Methods for Analyzing Sedimentary Series

The comprehensive study of **Sedimentary Series** (stratigraphy, composition, and history) relies on a suite of integrated techniques, broadly categorized into field observation and detailed laboratory analysis.

Laboratory and Theoretical Methods

1. Sedimentation Principle and Application

Sedimentation is the process where solid particles settle from a fluid (liquid or gas) due to gravity. This principle is fundamental for separating solids from a solution (e.g., water treatment) and is widely applied in **Grain Size Analysis** to determine the size distribution of fine-grained sediment (silts and clays).

- **Theory:** Denser and coarser particles settle **faster** than lighter or finer particles when subjected to gravitational force. Settling speed is controlled by particle size, shape, and fluid viscosity.
- **Techniques:**
  - **Gravity Settling:** The simplest method involves flow through rectangular tanks where particles settle horizontally as the water moves.
  - **Centrifugation:** This method applies a **centrifugal force** to a heterogeneous mixture to rapidly separate particles based on small differences in **density** (and size), significantly accelerating the natural sedimentation process.

2. Analytical Techniques

Detailed studies of sedimentary rocks employ several specialized laboratory methods:

- **Grain Size Analysis:** Measuring the size of sediment grains (via sieving, sedimentation, or laser analysis) to determine their distribution and depositional history.

- **Mineralogical Analysis (XRD):** Studying the mineral composition, especially **clay minerals**, using techniques like **X-ray Diffraction (XRD)** to infer provenance, diagenesis, and depositional conditions.
- **Chemical Analysis:** Determining major, minor, and trace element concentrations or stable isotope signatures to understand source, diagenesis, and paleochemistry.
- **Microscopical Techniques (Thin Sections, SEM):**
    - **Optical Petrography:** The basis of routine description using **thin sections** (often enhanced with stains and peels) to recognize minerals, texture, and fabrics.
    - **Scanning Electron Microscopy (SEM):** Used for studying the **ultrastructure** of fine-grained rocks, surface textures, clay cements, and diagenetic features at high magnification.
- **Dating:** Using methods like Carbon-14 or thermoluminescence to establish the **absolute age** of the sediments.
- **Numerical Modeling:** Computer simulations to predict and understand complex sedimentary processes and depositional scenarios.

Field-Based and Coring Methods

The foundation of sedimentology is the collection of basic data from the field, which informs all subsequent analyses:

- **Field Analysis:** Direct observation of **rock outcrops** and sedimentary structures, including recording lithology, texture (grain size, shape, sorting), bed thickness, and sedimentary structures. Field records are compiled as **field notes**, **sketches/photographs**, and **graphic logs**.
- **Coring:** Collecting continuous, undisturbed subsurface samples at different depths to understand **stratigraphy** and deposit history.
- **Paleontological Studies:** Analysis of **fossils** to reconstruct past environments and depositional conditions.

Essential Methods in Sedimentary Analysis

A comprehensive understanding of sedimentary rocks and their formation environments is achieved by combining field and subsurface data collection with detailed laboratory analysis.

I. Data Collection and Core Acquisition

- **Field Analysis:** Direct observation of **rock outcrops** and sedimentary deposits to record features and collect initial samples.
- **Coring:** Acquisition of intact subsurface sediment samples at various depths to establish **stratigraphy** and depositional history.

II. Laboratory Analysis and Interpretation

These techniques investigate the physical, chemical, and historical characteristics of the samples:

- **Grain Size Analysis:** Measures the size distribution of sediment grains using methods like **sieving** or **laser analysis** to infer sediment transport and **provenance** (source area).
- **Mineralogical Analysis:** Identifies the minerals present (e.g., using **X-ray diffraction (XRD)**) to understand the sediment's origin and subsequent history.
- **Chemical Analysis:** Determines the elemental and isotopic composition to trace sediment sources and identify **diagenetic processes** (changes after deposition).
- **Dating:** Uses geochronological techniques (e.g., **Carbon-14** or thermoluminescence) to establish the **absolute age** of the sediments and deposits.
- **Paleontological Studies:** Analysis of **fossils** contained within the sediments to reconstruct past environments and depositional conditions.

III. Predictive and Synthesis Tools

- **Numerical Modeling:** Uses computer simulations to model sedimentary processes, aiding in the prediction of future deposits based on environmental scenarios.

The Stokes Law $F = r\eta v 6 \pi v$ or the V= see Tucker Method

With

r = is the radius of the sphere,

η = is the fluid's viscosity, and

v is the object's velocity

6 π constant of proportionality

F= Drag force (the resistance force exerted by the fluid) where the units are

Or; according to (Maurice Tucker, 1984 Tcheniues in Sedimentology), Stokes' law units:

where

v s is particle settling velocity (in **m/sec units**),

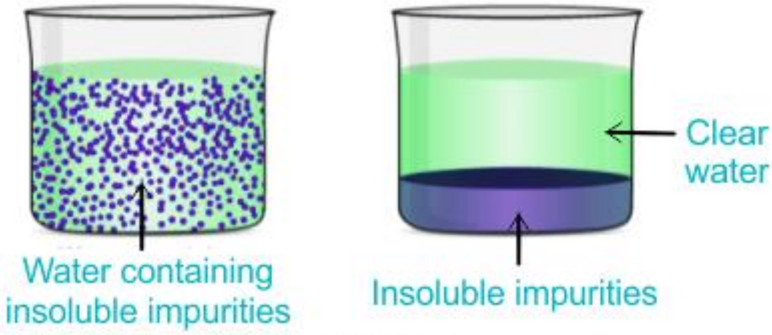
ρ is density of the particle (in kg/m^3 units),

ρ f is density of the carrier fluid (in kg/m^3 units),

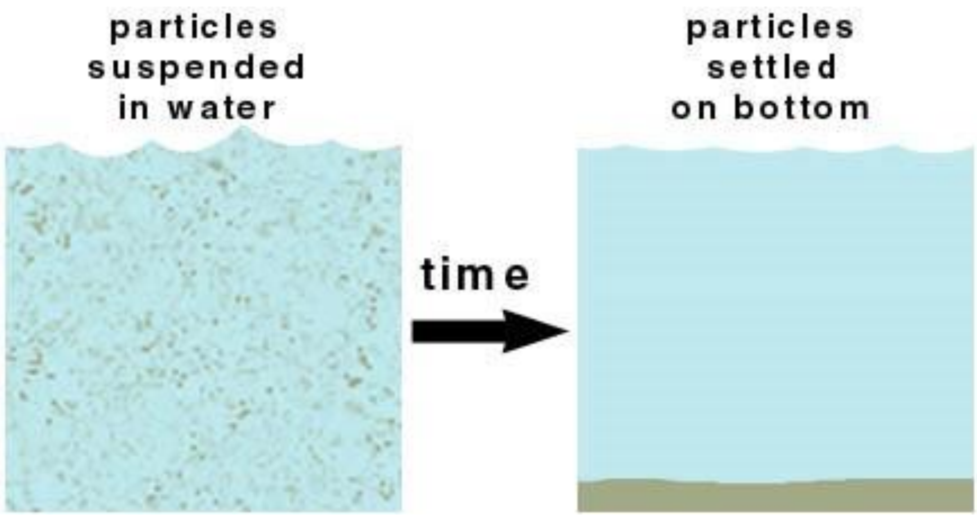
g is acceleration due to gravity (in m/sec^2 units),

d is diameter of the particle (in m units), and μ is viscosity of the carrier fluid (in Pascal)

$Vs = d^2(\rho\ solid - \rho\ water\ g / 18\ \mu$



Sedimentation



Sedimentation Process. Source: CASIDAY et al. (1999)

Facies Description and Environnemental Interpretation

- **3- Thin rippled siltstone and fine sandstone (Sr).**

The presence of ripples with gentle stoss side and steeper lee side corresponds to the current ripples of Allen (1978), interpreted as low flow regime bedforms (Miall, 1978). This facies is also believed to develop under waning bedload and suspension load sedimentation on overbank areas of the floodplain during flood events

- **4- Rippled laminated sandstone facies (Sr'),**

With relatively medium grained sandstone and higher amplitude of the ripples compared to Sr facies, this facies is considered to be transitional facies between floodplain deposits and in-channel deposits (Walker, 1984) and product of relatively higher energy conditions (Collinsons, 1982).

