AI-Driven Exploration and Predictive Modelling of Critical and Precious Mineral Resources in Karnataka and Andhra Pradesh

Introducing GeoMagnus - An AI based mineral visualization and prediction platform

PROJECT REPORT

TEAM NAME: GenX H4CK3RS!

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Introduction

Problem Statement:

To Identify new potential areas for exploration of critical minerals like REE, Ni-PGE, and copper, as well as other commodities like diamond, iron, manganese, and gold within a predefined 39,000 sq. km area in the states of Karnataka and Andhra Pradesh, India.

Objectives of the study:

- Locating concealed and deep - seated mineralized bodies with depth modelling.
- Developing AI/ML Algorithms for data cleaning, integration, modelling and validation.
- Generating mineral predictive maps showing exploration targets visualized through maps, sections etc

Scope and Area of Exploration:

Total Area Covered : 39000 sq.km
States Covered:

1. Karnataka
2. Andhra Pradesh

Exploration of critical minerals such as:

1. Rare Earth Elements (REE)
2. Nickel - Platinum Group Elements (Ni-PGE)
3. Copper

Exploration for Precious and Industrial Minerals such as:

1. Gold
2. Iron
3. Manganese
4. Diamonds

Importance of Critical and precious mineral targeting:

- **Strategic Security** - Reduces dependence on foreign imports for key minerals essential in defense, electronics, and green technologies.
- **Economic Growth** - Boosts local and national economy through high-value mineral extraction, job creation, and industrial development.
- **Technological Advancement** - Supports India's clean energy and tech goals by securing essential resources for EVs, solar, and wind energy systems.

Background Research

Literature Survey and study of existing work:

- Remote sensing techniques like hyperspectral imaging are widely used to detect surface mineral signature.
- Geophysical methods (e.g., magnetic, gravity, GPR) help in locating deep-seated and concealed mineral deposits.
- GIS-based multi-criteria analysis is effective for generating mineral prospectivity maps using weighted thematic layers.
- Machine learning algorithms (Random Forest, SVM, Neural Networks) are increasingly applied for mineral prediction and anomaly detection.
- Studies emphasize the importance of integrating geological, geochemical, geophysical, and remote sensing data for better exploration outcomes.

Geological and Mineralogical overview of Karnataka and Andhra Pradesh:

	Geological Setup	**Major Belts**	**Key Minerals**
Karnataka	Dominated by the Dharwar Craton, known for greenstone belts, schist belts and granitic intrusions	• Kolar and Hutti greenstone belts • Sandur schist belt	• Gold - Hutti, Kolar • Iron and Manganese - Ballari, Sandur • Copper and PGE - Chitradurga Belt • REEs and Chromium - associated with ultramafic rocks and laterite zones
Andhra Pradesh	Encompasses Eastern Ghats Mobile Belts (EGMB) and parts of the cuddapah and Nellore schist belts	• Cuddapah basin • Eastern Ghats Belt	• Barytes - World's largest deposit at Mangampet • Gold and Copper - Ramagiri-Pendakotta belt • Diamonds - Anantapur and Krishna Districts

Data Acquisition and Processing

Types and sources of data used:

Datasets provided by GSI: (AiKosh - IndiaAI)

1. Multi-Layer Geological Map of Karnataka and Andhra Pradesh (25K Scale)
2. Multi-Layer Geological Map of Karnataka and Andhra Pradesh (50K Scale)
3. Geochronology Map of Karnataka and Andhra Pradesh
4. Geomorphology Map of Karnataka and Andhra Pradesh
5. Lineament Features of Karnataka and Andhra Pradesh
6. Geochemical Data Points of Karnataka and Andhra Pradesh (National Geochemical Mapping (NGCM))
7. Aerogeophysical Magnetic Data of Karnataka and Andhra Pradesh
8. Aerogeophysical Spectrometric Data of Karnataka and Andhra Pradesh
9. Ground Gravity Data of Karnataka and Andhra Pradesh
10. Mineral Exploration Blocks in Karnataka and Andhra Pradesh
11. Mineral Maps from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Data – Karnataka and Andhra Pradesh
12. Technical reports on mineral exploration of Karnataka and Andhra Pradesh

Geological, Geochemical, Geophysical & Remote Sensing inputs:

To achieve accurate mineral prospecting, the project integrated multi-disciplinary inputs supported by a suite of modern software tools and APIs.

Geological Inputs:

1. **GemPY** - It is used to create 3d geological models representing subsurface stratigraphy and structure.
2. **QGIS** - It helped integrating geological maps and digitizing structural features and lithological boundaries. Also helped in analysing each layer individually and also superimposing layers on others gave a clear picture.
3. **Google Earth Engine** - Enabled Cloud based processing of large satellite datasets for anomaly detection and surface feature extraction.

Geochemical Inputs:

1. **Geo-referenced Field Data** - It helped in mapping regional lineaments, faults and formations.
2. Geochemical anomaly zones and ore-grade sampling data were analyzed to identify high-potential regions

Data Science and ML software:

1. **Numpy, Matplotlib, IPython** - These serve as foundational tools for scientific computing, visualization using charts and data prototyping.
2. **SpaCy** - This assists in NLP and is used in automated literature mining and geological report parsing to extract domain - relevant entries.
3. **Prototype Learning** - To classify regions (or locations) as likely or unlikely to contain a specific mineral based on geological, geophysical, geochemical, or remote sensing data, using learned prototypes of known mineral-bearing sites

Geophysical Inputs:

1. **GPRY (Ground Penetrating Radar)** - This and other ground penetration APIs were utilized for incorporating GPR and magnetometric data to identify deep-seated anomalies.
2. Subsurface features and structures were analyzed for continuity and mineralization potential.

Remote Sensing Inputs:

1. **Google Maps** - This assisted in visualizing and geocoding exploration areas.
2. **Geemap** - Enabled access to satellite datasets (Landsat, Sentinel) for vegetation, surface mineralogy and alteration zone detection.
3. **Hyperspectral Imaging and Spectrography** - This is used for identifying surface mineral signatures based on spectral reflectance patterns.

All other inputs, references taken from research papers, articles, and GitHub repositories are added in the bibliography section at the last.

Derived Data Layers and Feature Extraction

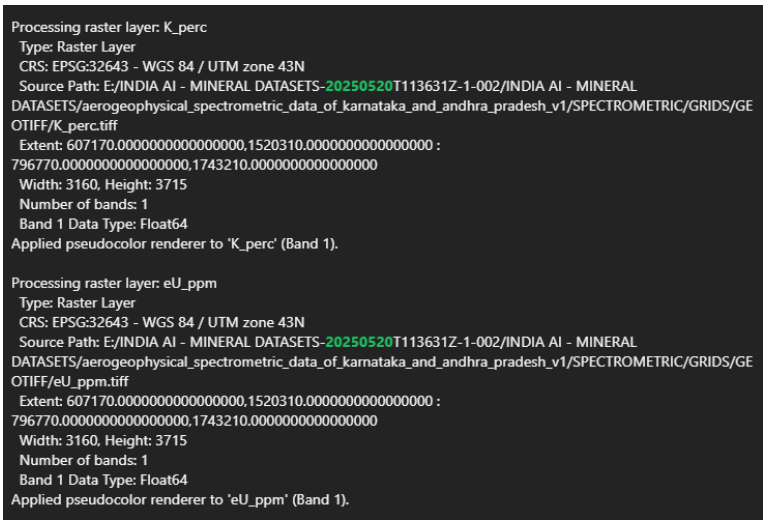
Extracted features from primary data:

Dzetsaka	The Dzetsaka plugin works in QGIS to take raster (often satellite imagery) data and uses a set of training data to build land type classifications
Python Console Plugin	Used for manipulating geospatial data and interacting programmatically through PyqGIS
QuickMapServices	A QGIS Plugin to add various map services in one click.
OpenStreetMap API	Used for editing, retrieving, or submitting map data.

