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A systematic approach for planning a geochemical survey for hydrocarbon exploration: An overview

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Abstract:

Exploration of oil and gas seepages employing geochemical techniques has helped to discover new hydrocarbon resources across the world. Oil and gas exploration techniques had substantial advancements in the late 2000s. Numerous geophysical and geochemical techniques have been created and are constantly improving along with the advancement of digital technologies. Geochemical techniques are being used with remarkable success in the hydrocarbon exploration business to take informed decisions on project viability. These techniques contributed to determining the different hydrocarbon types, the degree of basin maturity, and the reliability of other petroleum system components. Combining precise geological and geophysical techniques with geochemical approaches can considerably improve the prospect chance of success. The current study offers a thorough discussion of geochemical exploration methodology and recommends an appropriate design process for geochemical surveys. It presents a methodical overview of various survey types as well as the advantages and disadvantages of geochemical techniques in comparison to other techniques used in hydrocarbon exploration.

Keywords: Geochemical survey; Hydrocarbon exploration; Macroseepages; Microseepages; Geological and geophysical method

1. Introduction

The most important phase in the exploration of a petroleum field is the investigation of HC through oil and gas seepages. Oil seepages have led to the discovery of many fields around the world that are currently in production. For instance, the Drake well, which is also regarded as the first purposeful oil well in the USA, was found after oil seepages in the area were observed and finally, in the year 1859, the discovery was made. Although numerous wells were producing oil and gas prior to 1859, they were intentionally drilled for water and salt brine, and the discovery of oil and gas occurred by accident (Horvitz, 1985). Therefore, natural oil seepages are crucial to investigate the HC potential of the basin and establishing key petroleum system elements. Geochemical petroleum exploration includes the analysis of oil seeps using principles of chemistry. To establish evidence of hydrocarbon accumulation in an area, geochemical exploration can thus be defined as the search for hydrocarbons or their chemical properties by examination of direct agents like soil and water and indirect agents like plants (Deditius et al., 2018; Hosseini et al., 2022). Determining the qualitative and quantitative presence of hydrocarbon in soil and water samples taken from seepage sites is a part of direct geochemical exploration. The presence of hydrocarbons in these samples is also indicated by the presence of wax, paraffin, and bituminous materials (Nadoll et al., 2015). Because the evaluated samples may contain traces of HC, these approaches are categorized as a direct method. Indirect exploration is a subcategory of geochemical exploration techniques. The following are some examples of indirect exploration: (i) identifying different salts such as sulfates and bromides in soil, water and rocks (ii) determining the redox potential of soil and water (iii) evaluating the soil and water for bacteria that need hydrocarbon for various activities and (iv) examining vegetation growth patterns and correlating them with hydrocarbon accumulation (Hawkes and Webb, 1963; Frost and Frost, 2008; Rumbiak et al., 2022). Because the qualities being studied in the indirect approach could be caused by certain other things besides petroleum, it is less accurate than the direct method. In general, both direct and indirect approaches are used during a geochemical survey (Kirkwood et al., 2016a; Wu et al., 2021). The information gathered from both surveys is plotted manually or digitally to create maps that can be used to locate potential hydrocarbon accumulation sites by highlighting surface anomalies (Rumbiak et al., 2022).

The underlying idea of the geochemical exploration technique is based on petroleum seepages found at the surface. A seepage is formed when the upward migration of HC reached the earth's surface through permeable beds, faults/ fractures, and causes contamination of the rocks, soil and water. Migration of oil and gas typically occurs in an upward direction, however, lateral movement of hundreds of km is also observed in some basins (Zhi et al., 1990; Teruiya et al., 2008). There are a variety of mechanisms through which oil and gas migration can happen and lead to seepages (Fig. 1). For example, a deep-seated fault/ fracture can allow HC to seep to the surface and might be an indicator that the petroleum system's seals have become brittle (Razaz et al., 2020). There are a variety of factors that could lead to migration, but seepages of some kind can be seen in all petroleum basins worldwide. Macroseepages and microseepages are two different forms of seepages (Bacal et al., 2019). Both active and passive seepage are terms used to describe the actions connected to these processes. Macroseepages are large-scale, visually observable seepages of oil and gas through subsurface faults, unconformities, and fractures (Leonte et al., 2018). The presence of HC in microseepages must be confirmed through laboratory testing because they are inaccessible to the human eye. These may contain light hydrocarbons, bacteria and other evidence (Thiombane et al., 2018).

