



## 1. Acknowledgements:

*First of all, I want to thank God because He taught me that a debt of gratitude must be repaid. Through every trial and triumph, I've come to realize that with God by my side, I'm never alone.*

*I'm thankful for everything—the highs and lows, the comebacks and setbacks that made me who I am today.*

*I eagerly anticipate the presence of my family. To my dad, who taught me how to be resilient, thank you for making countless sacrifices along the way.*

*To the most important person in the whole world, my mother, a wonder woman, whose boundless love and steadfast prayers have been my guiding light throughout. There are 8 billion people on this planet, and you are the perfect mom for me.*

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*Lastly, I am deeply grateful to my roommates, who have stood by me through every challenge because this honor doesn't just belong to me i wouldn't come this far If it weren't for certain significant individuals in my life, beginning with my mother, father, brother, and my other family, who I'm so glad to have*

*i was under the misconception that my achievements were solely my own. Nothing can be further from the truth. I've been uplifted, supported, motivated, and embraced by an extraordinary circle of companions unlike any other Rayen Dabbabi, Rayen Ben Hassen, and Mouath Haffar*

*being here today, brimming with gratitude, I realize that my journey is just beginning. I carry the lessons, love, and support you've all given me as precious fuel for the road ahead. As I step forward, I promise to honor your encouragement, pay it forward with kindness, and strive to make you all proud. Thank you, for being the source of empowerment.*

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## **Chapter 1: Introduction**

### **General Context**

In the evolving field of energy exploration, the search for environmentally friendly methods of extracting hydrocarbons has brought together traditional geoscience and advanced technology.

With the demand for energy on the rise, there is a growing need to innovate hydrocarbon exploration methods. This initiative marks an effort that combines geoscience with modern artificial intelligence. Historically, discovering and describing oil and gas reservoirs has heavily relied on established models and time-consuming surveys. However, the emergence of machine learning offers an opportunity to enhance these approaches with data-driven insights and predictive analysis.

This project explores the potential of quantum machine learning (QML) in hydrocarbon exploration. Using quantum mechanics has unique features for managing datasets and potentially transforming reservoir identification processes. Relying on the capabilities of QML algorithms, we aim to surpass classical machine learning limitations and achieve unique accuracy in predicting reservoirs, but also pave the way for a future where energy extraction is optimized and environmentally responsible. I suggest that you join us on this cutting-edge exploration where technology and geoscience converge as we strive to unlock new avenues for the sustainable extraction of essential energy resources.

## **problem and objectives**

### **a. Problem**

The traditional approach to hydrocarbon exploration presents financial fortitude due to the substantial upfront investments, meticulous planning, and assembly of skilled teams needed. This process demands a significant amount of money, ranging from \$8 million onshore to over \$100 million offshore. To navigate this economic landscape more effectively, innovative solutions like the exploration of quantum machine learning (QML) are very promising.

By potentially optimizing drilling locations, reducing exploration time, and minimizing resource waste, a groundbreaking approach can revolutionize exploration methodologies and potentially alleviate the financial burdens associated with traditional methods.

### **b. Objectives:**

**Revolutionize traditional hydrocarbon exploration** by integrating **quantum machine learning (QML)** to significantly reduce the substantial financial investment and meticulous planning associated with the process.

**Leverage the unique capabilities of QML** to achieve **unprecedented accuracy** in reservoir predictions, **optimize resource extraction processes**, and **minimize environmental impact**.

**Develop a novel, efficient, and cost-effective approach** to hydrocarbon exploration that promotes **environmental sustainability**, thereby contributing to the **advancement of the energy industry** and addressing the limitations of traditional methods.

## **Chapter 2: LITERATURE REVIEW**

## **Introduction**

Finding hidden oil and natural gas resources is a major challenge. Traditional exploration methods can be very slow, taking years to get results. This process not only slows down new discoveries but also often overlooks the potential of natural gas reserves. We propose a new approach to make finding oil and gas easier by combining quantum mechanics with regular machine learning. This new hybrid strategy could change how we explore hydrocarbons by:

### **Accelerating the Exploration Process:**

Quantum machine learning can work with difficult data quickly. It unravels complex datasets linked to oil and gas exploration. Old machine learning methods battle with intricate geological data. However, quantum algorithms like the

Variational Quantum Eigen Solver (VQE) analyze this data much faster. As a result, possible locations for oil and gas reservoirs can be identified rapidly.

### Expanding the Hydrocarbon Scope:

Our plan goes beyond typical ways. We look for oil and natural gas together when exploring underground. This gives us a fuller picture of what's beneath the surface.

### Enhancing Predictive Accuracy:

The fusion of QML and ML holds the promise of unlocking a new level of predictive accuracy. Our enhanced technology allows for pinpointing probable mineral reservoirs more precisely.

## The Power Beneath Our Feet: Geology and the Exploration of Shale Oil and Gas

Our journey begins with the fascinating world of geology, the key to unlocking the secrets hidden beneath our feet, from valuable resources to beautiful minerals. Starting with the historical significance of hydrocarbons and contrasting the properties and uses of oil and gas, covering these concepts will pave the way for examining the challenges faced by traditional methods. Next, we will delve into how AI can revolutionize this industry by overcoming long-standing limitations and unlocking new possibilities for the future.

### 1. geology:

Geology is the study of the Earth's structure, composition, and processes. using a variety of techniques to locate where sizable quantities of hydrocarbon exist under the surface, primarily employing seismic imaging, which can also be called an ultrasound, which involves sending sound waves into the earth and recording the echoes that bounce back. Based on these records, geologists can create a prototype of the rock layers, leading them to determine the depth and thickness of the shale formations and their size as well. Year after year, we've seen the demand for natural resources such as oil and gas progressively increase, but onshore "conventional" plays have struggled to keep up. Big firms needed a solution to continue the demand, and shifting to unconventional methods was an option to grow production volumes and secure their country's energy future. Sedimentary rocks like shale can be full of organic matter, containing remnants of plants and algal material preserved inside of them. These rocks are buried deeper beneath the earth's surface, where the presence of the best factors like pressure and temperature increases over time, backing hydrocarbons like oil and gas. After identifying the targeted areas, geologists collect rock samples during drilling. These samples provide valuable information on the composition and characteristics of the shale, like porosity and permeability.



They can also run tests on the fossils in the rock to help identify the age of the shale, leading them to a better understanding of whether it's from the Cenozoic or any other geologic past in which the rock was formed, the environment, categorization, and organic matter composition. Based on that, they can determine the potential quantity and quality of the matter (gas and oil) that could have been generated over time. After gathering all the data, computer models simulate the movement of the oil. Energy companies use this information to design effective production techniques, such as hydraulic fracturing

**figure1: Graphic representation of typical Avis in a general-purpose geologic map that can be used to identify geologic hazards, locate natural resources**

