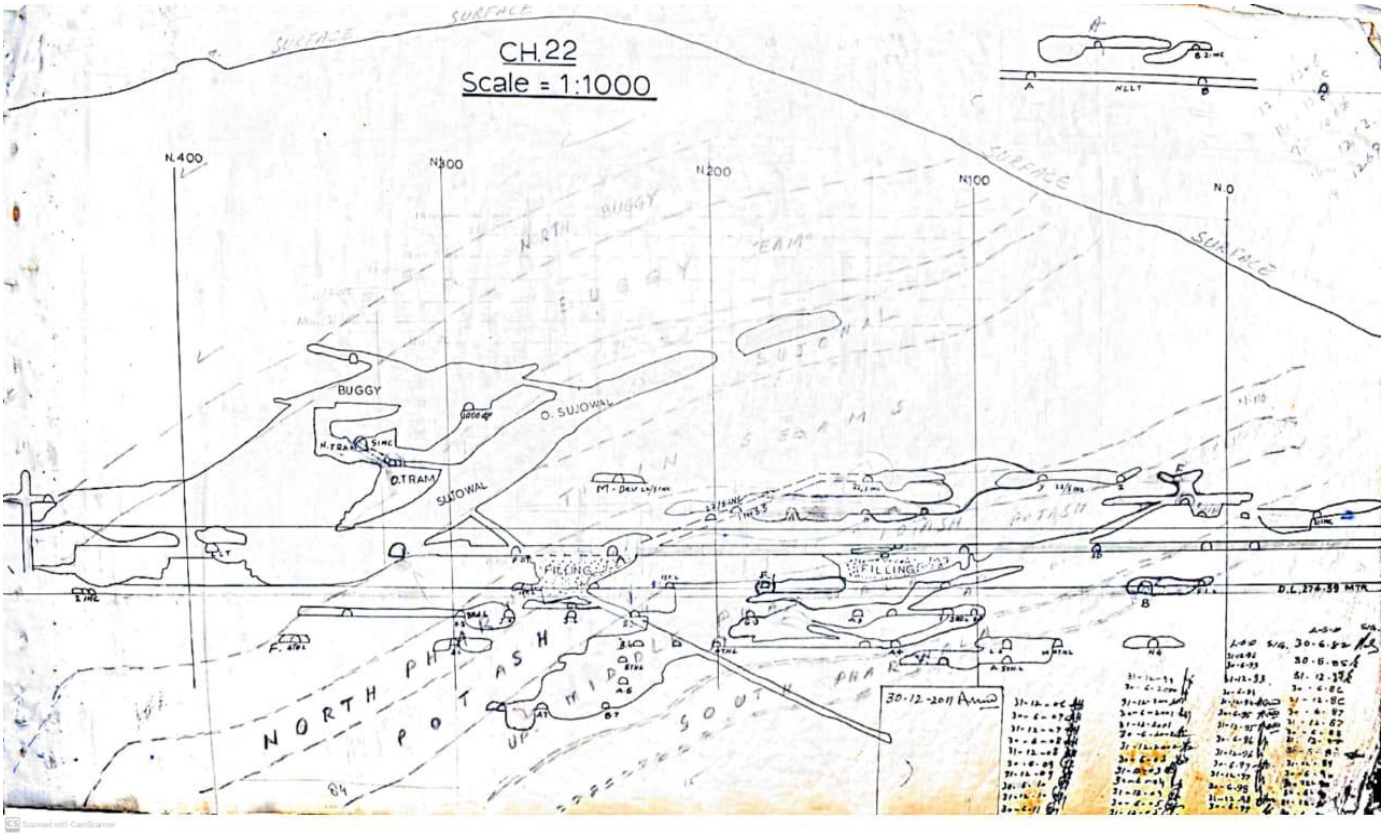


Figure 3: Previous hand compiled cross-section of Chamber 22.