Facies Description and Environnemental Interpretation

- **5- Massive bedded sandstone (Sm)**

This facies is medium grained homogeneous and structureless sandstone, occasionally interbedded with Sh and Fsc suggesting a change in flow velocity. The Sm is thought to be a result of rapid sedimentation at a rate which inhibited grain sorting and bedform development. (Collinson, 1982).

- **6- Thin parallel laminated sandstone (Sl)**
- This facies is a muddy fine to medium grained sandstone. Presence of fractures mainly orientated vertically to subvertically. This facies is taught to be from upper flow regime transport. Its alternation with the Sr facies suggests that such flow regime conditions were unstable (Harms et al., 1975).
- **7- Subhorizontal to inclined laminated sandstone (Sl')**
- This facies consists of medium grained muddy sandstone. This facies is also characterized by numerous fractures. Facies Sl' and Sl are composed of relatively coarse sandstone compared to the other facies and are interpreted as channel deposits produced by flash floods (Miall, 1978; Walker, 1984)

Facies Description and Environnemental Interpretation

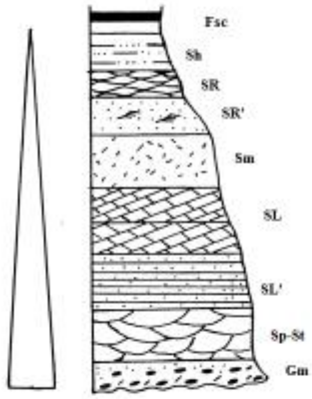
- **8- Cross-bedded sandstone (Sp-St)**

This facies consists of medium to coarse cross bedded sandstone characterized by planar and through sets. The sets are arranged in closets up to 12cm thick. The Sp-St facies is thought to represent the development of straight and/or sinuous crested dune bed forms under shallow lower flow regime conditions within a river channel (Miall, 1978; Walker, 1984; Harms et al., 1975).

- **9- Microconglomerates (Gm)**

Within the core Gm varies from 0.5 to 4 cm in thickness: matrix supported sandy clasts with occasional mudclasts. Unstratified, matrix/clasts is ≥ 1:1. Poor to moderately sorted with a lack of framework, such intraformational microconglomerates are defined as paraconglomerates (Collinson et al., 1982). Internally the clasts lack any obvious fabric or imbrication. They might be attributed to high viscosity mass flow deposition (Harms, 1975 and Collinson et al., 1986). They can also be deposited by fluvial processes where the streams are heavily charged with sediments. The Gm is usually found at the base of fining upward sequence and it is interpreted as a channel lag deposit overlying a scoured surface (Miall,1977 and 1978).

Type of Sequence (FUS)



Petrography Classification

- **Classification:**

Mineral composition of the reservoir sandstones BF have been classified according to the scheme of Dickinson (1970)

The ternary mineral components used in this scheme are:

Q=Quartz (monocystalline),

F=**F**eldspars,

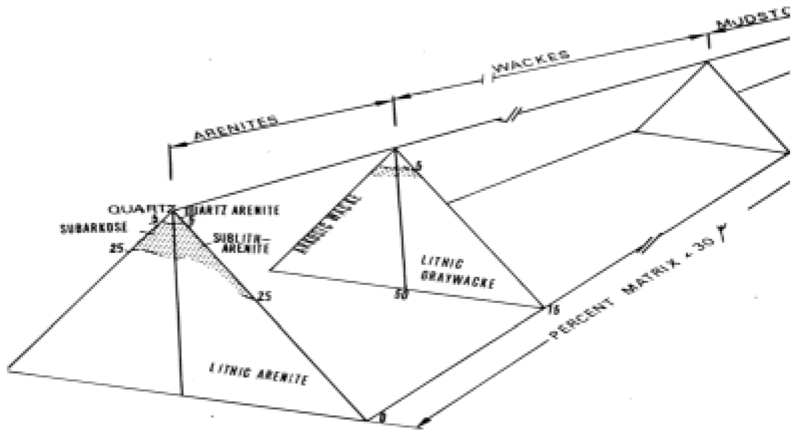
L=**P**olycrystalline quartz, including feldspar fragments and carbonate- mudclasts.

-

Petrography Classification

- Result: sediments with matrix sometimes more than 15% can be classified according to Dott's (1964) scheme as dirty to occasionally clean sandstone.
- Using the terminology defined by Pettit john (1957), Dott (1964) and Folk (1968),
- plots of compositional mineralogy indicate that the sediments classify as
- **subarkoses, lithic arenites and sublitharenites**, with a trend towards the latter type.

The Ternary Classification



- Mineralogical composition has been subjected to numerous different processes from the source rock to the basin of deposition:
- These parameters such as climate, weathering, burial conditions and type of rocks have led to a significant effect on the survival of minerals.
- Thus, type of sediments were found as mature to immature sediments.
- Consequently, the reservoir lithological log has revealed the diversity of mineralogical-rock components and thus heterogeneity.

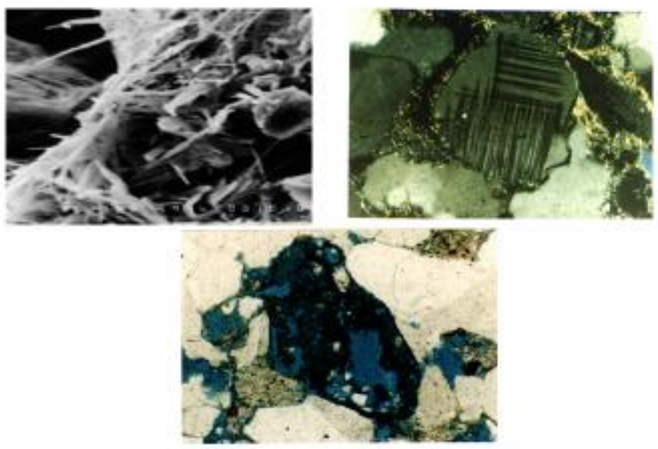
Clay minerals see S.E.M Atlas and Maurice Tucker, 1984 (see Techniques in Sedimntology both of them are available) References

Clay Minerals: Type origin and effect on reservoir quality:

- Clay minerals constitute few percent of the total rock composition of the reservoir field sediments.
- Their presence has a significant influence on diagenetic processes and on reservoir quality.
- Clay minerals have been found as coating on detrital minerals (fig.3) and
- pore filling or bridging pores between detrital minerals (fig.4)
- mudclasts floccules or biogenic pellets (fig 5).