## 1. gas vs oil:

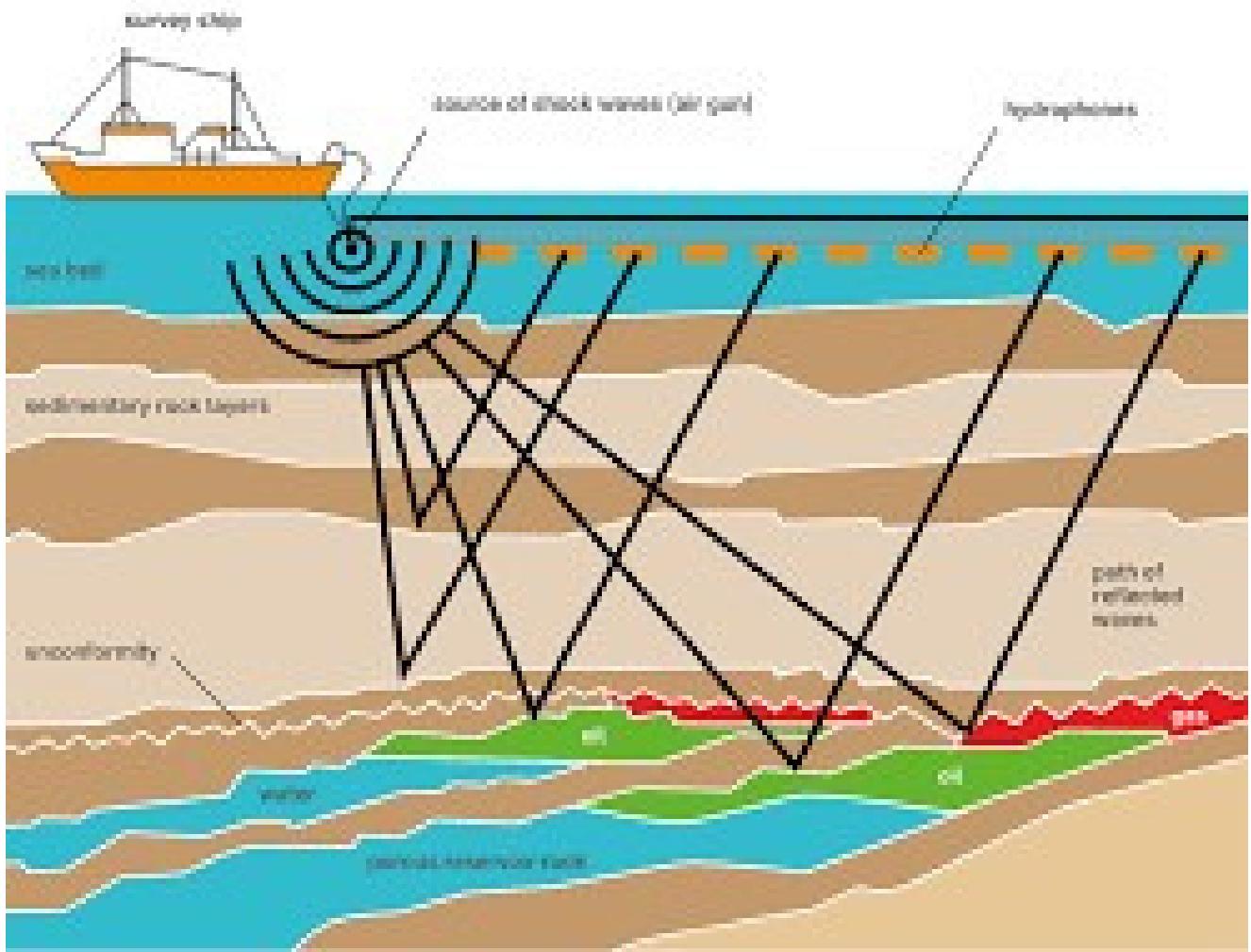
We've talked about hydrocarbons so far, which raises the question: What's the difference between oil and gas?

biologically speaking, they both come from prehistoric organisms that decomposed underground, as we talked about earlier, but the main difference in the composition and physical state is that crude oil is a complex format of hydrocarbon compound; along with hydrogen and carbon atoms, there is also a small amount of sulfur, nitrogen, and oxygen. Natural gas, on the other hand, is a simple chemical compound of methane ( $\text{CH}_4$ ); it may also have some propane. Also, crude oil is a liquid at standard atmospheric conditions, while natural gas is a gaseous state hydrocarbon lighter than air. Extraction methods can also be different for the oil. After drilling, additional techniques can be applied, like hydraulic fracturing and horizontal drilling, while for the gas, instead of releasing oil, it releases gas.

## 1. A Century of Progress:

The natural gas and oil industry has come a long way since its early days in the mid-1800s. From the very first oil well drilled in Pennsylvania in 1859 to the advanced drilling techniques used today, this industry has grown rapidly and significantly impacted the world. In the beginning, oil was mainly used for lighting and lubrication. However, as the world became more industrialized, oil became essential in producing a wide range of products, from plastics to gasoline. The discovery of natural gas, a cleaner-burning fuel, in the early 1900s further increased the importance of this industry. But environmental concerns were a conundrum along with the fluctuating prices, and despite all that, it made incredible advancements. For example, hydraulic fracturing, or "fracking," has revolutionized the industry by allowing companies to extract natural gas and oil from previously inaccessible sources. Another major development has been the rise of renewable energy sources, such as wind and solar power.

The breakthrough wasn't as big as the oil but their increasing popularity is a testament to the changing demands of consumers and governments alike. Today, the natural gas and oil industry continues to innovate and adapt to new challenges. From using artificial intelligence to improve exploration and production processes to investing in carbon capture and storage technology, companies are working to reduce their environmental impact and ensure a sustainable future.



**figure2 : Diagram displaying the shape of numerous specific forms of oil and fuel line traps**

## 1. Challenges and Limitations of Traditional Exploration Methods:

While traditional exploration methods have played a major role in discovering and extracting hydrocarbons for centuries, they face several significant challenges and limitations:

**Difficulties in Identifying Potential Sources:** Traditional methods often struggle to access resources buried deep underground or located in environmentally sensitive areas. Additionally, limitations in data acquisition and analysis can lead to inaccurate assessments of potential reserve size and quality.

**High Costs and Time Consumption:** Activities like drilling and seismic surveys can be incredibly expensive and time-consuming; the cost alone is way too high, and the exploration process itself can take years to complete. Not forgetting that the lack of reach and depth penetration capabilities needed to access certain formations effectively and interpret the data collected through these methods can be complex and prone to errors. These challenges contribute to inefficiencies and increased costs in hydrocarbon exploration, paving the way for advancements like artificial intelligence to offer transformative solutions in the future.

## **1. artificial intelligence : New Solutions on the Horizon :**

Artificial intelligence (AI) is a game changer by offering a powerful set of tools to overcome the limitations of traditional methods. A subset of AI that enables algorithms to learn from vast datasets without explicit programming. By analyzing enormous volumes of geological, seismic, and production data, ML models can identify subtle patterns and correlations that would be impossible for humans to detect. This capability allows AI to predict the location of hydrocarbon reservoirs with greater accuracy, optimize drilling and extraction techniques, and reduce exploration costs.

A 2.0 form of machine learning called quantum machine learning (QML) is showing potential for further investigation. The principles of quantum mechanics, specifically the behavior of qubits, which can exist in multiple states simultaneously, unlike the bits in traditional computers. This unique property allows QML algorithms to explore a vast number of possibilities simultaneously and calculate the outcomes three times faster than average, potentially leading to breakthroughs in data analysis and problem-solving. While still in its early stages, QML has the potential to further revolutionize exploration by tackling complex geological challenges with unprecedented power and efficiency.

# **Chapter 3: Bridging the Gap From Remote Sensing to AI-powered Hybrid QML in Geomatics**

## **Introduction:**

This chapter connects the dots between technologies, such as remote sensing features, within the field of geomatics.

### **2.1 Unveiling the Earth's Secrets: Remote Sensing:**

Remote sensing is a powerful tool, providing valuable insights into Earth's surface and subsurface characteristics without physical contact. This technology utilizes various platforms to collect data from a distance, helping us "see" the Earth in ways traditional exploration methods cannot.