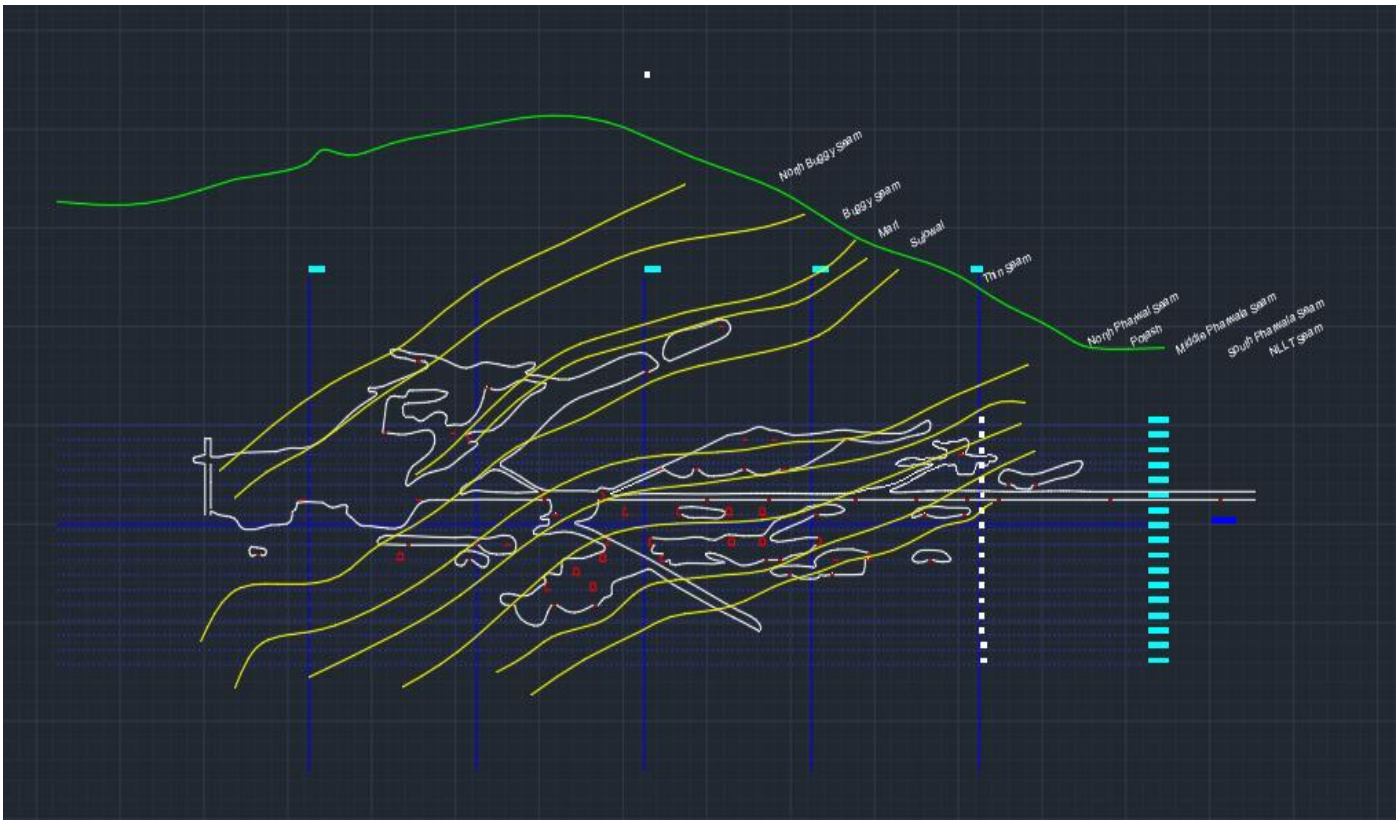


Figure 4: Digitized Cross-section of Chamber # 22.

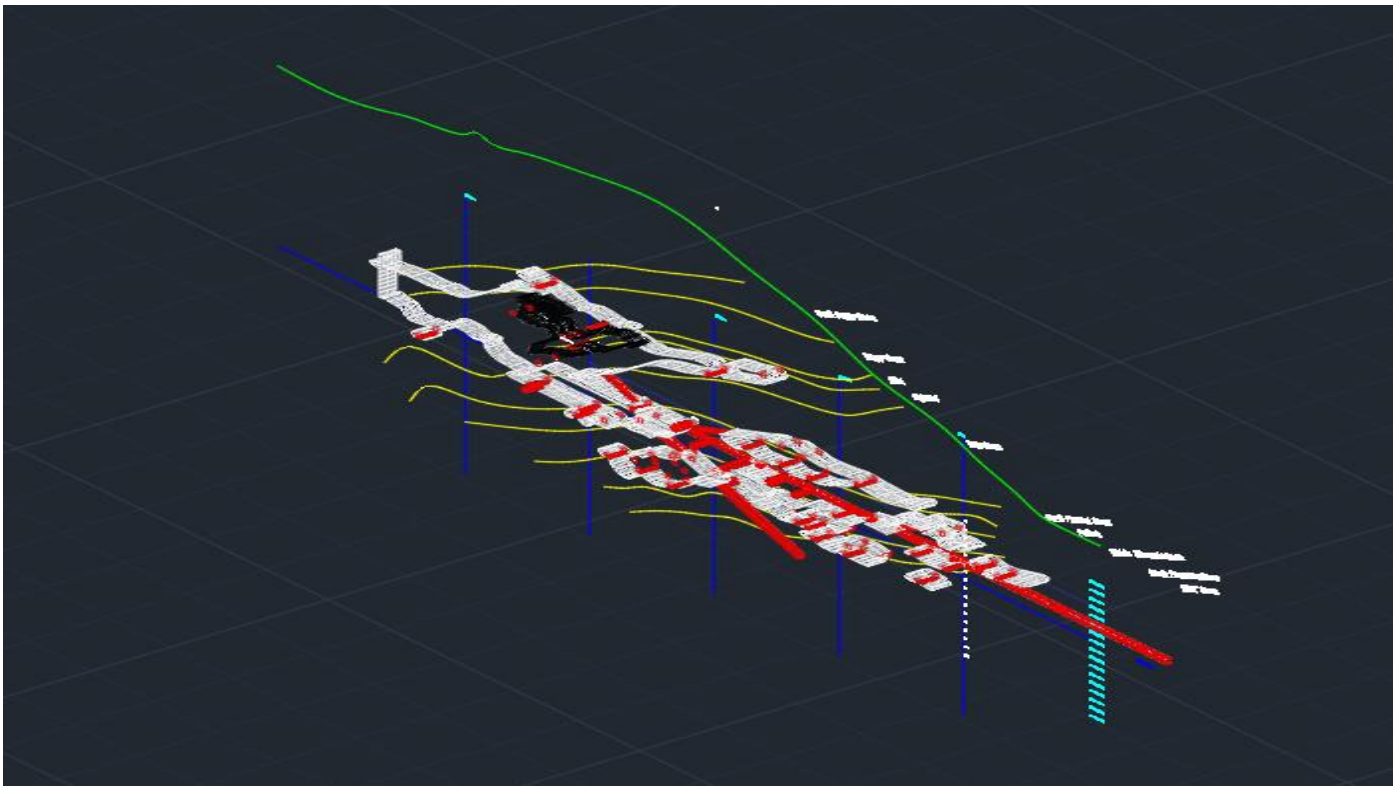


Figure 5: 3D Cross section of Chamber # 2.

