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Probelmatic: Many agencies and institutes are describing the pressing need to more fully develop tools and approaches that can be used to characterize, monitor, and investigate hydrogeological parameters to improve groundwater recovery and ensure

water resource sustainability.

Limitation: Conventional techniques for characterizing hydrogeological properties (such as pumping, and slug tests) typically rely on borehole access to the subsurface. Because their spatial extent is commonly limited to **the vicinity near the wellbores**, these methods often can not provide sufficient information to describe key controls on subsurface flow and transport. The natural heterogeneity and the **large spatial variability** of hydraulic parameters that control infiltration and transport of groundwater is widely recognized.

Alternative: The geophysical methods are a very good alternative that commonly used for shallow subsurface characterization; by applying geophysical principles/methods to link the petrophysical properties to hydrological properties. Hydrogeophysics builds on previous experience and developments associated with the hydrocarbon and mining industries.

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- **Geophysics** has been used as a tool for petroleum and mining industries for so long to define lithological boundaries and other subsurface structures. It is an application of physical methods, such as seismic, gravitational, magnetic, electrical and electromagnetic at the surface and/or the subsurface of the Earth to measure the physical properties of the subsurface which give a relatively good understanding of petrophysical properties and associated fluids that reach a consolidated, high pressure, high temperature and deep subsurface environment.
- However, the subsurface conditions for **hydro-geophysics** studies are quite different. The shallow, low temperature, low pressure, and less consolidated environments characterize most hydrogeological investigation sites. Hydro-geophysical research has been also performed as near-surface where shallow geophysics methods applied (<250 m) with a minimum exceptions for deep confined water (ex: Continental intercalaire in Algeria Desert).

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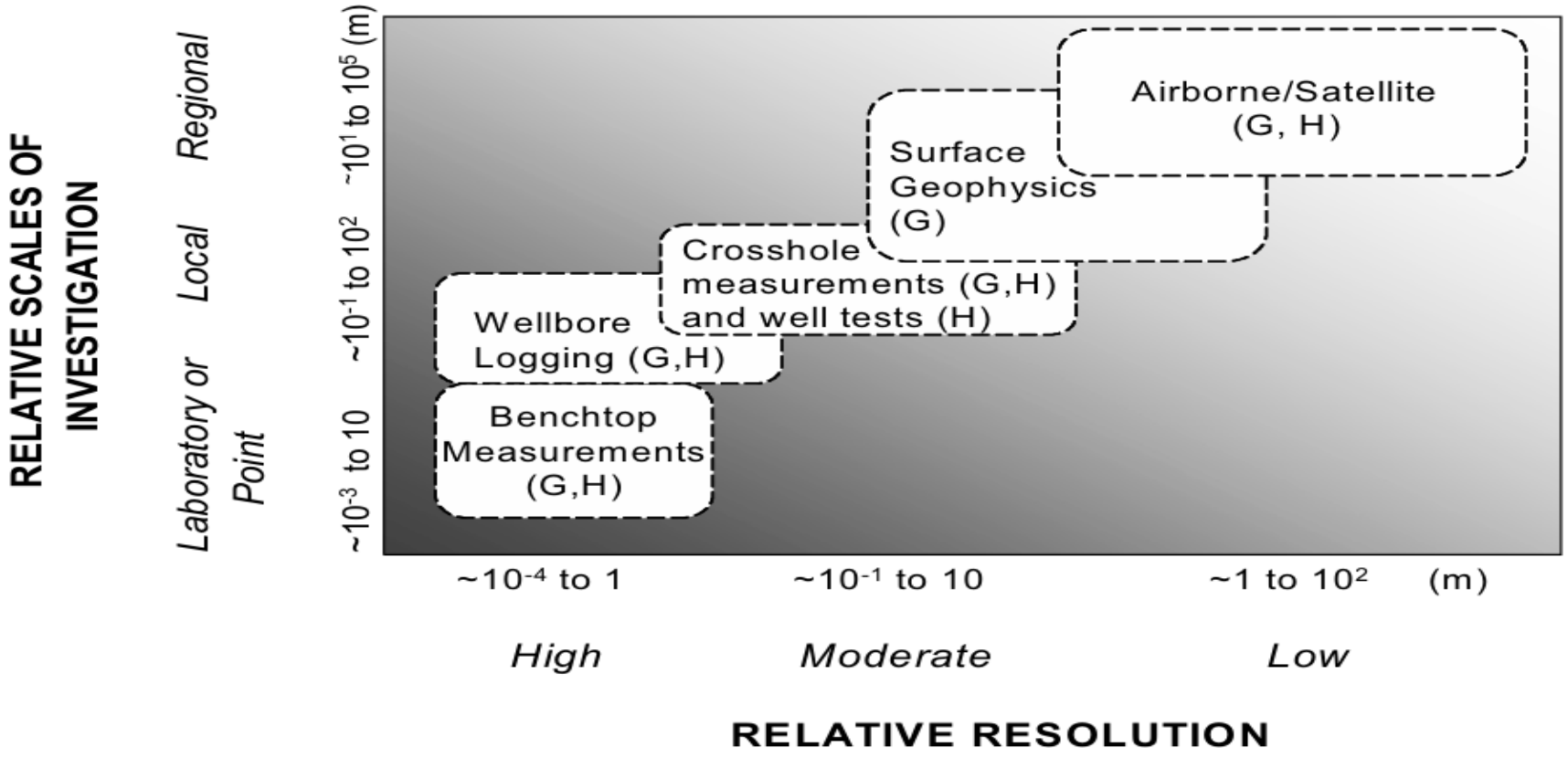
- As a result Hydro-geophysics is the process of making geophysics methods in service of hydrogeology or groundwater exploration and saline water intrusion at different scales from core sample to satellite and airborne (plane) images. See in figure-1 below how can data characterization scale spread and the right technique to be used.