Example for applied description:

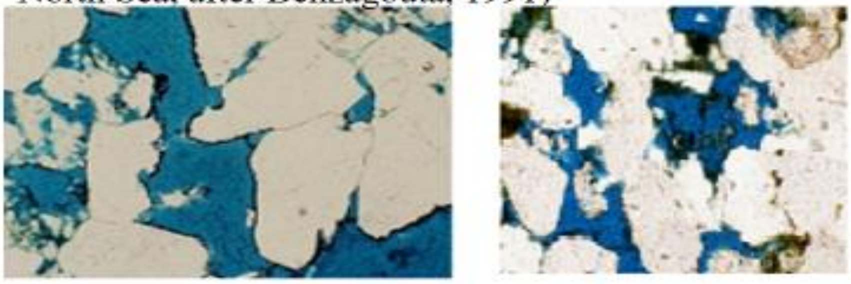
Illitisation and Kaolinitisation of Microcline Feldspar-on edges-pore filling and bridges-flocules:
Diagenetic effect on reservoir quality



Diagenetic Approaches

Clay rims-Dissolution and Channels constitue the main factors of Poroperm preservation

- Interconnected pores (channels) and dissolution grains are well shown in this reservoir by the use of blue dye) (Buchan Field North Sea, after Benzagouta, 1991)



Diagenetic Impact

- Reaction on feldspar alteration and its transformation to clay mineral formation is an hydrolysis associated to the availability of carbon dioxide (CO_2), mainly sourced from organic matter present ascribed to the decarboxhylation **(Selley, 1998, Benzagouta, 2001-2009)** . The main important outcome is the creation of secondary porosity or microporosity by dissolution and occlusion in the presence of authigenic material is not excluded.

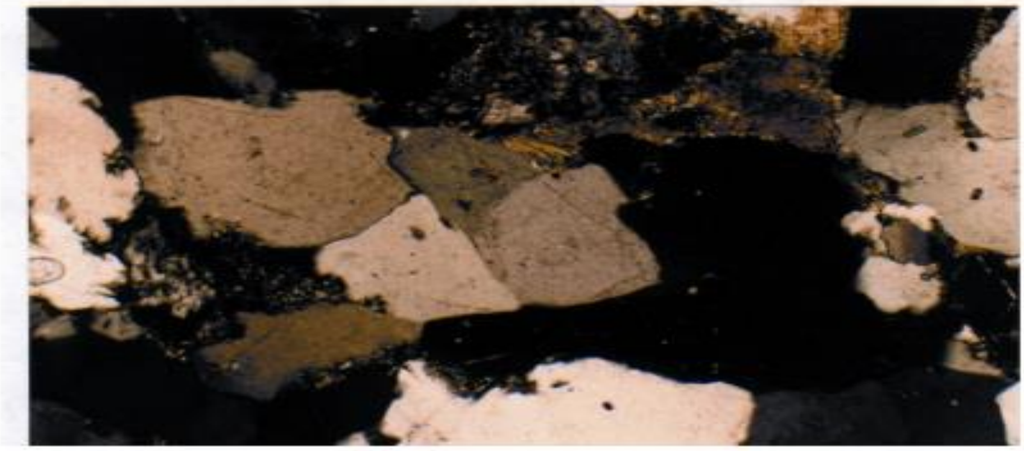
Carbonate cement as diagenetic control on reservoir characteristics

- Diagenetic control on reservoir characteristics is expressed through the presence of carbonate cement, which consists, mainly on calcite and dolomite. These carbonate cements occur mainly as pore filling. Identified Calcite cement, is the most common mineral affecting essentially mature material (Q-F poles).

Carbonate Cement as Pore filling Spaces

- **Own to greater abundance of intergranular pore spaces, carbonate cement is found as reducing the pore volume by occluding intergranular pore spaces but also maintaining and preserving the detrital framework from the effects of compaction.**

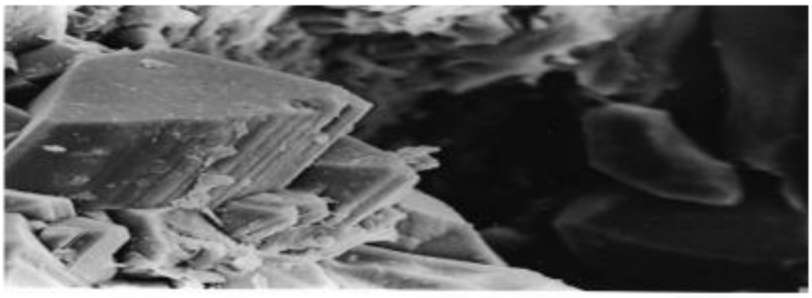
Quartz Cement as Pore Space reducing Parameter



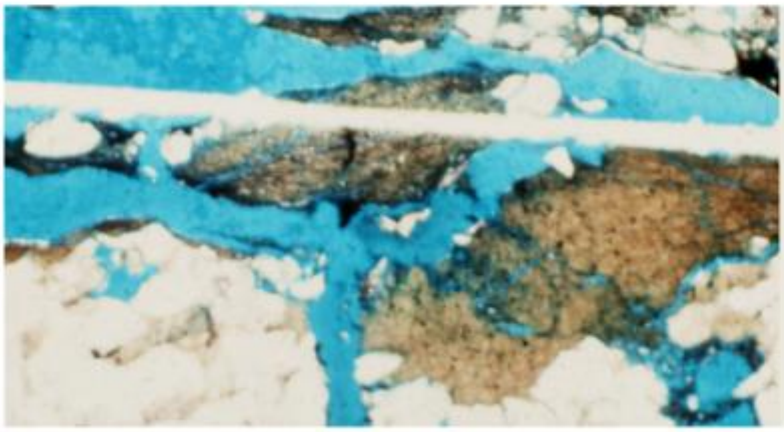
Quartz overgrowth well developed around detrital grains is reducing the pore spaces as well.

Mechanical Compaction

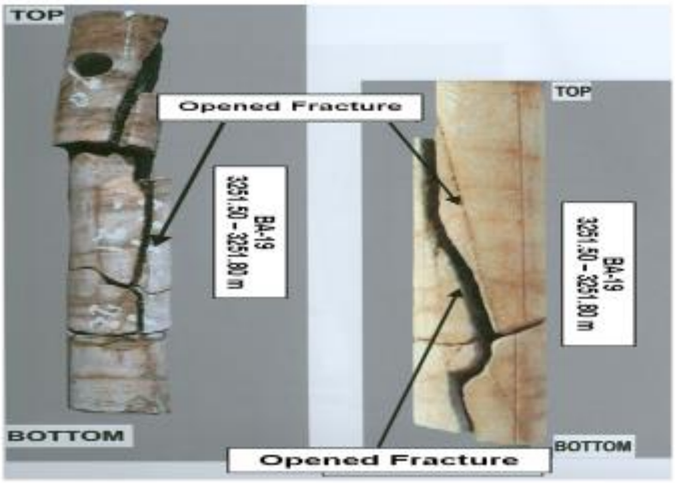
- Compaction can be seen from grain to grain contacts, which are depth dependant. Sources for such cements include several internal and external locations (Benzagouta, 1991)