Initially, data is cleaned and normalized using NumPY, Pandas etc. Using all these plugins, we try to unravel each layer provided in the dataset individually, check if it is a vector or a raster layer. We next obtain all the fields that each layer contains. We additionally get latitude/longitude, current weather data, rainfall forecast, soil moisture, elevation etc.

We next apply a pseudocolor renderer to a given raster layer, define the color, and create a new raster layer representing the Mineral Potential Index. We next create exploration target points.

The user is required to prompt a message containing the latitude/longitude and performs the environmental analysis for that particular place



Using this, we can clearly understand what each layer of the dataset is offering and what it contains.

Role and Relevance of each layer in targeting:

Vector Layers: (A few ones)

1. lithology_gcs_ngdr
   Fields: Lithological, stratigraphic, and age-related data.
   Relevance: Helps in identifying the rock types and their stratigraphic sequences, which is crucial to understand mineral host rocks and formation history.

2. Fold
   Fields: Fold type, geometry
   Relevance: Fold structures can control the structural traps for mineralization and host mineral veins along hinges or axial planes.

3. dyke_line_25k_ngdr
   Fields: Dyke type, lithology, stratigraphy.
   Relevance: Dykes often relate to magmatic intrusions and are associated with metallic mineralization like nickel, copper, and platinum group elements (PGE).

4. lineament_250k_ngdr
   Fields: Lineament descriptions.
   Relevance: Lineaments are linear features (faults/fractures) that serve as conduits for hydrothermal fluids, which are essential for many mineral deposit types.

5. lineament_form
   Fields: Basic lineament identifiers.
   Relevance: May represent processed/formalized interpretation of raw lineament data — used for structural analysis.

6. lineament_Tectonics
   Fields: Tectonic codes and descriptions.
   Relevance: Indicates tectonic stress zones, helpful in targeting regions influenced by regional geodynamics for mineral control.

7. lineament_Types
   Fields: Types of lineaments.
   Relevance: Distinguishes between faults, joints, fractures, etc., each of which has different implications for ore migration and mineral emplacement.

Raster Layers: (A few ones)

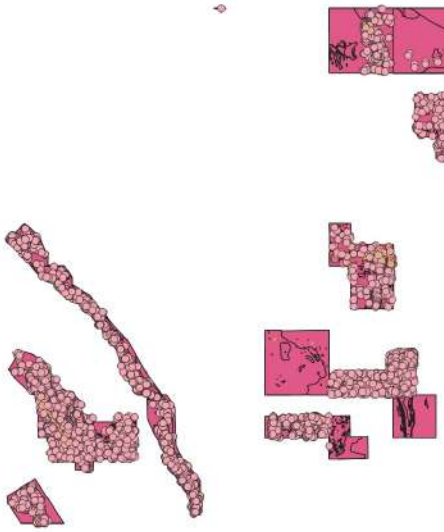
1. **`K_perc`** (Potassium concentration)
   Data Type: Float64 (Spectrometric)
   Relevance: High potassium can indicate felsic rocks, potassic alteration zones, and potential uranium/gold mineralization.

2. **`eU_ppm`** (Equivalent Uranium)
   Relevance: Key indicator for uranium exploration; can also highlight hydrothermal alterations often associated with gold and rare earth elements.

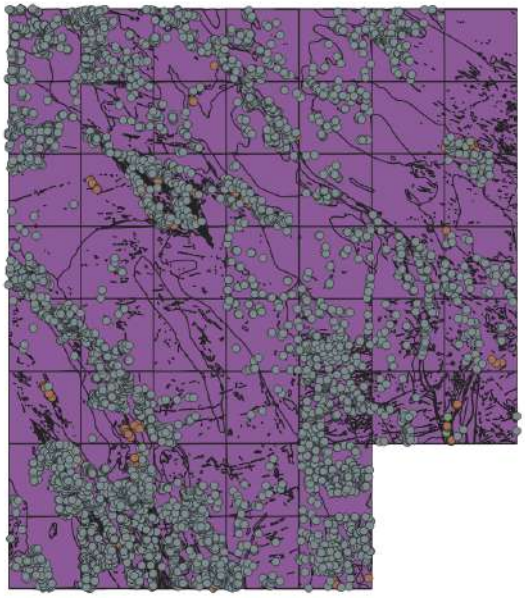
3. **`eTh_ppm`** (Equivalent Thorium)
   Relevance: Used in conjunction with K and eU to identify radioactive mineral zones, commonly linked to granites and pegmatites.

4. **`Dose_rate_TC`** (Total Count Dose Rate)
   Relevance: Aggregated radiometric reading – useful for identifying anomalous zones of radioactivity that correlate with mineralized areas.

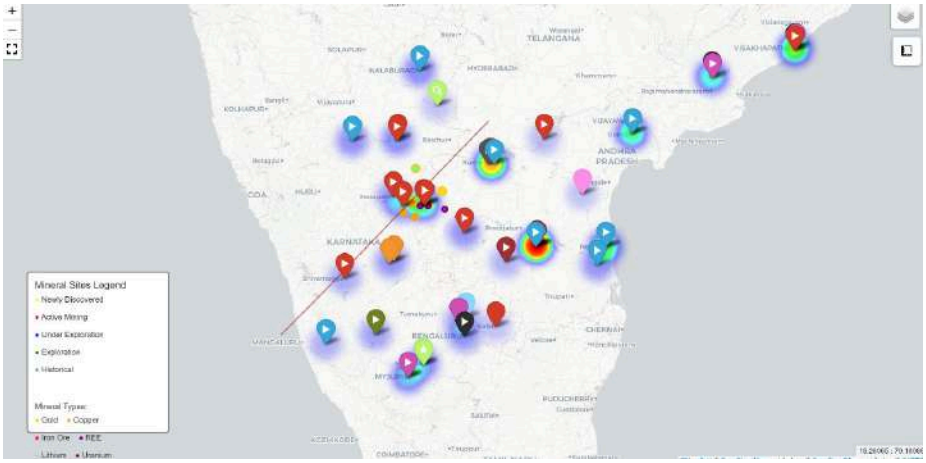
5. **`NGPM_BA`** (Gravity Anomaly – Bouguer)
   Relevance: Shows density variations in subsurface, helpful for detecting ore bodies, basement highs, and structural traps.



Superimposition of layers on QGIS (25K)



Superimposition of layers on QGIS (50K)



Mineral Potential Index showing areas for exploration of different minerals in AP and Karnataka

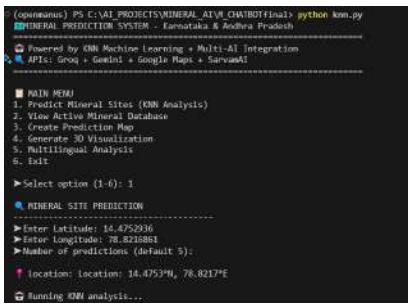
Methodology

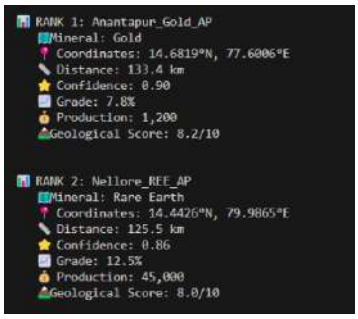
Overview of the workflow:

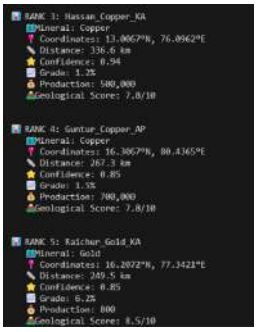
- Acquired geological, geophysical, geochemical, and remote sensing data from various sources. Cleaned and normalized raw datasets using NumPy, Pandas, and IPython. Filtered out irrelevant or noisy data points.
- Aligned spatial data using QGIS and GEE for consistent projection and resolution, extracted features from primary data and generated composite layers.
- Using XGBoost and KNN, we perform supervised learning training on these deposit locations. Data is clearly labeled as ‘Mineralized’ and ‘Non-Mineralized’ Zones, and the model predicts based on user input.
- Cross-validated predictions using known mineral belts are done and performance metrics are evaluated.
- Generated mineral prospectivity maps showing high, medium, and low potential zones are generated in 2D and 3D format.