### **2.2 Satellite Imagery: A Window to the Earth's Surface**

Satellite imagery is a transformative technology that reshapes our perception and understanding of our planet. These images, captured by satellites, offer invaluable insights into Earth's features, anomalies, and patterns, as well as

responses to various issues.

### Satellite Imagery Definition:

Literal to its name, Satellite Imagery refers to images captured by satellites, presenting a digital visual representation of the Earth's surface through cameras or sensors mounted on satellites orbiting the Earth.

### Active and Passive Satellites:

Satellites are categorized as active or passive. Active Satellites use remote sensors to detect reflected responses from objects irradiated by artificially generated energy sources. In contrast, Passive Satellites use sensors to detect reflected or emitted electromagnetic radiation from natural sources, such as the sun, magnetism, or geothermal activity.

### Types of Satellite Imagerie :

#### 1. *Visible Satellite Imagery*:

Captures images using satellites to detect and record visible light wavelengths, providing a visual representation of the Earth's surface and cloud cover. Available only during the day.

#### 2.*Infrared (IR) Satellite Imagery*:

Captures infrared radiation emitted or reflected by objects on the Earth's surface, highlighting temperature variations. It is valuable for weather forecasting, temperature analysis, and detecting heat signatures in different environments. Available day and night.

#### 3.*Water Vapor Satellite Imagery*:

Designed to detect the concentration and movement of water vapor in the Earth's atmosphere, offering insights for weather analysis, moisture tracking, and predicting atmospheric instability. Crucial for identifying potential rainfall or thunderstorm development.

### Resolution Matters:

Resolution is a pivotal aspect in satellite imagery, determining the quality and quantity of the captured images.

#### 1. **Spatial Resolution:**

Refers to the level of detail captured in an image, determining the smallest distinguishable object. Higher spatial resolution allows for the identification of smaller objects, providing a more detailed representation of the Earth's surface.

#### 1. **Spectral Resolution:**

Relates to a sensor's capacity to discern and capture specific wavelength intervals within the electromagnetic spectrum. High spectral resolution provides detailed information about the Earth's surface composition.

### **3.Multispectral and Hyperspectral Sensors:**

Multispectral sensors capture data in specific spectral bands, enhancing our understanding of the environment. Hyperspectral sensors collect detailed information about materials and substances across numerous narrow spectral bands.

### Temporal Resolution:

Temporal resolution denotes the frequency at which a satellite captures data for a specific location over time, indicating how often the same area is revisited.

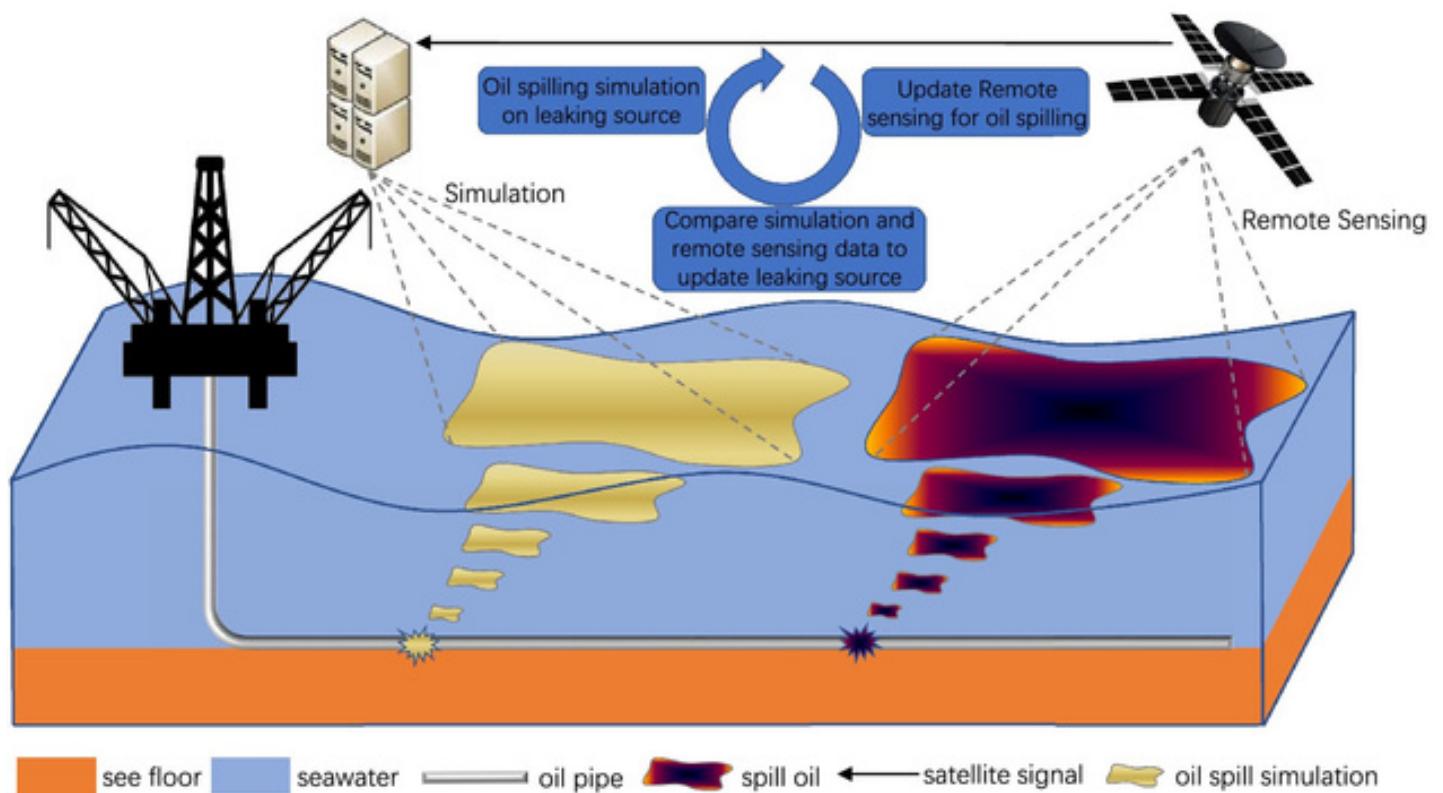
Importance of Temporal Resolution:

Crucial for monitoring dynamic processes such as land cover changes, vegetation growth, urban development, wildfires, or floods.

#### Radiometric Resolution:

Radiometric resolution refers to a sensor's sensitivity to variations in electromagnetic radiation intensity received from the Earth's surface, indicating the number of grayscale levels that can be imaged.

**figure3 : Cyber-physical oil spill monitoring and detection for offshore petroleum risk management service**



## 2.3 Satellite Imagery: Landsat

The Landsat program, initiated in the 1960s under Secretary Stewart Udall, has been a pioneering force in the realm of remote sensing. Encompassing a series of Earth observation satellites known as the Landsat Missions, this program, now boasting eight operational satellites, has played a pivotal role in providing valuable data and images of the Earth's surface. These data, originating from the launch of Landsat 1 (ERTS-1) in 1972, were groundbreaking for their ability to observe changes wrought by various forms of human activity. From the resolution that can easily identify larger roads, buildings, and urban development patterns globally to the continuous collection of data, Landsat allows multidecade comparisons, revealing landscape transformations due to activities like urbanization and "slash-and-burn" agricultural practices. Over time, the program has faced challenges, including commercialization efforts in the 1980s, but recognition of the data's value led to its reacquisition by the government, resulting in the more accessible Landsat 7 data. Landsat 5, setting a world record as the longest-operating Earth observation satellite, operated for an impressive 28 years, with Landsat 8 successfully taking the reins following its decommissioning. Despite some technical challenges, the Landsat program's

enduring legacy has revolutionized our understanding of the Earth's surface and continues to be integral in monitoring environmental changes worldwide. The upcoming Landsat Next mission in 2030 promises further advancements, introducing a constellation of three observatories for enhanced temporal revisit, expanded spectral bands, and increased data collection capacity.