Mechanical Compaction resulting on fracturing Patheways System



Opened Fractures from Core Analysis



Relative late Diagenetic Events and Effects on Fracturing System: Occlusion

Subsurface Records

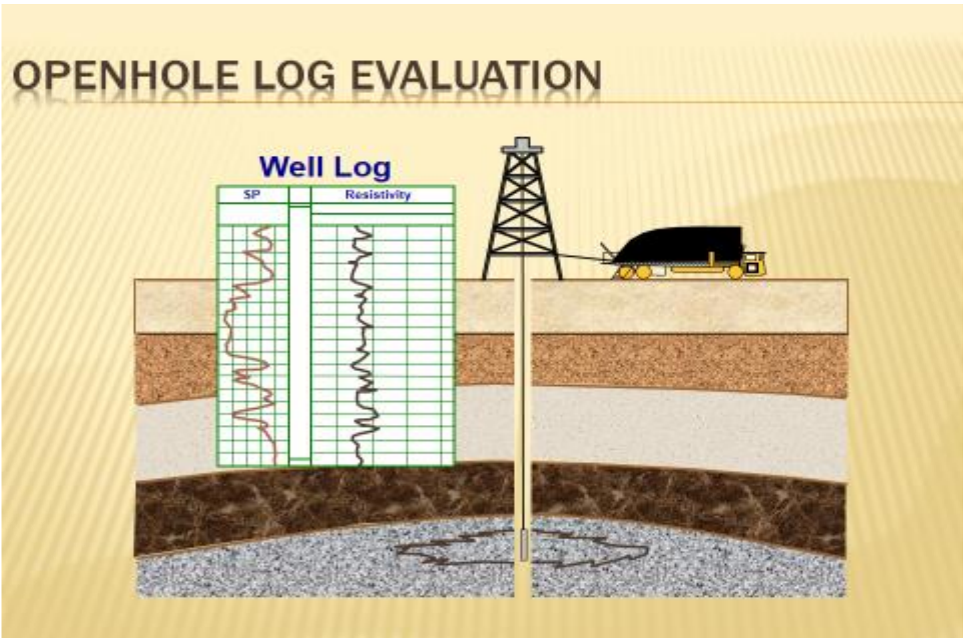
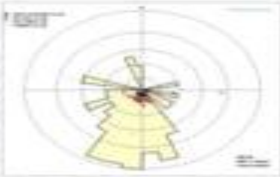


Image log & dipmeter analysis course

Sedimentological interpretation Part 1 methodology



Objective

Provide methodology for image interpretation

- Interpretation confidence.
- Image facies analysis.
- Dip picking and interpretation.
- Core calibration.

The methodology can be demonstrated in a classroom; the rest is PRACTICE AND EXPERIENCE.

Core calibration

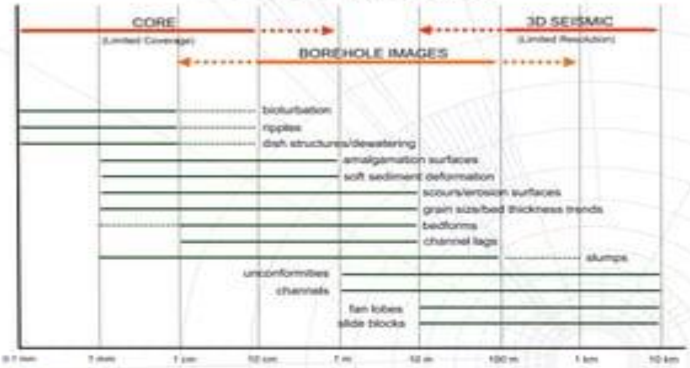
Approach to image analysis

Description

- Core integration (if available).
- Image facies description.
- Image facies associations.
- Dip picking.
- Removal of structural dip.
- Palaeotransport/ palaeoslope.
- Sedimentological/environmental interpretation.
- Identification of correlatable. surfaces/sequence boundaries.
- Sequence stratigraphy.
- Seismic integration.

Interpretation

Core calibration



COMMON LITHOLOGY MATRIX TRAVEL TIMES USED

Lithology	Typical Matrix Travel Time, Δt_{ma}, μsec/ft
Sandstone	55.5
Limestone	47.5
Dolomite	43.5
Anydridte	50.0
Salt	66.7

Sonic velocities and interval times for the common matrix

Sonic velocities and interval times for the common matrix and fluids Δt_{ma}(μs/ft) and Δt_f (μs/ft) (after, (O. Serra, 1984, 1987) ((Schlumberger, 1979) in A.A.P.G 1982, (George Asquith and Charles Gibson, 1982) including **fluid** : fresh water with Δt_f (μs/ft) 185 and 189 (μs/ft) for brine

			Δt_{ma}(μs/ft)
Lithology	V_{ma}(ft/sec)	Δt_{ma} (μs/ft)	Commonly used
Sandstone	18000 -19500	55.5 - 51.0	55.5-51.0
Limestone	21000-23000	47.6-43.5	47.6
Dolomite	23000-26000	43.56 - 38.5	43.5
Anhydrite	20000	50	50
Salt	15000	66.7	67
Casing: Iron	17500	57	57

Core versus images – complementary techniques
Advantages

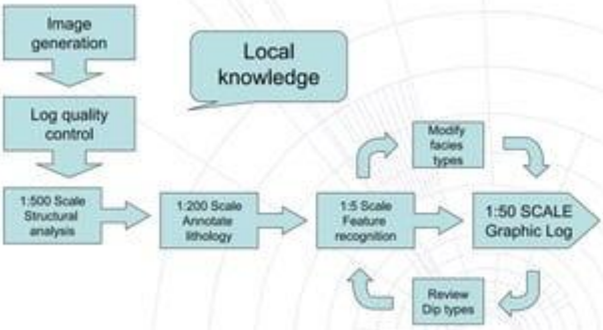
Core

- Quantify lithological, textural & mineralogical information.
- Quantify ϕ, K & saturation.
- Good bed resolution.
- Detail of bedding and/or lamination types.
- **And much more…**

Images

- Larger aerial coverage.
- Accurate orientation information.
- Continuous regularly sampled dataset.
- Good data on bedding and/or lamination continuity

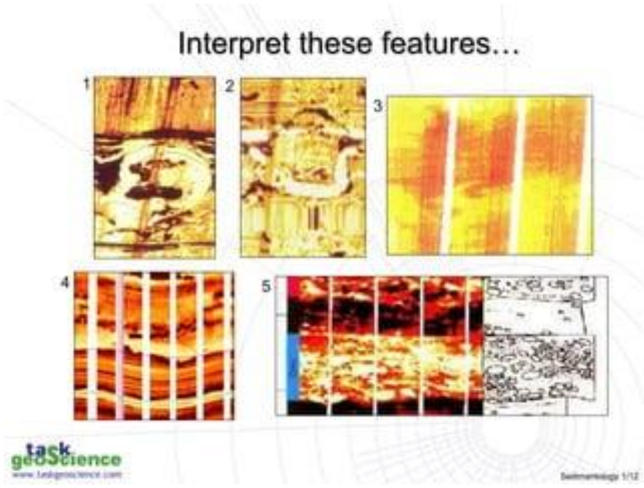
Image interpretation sequence



After Bourke 1992

Image interpretation confidence

- Grade 1
  - Features which can be categorically identified
- Grade 2
  - Features which do not have a unique interpretation
- Grade 3
  - Features which are ambiguous, i.e. probably non-geological