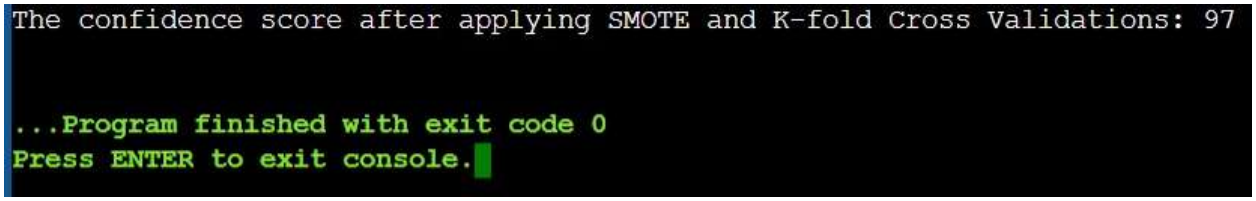
AI/ML Techniques applied:

- Resnet, Resunet, Unet, image segmentation models, efficientNet CNNs, torchgeo, Vision Transformers (ViT)
- 3dmpm, Ganomoly, Finite Difference, Piecewise Linear, RBF, diffusionSat, Gempy, Loop3d, GPRPy
- Time series forecasting models for dynamic parameter variance checks (ARIMA, RNN, LSTM)
- Raster data (.tiff, .dem, .shp) & satellite imagery analysis
- Prospectivity modelling & predictive mineral index figures analysis, identifying target activation site signatures, soil strata depth analysis through heatmaps