## 2.4 Satellite Imagery: sentinel

The Sentinel program, a cornerstone in contemporary Earth observation, is jointly managed by the European Space Agency (ESA) and the European Commission, offering a comprehensive fleet of satellites equipped with advanced radar and optical imaging technologies. Commencing with the launch of Sentinel-1A in 2014, these satellites have made significant contributions to various fields, including environmental monitoring, climate change analysis, and disaster response. The program's open data policy ensures global access to high-quality imagery for research and operational purposes.

ESA, in conjunction with the Copernicus program, is developing a new family of missions known as Sentinels, specifically designed to meet the operational needs of Copernicus services. These Sentinels consist of satellite constellations carrying advanced technologies, including radar and multi-spectral imaging instruments. The Sentinels play a vital role in environmental and climate monitoring, offering robust datasets for Copernicus by fulfilling revisit and coverage requirements. Specific missions, such as Sentinel-1 for radar imaging, Sentinel-2 for high-resolution land monitoring, and Sentinel-3 for ocean and atmospheric monitoring, cater to distinct services within Copernicus, providing essential data for policymakers and land managers. Additionally, the program's user-friendly data access and extensive coverage make Sentinel a cornerstone in addressing contemporary environmental challenges and enhancing our understanding of the dynamic processes shaping the Earth's surface. Both the Sentinel program and ESA's Sentinel Expansion missions, aligning with EU policy requirements, collectively contribute to a sustained and advanced Earth observation infrastructure.

### 1. 5-limitations of remote sensing data:

In the realm of remote sensing, the orchestration of data encounters its set of limitations—a symphony where spatial and temporal resolutions harmonize with atmospheric nuances, spectral paucities, and the cadence of cost and accessibility challenges. Sensory intricacies and the labyrinth of vegetation and topography stand as artistic obstacles, painting the canvas of interpretation with complexity. Processing, akin to crafting a masterpiece, unveils its own challenges. These constraints, though formidable, are integral notes in the melody of data interpretation. Users, as the virtuosos of this grand composition, find it paramount to attune themselves to these nuances, understanding that amidst limitations, the symphony of remote sensing unfolds its richness for diverse applications.

## 3-Bridging the Gap: Integrating GIS and Geomatics

In the never-ending quest to find new stuff we need, a wide range of tools and techniques is needed to maximize success. This section explores how geographic information systems (GIS) seamlessly integrate with geoscience and remote sensing data to create a more efficient advanced research practices

### 3.1-Unveiling the Power of GIS:

**GIS** plays a pivotal role in resource exploration by acting as a central repository and analysis platform for various types of data. It acts as a digital bridge, connecting the dots between:

**Remote sensing data:** Satellite imagery, radar data, and other remotely sensed information can be integrated into a GIS platform for analysis and visualization.

**Geospatial data:** Existing datasets, such as geological maps, topographic data, and infrastructure information, can be incorporated into the GIS for comprehensive analysis.

**Fieldwork data:** Data collected during field surveys, including GPS coordinates, physical samples, and observations, can be integrated for further analysis and visualization.

### 1. Understanding the Role of Geomatics:

**Geomatics** encompasses a diverse range of techniques and technologies utilized to acquire, manage, analyze, and interpret spatial data related to the Earth. It is vital in resource exploration by providing:

**Surveying:** Traditional and advanced surveying techniques, like GPS and LiDAR, allow for the precise measurement of the Earth's surface, facilitating the identification of potential resource locations and providing critical data for further analysis.

**Seismic Surveys:** Subsurface exploration techniques, such as seismic surveys, offer valuable insights into the Earth's geological structure, aiding in identifying potential resource deposits hidden beneath the surface.

**Geospatial modeling:** Creating three-dimensional models of the Earth's subsurface structure can help visualize potential resource locations and guide further exploration activities.

### 1. The Symphony of Integration:

The true power lies in **integrating** these technologies. By combining GIS, remote sensing data, and geomatics information, we can gain a comprehensive understanding of the target exploration area:

**Spatial analysis:** GIS allows for overlaying and analyzing various datasets, enabling the identification of spatial relationships and patterns that might be indicative of potential resource locations.

**Decision-making support:** The combined insights from different data sources provide valuable information for informed decision-making throughout the exploration process.

**Enhanced visualization:** Integrating data into GIS allows for creating visual representations, such as maps and 3D models, facilitating better communication and collaboration between different stakeholders involved in the exploration project.

### Conclusion :

The integration of GIS, geomatics, and remote sensing data plays a pivotal role in modern resource exploration practices. This combined approach allows for:

**More efficient and targeted exploration efforts.**

**Improved accuracy and reliability of exploration results.**

**Enhanced communication and collaboration within exploration teams.**

By understanding the individual strengths of each technology and embracing their synergy, we can unlock the full potential of remote sensing data and pave the way for sustainable and responsible resource exploration practices.

### 1. Harnessing the Power of Intelligence: AI/QML in Exploration

Geo AI is a new research and application field combining spatiotemporal big data analysis and artificial intelligence technology. These cutting-edge technologies bring unprecedented capabilities to analyze vast datasets, enabling the identification of intricate patterns and trends for efficient and insightful exploration practices.

### 1. Unveiling Hidden Insights:

Old methods often rely on human expertise for data analysis. AI/ML algorithms, however, possess the ability to:

Process vast quantities of data: They can analyze massive datasets from remote sensing, GIS, and other sources, identifying patterns and trends that might be missed by human analysts.

Identify subtle relationships: AI/ML can identify subtle relationships between different data points, providing valuable insights into potential resource locations and geological characteristics.

Automate repetitive tasks: They can automate time-consuming and repetitive tasks like data cleaning and feature extraction, freeing up valuable resources for further exploration activities.

### 1. Embracing a Hybrid Approach: Classical vs. Quantum ML:

#### Classic:

Classical bits: Operates on bits, which can be either 0 or 1. Think of a light switch, on or off.

Sequential processing: Analyzes data one piece at a time, similar to solving a math problem Limited by complexity: Struggles with highly complex problems with many variables.

