SUSTAINABLE MINING AND GEOINFORMATION

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Week – 03

Lecture 11: Exploration Mapping

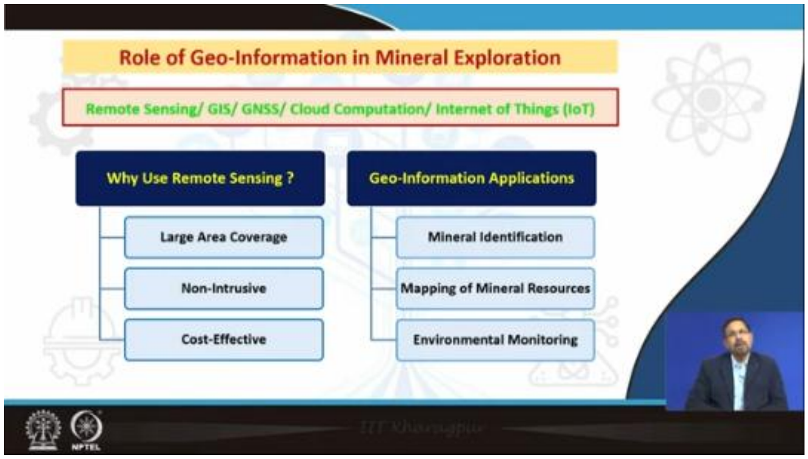
Welcome, welcome to the 11th lecture on mineral exploration. This is the 11th talk as far as the sustainable mining and geoinformation course is concerned. We will be discussing these three things. One is the applications of remote sensing, GIS, GNSS, even cloud computation and the Internet of Things, which together are regarded as geoinformation techniques. So, we will talk about geoinformation techniques for mineral exploration, and we will emphasize more on hyperspectral imaging and also take a look at airborne geophysics.

Furthermore, we will also discuss how integration with GIS techniques or GIS-derived databases helps in geological data and in identifying potential mineral deposits. Of course, we will take one or two case studies to discuss mapping ore bodies and resource evaluation using geoinformation tools as a whole. So, let us understand what we mean by exploration mapping, particularly mineral exploration mapping. Exploration mapping is defined as a set of techniques used to identify, locate, and evaluate mineral resources. This means we need to use this technology to identify where it is and how much it is.

This means once we identify and locate, we have to evaluate the strength and other parameters. This exploration mapping combines geoinformation data, geological observations, including mineral and mining-related techniques. Then, we also analyze and implement geoinformation technology over mineral-rich areas. Essentially, exploration mapping, or mineral exploration mapping, is a set of techniques used to identify, locate, and evaluate mineral resources, and it benefits from the application of geoinformation techniques. So, as far as the importance in mining goes, the location of mineral deposits is very important, as is appropriately minimizing the environmental impact.

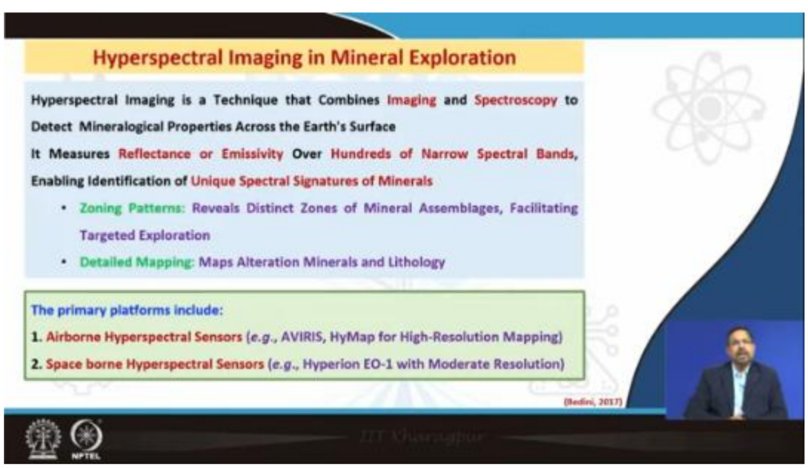
So, in exploring this mineral deposit or wherever, how much is present. So, in this course, we need to minimize the environmental impact. So, geophone technologies also help us in contributing to this aspect of minimization as far as the environmental impact is concerned in exploration mapping. So, exploration mapping is integral to sustainable mining because it enhances precision, and with high precision, we can do the exploration and mapping. It also minimizes the exploration cost because ground-based activities mean exploration costs are higher than satellite or geoinformation-based technology-related costs.