5. GENERATION OF 3D MODEL

All cross-sections of chambers converted into 3D were placed one by one on the baseline started from chamber E up to last chamber 65. in the lost step, in 3D converted cross-section all features were extended to the next adjacent cross-section feature. A substantial giant 3D Model was resulted in having all underground and surface features at one point, as shown in figures 6, 7, 8 & 9. A different color differentiated these features for easy understanding.

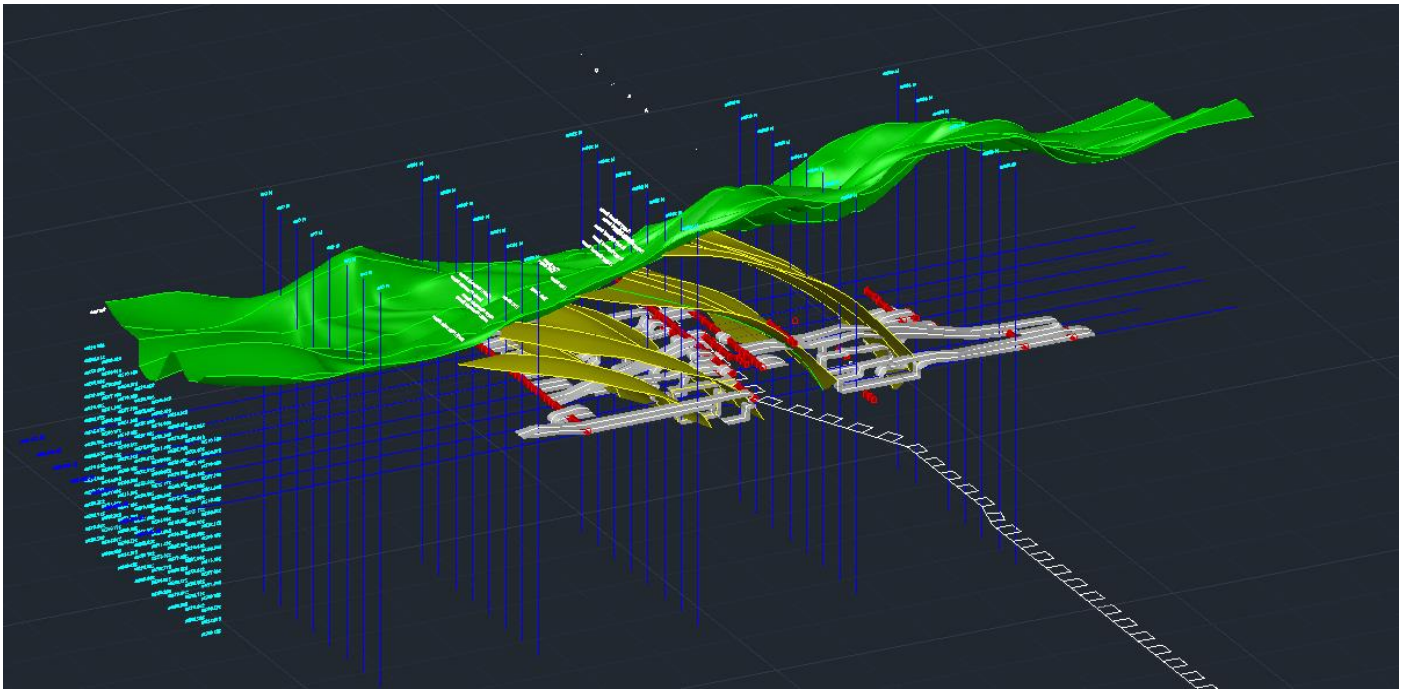


Figure 6: 3D Model of first seven chambers showing all feature of salt chambers.