#### Quantum:

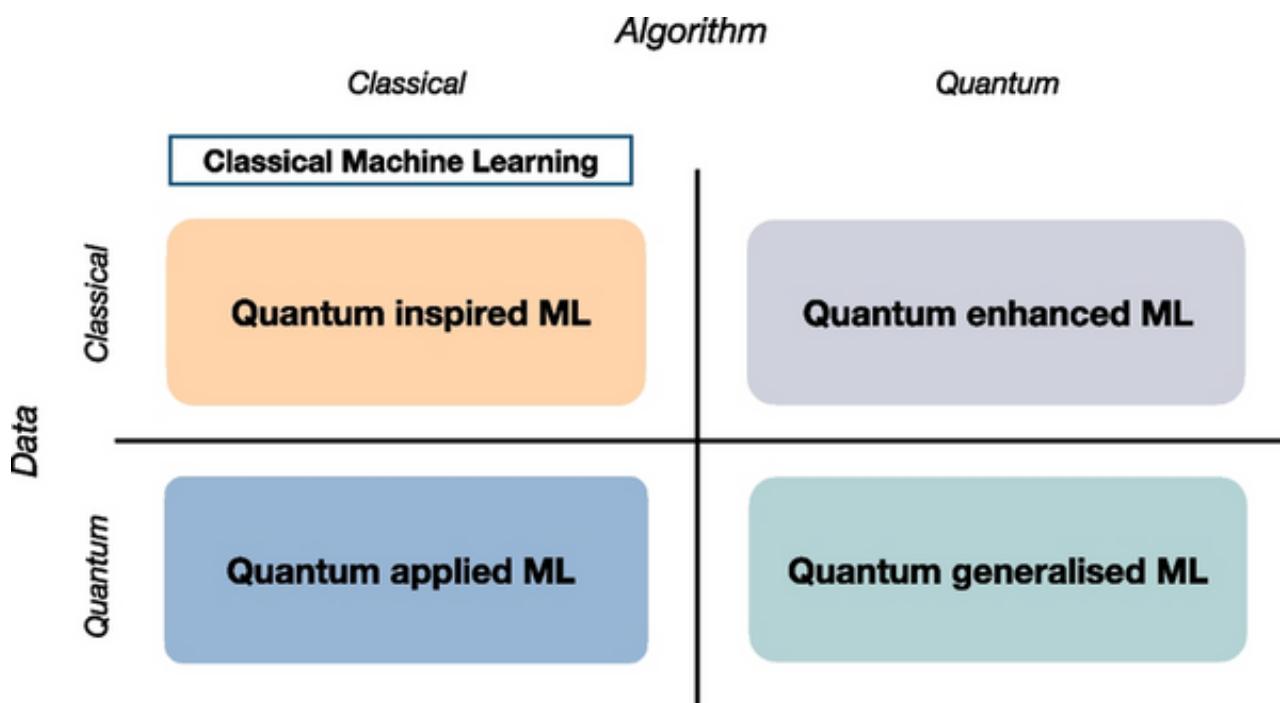
Quantum bits (qubits): Utilizes qubits, which can hold both 0 and 1 simultaneously, a concept known as superposition. Imagine a light switch being both on and off at the same time (not possible in our current understanding of physics, but an important concept in quantum mechanics).

Parallel processing: Explores multiple possibilities simultaneously, like checking all the answers in a math test at once.

Potential for tackling complex problems: Holds promise for solving problems intractable for classical ML due to their inherent complexity.

While QML holds immense potential, full-fledged quantum computers are still under development. Therefore, this project adopts a **hybrid approach** We combine the strengths of traditional ML, which excels at handling large datasets, with the potential benefits of QML for specific tasks like the complexity of the data and the GPU usage

**figure4 : quantum machine learning development paradigms compared against data and algorithms type**



#### **4.4 Synergistic Integration with Geomatics:**

Integrating AI/ML and geomatics techniques unlocks a new level of exploration:

**Data analysis and interpretation:** AI/ML algorithms can analyze geomatics data (e.g., seismic surveys) to identify potential resources or understand subsurface structures.

**Enhanced decision-making:** Combining AI/ML insights with geospatial data and geomatics interpretations leads to informed exploration decisions.

### **1. The Synergy in Action: A Collaborative Approach:**

#### **5.1 Orchestrating the Symphony: A Combined Workflow**

Our project's exploration workflow thrives on the **synergy** between various technologies:

1. **Remote sensing data acquisition:** We utilize satellite imagery (Landsat, Sentinel) to capture high resolution images of the Kansas City.
  
1. **GIS analysis:** We integrate the acquired data into a GIS platform, combining it with existing geospatial datasets and field survey data.
1. **Geomatics exploration:** We leverage geomatic techniques like LiDAR to gather high-precision elevation data and potentially seismic surveys to probe deeper into the subsurface structure.
1. **AI/QML integration:** We employ AI/QML algorithms to analyze the combined data, searching for hidden patterns.

#### **1. 5.2 A Collaborative Advantage: A Hypothetical Example**

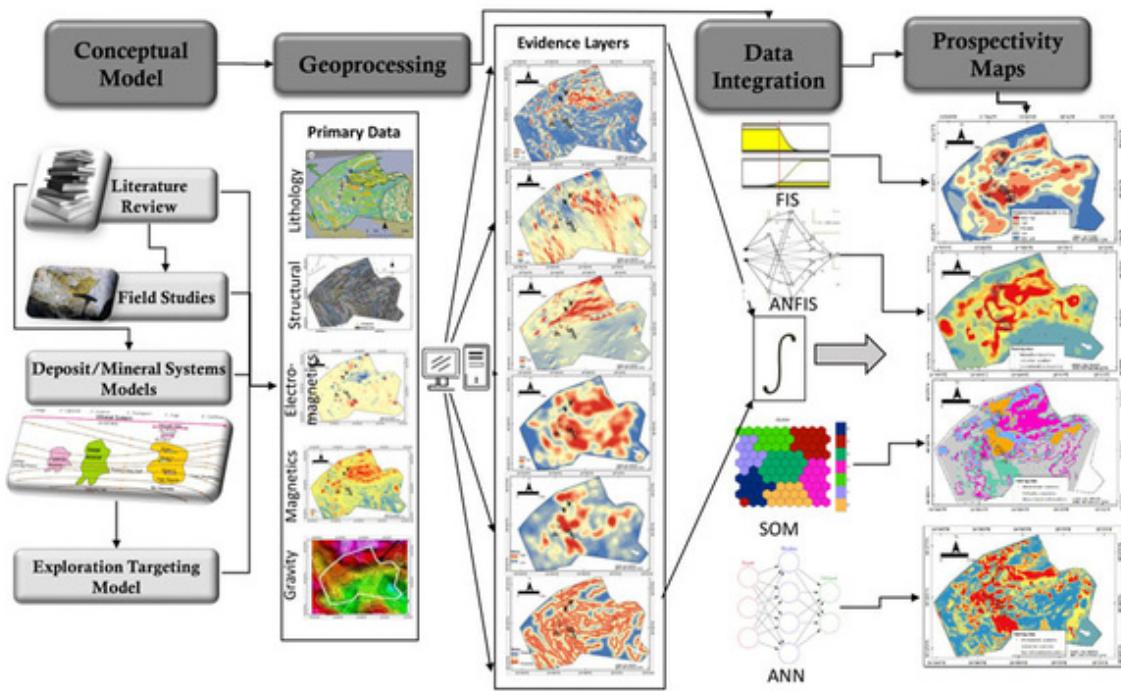
Imagine exploring a vast desert region for potential mineral deposits. Traditionally, geologists might rely on:

**Visual inspection of satellite imagery:** This approach is time-consuming and prone to overlooking subtle anomalies.

**Limited field surveys:** Ground surveys are expensive and can only cover a small fraction of the area.

**Our combined approach offers distinct advantages:**

- We can analyze vast imagery datasets, identifying potential areas of interest based on spectral signatures or subtle geological features.
- By overlaying geological maps and existing exploration data in GIS, we can prioritize these areas for further investigation
- Utilizing LiDAR data, we can create detailed terrain maps, guiding field surveys to the most promising locations identified through AI/QML analysis
- Seismic surveys, combined with AI/QML analysis, can provide valuable insights into potential subsurface structures indicative of mineral deposits
- By focusing on high-potential areas, we can conduct fewer but more targeted field surveys.