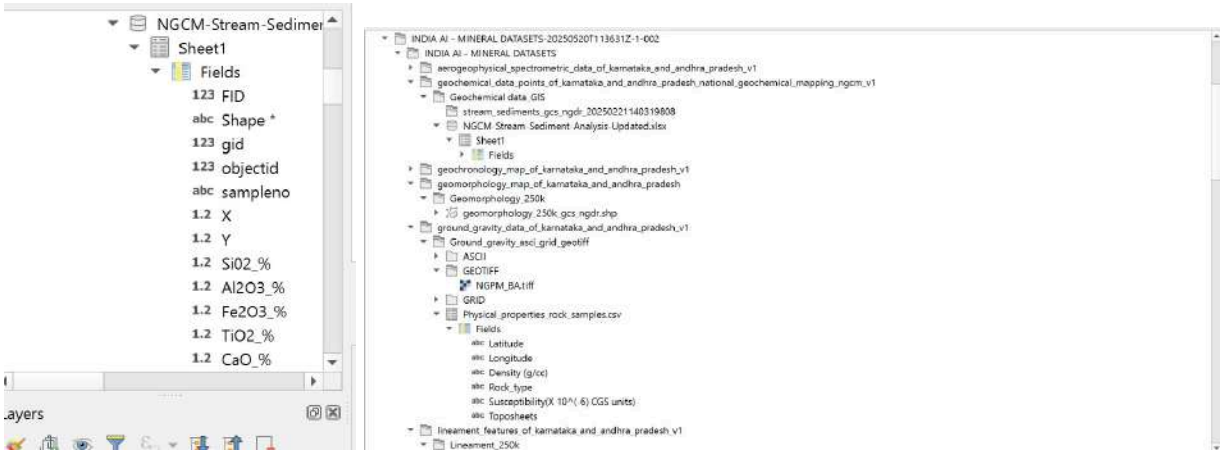






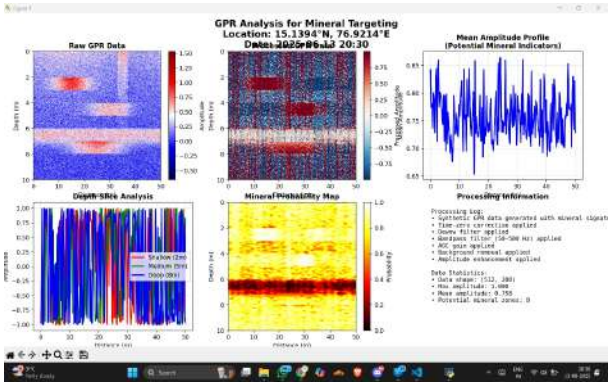


Visual Representation and Interpretation

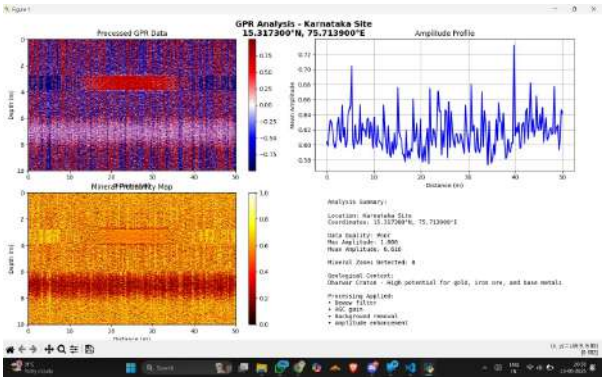


Layers extracted from the given dataset

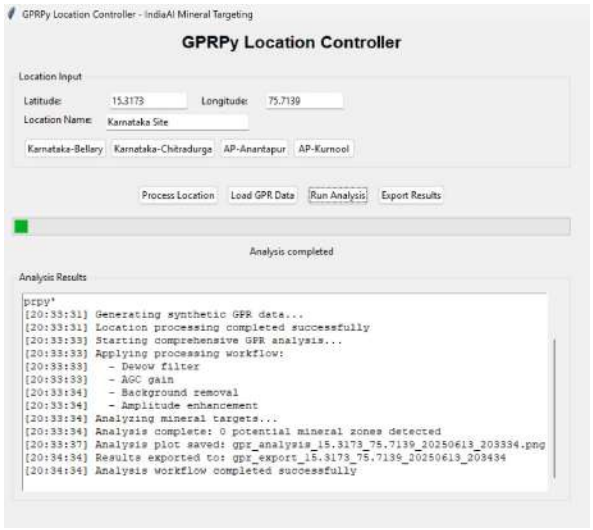
Predictivity index figures

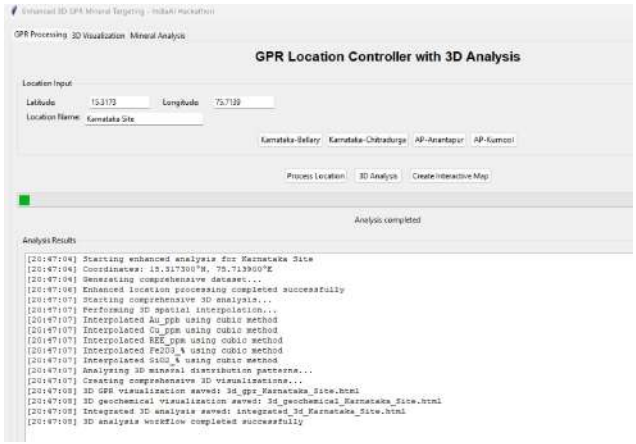


Mineral targeting site activation for a coordinate range output

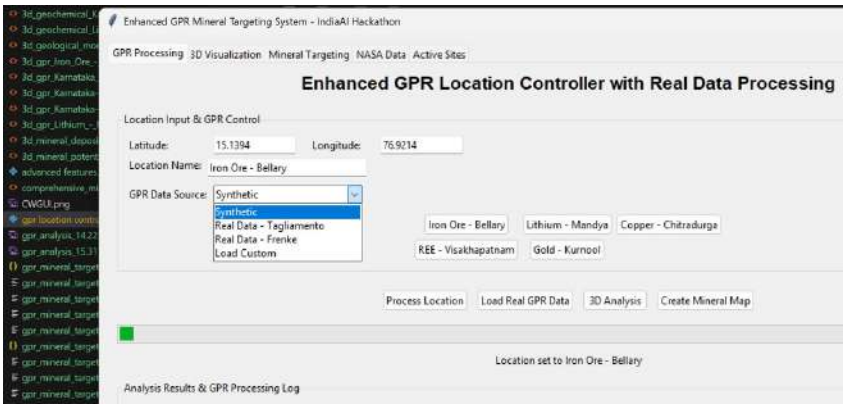


GPR data processing with ground penetration radar API

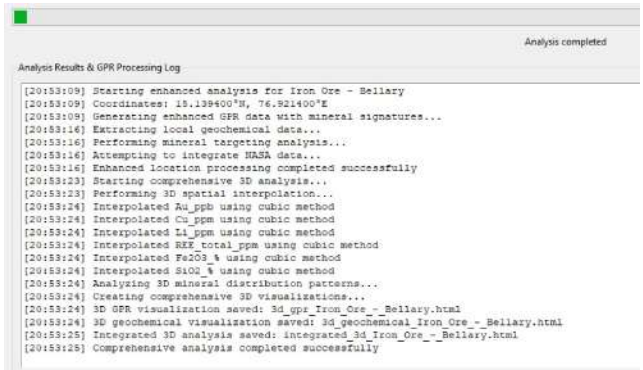


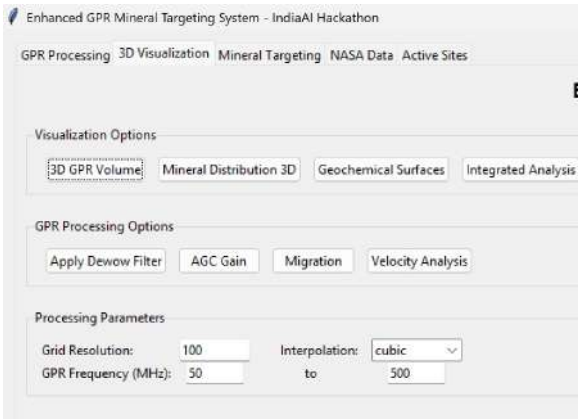


GPRPy Location Controller and 3d GPR mineral excavation load with interactive dynamic 3d html file analysis



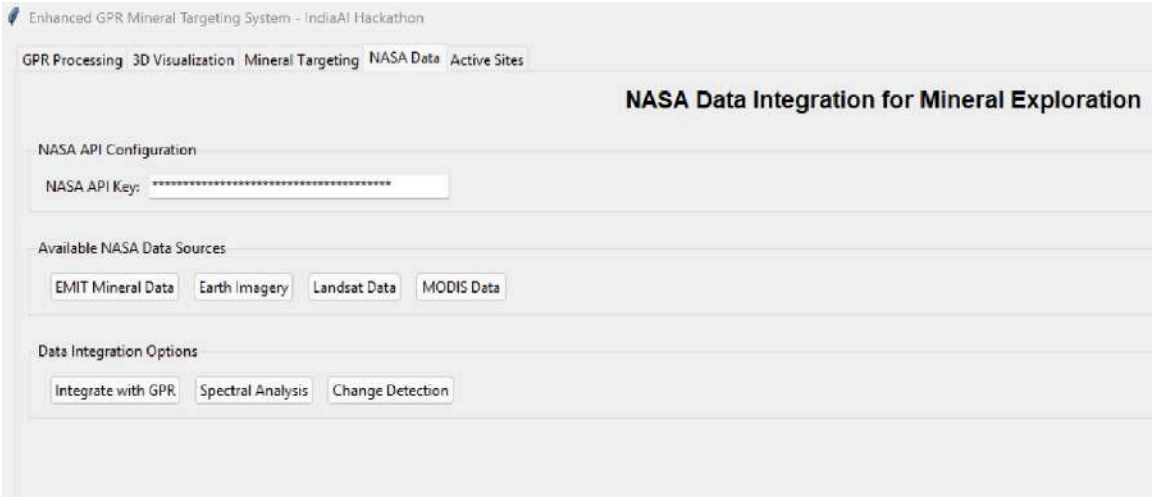
Enhanced GPR Location controller with Real Data Processing



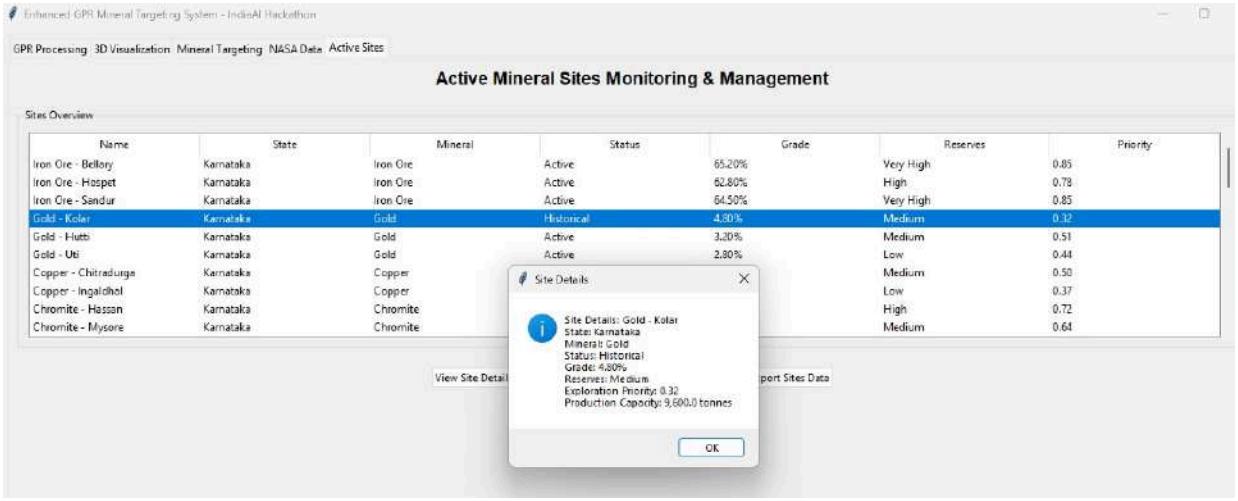


3d visualization options (customizable handling localization at a particular target site)