Interpret these features…
1
2
3
4
5
task geoScience

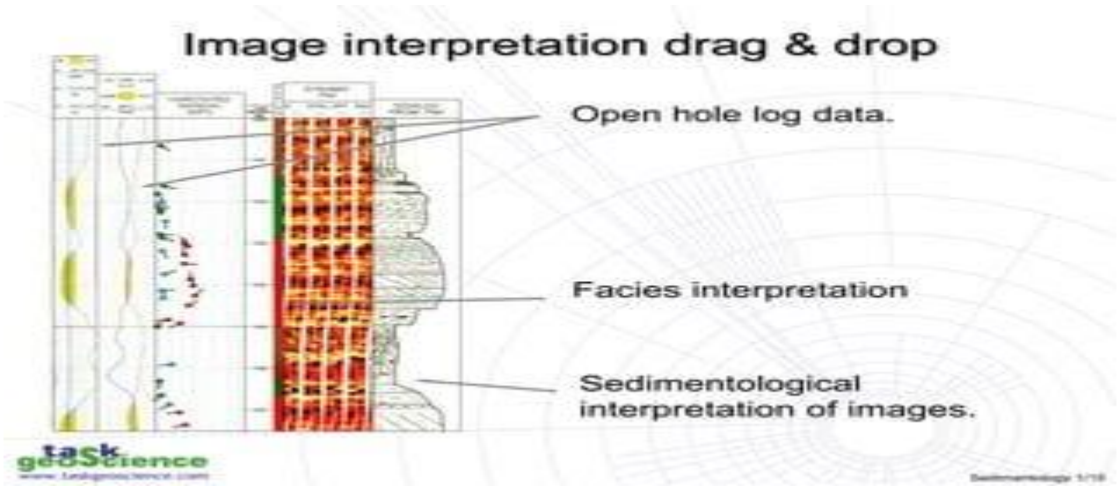
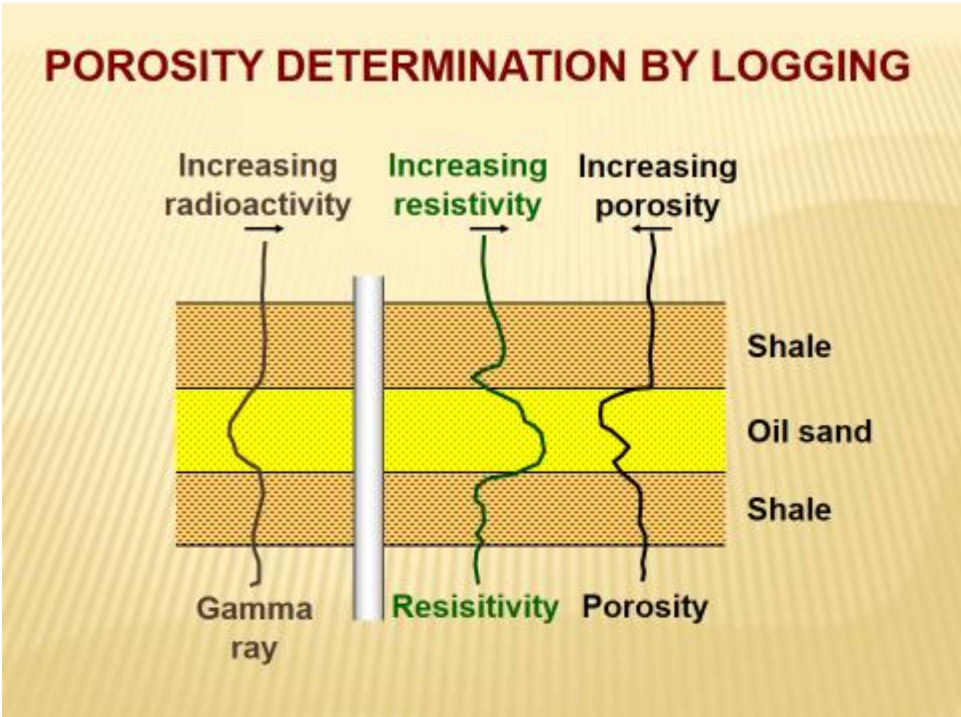
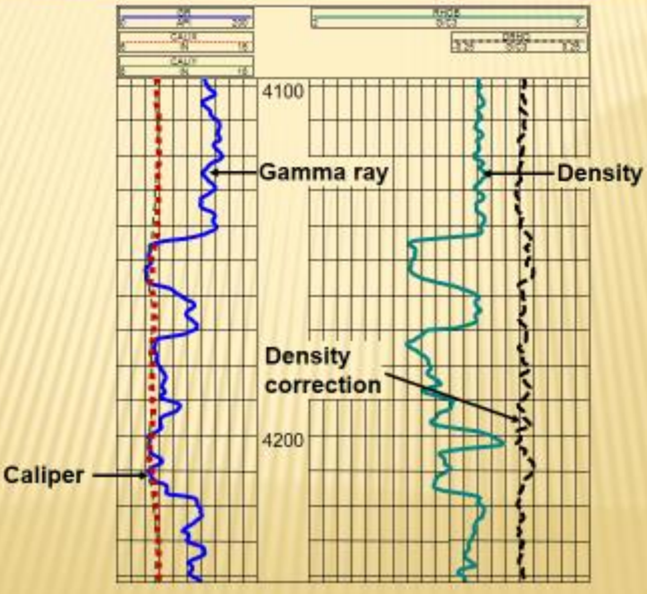


Image interpretation drag & drop
Open hole log data.
Facies interpretation
Sedimentological interpretation of images.
task geoScience

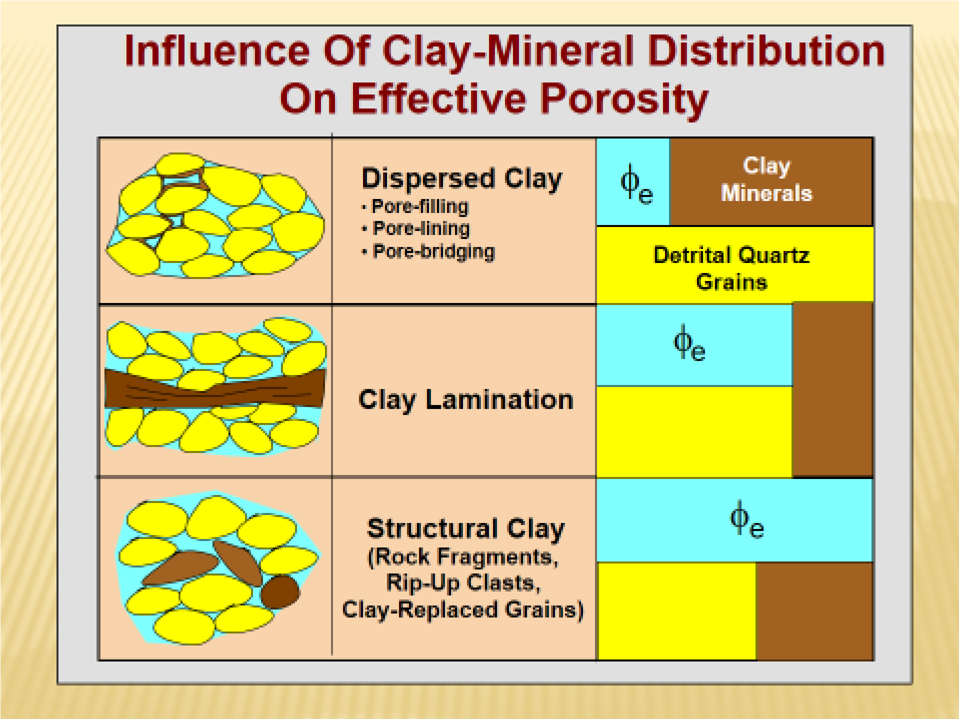

POROSITY DETERMINATION BY LOGGING
Increasing radioactivity
Increasing resistivity
Increasing porosity
Shale
Oil sand
Shale
Gamma ray
Resisitivity
Porosity