**figure5: Illustration of a Collaborative Exploration Workflow for Desert Mineral Deposit**

### 5.3 Conclusion:

The fusion of remote sensing, GIS, geomatics, and AI/QML, we unlock a powerful and efficient approach for resource exploration. This collaborative approach makes a roadmap for a future of sustainable and responsible resource discovery.

# Chapter 4: Study conception from pixels to predictions

## Introduction:

In this chapter, we are going to dig deeper into the roadmap of our AI/QML-driven resource exploration project. Our primary objective is to outline the workflow, detailing the specific software tools we will utilize and the different types of data we will employ, development platform and model, the data acquisition process for various sources, and the image processing steps to prepare the data for analysis. By outlining this comprehensive workflow, we aim to establish a solid foundation for building and applying our model for successful search.

## 1- Building the Foundation: Software Selection:

The building blocks of any study are the proper selection of the right software, and as GIS scientists, we know for fact that ArcGIS and other GIS software are crucial for this. With our finest programs, we begin with ArcGIS.

### 1a- ArcMap vs ArcGIS Pro :

While both ArcMap and ArcGIS Pro are products from Esri and fall under the ArcGIS suite, they cater to different needs and workflows, but in this project, we used both software's to maximize all the benefits from them.

#### ArcMap:

##### Strengths:

**Maturity and Stability:** ArcMap has been around for a longer time, offering a mature and stable platform with a vast library of extensions and functionalities.

**Customization:** ArcMap offers a high degree of customization through add-ins and extensions, allowing users to tailor the software to their specific needs.

##### Weaknesses:

**Limited Support:** Esri has shifted its focus to ArcGIS Pro, resulting in diminished support for ArcMap.

Future updates and bug fixes might be less frequent.

**32-bit Architecture:** ArcMap operates on a 32-bit architecture, limiting its ability to handle very large datasets. Or 64-bit float architecture

**Limited Python 3 Support:** ArcMap's Python scripting capabilities primarily rely on Python 2.7, which is reaching end-of-life.

#### ArcGIS Pro:

##### Strengths:

**Modern Architecture:** ArcGIS Pro leverages a 64-bit architecture, allowing it to handle large and complex datasets more efficiently.

**Advanced Functionality:** ArcGIS Pro offers a wider range of built-in functionalities compared to ArcMap, including advanced spatial analysis tools and improved 3D visualization capabilities. **Active Development:** Esri actively develops and updates ArcGIS Pro, ensuring access to the latest features and bug fixes.

**Python 3 Support:** ArcGIS Pro fully supports Python 3, opening doors for leveraging a wider range of Python libraries and functionalities for geospatial analysis and AI/QML integration.

### **Weaknesses:**

**Learning Curve:** Due to its newer interface and functionalities, ArcGIS Pro might have a steeper learning curve for users accustomed to ArcMap.

**Limited Customization:** While customization options exist, they are not as extensive as those offered by ArcMap.

While both ArcMap and ArcGIS Pro are valuable tools ArcGIS Pro aligns better with the contemporary approach to geospatial analysis, particularly its integration with Python 3, which is more than necessary for AI/QML development

The 64-bit architecture of ArcGIS Pro facilitates working with more complex dataset like ours, which is likely encountered in resource exploration involving satellite imagery and other geospatial information.

### **QGIS (Quantum GIS):**

**Open-source:** Free and readily available, making it a cost-effective option for our case as a student or organizations with budget constraints.

**Wide Functionality:** Offers a comprehensive set of functionalities for GIS data visualization, spatial analysis, and basic image processing.

**Python Integration:** Similar to ArcGIS Pro, QGIS supports Python scripting, allowing for custom workflows and integration with AI/QML libraries (though potentially requiring more technical expertise compared to ArcGIS Pro).

### **Strengths:**

Strong user community with extensive online resources and tutorials.

Offers plugins for specialized tasks, potentially including some related to AI/QML (although these might be less developed compared to commercial software).

### **Weaknesses:**

Limited native support for advanced image processing tasks often encountered in resource exploration (compared to specialized software like ENVI).

require more technical expertise to set up and customize workflows compared to user-friendly commercial options.

### **ENVI (Environment for Visualizing Images):**

**Commercial Software:** Paid software with a licensing fee, offering a range of functionalities tailored for remote sensing image processing and analysis.

**Advanced Image Processing:** ENVI excels in advanced image processing tasks like atmospheric correction, spectral band manipulation, and feature extraction, which is exactly what we need in this particular project for preparing remote sensing data for resource exploration applications.

**Specialized Workflows:** Offers pre-built workflows and tools designed specifically for resource exploration tasks, potentially including mineral mapping or hydrocarbon exploration.

## **Weaknesses:**

**Cost:** The commercial license can be expensive, especially for individual users or smaller research projects.

**Slower Learning Curve:** The extensive functionalities might require more time and effort to master compared to user-friendly GIS platforms like ArcGIS or QGIS.

## **MAGMAP (MAGnetic MAPping):**

**Commercial Software:** MAGMAP is a paid software solution with a licensing fee, catering to professionals and organizations involved in geophysical exploration and research. Its pricing model typically includes commercial licenses, which can vary depending on the scale of usage and specific requirements.

**Advanced Magnetic Data Processing:** MAGMAP stands out for its advanced capabilities in magnetic data processing and interpretation. It offers a suite of tools and algorithms tailored to handle magnetic data effectively. This includes functionalities such as data visualization, filtering, modeling, and interpretation, essential for analyzing our magnetic anomalies and identifying potential subsurface structures. We used it to manipulate our magmatic map and the LAS file

**Specialized Workflows:** MAGMAP provides specialized workflows and tools explicitly designed for resource exploration tasks, particularly in the field of geophysics. These workflows are optimized for magnetic data interpretation and analysis, covering various exploration activities such as mineral mapping and hydrocarbon exploration.

By offering pre-built workflows and specialized tools, MAGMAP streamlines the exploration process, enabling efficient data analysis and decision-making.

## **Weaknesses:**

**Cost:** One of the primary drawbacks of MAGMAP is its cost. The commercial license is very expensive. Organizations or research teams considering MAGMAP may need to allocate sufficient resources to cover the licensing fees.

## **Visual Studio Code (VS Code):**

**Open-source and Free:** VS Code is free to use and open-source,

**Extensive Language Support:** Offers support for numerous programming languages, including Python, R, which is widely used in GIS scripting and automation.

**Customizable:** VS Code is highly customizable with a vast library of extensions, allowing users to tailor their development environment to their specific needs.

**Integration with Git and copilots:** Built-in Git support enables version control and collaboration on geospatial projects and chat copilots helps with coding.

- **Well-suited for Scripting and Development:** VS Code is particularly well-suited for scripting, development, and integrating with other tools and libraries commonly used in GIS workflows, such as GDAL and geospatial Python libraries.

**Lacks Built-in GIS Functionality:** While VS Code provides a versatile development environment, it lacks built-in GIS functionality for spatial analysis, visualization, and data processing compared to dedicated GIS software like ArcGIS and QGIS.

**Requires Additional Extensions:** installing extra extensions or plugins to add GIS-related functionalities is needed, which may not always provide the same level of integration and ease of use as dedicated GIS software.

## Conclusion:

a variety of software platforms cater to different needs and project requirements. Having experience with ArcGIS, **QGIS**, and **ENVI** allows for a flexible approach.