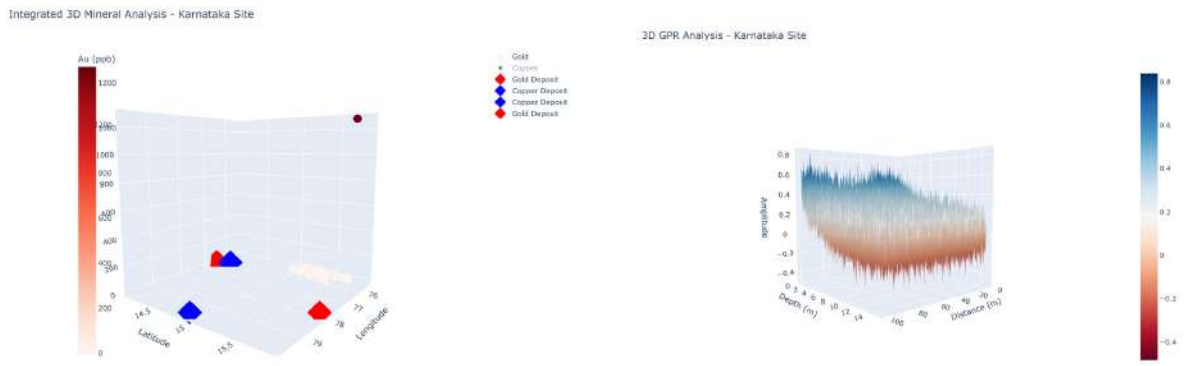
Advanced mineral targeting and geochemical analysis



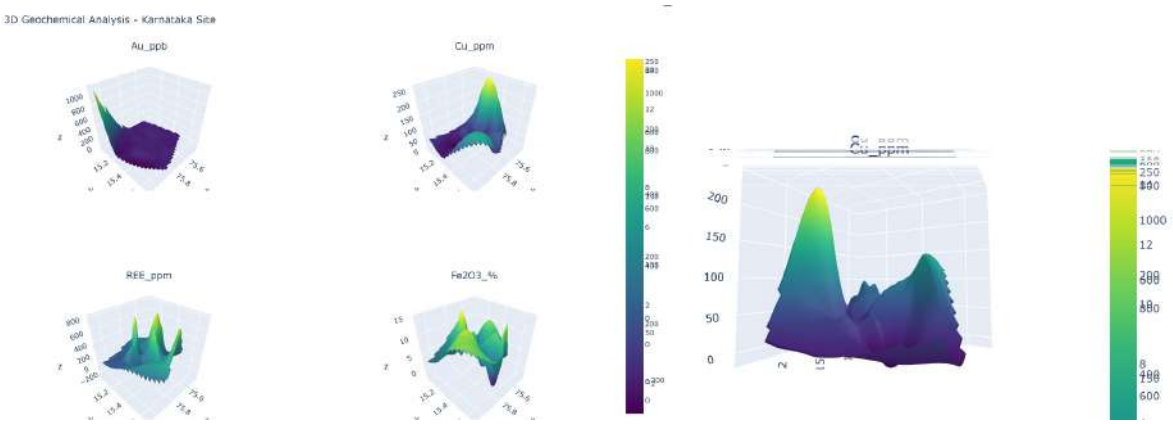
System log integration with NASA raster data and satellite imagery analysis using deep learning NASA power APIs and other models are used



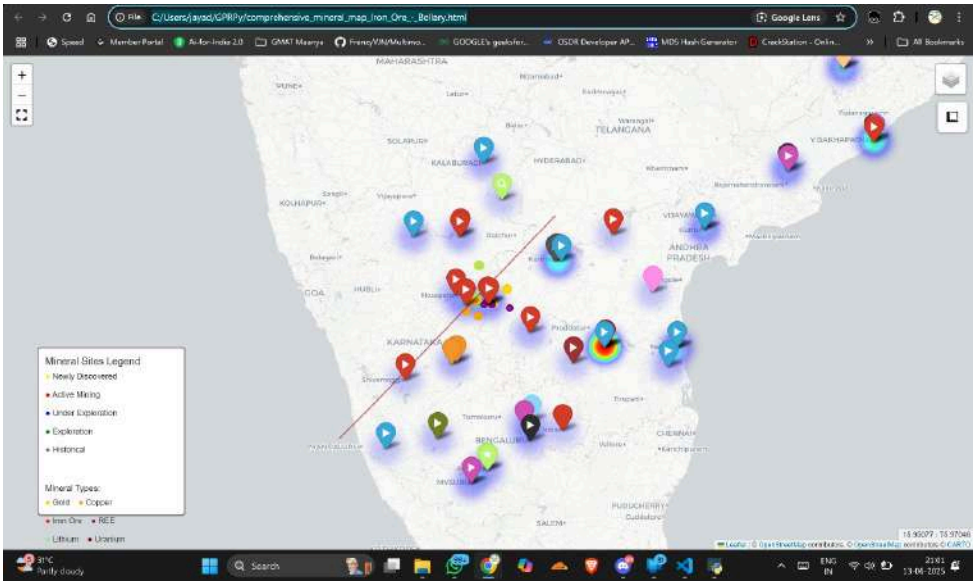
Digital twin simulation to monitor mineral signature activation and site status at custom locations



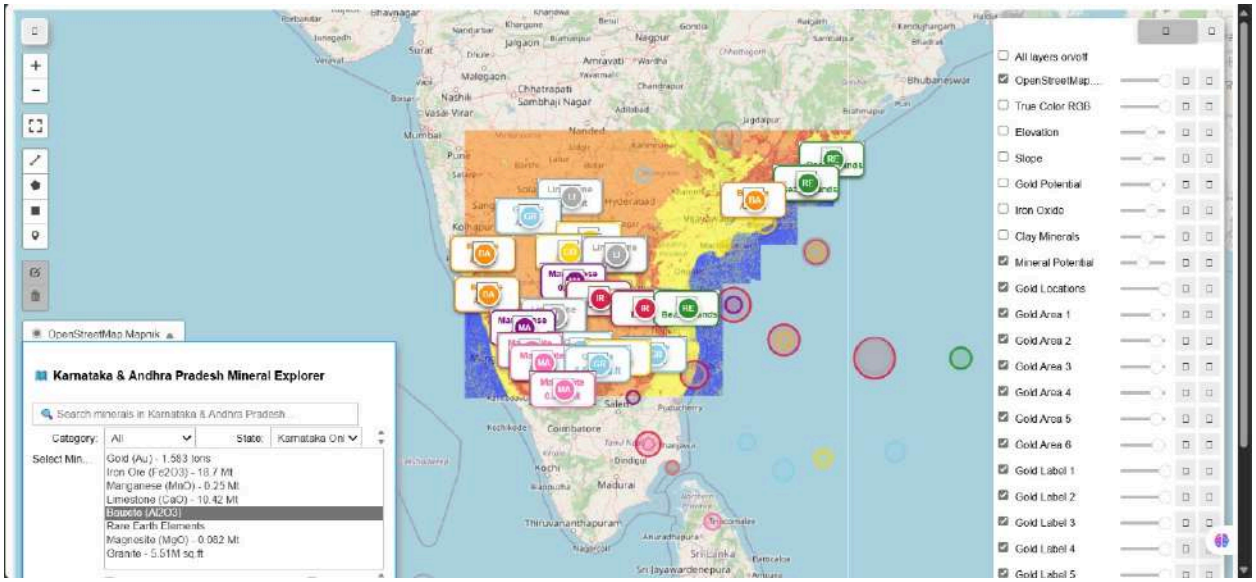
Integrated 3D Mineral analysis and 3D GPR Analysis of Karnataka