Hydrocarbon migration in the subsurface relies on numerous factors and the most crucial one is a litho-static force exerted by the overlying layer of rock and the buoyancy force of the liquid. It is one of the important aspects that define the hydrocarbon perspectivity of a basin. The migration of HC is a crucial subterranean process that occurs when molecules of oil and gas are expelled from source rock and migrate towards favorable entrapment conditions or seeped out to the surface. The migratory pathway can clearly demonstrate the source rock's position and its subsurface relationship to other petroleum system elements (Luofu et al., 2005).

The source rock maturity and movement information is used in seismic interpretation and basin modeling to identify subsurface geological structures such as folds, faults, salt domes, unconformities, etc. that may serve to create a trapping mechanism for HC buildup (Zhang and Zhao, 2004). Also, with the development of technology, it has become necessary for the E&P industry to integrate geochemical analysis and HC migration data to get a robust subsurface model. Fig. 1 shows different migration mechanisms and associated leakage phenomena to them.

Several researchers across the globe are utilizing artificial intelligence (AI) and machine learning (ML) techniques during the advancement of the oil and gas industry such as geochemical mapping & data interpretation (Kirkwood et al., 2016b), field planning (Kumar, 2019), lithology mapping and reservoir characterization (Joshi et al., 2021; Wu et al., 2021; Mishra and Patidar, 2022) and well log data interpretation (Kilrani et al., 2021). Due to their quick reaction times and powerful generalization capabilities, AI techniques are attracting a great deal of interest. These digital techniques include algorithms that gain insights directly from data and make predictions. There are several key advantages associated with the implementation of modern digital techniques in geochemical surveys which includes handling large data sets to reduce the time and cost of the project. These techniques can quickly identify complex anomalies that manual interpretation might overlook (Larsen et al., 2017). Geochemical data collected from the surface or subsurface can be fed directly to algorithms as input data which can be correlated through various means before the final prediction/ interpretation. Petroleum companies across the globe have different AI platform, like Shell has Geodesic, Chevron, and Schlumberger use DELFI, Baker Hughes and Halliburton use Azure and Exxon Mobil have XTO. These platforms are highly selective in nature and are being used for handling different data sets for both geochemical and geophysical studies (Kuang et al., 2021). Moreover, integrated modeling of geophysical and geochemical data using AI/ML algorithms may precisely characterize subsurface conditions and can be quite helpful to resolve complex geological circumstances.

These modern digital techniques have been used to solve a variety of reservoir engineering problems and to supplement conventional methodologies (Kumar, 2019). Understanding the fundamentals associated with the geochemical approach of hydrocarbon exploration will help in better integration of generated data sets with other data generated through gravity, magnetic and seismic surveys. The utilization of green computing techniques in the petroleum sector is rapidly progressing, as the concept of AI progressively permeates various phases of the industry, like intelligent drilling, sustainable development, sensor-based pipeline monitoring, smart processing units, etc. Real-time decision-making flows can be developed through these digital methods at different phases of E&P, which might assist management in making better decisions. The benefits of information may be achieved in the future if appropriate procedures are followed and systematic data sets are generated that could aid in making wise decisions (Anifowose et al., 2017; Kumar, 2019; Zhang et al., 2020).

As tools for categorization and regression issues, numerous research applies sophisticated ML techniques such as Fuzzy Logic (FL), Artificial Neural Networks (ANN), Supporting Vector Machines (SVM), and Response Surface Models (RSM). Several reservoir engineering applications often utilize evolutionary optimization strategies, such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) (Zhang et al., 2020). Due to the rising population and increasing energy demand, the oil & gas industry is turning to be more unpredictable and competitive. Several companies have adopted AI/ML based techniques to manage larger