It also reduces the environmental footprint. So, how much disturbance you are causing to the environment in terms of exploration mapping is very well reduced by the application of geo-enforced technology. So, in a sense, if we use geo-enforced technology for mineral exploration mapping, we are practicing sustainable mining principles. Now, coming to the role of geoinformation in mining or mineral exploration. As we have already discussed in the last two weeks over 10 classes, the potential of remote sensing in terms of different data.



Optical, microwave, lidar, and the integration platform that is the geographic information system, abbreviated as GIS, and also the global navigation satellite system, GNSS. And in the last two classes, we discussed cloud computing and the Internet of Things. So, all these together have a definite role to play in mineral exploration. As far as remote sensing is concerned, it enables us to provide data over a larger spatial scale and it operates in a non-intrusive mode. We do not dig into something or so; it is mostly a surface phenomenon, and we get the information from the satellite, which is hundreds or thousands of kilometers from our surface.

And it is very, very cost-effective in comparison to ground-based exploration. This satellite-based or remote sensing-based exploration is very, very cheap. Now, in terms of the application using geo-enforced technology, yes, it helps in mineral identification, mapping of mineral resources, and thereby environmental monitoring. Let us take a look at hyperspectral remote sensing or hyperspectral imaging. Hence, we have not discussed it much in our previous classes because we have kept it reserved to discuss in this particular class of the 10th lecture, sorry, the 11th lecture.

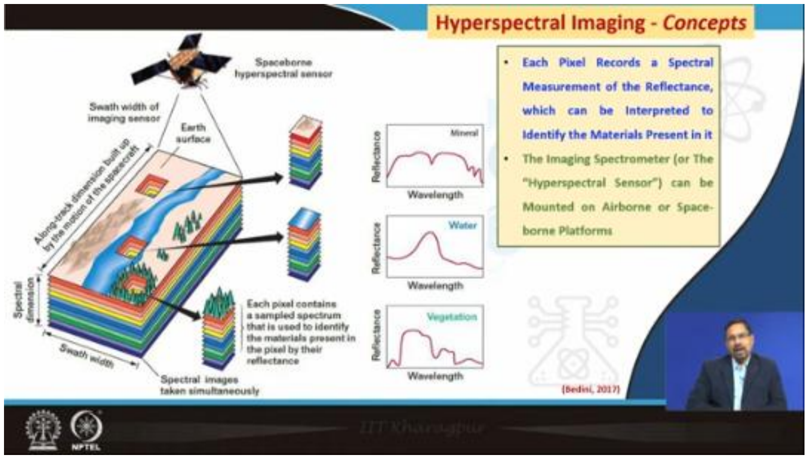


So, if you can see, hyperspectral imaging is a technique that combines imaging and spectroscopy. So, it combines imaging and spectroscopy to detect mineralogical properties across the Earth's surface. So, that means it measures reflectance or emissivity over hundreds of narrow spectral bands. So, we discussed the electromagnetic spectrum, which we study in order of increasing wavelength, from cosmic rays, gamma rays, and X-rays. Then, ultraviolet, visible, and we have the infrared, microwave, and the radio wave regions.

So, within the electromagnetic spectrum, where the spectroscopy or imaging is done using this hyperspectral or any remote sensing sensor, in the case of hyperspectral, we are using hundreds of narrow spectral bands because these hundreds of narrow spectral bands enable the identification of unique spectral signatures, which are coming from different minerals. So, that means the characteristic spectral reflectance curves can be very well distinguished from each other if we go for hyperspectral imaging with hundreds of narrow spectral bands, and that is how it serves as a step ahead in terms of advantages in discriminating between and among minerals in contrast to multispectral remote sensing. So, let us talk about these two in terms of zoning patterns and detailed mapping.