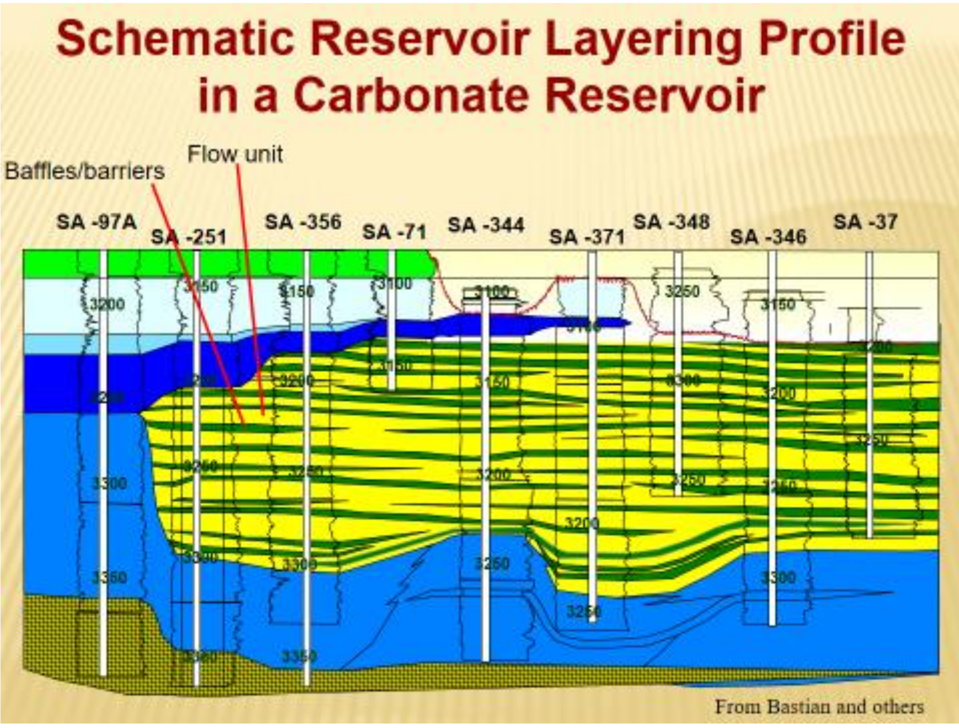
DENSITY LOG



COMMON LITHOLOGY MATRIX TRAVEL TIMES USED

Lithology	Typical Matrix Travel Time, Δt_{ma}, μsec/ft
Sandstone	55.5
Limestone	47.5
Dolomite	43.5
Anydridte	50.0
Salt	66.7


Influence Of Clay-Mineral Distribution
On Effective Porosity
Dispersed Clay
• Pore-filling
• Pore-lining
• Pore-bridging
ϕ_e
Clay
Minerals
Detrital Quartz
Grains
Clay Lamination
ϕ_e
Structural Clay
(Rock Fragments,
Rip-Up Clasts,
Clay-Replaced Grains)
ϕ_e


Schematic Reservoir Layering Profile
in a Carbonate Reservoir
Baffles/barriers
Flow unit
SA -97A
SA -251
SA -356
SA -71
SA -344
SA -371
SA -348
SA -346
SA -37
From Bastian and others

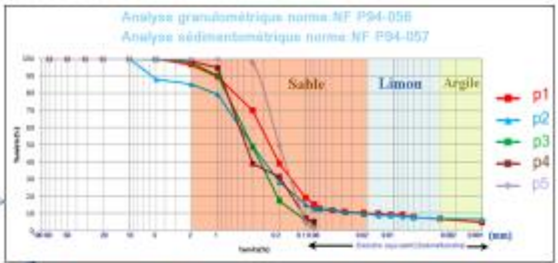
Sedimentary Rock Components

Sedimentary rocks are made up of three **main components**, framework grains (called allochems in carbonate rocks), matrix, and cement

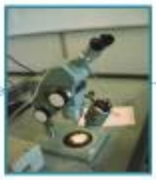
Identification des matériaux utilisés

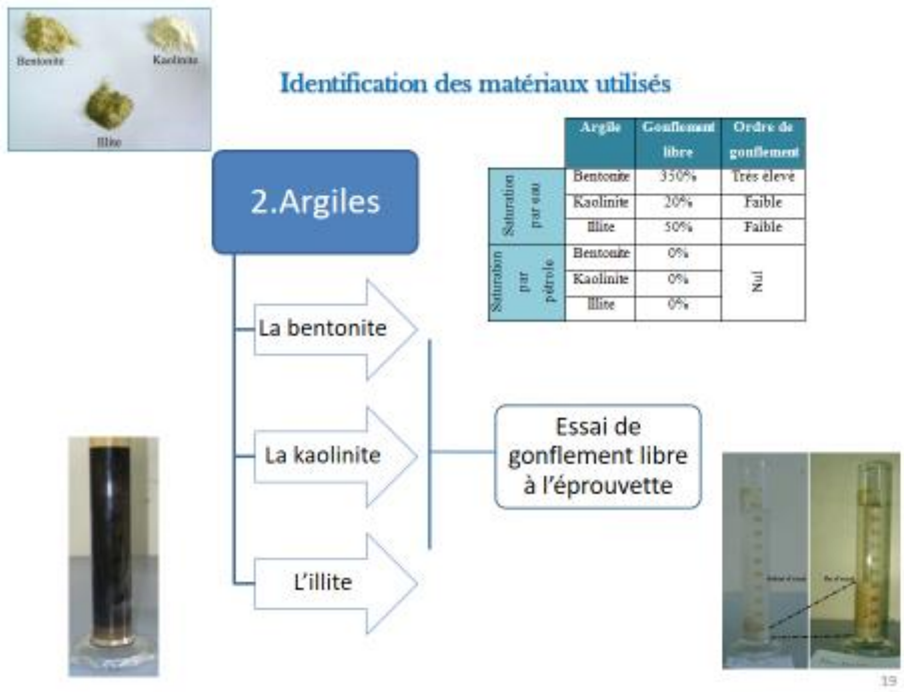
1.Sables

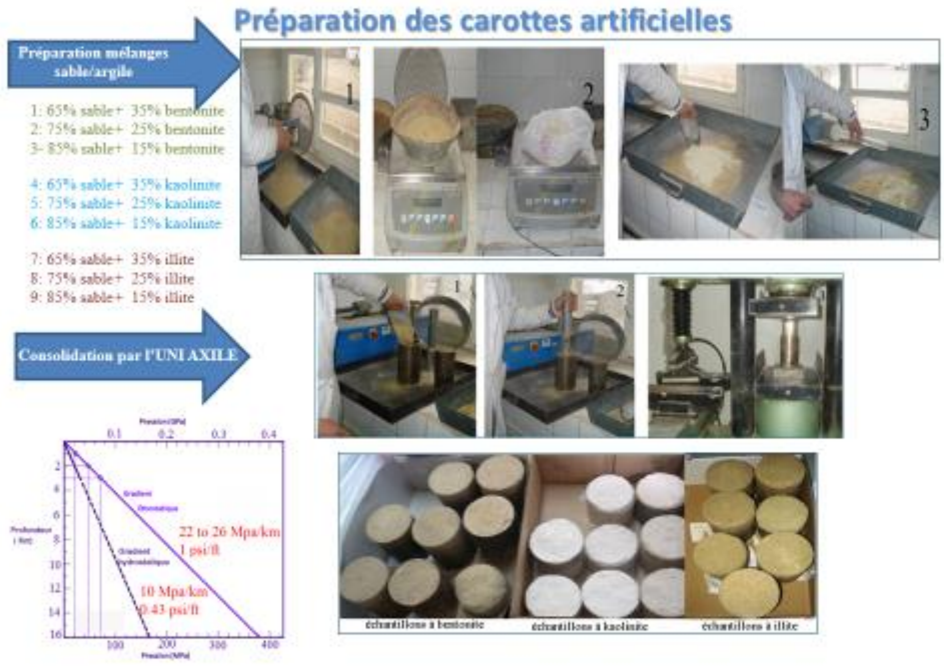
- Analyse granulométrique
- Analyse sédimentométrique
- Analyse chimique
- Morphoscopie



prélèvement N°	teneurs exprimées en % par rapport aux matériaux secs		
	Insolubles (%)	Carbonates $CaCo_3$ (%)	Sulfates $So4^{-}$ (%)
P1	79.0	19.13	Traces
P2	59.5	39.13	Traces
P3	87.6	10.43	Traces
P4	97.2	1.74	Traces
P5	96.6	1.74	Traces







This detailed text describes the contents of a sedimentology handbook, outlining the fundamental techniques used to study sedimentary rocks.