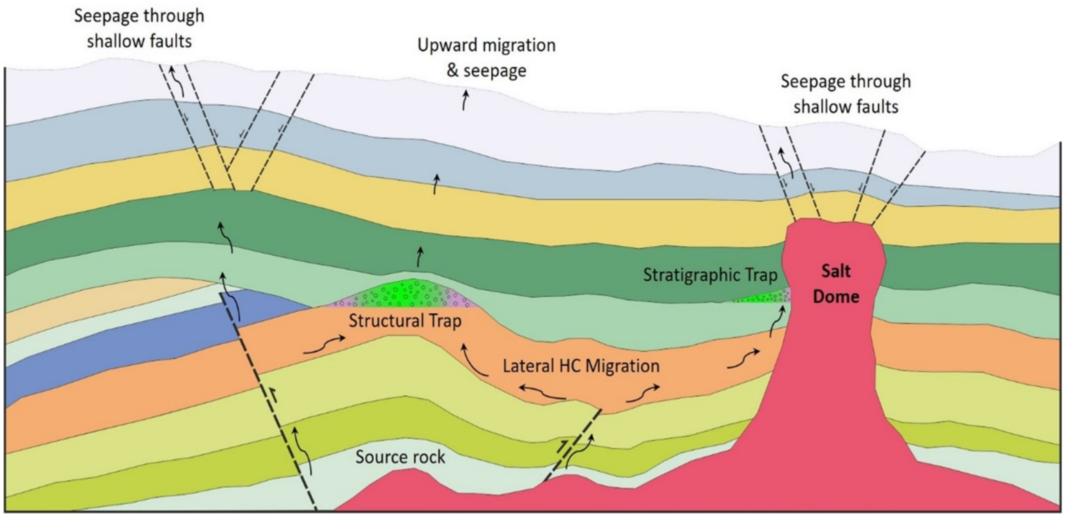

Figure 1. A conceptual diagram showing different leakage mechanisms for oil and gas observed under various subsurface conditions. Subsurface stratigraphic levels are represented by various color layers. The dashed line represents faults extending into the subsurface.

data sets and efficiently process them in order to reduce costs and improve workplace safety. This method necessitates having a lot of data in memory. Data sets are provided to defined algorithms as input layers during AI/ML modeling. These algorithms are then automatically processed and systematically characterized to generate comparatively accurate correlations (Anifowose et al., 2017). Exploration activities include huge risks both in terms of investment and safety and to mitigate this risk, technological advancement is being adopted in almost every phase including Geochemical surveys. A hydrocarbon exploration requires precise and accurate data for subsurface mappings which can help in determining prospective drilling sites and related activities. Also, seepage data can be employed to determine source rock maturity, organic matter & kerogen type and timing of migration. However, there are several benefits and drawbacks to using these approaches. Some potential advantages & disadvantages are listed below in Table 1.

The completion of a hydrocarbon project cannot be successfully achieved by a geochemical survey alone. The only way to produce a cumulative dataset that can provide firm evidence of the presence of economic hydrocarbon potential is to integrate the survey results with geological and geophysical methods (Cloutier et al., 2008; Wang et al., 2014; Hosseini et al., 2022). The geophysical method of exploration, specifically seismic exploration, currently dominates the petroleum exploration industry. Although geochemical surveys are the first show of hydrocarbon in any field. Table 2. Depicts various advantages of geochemical surveys over geophysical surveys.

Recently Zavatsky et al. (2022) designed a geochemical model by analysis and interpretation of surface geochemical data. The study revealed the quantitative relationships that are occurring between oil shows and the oil-bearing capacity in West Siberia. The survey size enabled the determination of quantitative assessments of the surface geochemical field that realistically characterize regions where sections contain oil-bearing horizons despite the absence of a direct quantitative connection between the section's ability to hold oil and the intensity of surface hydrocarbon anomalies.

Sechman et al. (2020) evaluated the variations in direct and indirect surface anomalies displayed in parts of the Carpathians, Poland. The study analyzed the molecular composition, calcium content, magnetic susceptibility and pH of soil samples taken from fields. The results showed that the soil sample included methane, alkanes (C_2-C_5) and alkenes (C_2-C_4) with concentrations of 2100, 10.43 and 0.772 ppm respectively. The variation in magnetic susceptibility was recorded from 3.6 to 21.5 x 10–8 m3/kg. The value of calcium content was recorded at 29.92% by weight with pH ranging from 4.5 to 8.3. The results displayed showed a better understanding of migration and the presence of hydrocarbons which were later utilized for field development in outer parts of the Carpathians.