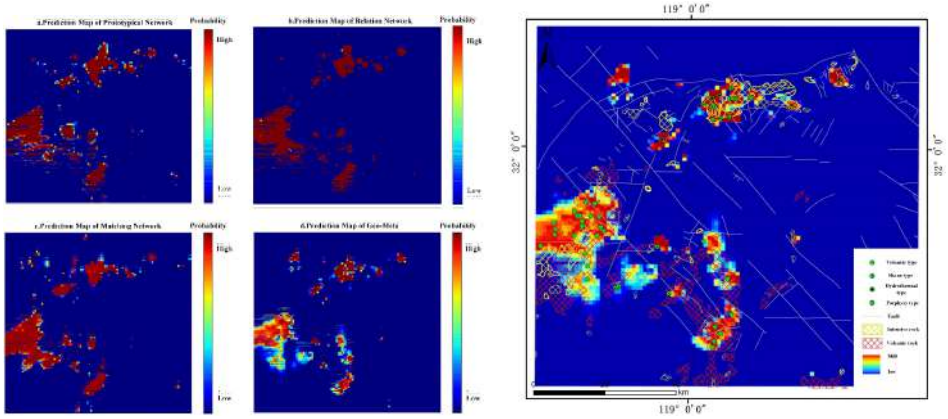
3D Geochemical Analysis and 3D visualization of copper as parts per million(ppm)



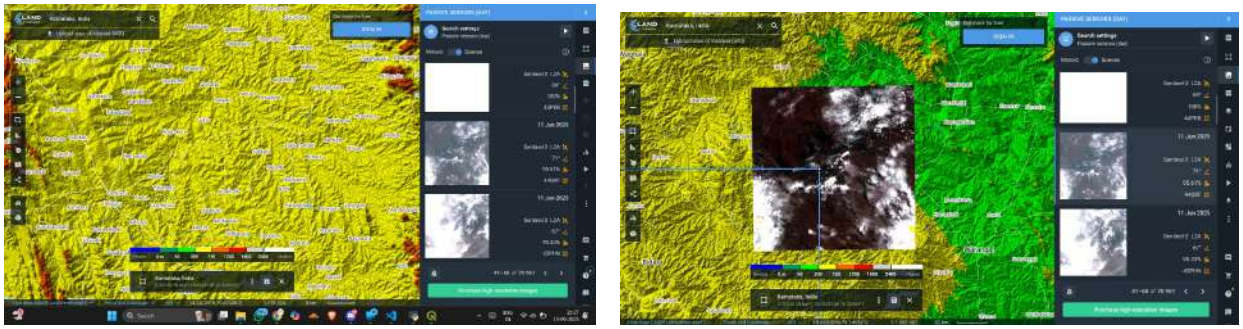
Mineral Predictivity Mapping



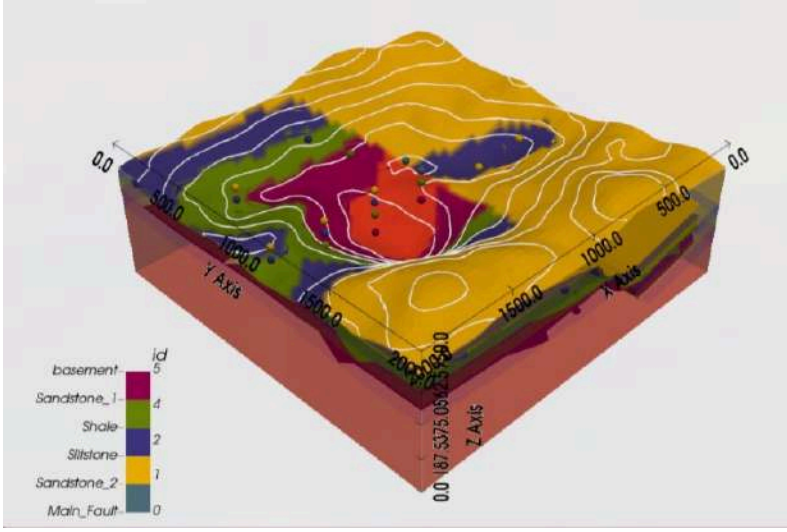
Mineral Prospectivity Mapping



Satellite view heatmap showcasing the percentage of a mineral using prototype learning