- **Figure 1: Data characterization scales**
- Source: Y,Rubin & Susan S Hubbard (2005)

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- The selection of which technique or acquisition approach to use for a particular investigation is made by considering many factors, such as:

1. The objective of the investigation relative to the sensitivity of different geophysical methods to that objective (Shallow or deep……).
2. The dimension of the project and allocated funds; cost monitoring is compulsory.
3. The desired level of resolution; conditions at the site; time, and computational resources available for the investigation (Software and computers) .
4. Experience of the investigator; and availability of other data. Data are often collected in a sequential manner , where lower-resolution acquisition approaches are used for reconnaissance investigation, followed by higher-resolution approaches to provide more detailed information as required.
5. Not all geophysical methods suits to hydrogeological investigation see table-1.

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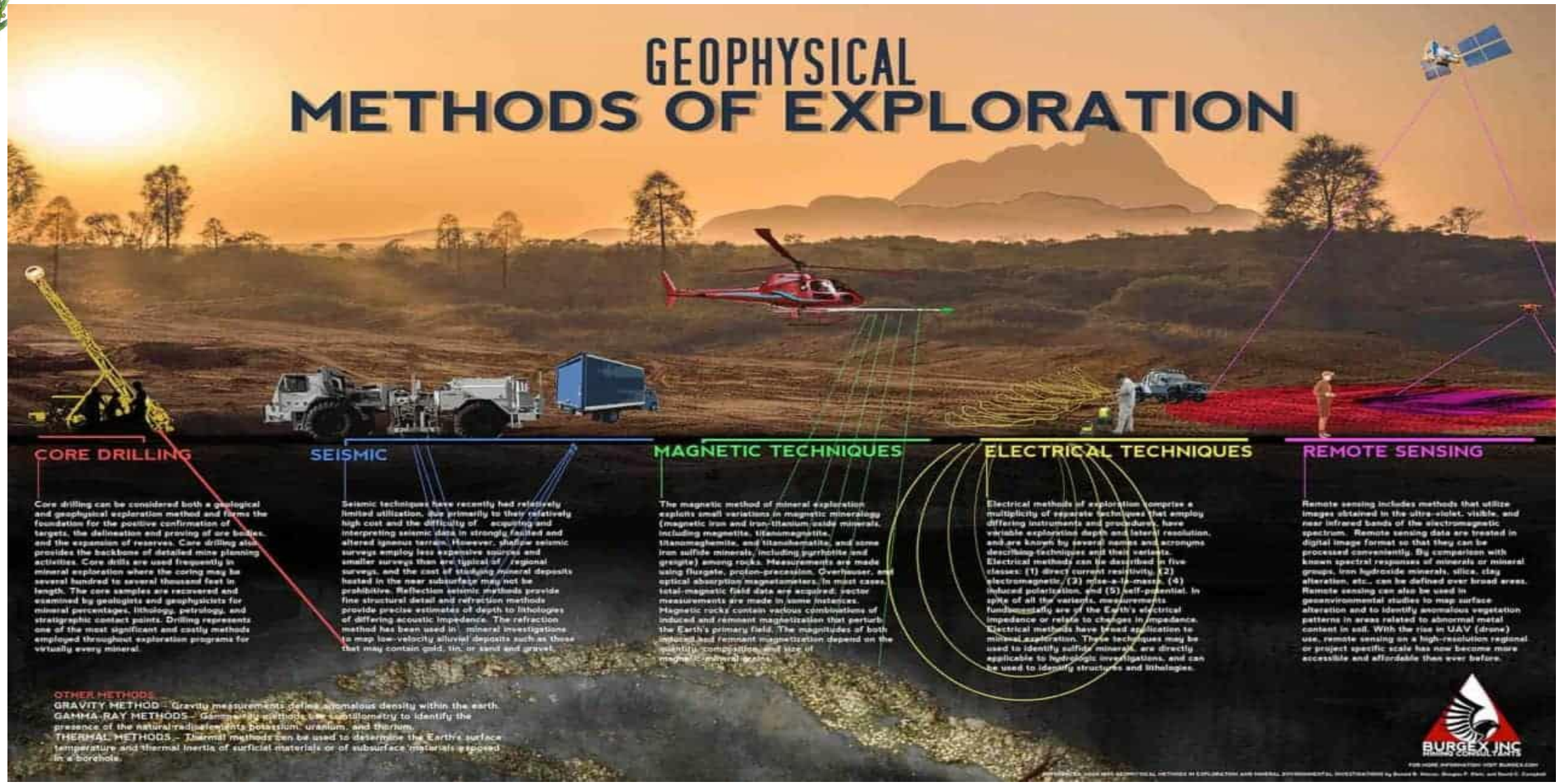