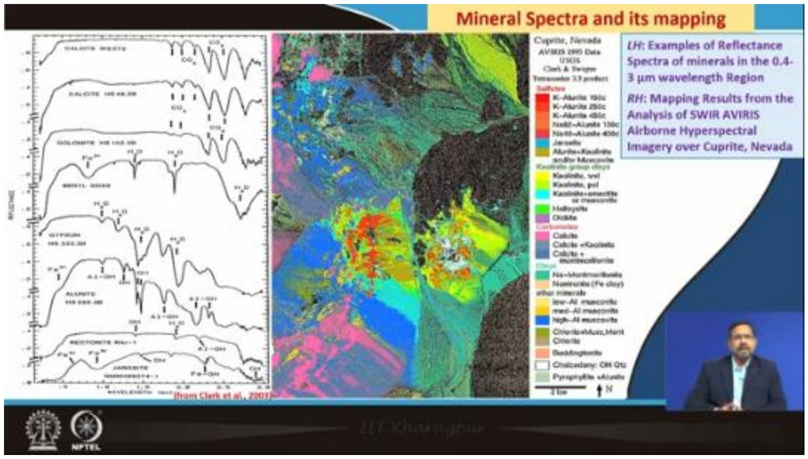
In zoning patterns, distinct zones of mineral assemblages are revealed, facilitating targeted exploration. So, this is how we find out a distinct pattern of mineral assemblages; different places have different assemblages. This enables or facilitates us to explore minerals in a targeted mode. Now, in terms of detailed mapping, we produce maps in terms of minerals and their lithology. So, that is how detailed mapping differs slightly from the zoning pattern.

So, the primary platforms, as far as hyperspectral imaging is concerned, include AVIRIS, which is an airborne platform, and HIMAP, also an airborne platform, offering very high-resolution mapping up to 4 meters on the ground. Whereas some of the space-borne hyperspectral sensors are Hyperion EO Earth Observation 1, which have a moderate spatial resolution. So, let us see this in terms of a demonstration or depiction; we can observe how narrow spectral bands give different types of spectral reflectance for the same object. Across the electromagnetic spectrum. So, this particular picture gives us a very clear understanding of how it happens.



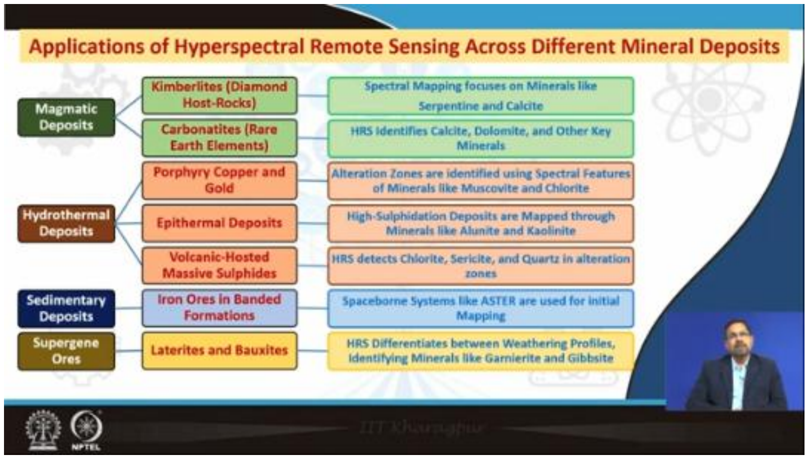
So, now look at the reflectance for mineral, water, and vegetation. The smooth curves are derived from the data or the spectral reflectance in terms of digital numbers captured by the hyperspectral sensor. So, the point I wanted to mention is that the smooth curve can only be achieved if we have more than hundreds of data points, which then join to give us a smooth spectral reflectance curve. So here, the upper spectral reflectance curve for minerals is so distinct from that of the other two, water and vegetation, at different parts of the electromagnetic spectrum. So, that is actually the beauty.

So, each pixel records a spectral measurement of the reflectance, which can be interpreted to identify the materials present in it. That means the imaging spectrometer, or we call it the hyperspectral sensor, can be mounted either on an airborne platform or on a space-borne platform, including satellites. Let us have a look at a few minerals, particularly calcite on the left-hand side, dolomite, beryl, gypsum, alunite, and rectorite. And correspondingly, the map which has been prepared using these mineral spectra over a region, as given by Clark et al. in 2003. So, if you have a look at the map, you will very well see that the sulfates in terms of variations in 1, 2, 3, 4, 5, 6, 7, 8, and the kaolinite group clays having



3 plus 2, 5 different variations, the carbonates having 3 variations of calcites, the clays, and other minerals could be very well separated, identified, and mapped using hyperspectral imaging. So, the examples of these spectra vary between 0.4 to 3 micrometers in wavelength region. And on the right-hand side, we have shown the mapping results from the analysis of shortwave infrared average airborne hyperspectral imagery from Nevada. It is a site in the USA. So, the point is very clear that over a small region, using hyperspectral imaging, we can identify and map different minerals using mineral spectroscopy or the reflectance spectra corresponding to different minerals.