2. Objectives of the study

In the past decade, the geochemical exploration method has emerged as a result of advancements in analytical testing and interpretation methodologies. A full grasp of the various strategies used in this method, as well as how they might be applied in the actual world, is absolutely necessary to improve the accuracy and precision of the method. Hydrocarbon E&P activities necessitate a significant financial commitment, and even a little miscalculation at any stage might result in a significant financial loss. This brief review discusses various aspects associated with geochemical exploration methods and their integration with HC exploration. When writing this work, the following main objectives were taken into consideration. (i) to provide a fundamental grasp of a geochemical survey, including its various types (ii) to describe different geochemical survey techniques employed in real-field situations and (iii) to discuss the real-world applications of geochemical survey.

The subsequent section of the paper includes different types

Table 1. Potential advantages of using a geochemical approach in hydrocarbon exploration & production.

Advantages (Cheng, 2007; Cheng et al., 2011; Talebi et al., 2019; Mishra and Patidar, 2022)	(a) It is possible to directly detect HC both onland and offshore. (b) It can be useful in illustrating the petroleum system in the specified potential area or basin. (c) A systematic analysis can raise a prospect's likelihood of finding hydrocarbons and success rate. It might also be useful for planning future geological and geophysical surveys. (d) A proper geochemical survey can aid in improving the oil and gas project's financial management. (e) To fill in the space between 2D seismic lines and AVO/amplitude anomalies on a map, geochemical data can be used. (f) Areas that are seismically inaccessible or geologically vulnerable can use this strategy. (g) They don't harm the environment in any way.
Disadvantages and Limitations (Kirkwood et al., 2016a; Guartán and Emery, 2021; Ge et al., 2022)	(a) They are not applied everywhere. They operate precisely in seepage-prone areas. (b) Subsurface features like source or reservoir rock cannot be linked to geochemical abnormalities. (c) Wrong interpretation of results might come from errors (human, instrumental, etc.) in sample collection, storage, or testing. (d) This approach is unable to forecast the economic presence of hydrocarbon. (e) It cannot take the place of geophysical and geological exploration methods. Although integration of all these methods can offer better confidence in evaluating an area.

Table 2. Advantages of geochemical surveys over geophysical surveys.

S.No.	Geochemical surveys	Geophysical surveys
1	This can directly depict the hydrocarbon or hydrocarbon alteration on the surface	Geophysical data cannot depict such possibilities of hydrocarbon show on the surface
2	These surveys are useful for the pre-assessment of basins, play or prospects before acquiring a lease	These surveys require full rights and lease of land after getting preliminary data of an area that confirms the presence of hydrocarbon
3	Geochemical surveys are generally cost-effective and do not require a large investment	Geophysical surveys especially the seismic method of exploration are costly but extremely important for hydrocarbon exploration
4	These types of surveys can be incorporated for data collection in all types of regions where geophysical data is hard or impractical to achieve	They cannot be applied to all types of terrains. For instance, seismic data collection in rugged topography (onland) or ultra-deepwater (offshore) might increase the project cost.
5	Have a less or negligible impact on the environment	These surveys can impact the environment

of geochemical approaches viz., direct, and indirect methods followed by planning of geochemical survey by considering its real field application.

3. Types of geochemical method

Generally, there are two types of geochemical techniques: direct and indirect (Fig. 2). In the earlier method, samples are directly examined for the presence of hydrocarbons. The sample being examined may be water, rock or soil that has been contaminated with oil and gas (Horvitz, 1985). The latter method makes conclusions regarding the potential presence of hydrocarbons by measuring chemical features like the redox potential of soil and water, geobotanical changes, the presence of salts like bromides, etc. Currently, oil and gas projects do not frequently employ this method since it is less accurate (Hosseini et al., 2022).

Procedures including micro-gas surveys, gas logging, hydrochemical surveys, sniffer surveys, organo-hydro chemical surveys, etc. are used in the direct technique. This can be used to identify both light and heavy hydrocarbons (Nadoll et al., 2015). It is currently one of the most studied methods as well as one of the oldest methods for geochemical surveys to identify light hydrocarbons. Light hydrocarbons may be present in soil samples as free gas or adsorbed gas in the effective pore space (Cloutier et al., 2008; Guartán and Emery, 2021). Geochemical modeling was done by Sechman et al. (2020) to detect the pH, calcium content and type of hydrocarbon in part of the Carpathians, Poland. Later, quantitative modeling was performed to establish the relationship between oil show and oil-bearing capacity in the Siberia region by Zavatsky et al. (2022) . A gas sample that is dissolved in water can be examined in labs. Particularly when migration progresses via fault and fracture channels, heavier hydrocarbons, such as aromatic compounds & even regular/biodegraded oils, might be found. Numerous approaches for sampling and testing hydrocarbons have been developed in the recent past (Kirkwood et al., 2016a; Ge et al., 2022).