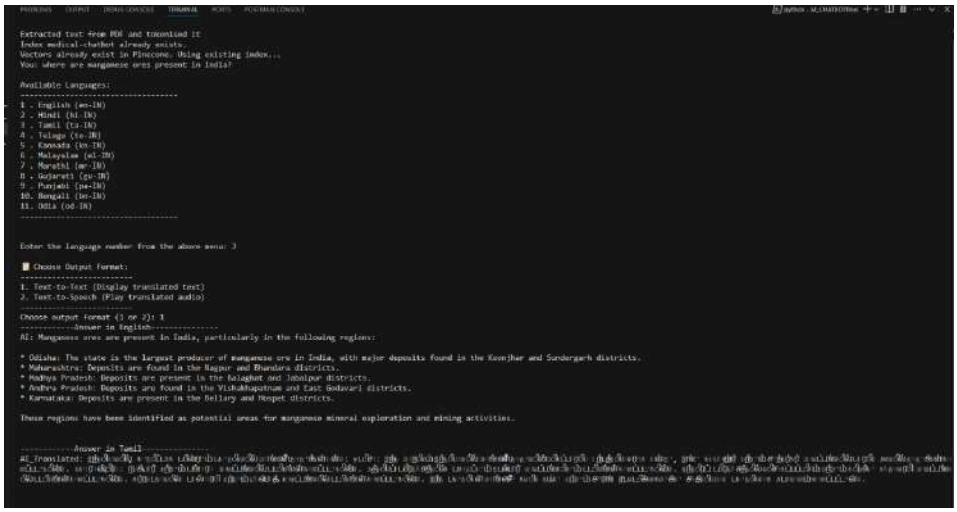


EOS landsat viewer for satellite based mineral excavation

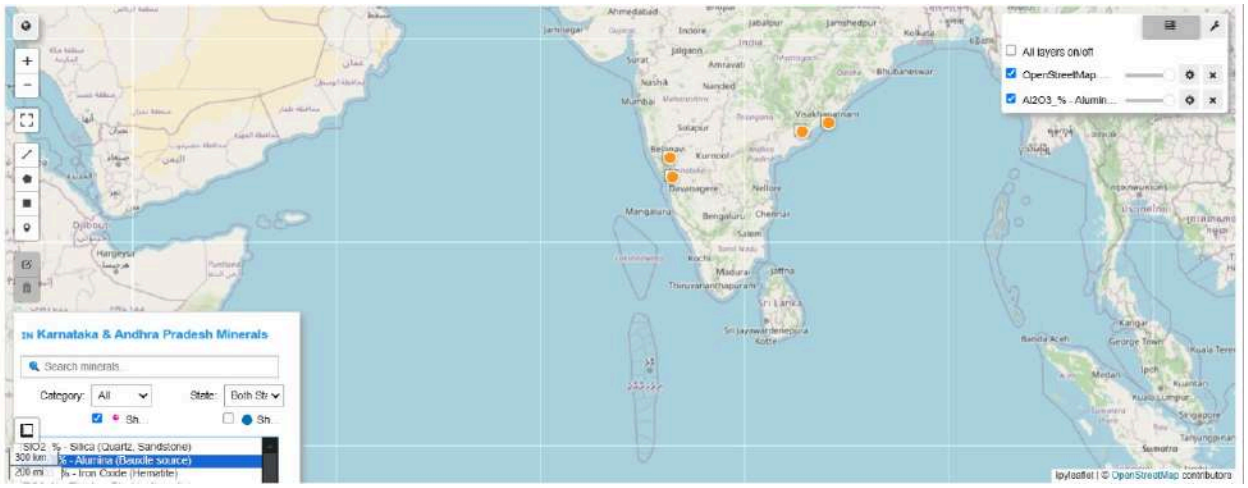


GemPy Cross Sectional 3D Mapping

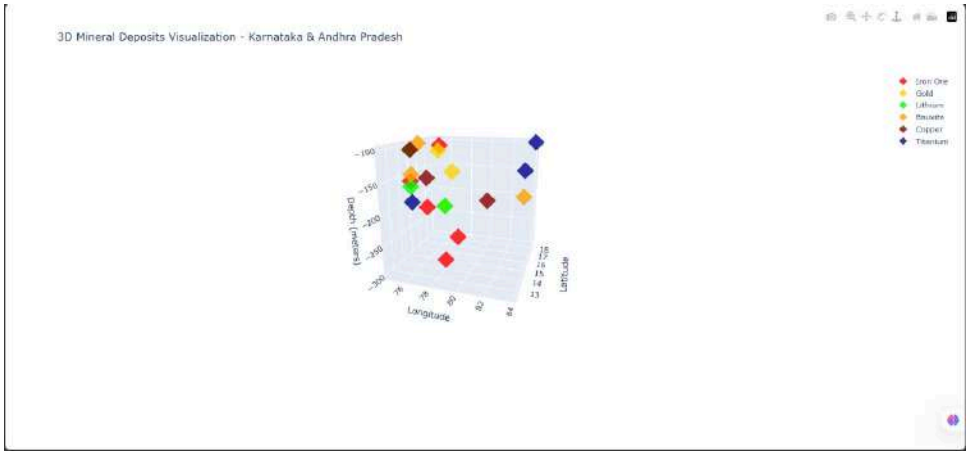
ML-Based Geological Segmentation using SegGIS



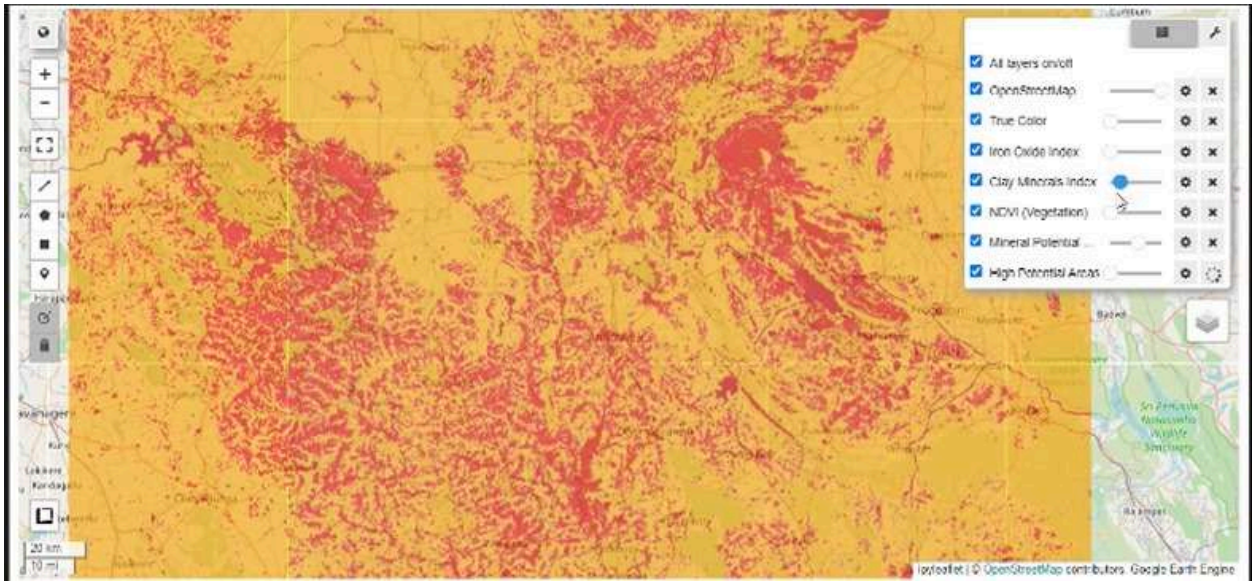
RAG based Chatbot for Mineral Analysis & Integration of Sarvam AI for multilingual translations



Mineral Toggle Bar Selection Menu



3D Mineral Deposits Visualization

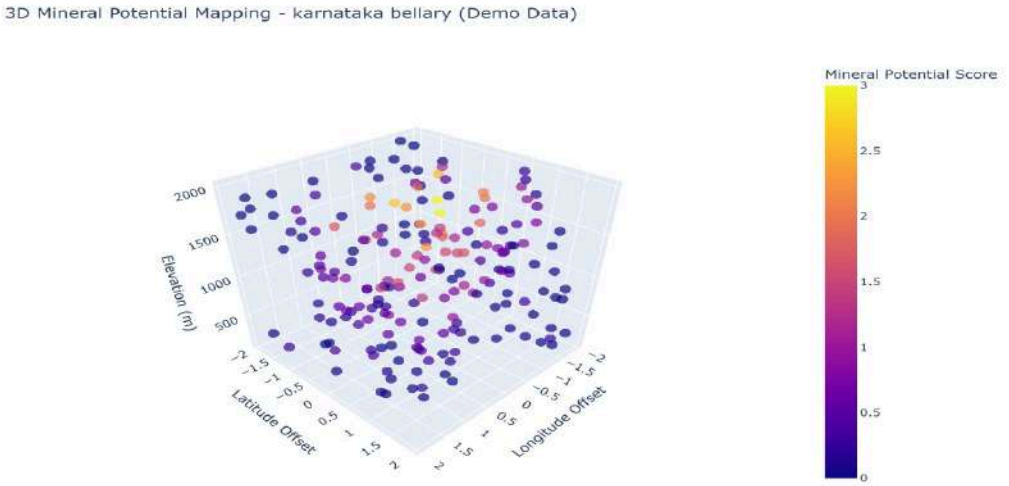


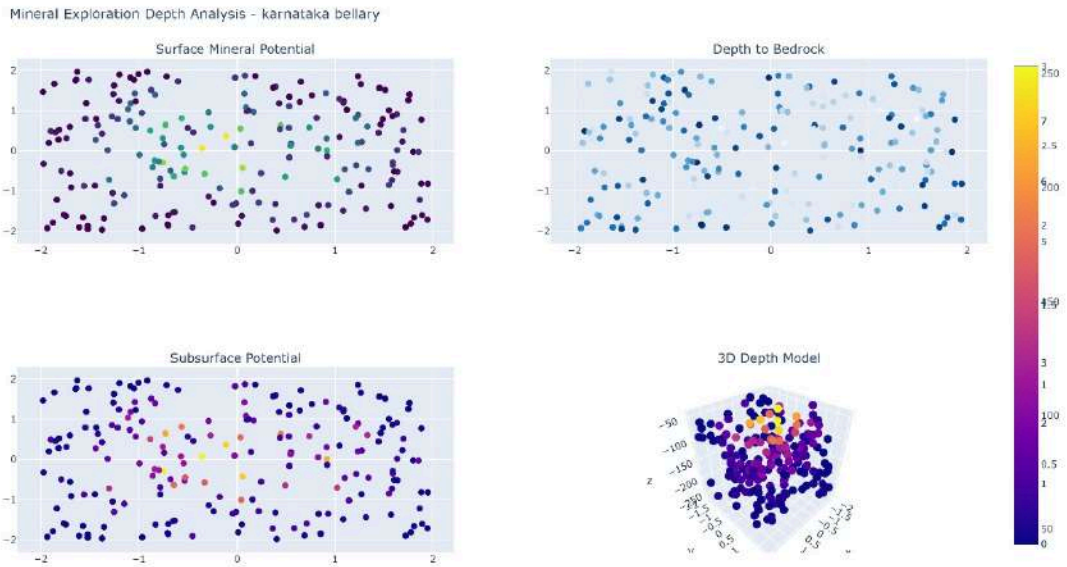
Heatmap potential index & mineral visualization mapping