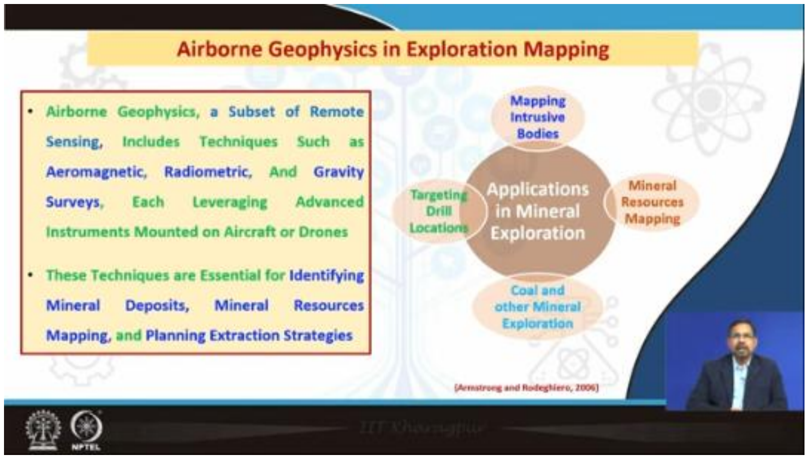
Let us try to put them together in terms of the applications of hyperspectral remote sensing across different mineral deposits. So, the magmatic deposits, the hydrothermal deposits, sedimentary deposits, and supergene ores. So, as far as the magmatic deposits are concerned, we can have the kimberlites and examples like diamond host rock type, the carbonatites, and rare earth elements. So, for this, the spectral mapping focuses on minerals like serpentine and calcite, whereas in terms of hyperspectral remote sensing, it identifies HRS, calcites, dolomites, and other key minerals. With respect to the hydrothermal deposits such as porphyry, copper and gold, epithermal deposits, volcanic-hosted massive sulfides, we can have alteration zones identified using spectral features of minerals like muscovites and chlorides.



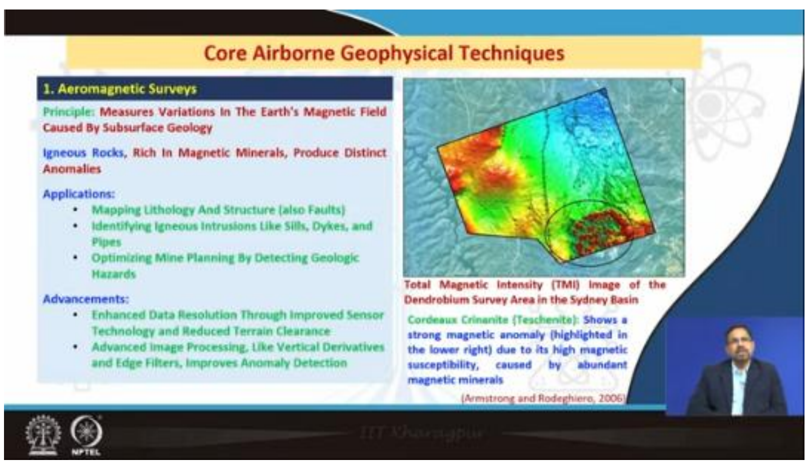
For epithermal deposits, High-sulphidation deposits are mapped through minerals like alunite and calonite. For volcanic-hosted massive sulphides, HRS detects chlorides, sericite, and quartz in alteration zones. Let us have a look at the sedimentary deposit, which could be having iron ores in banded So, space-borne systems like ASTER and other datasets are useful for initial mapping to come out with the sedimentary deposit having iron ore banding.

Then, coming to supergene ores having laterites or bauxites, HRS differentiates the hyperspectral remote sensing. It differentiates between weathering profiles, thereby identifying minerals like geronitites and gypsite. So, these are some of the broad, or you could say handy tips, on how you differentiate using hyperspectral remote sensing as far as magmatic, hydrothermal, and sedimentary deposits are concerned, including the supergene ores. So, let us go to the next component. So, we learned about hyperspectral.