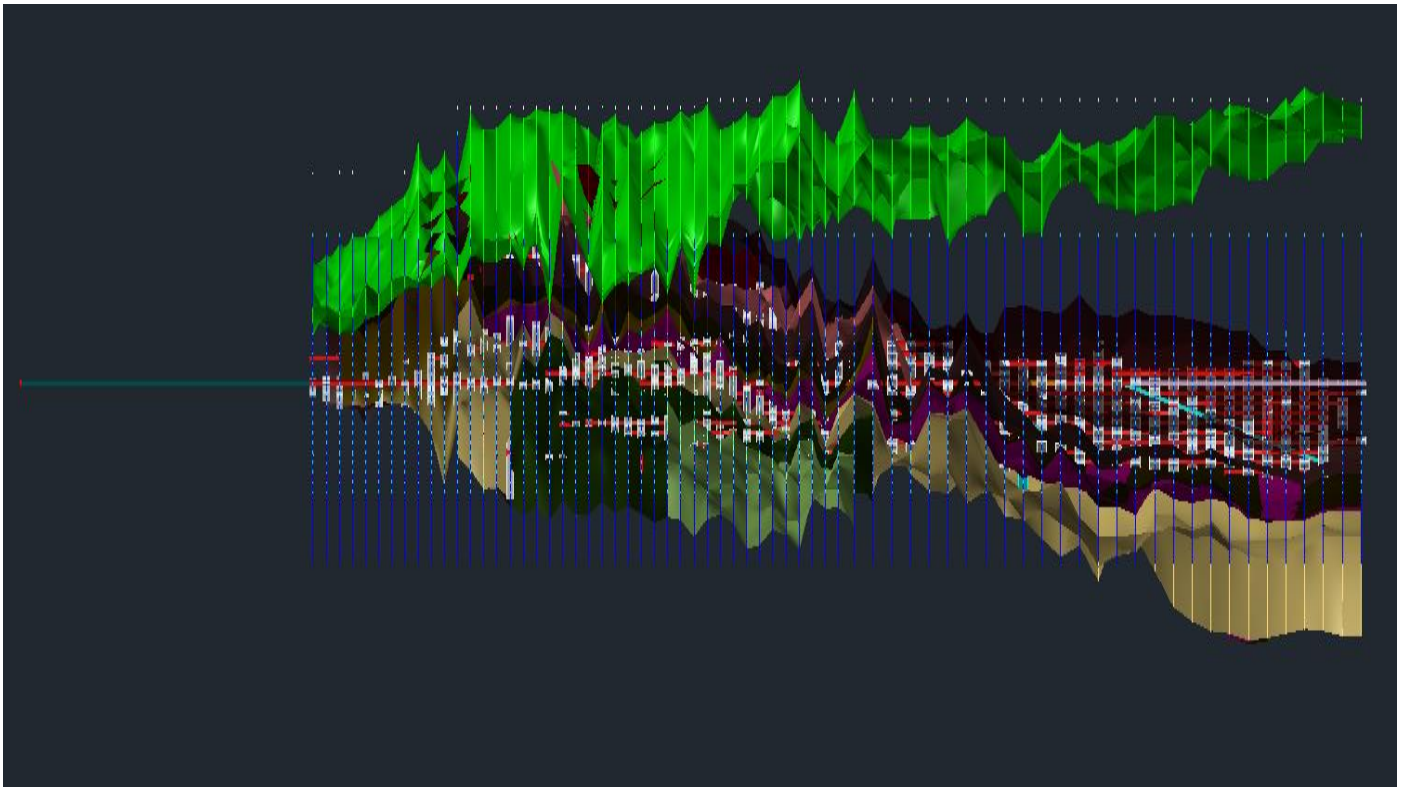


Figure 7: 3D Model showing Salt seams and surface of first seven chambers.

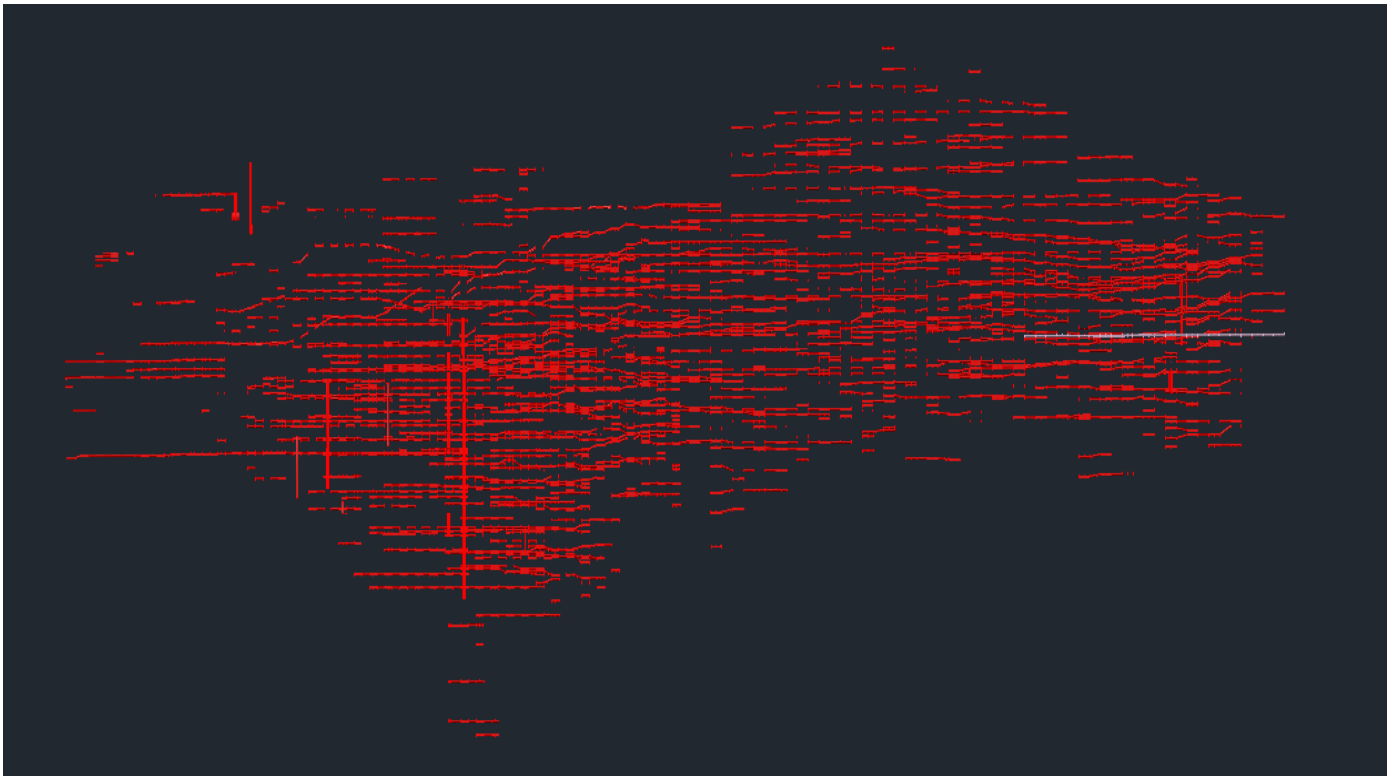


Figure 8: Top view of tunnels network in Khewra Salt Mines.