Here is a reformulation that organizes and concisely presents the core topics and methodologies.

Techniques in Sedimentary Rock Analysis

The study of sediments and sedimentary rocks is accomplished through a combination of **field observations** and specialized **laboratory experiments**, which are crucial for interpreting depositional environments, provenance, and diagenetic history.

Field and Basic Data Collection (Chapters 1 & 2)

Sedimentological studies begin with fieldwork to record macro-scale information. The primary goals are the interpretation of depositional environments and stratigraphic correlation.

- **Field Data Analysis:** Involves the direct observation and recording of sedimentary structures, lithologies, and textural parameters (grain size, shape, sorting).
- **Palaeocurrent Data:** Collection and analysis of directional features, essential for facies analysis and **palaeogeographical reconstruction**.
- **Field Records:** Information is documented via **Field Notes**, **Drawings and Photographs**, and **Graphic Logs** (measured vertical sections).
- **Parameters Recorded:** Lithology, Texture, Bed geometry/contacts, Sedimentary Structures, Fossil Content, and Palaeocurrents.

Core Physical and Microscopic Techniques (Chapters 3, 4, & 5)

These methods focus on the physical characteristics and petrography of the rock fabric.

- **Grain Size Determination (Chapter 3):** Procedures for accurately measuring grain size distribution (using **sieving, sedimentation,** or **Coulter counter** for unconsolidated samples; **microscopic measurements** for lithified samples). The resulting statistical parameters allow for deductions about the environment of deposition.
- **Microscopical Preparation (Chapter 4):** Techniques for preparing rock thin sections, including **double-polished slides**, **impregnating**, **staining**, and **etching** to enhance microscopic description. The preparation of **acetate peels** for limestones is also covered.

- **Principles of Sedimentary Petrography (Chapter 5):** Explains the interpretation of minerals and textures in thin section, applicable to all rock types. Key areas include:
  - **Depositional Fabrics:** Grain identification, modal composition (**point counting**), grain morphology, and **provenance studies**.
  - **Diagenetic Fabrics:** Detailed analysis of **compaction** (mechanical/chemical), **cementation** (varieties, timing), **dissolution**, alteration, and replacement to understand the rock's post-depositional history and **porosity types**.

Alizarin Red S Staining Results Table

The following table summarizes the typical results when using an Alizarin Red S solution (usually 0.1-0.2% Alizarin Red S in dilute 0.2-1.5% HCl):

Mineral	Description	Staining Result (Color)
Calcite ($CaCO_3$)	Reacts quickly with the dilute acid in the stain	**Bright red to pink** (color tone may vary with crystal orientation)
Dolomite ($CaMg(CO_3)_2$)	Reacts very slowly or not at all with cold, dilute acid	**No change** (colorless or faint pink/yellow, similar to background)
Ferroan Calcite	Contains some iron (Fe^{2+})	Lilac, pinkish-purple to royal blue (if potassium ferricyanide is also used in the solution)
Ferroan Dolomite	Contains some iron (Fe^{2+})	Stains blue or turquoise (if potassium ferricyanide is also used in the solution)
Non-carbonate minerals	Silicates, etc.	No change (remain their original color)

Advanced Analytical Techniques:

Summary of Geochemical and Microscopic Techniques

The table reformulates the provided information to present key analytical techniques used in geological studies, particularly for understanding diagenesis and rock composition

These specialized instruments provide detailed chemical and ultra-structural information often invisible under a standard microscope.

Technique	Primary Application	Key Insight
Cathodoluminescence (CL)	**Carbonate Diagenesis** and Cementation	**Reveals different generations of cement**, distinguishes replacement from cement, and differentiates quartz grain types.
X-Ray Diffraction (XRD)	**Mineralogy of Fine-Grained Rocks** (e.g., mudrocks)	**Standard for determining clay mineralogy**; used to infer palaeoclimate, transport history, and diagenesis in fine-grained sedimentary rocks.
Scanning Electron Microscopy (SEM)	**Ultrastructure and Fine Detail**	**Studies the ultrastructure of grains, fossils, and cements**; essential for observing clay cements and evidence of dissolution in sandstones.
Chemical Analysis	**Geochemistry and Diagenetic Fluids**	**Determines major/trace element and stable isotope signatures** to infer depositional conditions, diagenesis, and pore fluid chemistry. Focuses on analyzing individual grains/growth zones rather than bulk rock.

2. Collection and Analysis of Field Data: The Fundamentals

The primary objective of field data collection is to interpret **depositional environments** and establish **stratigraphic correlation**. This involves systematically recording specific attributes of sedimentary rocks at outcrops.

A. Key Field Parameters Recorded

Parameter	Detailed Observations
Lithology	Rock's **mineralogy/composition** and **colour**.
Texture	**Grain size**, **grain shape**, **sorting**, and **fabric** (arrangement).
Beds	**Designation of beds** and bedding planes, **bed thickness**, **bed geometry**, and **contacts between beds**.
Sedimentary Structures	**Internal structures** of beds (e.g., laminations), structures on **bedding surfaces**, and **larger-scale structures**.
Fossil Content	**Type**, **mode of occurrence**, and **preservation** of both body fossils and **trace fossils**.
Palaeocurrent Data	**Orientation** of palaeocurrent indicators and other essential structural information.

2 Collection and analysis of field data

Lithology:

Texture: Beds:

Sedimentary structures:

Fossil content:

Palaeocurrent data:

mineralogy/composition and colour of the rock.

grain size, grain shape, sorting and fabric,

designation of beds and bedding planes,

bed thickness, bed geometry,

contacts between beds.

internal structures of beds,

structures on bedding surfaces and larger scale structures involving several beds, type, mode of occurrence and preservation of both body fossils and trace fossils.

orientation of palaeocurrent indicators and other essential structural information.

In some successions there will be an abundance of information, which must be recorded concisely and objectively. Records are normally produced in three complementary forms and may be augmented by data from samples collected for further laboratory work.

These are:

(i) Field notes: These are written descriptions of observed features which will also include precise details of location. Guidance on the production of an accurate, concise and neat notebook is given in Barnes (1981), Moseley (1981) and Tucker (1982).

(ii) (ii) Drawings and photographs: Many features are ' best described by means of carefully labelled field sketches, supplemented where possible by photographs. All photographs must be cross referenced to field notes or logs and it is important to include a scale on each photograph and sketch.

(iii) (iii) Graphic logs: These are diagrams of measured vertical sections through sedimentary rock units. Ther e are a variety of formats which are discussed below (Section 2.2.9). Although many logs are constructed on pre-printed forms, additional field notes accompany them in most cases.