Let us talk about another technique, that is airborne geophysics applications or utility in exploration mapping. Airborne geophysics is a subset of remote sensing that includes techniques such as aeromagnetic, radiometric, and gravity surveys. So, the techniques, particularly aeromagnetic, radiometric, and gravity surveys, each leverage advanced instruments mounted on either aircraft, drones, UAVs, or manned aerial vehicles. So, these techniques, particularly these airborne geophysics techniques, are essential for identifying mineral deposits, mineral resource mapping, and planning extraction strategies. So, we can put them like mapping intrusion bodies, coal, and other mineral exploration.



Mineral resources mapping and also targeting drill locations. So, this has been taken from Armstrong and Ruggiero, published in 2006. So, let us see the aeromagnetic survey as far as core airborne geophysical techniques are concerned. The principle applied here is that it measures variations in the Earth's magnetic field caused by subsurface geology. So, the variation in the Earth's magnetic field is measured.



In terms of igneous rock, which is rich in magnetic minerals, it produces distinct anomalies. So, that is how the aeromagnetic survey has applications such as mapping lithology and structure, also the faults, identifying igneous intrusions like sills, dikes, and pipes, and optimizing mine planning by detecting geologic hazards. But let us also have a look at the advancements. Hence, the advancements are enhanced data resolution through improved sensor technology and reduced terrain clearance.

And also advanced image processing like vertical derivatives and edge filters that help in improving anomaly detection. As far as the right-hand side, upper right-hand side image is concerned, you can see the aeromagnetic survey or the Total Magnetic Intensity (TMI) image of a Dendrobium survey from the basin area in Sydney, Australia. So, look at the rounded area where little dark red color features are shown very clearly. So, this area shows a strong magnetic anomaly which is highlighted in the lower right portion because this strong magnetic anomaly is due to its high magnetic susceptibility caused by abundant magnetic minerals. Look how clearly this is shown, which gives evidence of deposits as far as magnetic minerals are concerned.

Let us also understand what a radiometric survey is and what airborne gravity techniques are. So, the principle of a radiometric survey is that it detects gamma radiation emitted by radioactive elements like uranium, thorium, and potassium in surface rocks. So, this is the key principle as far as the radiometric survey is concerned: it detects gamma radiation. So, the applications include mapping lateral changes in surface geology and mineral resources, which means mapping alteration zones or using both means, all of which have utility in the mining sector. The advantages are that it is also like satellite remote sensing.

It is also a non-invasive technique that complements aeromagnetic data. So, it complements because, in terms of aeromagnetic data, it is based on magnetic behavior. This one is based on radiometric surveys, which are based on gamma radiation. So, both of them can be complementary to each other. With additional knowledge, you get more information over the same area as far as mineral resource mapping is concerned.

So, the principle of the airborne technique is that it measures changes in Earth's gravitational fields due to density variations in subsurface geology using gravity gradiometers, thereby having a lot of potential in terms of mineral resource mapping. So, mineral mapping and detection of large subsurface formations are also useful for seals and other igneous intrusions if the density contrast is sufficient enough. So, the advantage of this airborne gravity technique is that it is useful in terms of terrain correction, and thin, low-contrast formations can also affect the data reliability. So, we have to be very careful as far as the contrast and sensitivity are concerned, especially with low-contrast formations, because that could also affect the reliability.

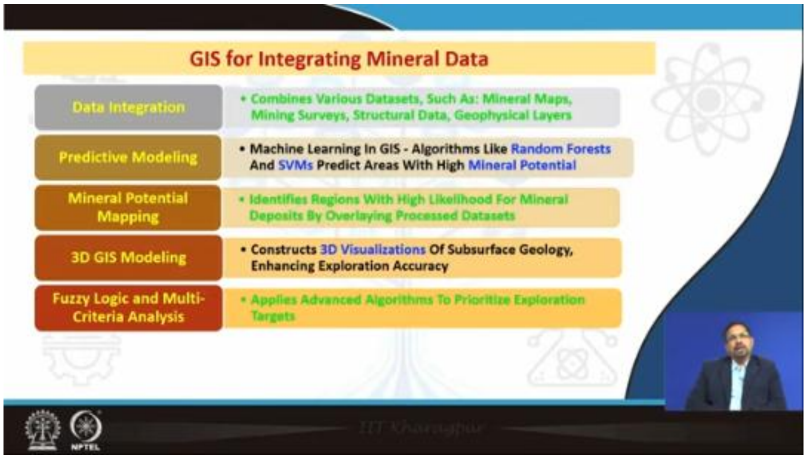
So, the advantages are terrain corrections and thin, low-contrast formations. Now, let us have a look at the other satellite datasets coming from remote sensing for mineral exploration. So, we all know about optical and multispectral remote sensing. So, let us take two examples; the dominant one is the Landsat series of data available. So, this Landsat series data highlights the presence of iron oxide clays and thereby maps surface mineralogy and structures very easily.