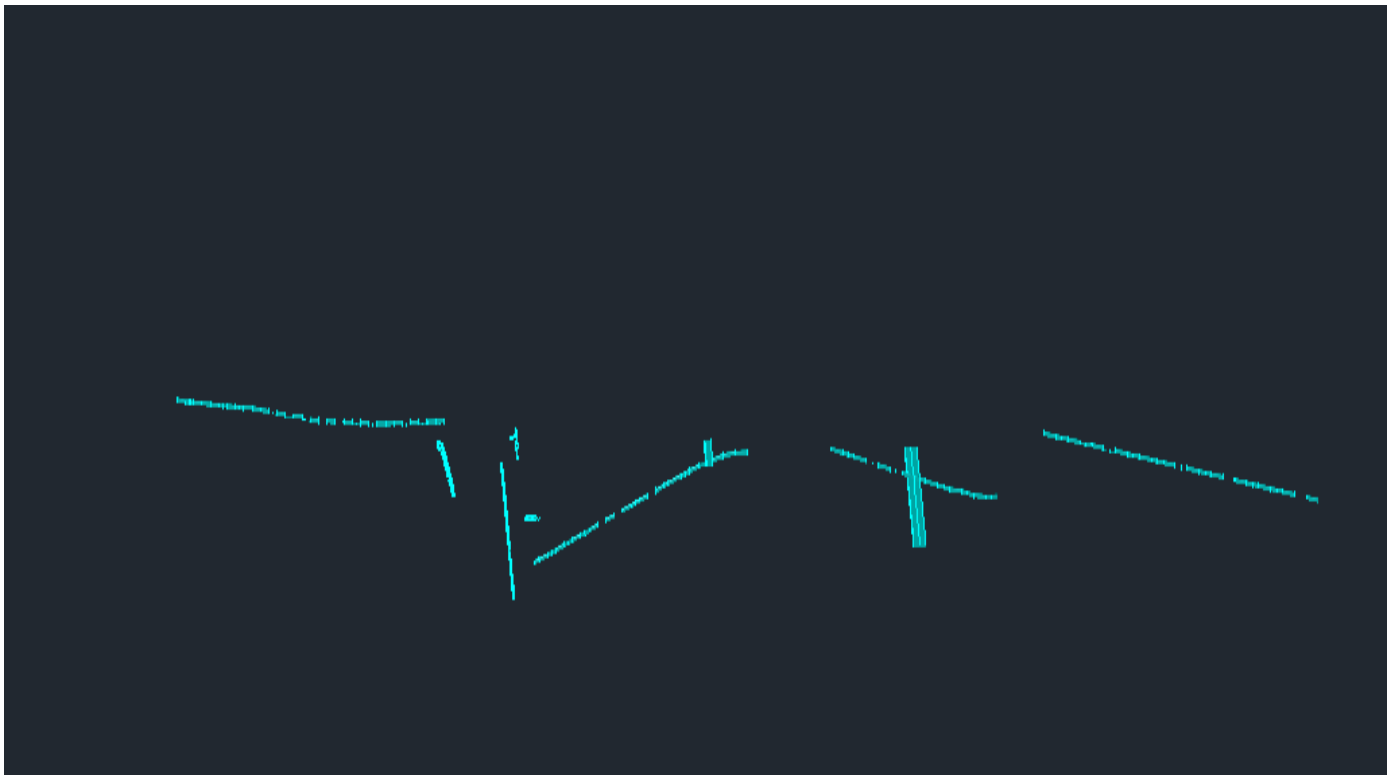


Figure 9: Oblique view of Inclines in Khewra Salt Mines.

6. CORROBORATION OF THE MODEL

3D Model generated was corroborated with the production history of the mine. The record shows a total of 21.299 million MTs production. The tonnage calculation from the 3D Model volume is 18.646 million MTs. The remaining difference is of the salt excavated from other adjacent leases like Khura, Sohal, New Mines, and Makrach, etc.

7. 3D TOPHOGRAPHIC MODELLING

3D Surface Model and topographic Modelling of Khewra Salt Mines are generated using Unmanned Aerial Vehicle (Drone), photogrammetry, and GIS software as shown in figures 10 and 11.

The ODM quality report Dataset Summary provides information of the area covered, processing time, reconstructed images, detected and reconstructed features, Average Ground Sampling Distance (GSD), reconstructed points, reconstructed components, and Geographic reference as given in figure 12. Orthophoto and Digital Surface Model generated is shown in figure 13, Feature and reconstructions details are shown in figure 14, Survey Data and Geographic reference details are shown in figure 15 while track details are shown in figure 16.