Future Scope:

```
==================================================
ENHANCED GPR MINERAL TARGETING SYSTEM
IndiaAI Hackathon - Mineral Discovery Tool
==================================================
GPRPy Available: True
RGPR Available: False
SciPy Available: True
Rasterio Available: True
Active Mineral Sites Loaded: 63
Geochemical Samples: 350
==================================================
```

Mineral Depth Excavation Analysis





```
Target ID: IRON_001
Coordinates: 15.1456°N, 76.5523°E
Surface Abundance: 78.5% ± 8.2%
Predicted Depths:
- Weathered Zone: 0-35m (Goethite dominant)
- Transition Zone: 35-120m (Mixed oxides)
- Primary Zone: 120-450m (Hematite dominant)
Confidence: 87%
Drilling Recommendation: Diamond drilling to 500m
```

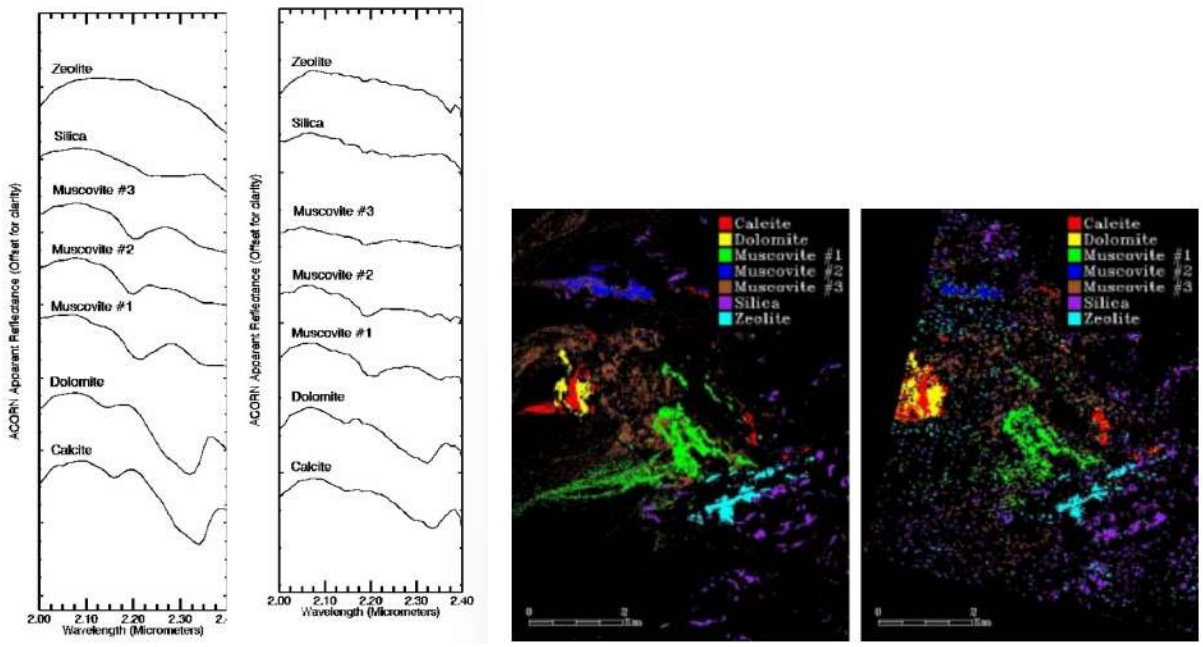
Iron

```
Sample Location: Tungabhadra River tributary
Coordinates: 15.1234°N, 76.5678°E
Depth Profile:
- 0-2m: Recent alluvium (clay-silt-sand)
- 2-8m: Older alluvium with heavy mineral concentrates
- 8-15m: Basal gravels with iron ore fragments

Heavy Mineral Content:
- Magnetite: 15-25% (0-5m depth)
- Hematite: 8-18% (2-10m depth)
- Ilmenite: 3-8% (throughout profile)
- Garnet: 5-12% (basal gravels)
- Chromite: 1-3% (scattered)

Placer Potential: HIGH
Economic Minerals: Iron ore, titanium minerals
Recommended Depth: 0-12m for alluvial mining
```

Stream Sediment Sampling Results

```
Target ID: MN_001
Coordinates: 15.1389°N, 76.5445°E
Surface Abundance: 42.3% ± 12.1%
Predicted Depths:
- Supergene Zone: 0-25m (Pyrolusite/Psilomelane)
- Hypogene Zone: 25-180m (Rhodochrosite/Braunite)
- Primary Zone: 180-350m (Spessartine garnet)
Confidence: 73%
Drilling Recommendation: RC drilling to 200m, then diamond drilling
```

Manganese



EMIT L2B Mineral Depth Analysis (Mineral Mapping with AVIRIS and EO-1 Hyperion)

Conclusion and Bibliography

This project presents a comprehensive, data-driven approach to mineral exploration across select regions of Karnataka and Andhra Pradesh. By integrating geological, geochemical, geophysical, and remote sensing data, we identified zones with high potential for critical and precious mineral occurrences, including REEs, gold, copper, and iron.

Through a structured workflow involving data cleaning, modeling, and visualization, we were able to locate both surface-level and deep-seated mineralized bodies. The generated predictive maps and 3D subsurface models offer valuable insights for further exploration and investment planning.

This methodology demonstrates how modern digital tools and multi-source data integration can significantly enhance the efficiency and accuracy of mineral targeting in complex geological terrains.

References:

1. https://github.com/RichardScottOZ/mineral-exploration-machine-learning
2. https://github.com/openlandmap/scikit-map
3. https://github.com/nkarasiak/dzetsaka/
4. https://github.com/nextgis/quickmapservices
5. https://eumap.readthedocs.io/en/latest/
6. https://gitlab.com/geoharmonizer_inea/eumap
7. https://github.com/gempy-project/gempy
8. https://github.com/cbn001012/Mineral-prediction-based-on-prototype-learning
9. https://www.iosrjournals.org/iosr-jagg/papers/Vol.%205%20Issue%204/Version-3/G0504035558.pdf
10. https://nsgeophysics.github.io/GPRPy/
11. https://ibm.gov.in/writereaddata/files/17454767536809dc9139ba8IMYB_BOOK_2023.pdf
12. https://ibm.gov.in/writereaddata/files/10012020172151RareEarth_2019_AR.pdf
13. https://ntrs.nasa.gov/api/citations/20050192448/downloads/20050192448.pdf
14. https://github.com/EarthByte/MPM_Gawler
15. https://catalog.data.gov/dataset/previous-mineral-resource-assessment-data-compilation-georeferenced-tiff-images
16. https://eos.com/products/landviewer/
17. https://www.samarkhanna.com/DiffusionSat/#:~:text=Diffusion%20models%20have%20achieved%20state,monitoring%20and%20crop%2Dyield%20prediction.
18. https://github.com/Loop3D/LoopStructural
19. https://github.com/MichaelHillier/GeoINR/tree/main
20. https://github.com/masseygeo/earthscape
21. https://github.com/PCleverleyGeol/Geological-Image-Classifier
22. https://github.com/swaxi/SGTool
23. https://github.com/javfurchu/LitMod3D_V3.1

24. https://github.com/trincadev/samgis-be
25. https://github.com/microsoft/torchgeo
26. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2009GC002391
27. https://github.com/ChengYeung1222/3DMPM/tree/main?tab=readme-ov-file
28. https://ntrs.nasa.gov/api/citations/20050192448/downloads/20050192448.pdf
29. https://github.com/nasa/EMIT-Data-Resources/blob/main/python/tutorials/Working_with_EMIT_L2B_Mineralogy.ipynb
30. QGIS documentation.