It is well established that, using the Landsat data, the iron oxide, clay, surface mineralogy, and structural mapping are very well done. Using ASTER, the ASTER data also maps clays, carbonates, and silica, which are useful for hydrothermal alterations. So, studies concerning the hydrothermal aspect are very well done or practiced using the ASTER data. Now, let us have a look at the next one, which is thermal, where temperature differentiation is the rule. So, based on thermal remote sensing, we can detect silicates, carbonates, and sulfates, which have variations in their surface temperature or emissivity.

So, if there is variation in emissivity and surface temperature, then the utility of thermal infrared remote sensing is a must. Now, let us have a look at the ranging synthetic aperture radar, abbreviated as SAR. So, Sentinel-1, ALOS PALSAR, which is useful, you have 1A, 1B, and also from ALOS PALSAR, you have longer wavelength data, L-band; Sentinel-1 gives us the C-band data. So, they are useful in the identification of surface roughness, structural features, soil moisture, and in that way, they give an indication of the presence of different minerals. In a sense, they serve in mineral exploration in the principle of sustainability.

Now let us have the LiDAR light detection and ranging principle. The LiDAR creates 3D topographic maps. They are useful for mapping fault lines, structures, and fractures. So if we can clearly detect the fault lines and the fractures, then these fault lines and fractures could carry information about the presence of different minerals.

So that is how the LiDAR-based topographic maps are useful in mineral exploration and indication. So, GIS for integrating mineral data, GIS is very useful as we all already understood that in GIS we have the power of having both the spatial and non-spatial databases which interact and in a sense of query and other things they come out with a lot of new analysis. So, if we have the data or database in place in the form of a GIS layer, this GIS-enabled database combines with various other datasets such as mineral maps, mining surveys, structural data, and geophysical layers and thereby helps in mineral exploration studies. Also, using these datasets we can get into a lot of analytics and predictions using different statistical and other models, so machine learning models in GIS we can have, and there are examples already people have done using various machine learning algorithms such as decision tree-based random forest, support vector machine.

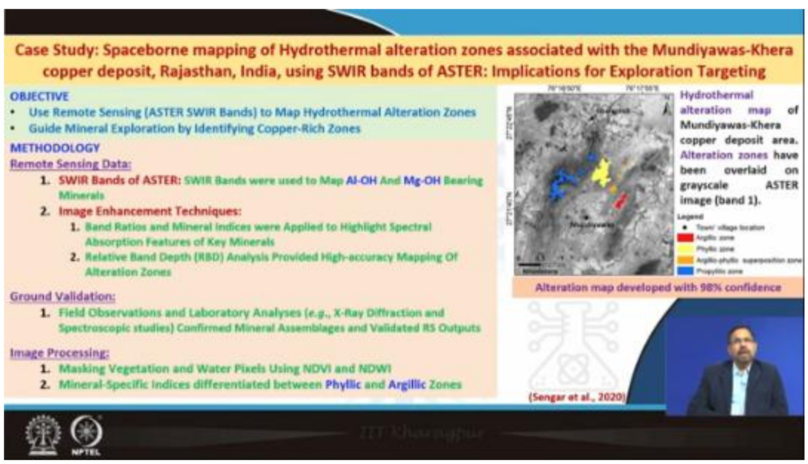


These all are useful in predicting the mineral potential over a region or prioritizing the mineral potential over a region. So, mineral potential mapping identifies regions with a high likelihood for mineral deposits by overlaying processed datasets. Now, let us have a look at the three-dimensional GIS modeling. Yes, the moment we have the three-dimensional data, we already discussed in terms of our derived or our LiDAR-derived or