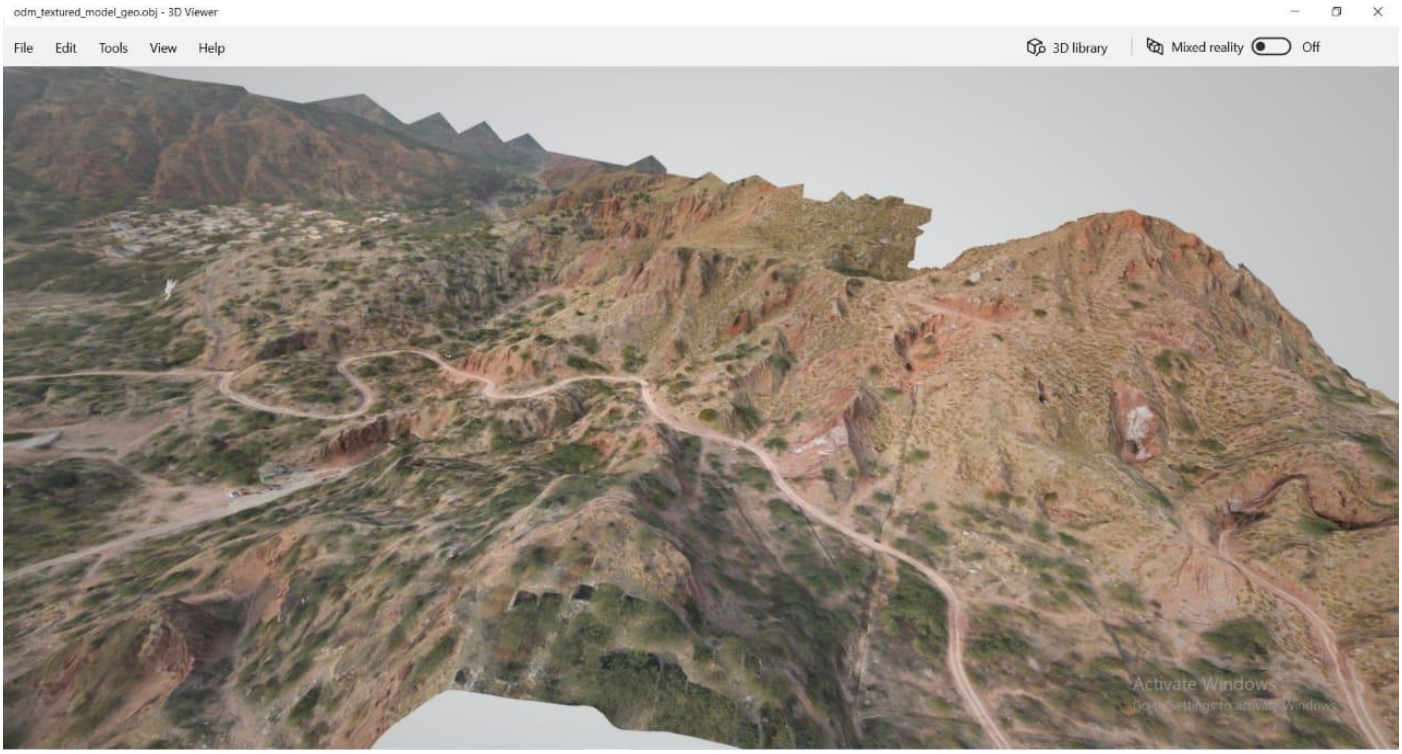


Figure 10: 3D Surface Model of Khewra Salt Mines generated using Unmanned Aerial Vehicle (Drone), photogrammetry and GIS softwares.