**ArcGIS Pro** remains the primary platform for this project due to its strengths in

- Python 3 support simplifies
- Data Integration

**Qgis** is the secondary platform for exceling at:

- Open source
- Python scripting

**Envi** was the best when it comes to

- feature extraction such as performing liniment analyze
- Spectral band manipulation

This section acknowledges the value of all six software's, from data acquisition and processing to model development and analysis. It also showcases my expertise in working with all six platforms and explains how each can contribute to the overall workflow. Now that we have covered all the software we need, let's move a step forward into data analysis and types.

## 2- Data Acquisition: Gathering the Raw Materials:

This section of Chapter 4 will cover the strategy for acquiring the different data types essential for an AI/QML driven resource exploration project. Here's a breakdown of the key points:

### 2-1. Remote Sensing Data :

**USGS Earth Explorer** <https://earthexplorer.usgs.gov/>

Given its extensive data archive and free access, the Landsat program offered by USGS presents a valuable resource for our remote sensing data acquisition. We will explore the available Landsat imagery for our target area (Kansas), focusing on selecting spectral bands that effectively detect hydrocarbons. This selection will consider the trade-off between spatial resolution (30 meters) and data volume. The downloaded Landsat data, in a format compatible with our GIS platform, will form a key component of our AI/QML model development.

### Landsat 9 :

Launched on September 27, 2021, Landsat 9 is the newest satellite in the Landsat program, which has been providing valuable Earth observation data since the early 1970s. Landsat satellites take high-resolution pictures of the Earth's

surface, which are utilized for a variety of applications such as agriculture, urban planning, forestry, environmental monitoring, and disaster relief.

The explanation of Landsat 9 and the factors that make it superior to Landsat 8 is provided below:

**Better Sensor Technology:** The Thermal Infrared Sensor 2 (TIRS-2) and Operational Land Imager 2 (OLI-2) in Landsat 9 are better sensors than those on Landsat 8. These sensors' improved spectral, radiometric, and spatial capabilities result in crisper, more detailed images of the Earth's surface.

**Continuity of Data:** Landsat 9 ensures the continuity of the Landsat program's data record, which is crucial for monitoring long-term changes in Earth's environment. By providing consistent, high-quality imagery, Landsat 9 contributes to ongoing research and applications in areas such as land use planning, natural resource management, and climate change monitoring.

**Extended Lifespan:** Landsat 9 is designed to operate for at least five years, with the potential for an extended mission lifespan. This ensures a reliable and continuous stream of data for the scientific community, allowing for the monitoring of both short-term events and long-term trends.

Overall, Landsat 9 represents a significant advancement in Earth observation technology, building upon the success of previous missions like Landsat 8. With its enhanced sensors, improved **spatial** and **temporal** resolution, and **continuous data**, Landsat 9 **will provide** researchers and **decision makers** with valuable **insight** into the dynamic processes **that shape the Earth..**

Nine spectral bands:

Band 1 Visible Coastal Aerosol (0.43 – 0.45 µm) 30-m

Band 2 Visible Blue (0.450 – 0.51 µm) 30-m

Band 3 Visible Green (0.53 – 0.59 µm) 30-m

Band 4 Red (0.64 – 0.67 µm) 30-m

Band 5 Near-Infrared (0.85 – 0.88 µm) 30-m

Band 6 SWIR 1(1.57 – 1.65 µm) 30-m

Band 7 SWIR 2 (2.11 – 2.29 µm) 30-m

Band 8 Panchromatic (PAN) (0.50 – 0.68 µm) 15-m

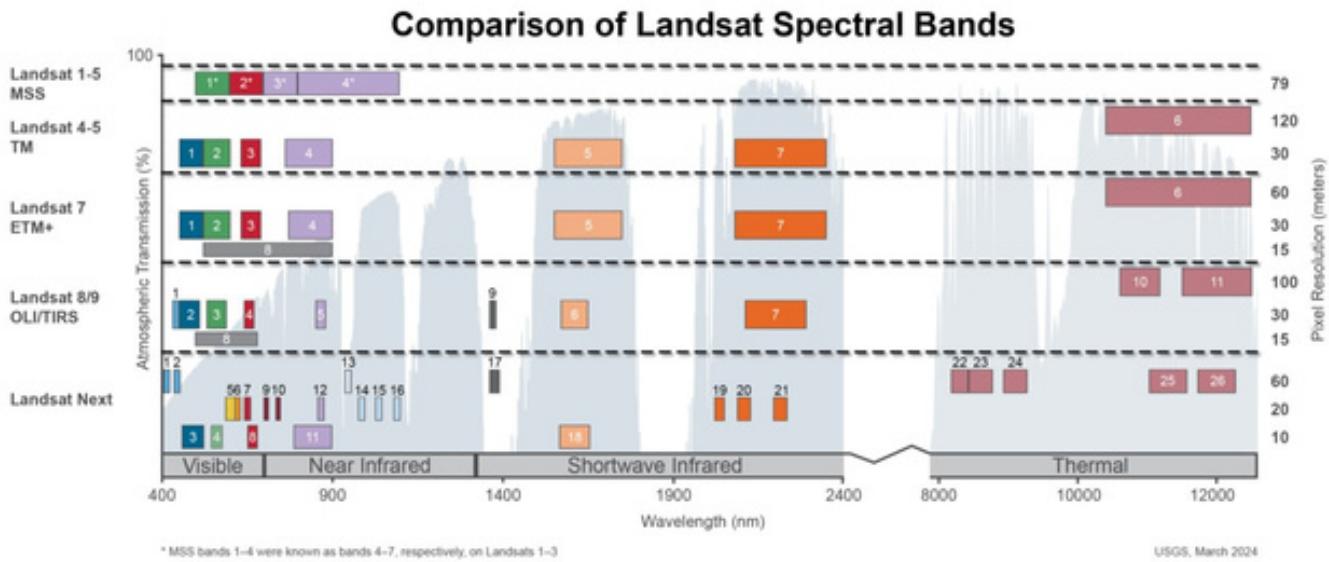
Band 9 Cirrus (1.36 – 1.38 µm) 30-m

## Thermal Infrared Sensor 2 (TIRS-2)

Landsat 9's Thermal Infrared Sensor 2 (TIRS-2) measures thermal radiance emitted from the land surface in two thermal infrared bands using the same technology that was used for TIRS on Landsat 8, however TIRS-2 is an improved version of Landsat 8's TIRS, both with regards to instrument risk class and design to minimize stray light. TIRS-2 provides two spectral bands with a maximum ground sampling distance, both in-track and cross track, of 100 m (328 ft) for both bands. TIRS-2 provides an internal blackbody calibration source as well as space view capabilities. TIRS-2 is designed by NASA Goddard Space Flight Center in Greenbelt, Maryland.

Two spectral bands:

Band 10 TIRS 1 (10.6 – 11.19 µm) 100-m



**Figure6: Landsat Spectral Bands**

## 2-2 Region of interest ( Kansas City ) :

Nestled at the confluence of the Kansas and Missouri Rivers, Kansas City emerges as a vibrant metropolis steeped in rich history, cultural diversity, and economic significance. Situated at approximately 39.0997° N latitude and 94.5786° W longitude, the city spans across the borders of both Kansas and Missouri, serving as a beacon of Midwest charm and dynamism. But beyond its bustling urban landscape lies a lesser-known aspect of Kansas City's past and present – its role in the exploration and extraction of oil and gas resources.