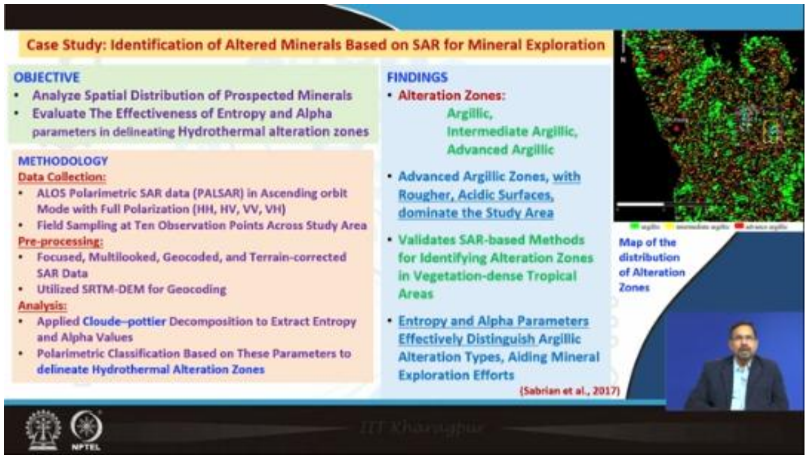
SAR interferometry-derived datasets where we get the 3D information of the terrain or the visualization in terms of three dimensions

of subsurface geology. So that is how it is useful in enhancing exploration accuracy. So fuzzy logic and multi-criteria analysis are also applied in the sense of advanced algorithms to prioritize exploration targets. So, machine learning, artificial intelligence, fuzzy logic, these all are useful for a lot of data analytics, that is how they help in prioritizing or optimizing the mineral exploration over an area.

Now let us have a look at a case study which comes from the space-borne mapping of hydrothermal alteration zones associated with the Mundiywas Khera copper deposit, which is there in Khera, as we know it is there in Rajasthan, India, a well-known copper mining site. So, here the shortwave infrared bands and ASTER have been used for exploration targeting. The objective used by Sanger et al. in 2020 is they use remote sensing, that means ASTER shortwave infrared bands, to map the hydrothermal alteration zones. And that is how they were able to guide mineral exploration by identifying copper-rich zones. Friends, this satellite data, particularly shortwave infrared and ASTER data, they are used by Sanger et al. in 2020, the publication they made out of this study.



They used it to map the aluminum hydroxide and magnesium hydroxide-bearing minerals. So, they also used different image enhancement techniques and further went on to ground validation. And on this basis, they could clearly come out and differentiate between phyllic and argillic zones. On the right-hand side, the map talks about or shows this differentiation between phyllic and argillic zones, which, with respect to ground validation, have more than 98% corroboration, that is why a 98% confidence level. Another study in terms of altered minerals based on SAR data for mineral exploration.



So here the objective was to analyze the spatial distribution of prospected minerals that were evaluated using the effectiveness of entropy and alpha parameters in delineating hydrothermal alteration zones. The ALOS PALSAR SAR data and fully polarimetric, that is HH, HV, VV, and VH, and field sampling have been done. Pre-processing was done, and satellite data, particularly SRTM-DEM, was used. And in terms of analysis, the Cloude-Pottier decomposition technique was used to extract entropy and alpha values.

And polarimetric classification based on these parameters was conducted to delineate the hydrothermal alteration zones. So, these alteration zones, in terms of findings, could be the argillic, intermediate argillic, and advanced argillic. So, these zones could be identified and mapped as dominant in the study area. So, entropy and alpha parameters are effective in terms of distinguishing between the argillic alteration types, thereby aiding in mineral exploration, as given by the study by Sabrian et al. in 2017. So, these six references have been used for the discussion of this eleventh lecture, and let us conclude with these four points.

So, exploration mapping supported by geo-information technologies such as hyperspectral imaging, airborne geophysics, and GIS together plays a crucial role in modern mineral exploration. By integrating diverse data sources and employing non-invasive techniques, it enhances the accuracy, efficiency, and sustainability of identifying and evaluating mineral deposits. These methods not only help minimize environmental impacts or disturbances but also enable more precise targeting of mineral resources, ultimately contributing to more sustainable mining practices, thereby reducing unnecessary disturbance to the site or the ecosystem. So, the combination of these technologies, together under the geo-information tag, has the potential to transform the way mineral resources can be explored, mapped, and extracted. And that is how driving both economic and environmental benefits using sustainability principles for the mineral industry or mining sector.

Thank you very much.