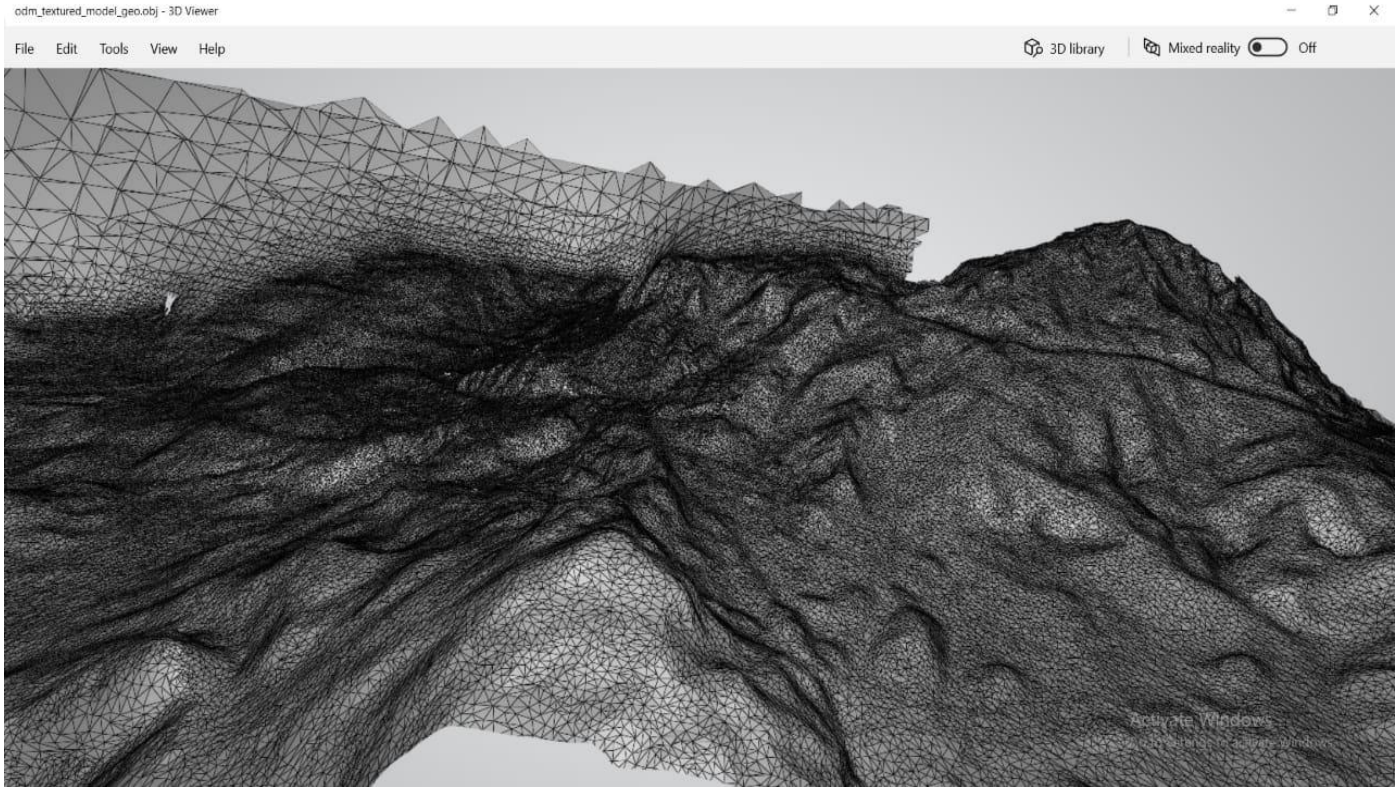


Figure 11: 3D Topographic Model of Khewra Salt Mines generated using Unmanned Aerial Vehicle (Drone), photogrammetry and GIS softwares.

Dataset Summary

Date	07/02/2021 at 20:52:09
Area Covered	0.136527 km²
Processing Time	1.0h:0.0m:0.0s

Processing Summary

Reconstructed Images	329 over 462 shots (71.2%)
Reconstructed Points (Sparse)	295866 over 1068616 points (27.7%)
Reconstructed Points (Dense)	5,304,644 points
Average Ground Sampling Distance (GSD)	3.7 cm
Reconstructed Components	3 component
Detected Features	14,800 features
Reconstructed Features	3,020 features
Geographic Reference	GPS
GPS errors	2.43 meters

Figure 12: ODM Quality Report Dataset Summary Processed with ODM version 2.4.1.

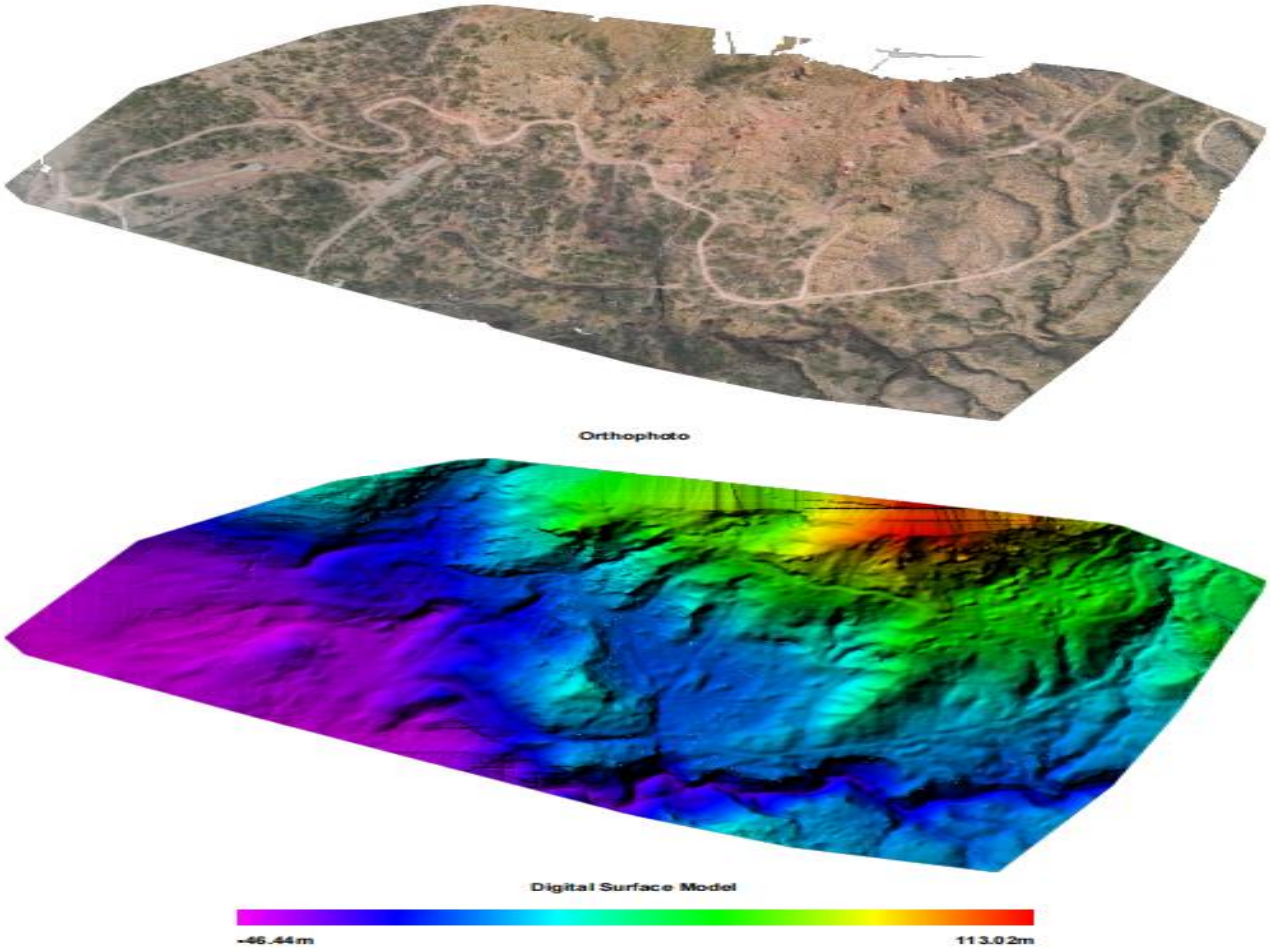
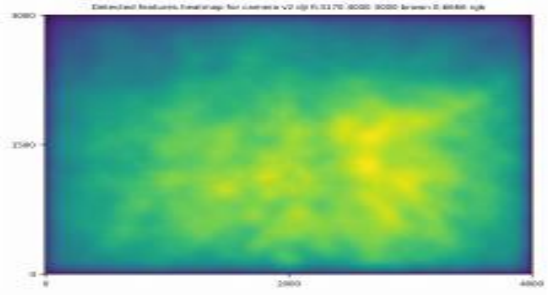


Figure 13: Orthophoto and Digital Surface Model generated.