Kansas City's location in the center of the United States indicates its strategic location in the region. The city's location near the geographic center of the American continent indicates its vital role as a crossroads of transportation, commerce, and cultural exchange. These coordinates not only indicate your physical location, but are also gateways to the great center of the United States.

The latitude of Kansas City, Missouri, USA is 39.099724 and the longitude is -94.578331. Kansas City, Missouri, United States is located in the United States in the urban areas zone with GPS coordinates 39° 5' 59.0064" N and 94° 34' 41.9916" W

Kansas City's oil and gas history dates back to the late 1800s, when miners began tapping the vast underground reserves beneath the fertile plains of the Midwest. Originally an oil finds in neighboring states such as Texas and Oklahoma, Kansas City soon became a center for exploration and drilling.

One of the region's earliest and most important oil discoveries was made near the city in 1892, south of Paola, Kansas City. The resulting oil boom not only transformed the local economy, but also spurred rapid urbanization and infrastructure development in and around Kansas City.

Kansas City's energy exploration landscape has evolved over the decades, and advances in technology have led to more efficient extraction methods and increased production rates. Today, the city and surrounding areas are dotted with oil wells, platforms and refineries, a constant reminder of the region's rich oil heritage.

Due to its deep ties to the energy industry, Kansas City has also embraced renewable energy sources. In recent years, reflecting the growing global trend towards sustainable development and environmental protection. Wind farms, solar farms and biofuel plants have become increasingly common sights in the region, signaling a shift toward cleaner, more sustainable energy options.

In addition to its role in energy exploration, Kansas City continues to attract visitors with its own vibrant cultural life., a world-famous barbecue and thriving arts community. From the iconic fountains of Country Club Plaza to the historic jazz clubs at 18th and Vine, the city offers residents and tourists a variety of attractions and experiences.

As we look to the future, Kansas City remains a dynamic and evolving landscape shaped by its past with an eye to tomorrow. Whether you explore its bustling city streets or venture into the peaceful countryside, one thing is for sure, this Midwestern gem continues to inspire and fascinate all who encounter its boundless energy

## **2-3 -2 Well Logs & Geologic Information: Subsurface Insights:**

This subsection highlights the importance of well logs and geologic information for the project. with a breakdown of the key points.

### **Data Description:**

Well logs are digital information compiled in the course of the drilling procedure of oil and fueloline wells, supplying important insights into subsurface situations. They embody numerous parameters such as:

#### **Depth Measurements:**

Records the intensity at which every information factor is measured alongside the wellbore, facilitating unique evaluation and correlation of geological features.

#### **Lithology:**

Describes the varieties of rocks encountered in the course of drilling, helping in information the geological formations and predicting reservoir characteristics.

#### **Porosity:**

Indicates the share of void areas inside the rock formation, important for assessing the reservoir's cap potential to save hydrocarbons.

#### **Permeability:**

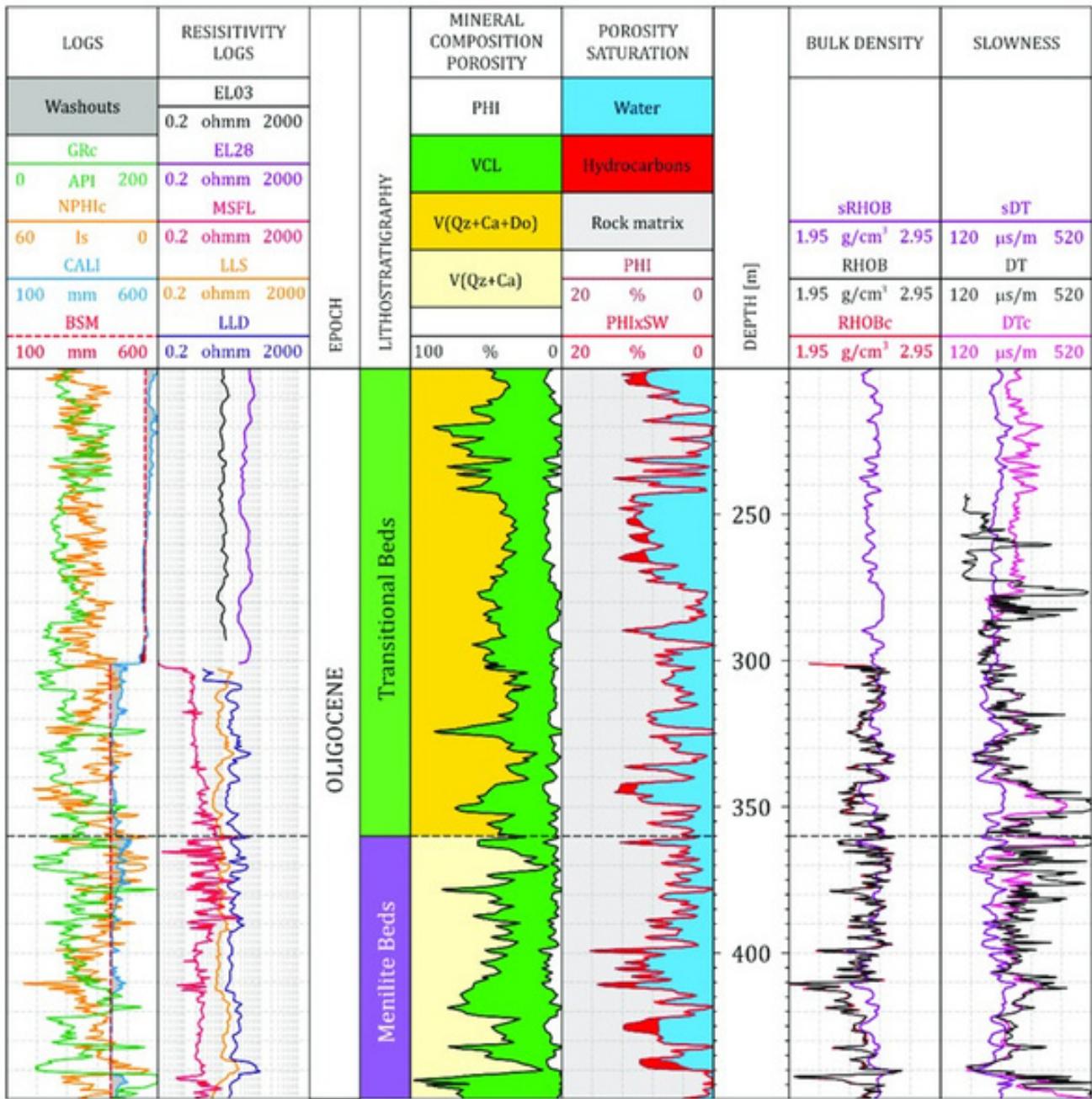
Reflects the rock's cap potential to permit fluid waft thru its pore areas, influencing the convenience with which oil, fueloline, or water can circulate inside the reservoir.

#### **Fluid Content:**

Identifies the presence and distribution of various fluids (e.g., water, oil, fueloline) inside the formation, critical for estimating hydrocarbon reserves and making plans manufacturing strategies.

These information factors are pivotal for reservoir characterization, formation evaluation, and decision-making approaches in oil and fuel line exploration and manufacturing operations.

Well logs function crucial equipment for geoscientists and engineers to recognize subsurface situations and optimize drilling and manufacturing strategies.



**figure6: diagram of Well logging data in the uppermost depth section of the D-1 borehole**

**Created by:**