Processes like ferric iron conversion to ferrous iron via hydrocarbon migration in a reservoir are examples of indirect techniques (Fig. 2). The local vegetation's ability to grow is directly impacted by this conversion. Testing plant leaves and needles for high ferrous iron concentrations can reveal the presence of hydrocarbons (Cheng et al., 2011; Wang et al., 2014). Ferrous iron is essential for plant growth. Even though other factors can cause the concentration of ferrous in plants to rise, this approach is not practical for petroleum exploration. The decomposition of carbonates at high temperatures between 500 °C- 600 °C is another significant process that has been applied in various projects. Halo-type anomalies (also known as negative anomalies seen in the upper layer of soil having less concentration of oil and gas show due to microbial activities) are generated by CO_2 produced from carbonate decomposition. These anomalies are occasionally associated with subsurface petroleum deposits (Cheng, 2007; Talebi et al., 2019).

4. Planning a geochemical survey

In general, geochemical surveys are conducted to achieve two main goals (Cheng, 2007). (i) identify the presence, distribution, and composition of hydrocarbons in an area (ii) determine the probable hydrocarbon charge for specific leads and prospects for exploration. Geochemical procedures also require careful planning, just like other petroleum exploration techniques. Planning for a geochemical survey that can also be influenced by several things like earlier success rates, geological complexity, and other things requires consideration of the basin's historical patterns and HC probability (Thiombane et al., 2018; Bacal et al., 2019). A flowchart for undertaking a geochemical survey is shown in Fig. 3.

A reconnaissance survey seeks leaks and microseeps which give definitive proof of thermogenic hydrocarbon generation, i.e., they record the existence of a functional petroleum ecosystem. Additionally, the type of leakage could indicate whether a reservoir or play is more likely to contain oil or gas. Hydrocarbons from land and seabed leaks can be compared to the existent oils and gases to identify the pre-

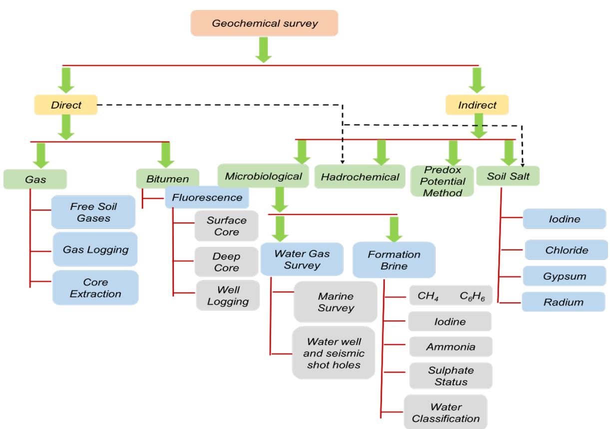

Figure 2. Different types of surveys are included in the geochemical exploration method (modified after Jones et al. (1999)).

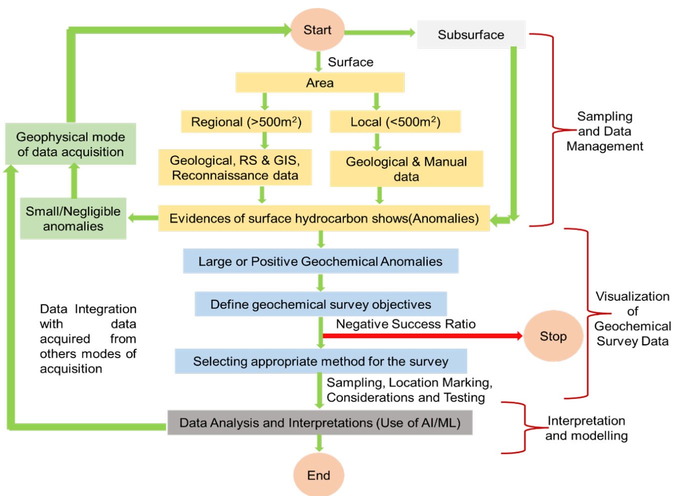

Figure 3. Flowchart showing steps involved in geochemical surveys. The basin area wise categorization and the associated flow of the geochemical survey are illustrated.