Figure 2: Geophysical exploration methods

Source: https://www.burgex.com/2017/07/02/geophysical-exploration-methods/

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Table 1: Main Geophysical methods and their main applications

Geophysical method	Chapter number	Dependent physical property	Applications (see key below) 1	2	3	4	5	6	7	8	9	10
Gravity	2	Density	**P**	**P**	s	s	s	s	!	!	s	!
Magnetic	3	Susceptibility	**P**	**P**	**P**	s	!	m	!	**P**	**P**	!
Seismic refraction	4,5	Elastic moduli; density	**P**	**P**	m	**P**	s	s	!	!	!	!
Seismic reflection	4,6	Elastic moduli; density	**P**	**P**	m	s	s	m	!	!	!	!
Resistivity	7	Resistivity	m	m	**P**	**P**	**P**	**P**	**P**	s	**P**	m
Spontaneous potential	8	Potential differences	!	!	**P**	m	**P**	m	m	m	!	!
Induced polarization	9	Resistivity; capacitance	m	m	**P**	m	s	m	m	m	m	m
Electromagnetic (EM)	10	Conductance; inductance	s	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	m
EM–VLF	11	Conductance; inductance	m	m	**P**	m	s	s	s	m	m	!
EM – ground penetrating radar	12	Permitivity; conductivity	!	!	m	**P**	**P**	**P**	s	**P**	**P**	**P**
Magneto-telluric	11	Resistivity	s	**P**	**P**	m	m	!	!	!	!	!

P = primary method; s = secondary method; m = may be used but not necessarily the best approach, or has not been developed for this application; (!) = unsuitable

Applications

1 Hydrocarbon exploration (coal, gas, oil)
2 Regional geological studies (over areas of 100s of km^2)
3 Exploration/development of mineral deposits
4 Engineering site investigations
5 Hydrogeological investigations
6 Detection of sub-surface cavities
7 Mapping of leachate and contaminant plumes
8 Location and definition of buried metallic objects
9 Archaeogeophysics
10 Forensic geophysics

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The methods can be classified as primary or secondary use because of:

- The geophysical/ hydrogeological properties and parameters they can give.
- The implementation procedure and the dimension of the project.
- The cost/benefit related to the use of specific methods.
- The nature of hydrogeological study; groundwater exploration and subsurface contaminant use different methods in their studies.

Note there are other new methods confirming their efficiency such as GPR (Ground Penetration Radar) , VSP (Vertical Seismic Profil) that are in common use recently.

We will go through each method from the less used to the most and the best in use.