Features Details



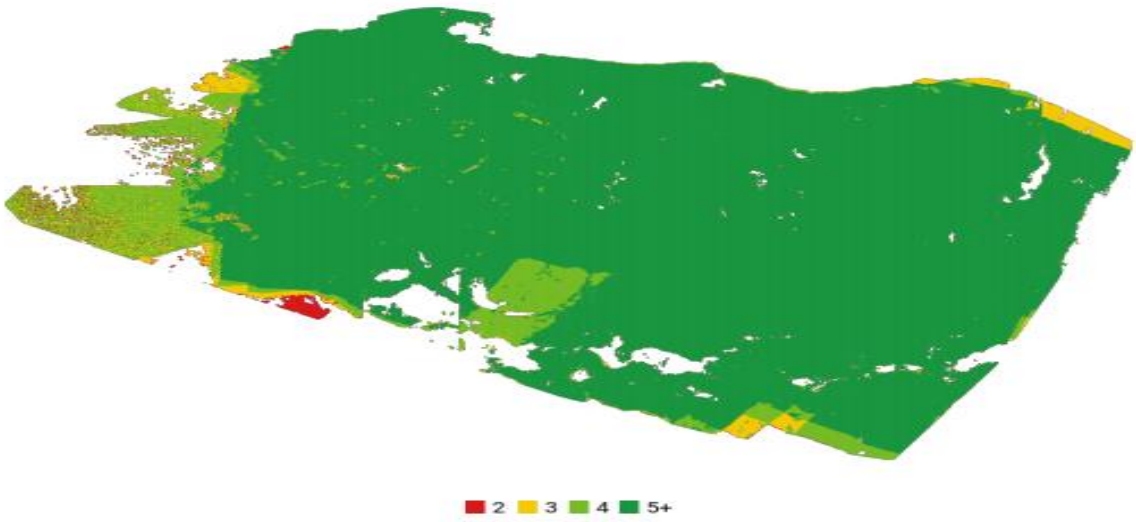
	Min.	Max.	Mean	Median
Detected	8041	27825	14552	14800
Reconstructed	13	20746	4480	3020

Reconstruction Details

Average reprojection Error	0.54 pixels
Average Track Length	4.99 images
Average Track Length (> 2)	6.61 images

Figure 14: Feature and Reconstruction details of the Digital Surface Model generated.

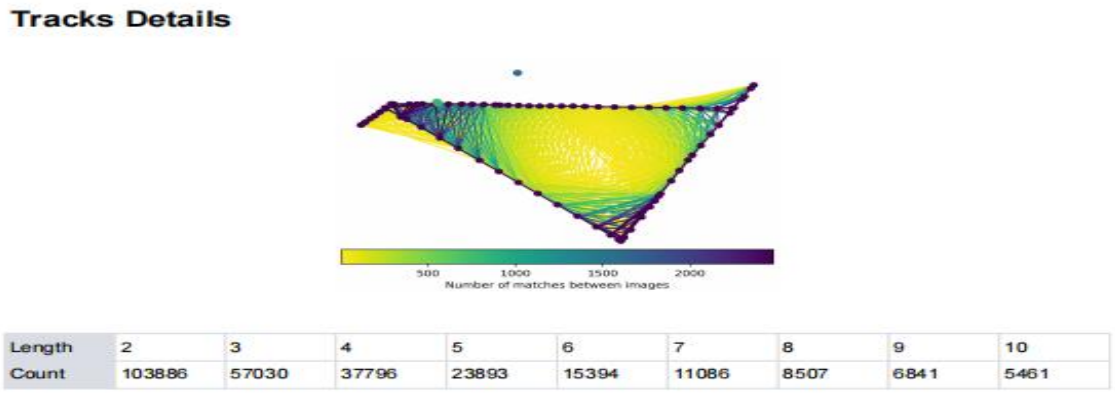
Survey Data



GPS/GCP Errors Details

GPS	Mean	Sigma	RMS Error
X Error (meters)	0.008	0.425	0.425
Y Error (meters)	-0.002	0.543	0.543
Z Error (meters)	-0.000	2.837	2.837
Total			2.434

Figure 15: Survey Data and Geographic reference details of the Digital Surface Model generated.



Length	2	3	4	5	6	7	8	9	10
Count	103886	57030	37796	23893	15394	11086	8507	6841	5461

Figure 16: Track details of Unmanned Aerial Vehicle (UAV) for generating 3D Surface Model.

CONCLUSION

i. 3D Modeling of underground room and pillar mining operations and salt seems in CAD provides a computerized mineral inventory of raw material.
ii. Mineral inventory of salt of various grades are maintained and updated as a CAD and GIS file.
iii. Production schedules for various working faces are prepared for planning and monitoring of weekly, monthly and annual progress.
iv. 3D Surface/topographic Modelling can be used for maintenance and monitoring of changes in surface topography.
v. 3D topographic Modelling can also be used for area, volume calculations, and planning of remedial actions for rainwater inundations inside the mine.
vi. Different salt seams thickness, quality, and dipping are visualized for development and future mining.

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