cise petroleum system implicated. An explorationist can quickly screen and correlate large areas using seepage data and identify the prospective locations for future exploration (Zhi et al., 1990; Teruiya et al., 2008).
Geochemical survey data can help in identifying leads related to significant hydrocarbon anomalies, allowing high-grading prospects based on their correlation with hydrocarbon markers (Teruiya et al., 2008; Rumbiak et al., 2022). Regional geochemical surveys can assist geoscientists/ project managers to determine the prospective area of the basin having a higher probability of hydrocarbon presence. By identifying structures that are hydrocarbon-charged, microseepage investigations may enhance the quality of seismic data interpretation and modeling (Kirkwood et al., 2016a; Wu et al., 2021).
While conducting a geochemical survey in any region, many studies should be taken into account. To plan a survey, geological plots, a geophysical cross-section of the basin, electrical/ magnetic data, and previous geochemical survey data (if available) are some of the key considerations. Calculation of the geochemical survey's success rate is based on the interpretation of the data produced by considering the above-mentioned factors (Hawkes and Webb, 1963; Wang et al., 2020). For exploration in areas with a high success rate, geochemical surveying will be both economically viable and productive. Whereas, it should be skipped when the success ratio is negative or near zero, and alternative methods for surveying may be used (Frost and Frost, 2008; Rumbiak et al., 2022). The most crucial stage in conducting a geochemical study is to choose the best survey methodology. It is necessary to list the numerous questions that need to be addressed by a survey before selecting a suitable methodology (Heath and Campbell, 2004; Deditius et al., 2018). The approach that will be able to respond to the most queries will be chosen. Other alternatives which are helpful in selecting a method include computer modeling, the number of a spot where seeps are visible, the total budget of the project etc (Nadoll et al., 2015; Hosseini et al., 2022). The creation of a questionnaire cannot be done by one person and needs an expert's views as well as pre-existing information. It is the outcome of extensive discussion between geologists, geoscientists, geochemists, geophysicists, and engineers involved in project development in that area (Cloutier et al., 2008). Some of the objectives discussed by Kirkwood et al. (2016a) and Guartán and Emery (2021) are listed below,
a) What is the primary goal of the survey? Regardless of whether we are searching for new petroleum systems or interested in delineating existing leads/prospects etc.
b) Is it possible to integrate the results of this survey with those from other studies, such as seismic and gravity surveys?
c) If this survey had been conducted in the past in the same or a nearby field, what was its success rate?
d) The likelihood of overcoming difficulties (geological barriers) that will affect the survey.
For any successful geochemical survey, a strategy must be defined based on the above-mentioned objectives or similar things according to project conditions. However, a direct, indirect, or combined approach can be used based on the available budget and project timeline. The direct method is typically employed because of its excellent precision and these relationships can also be used to assess the basin's maturity (Zhi et al., 1990; Cheng et al., 2011; Talebi et al., 2019). Table 3 illustrates various techniques for geochemical exploration. HC leaks that may be seen with the human eye typically mark the beginning of the geochemical investigation in frontier areas. Data can also be obtained from seismic line traces. Depending on the objectives, the sampling interval can range from 0.5 – 1 km to 0.5 – 100 m (Frost and Frost, 2008; Wang et al., 2020).

5. Data interpretation and discussion

The presence of hydrocarbons will be directly confirmed by oil and gas leaks. Additionally, HC presence at the surface indicates a weak sealing condition and its continuous upward or lateral migration through carrier beds, faults, and fractures from an underprivileged entrapment condition (Deditius et al., 2018). The understanding of diverse types of traps (structural/ stratigraphic) in the study area may help to narrow down the survey location (Hawkes and Webb, 1963; Nadoll et al., 2015; Rumbiak et al., 2022). It becomes challenging to interpret the geochemical anomalies if lateral migration dominates the basin. Geochemical anomalies cannot be identified vertically above the trap because lateral migration typically takes place through deeply seated faults or unconformities (Zhi et al., 1990; Cheng et al., 2011; Talebi et al., 2019).
Micro and macroseeps can also be used to interpret the type of HC in the basin and to determine the subsequent potential for further development (Kirkwood et al., 2016a). Samples from macroseeps are typically not pure since they have traveled a great distance, which could have caused processes like water washing and biodegradation to change their composition. Despite these modifications, isotopic and chemical analysis of these samples may still be able to reveal the nature and maturity of the source rock (Zhi et al., 1990; Thiombane et al., 2018) and can also be used to establish a correlation between reservoir and source rock. Samples collected from microseeps do not infer much about the petroleum system as they contain only light hydrocarbons. Therefore, extracting compositional information from microseeps would be time-consuming and impractical. Although tests like acid extract chromatography and carbon isotopic composition may be used on these samples to show characteristics of the oil and gas collected in reservoirs (Hawkes and Webb, 1963; Rumbiak et al., 2022).
Seeps provide conclusive evidence of the presence of oil and gas in a region. For instance, even after the first oil well was discovered in the United States, exploratory wells continued to be drilled close to seep locations for the next few decades, and almost all of them were successful in finding oil and gas (Hosseini et al., 2022). Nearly every petroliferous basin on earth has several oil seeps spots which are taking place because of gas and oil seeping from the subsurface traps. Subsurface deformation activities have the potential to degrade the entrapment condition and make it partially permeable, which could lead to hydrocarbons

Table 3. Different methods of geochemical exploration and their properties (Horvitz, 1985).

Location	Method	Sampling medium	Targets
Offshore	Radar/Laser	Atmosphere	Hydrocarbon Analysis
	Satellite, Air-borne sensors, Direct Sampling	Water Surface	Oil slick Analysis
	Marine Sniffers/Water Analysis	Water	Dissolved hydrocarbons
	High-Resolution Seismic, Direct Sampling, Side Scan Sonar	Sea Water	Macro/microseepages
Onshore	Geological Mapping, Historical Records, Direct Sampling, Satellites, Air-borne Sensors	Land Surface	Microseeps, Hydrocarbon induced alterations
	A probe or Adsorptive Collector	Soil/Air	Light hydrocarbons, Non-hydrocarbons
	Sample disaggregation, Acid extraction for chromatography, UV-Florescence	Soil/Sediments	Light Hydrocarbons
	Radiometric, Ground Magnetic, Electrical, Aeromagnetic	Soil/Sediments	Nonhydrocarbons, diagenetic anomalies

escaping to the surface. Most of the geochemical surveys performed include direct sampling which offers a high level of accuracy. Although, it is always recommended that multiple sampling techniques should be used. For example, integrating results from the direct and indirect methods will enhance the probability of success. Using multiple methods at a single location will surely reduce the uncertainty in interpretation as seepage-associated anomalies are likely to be amplified at those locations. In case the geological conditions or the financial constraints are making direct sampling difficult then alternative or indirect methods will be appropriate.

As petroleum E&P activities involve a heavy investment thus it becomes crucial to plan a geochemical survey individually as well as in integration with other geophysical methods. A geochemical survey alone cannot offer confidence to drill a well in a new field. A planned survey will always be less expensive and more effective than one that uses random sampling. The success rate of any geochemical investigation will be determined by the project objectives, stringent criteria for technique selection, data interpretation using numerous approaches, and their correlation.

6. Conclusion

Due to advancements in interpretation and analytical techniques, geochemical exploration has significantly increased since the late 2000s. The new generation data sets and their processing and interpretation using digital techniques have improved the rate of success of geochemical surveys during the exploration phase. Below mentioned conclusions are drawn from this brief review,

1. Geochemical surveying is an essential technique because it provides the first indication of hydrocarbon presence during the exploration and production phase of HC. The usefulness of this technique multiplied when combined with geological and geophysical methods.

2. A geochemical method is capable of detecting hydrocarbon seepage linked to weak petroleum system components in any basin. Since there is insufficient high-resolution exploration data available for offshore regions, analysis of hydrocarbon seepages is overlooked. Geochemical data can reduce the uncertainty and risk associated with the E&P business when appropriately acquired and integrated with other contemporary exploration techniques.

3. Geochemical prospecting technologies have advanced significantly, and their integration with AI/ML has made it feasible to read the subsurface in unique ways that were previously not possible.

4. The likelihood of a successful data interpretation will increase by addressing every concern that can be resolved through meticulous planning of geochemical surveys and systematic interpretation of recorded data. Nevertheless, delineating diverse subsurface petroleum system components and their interconnections in geologically complex terrains poses several challenges.

Authors Contributions
All authors have contributed equally in preparing the paper.

Availability of Data and Materials
Data is available on request from the authors. The data supporting this study's findings are available from the corresponding author, upon reasonable request.

Conflict of Interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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