2 . 2 RECORDING IN TH E FIEL D

1.2.1 Lithology identification and description

The ability to recognize different sedimentary rock types is included in geology courses texts such as Tucker (1981) and Blatt (1982). Such identification in the field. Although there is a huge range of sedimentary rock types, a successions may contain

mudrocks, sandstones, conglomerates, limestones and dolomites, evaporites,

Some comments are made here on the recording of these major rock types. MUDROCK S Mudrocks can be subdivided in the field according to a simple objective scheme such as (Ingram, 1953) approximate determination of grain size.

SANDSTONE as The lithology, in terms of the grains/ matrix ratio, the main detrital constituents, and the type of cement, although detailed description and classification require thin section analysis.

CONGLOMERATES

Conglomerates contrast with other rock types in that most of the measurement, description and classification is undertaken in the field, and laboratory study often takes a secondary role.

A full description will involve measurement of size, determination of clast or matrix support, description of internal fabric and structures and data on composition (Fig. 2.1). Some commonly used descriptive terms for these coarse grained sedimentary rocks are: Diamictite: a non-genetic term referring to any poorly sorted, terrigenous, generally non-calcareous, clast-sand-mud admixture regardless of depositional environment.

Breccia: a term used when the majority of the clasts are angular.

Extraformational: a term to describe clasts from source rocks outside the basin of deposition.

Intraformational: a term to describe clasts from fragmentation processes that take place within the basin of deposition and that are contemporaneous with sedimentation. Oligomict: a term to describe conglomerates where one clast type, usually of stable, resistant material, is dominant. Polymict (petromict): a term to describe conglomerates where several clast types are present. Description can be enhanced by using the dominant clast size and clast type as prefixes, e.g. granite boulder conglomerate. A special series of terms is used where volcanic processes are involved in conglomerate formation (Lajoie, 1984). Further information on the sedimentary structures present in conglomerates can be conveyed by use of the concise lithofacies codes as developed by Miall (1977, 1978), Rust (1978) and Eyles, Eyles & Miall (1983) (Table 2.2). Although these have been developed specifically for alluvial fan, fluvial and glacial lithofacies, there is every likelihood that they will and can be used for all conglomerates.

Intraformational and extraformational rudites
Rudites can be classified based on the source of the clasts. **Intraformational** conglomerates/breccias contain clasts that derive from the same sedimentary formation which they are part of. In intraformational rudites the clasts have the same composition of the matrix that surround them and of the other sedimentary rocks present in the formation where they are found. These rocks are produced by events of brecciation or clastic reworking that interrupt the normal sedimentation of a basin, for example a storm or an episode of emersion. In general such events produce intraformational shale or limestone pebbles (e.g. rip-up clasts torn off the bottom of a basin by a current).

Extraformational conglomerates and breccias consist of clasts sourced from outside of the sedimentary basin where they are deposited. In this case (which is the dominant situation in sedimentary rocks), the framework grains differ in composition from the matrix. Typical extraformational conglomerates contain fragments of igneous, metamorphic and sedimentary rocks of different age derived from the disintegration, weathering, and erosion of different rock types.

Classification of conglomerates and breccias based on the composition of the matrix
Beyond the well-accepted ortho- and para- classification above, there are many other schemes that classify gravel-bearing siliciclastic rocks based on the composition of the matrix between the clasts. One of the most widely used is the gravel-sand-mud diagram by Folk (1980), shown below (**slide** to see the corresponding sediment and rock names).

Rock

Sediment

Examples of conglomerate

Grain-supported orthoconglomerate with rounded pebbles of gabbro. Cyprus. Photo © Siim Sepp.


Different types of conglomerate in a concentrated density flow deposit in the Macigno Sandstone. The base is a grain-supported paraconglomerate, which passes upward to a matrix-supported paraconglomerate where gravel clasts are suspended in a sandy matrix. Cala del Leone, Quercianella, Italy. **[see post]**

Examples of breccia

Karst breccia (parabreccia) produced by the collapse of a cave. Everton Formation, Rush Creek District, Arkansas, USA. Photo © James St. John.

Layers of mudrocks can be eroded and redeposited in the same sedimentary environment, producing intraformational breccias consisting of rip-up clasts. Indian Cave Sandstone (Pennsylvanian), near Peru, Nebraska. Photo © Michael C. Rygel/Wikimedia Commons.

Transport and Sedimentation

"Freud equation" in the context of sediments or fluid dynamics.

It is highly likely you are referring to the **Froude number** (Fr) or related equations, which are fundamental in fluid mechanics and sediment transport studies. The Froude number is a dimensionless quantity, typically expressed as a single, core relationship, but it is incorporated into many different, more complex, transport equations and models.

The Froude Number

The standard Froude number equation is generally given as:

$$Fr = \frac{v}{\sqrt{gD}}$$

Where:

- Fr is the Froude number.
- v is the mean flow velocity.
- g is the acceleration due to gravity.
- D is the characteristic length (often flow depth in open channels).

Role in Sediment Transport

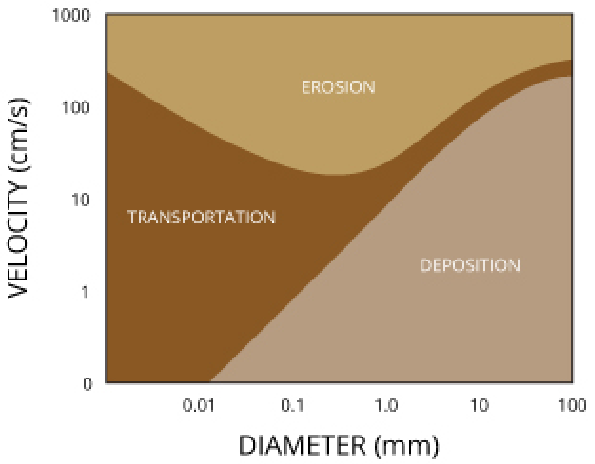
The Froude number is used in sediment transport research to:

- **Determine flow regimes:** It helps distinguish between subcritical flow ($Fr < 1$) and supercritical flow ($Fr > 1$), which have different implications for sediment movement and bedform development.
- **Predict initiation of motion:** A "particle densimetric Froude number" (F_*) is a variation used as a criterion to predict the critical conditions for when sediment particles begin to move.
- **Formulate transport equations:** It is a key dimensionless variable in many empirical and semi-empirical sediment transport formulas (e.g., in regression analyses for total sediment concentration).

In summary, there is no single "Freud equation" for sediments, but rather a central concept, the Froude number, and numerous different sediment transport equations that incorporate it as a key parameter.

Water Flow

Water flow, also called water discharge, is the single most important element of sediment transport. The flow of water is responsible for picking up, moving and depositing sediment in a waterway [26]. Without flow, sediment might remain suspended or settle out – but it will not move downstream. Flow is required to initiate the transport [18]. There are two basic ways to calculate flow. Water discharge can be simplified as area (a cross-section of the waterway) multiplied by velocity, or as a volume of water moved over time [25].



Whether sediment will be eroded, transported or deposited is depended on the particle size and the flow rate of the water.

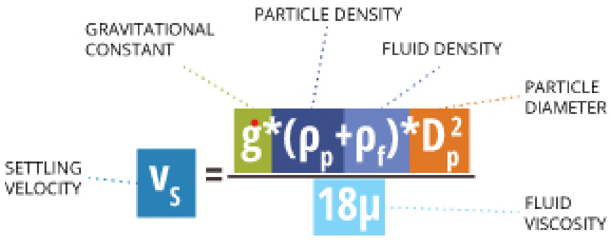
Flow (ft^3/s) =Area (ft^2) * Velocity (ft/s)
OR Flow (ft^3/s) =Volume (ft^3)/ Time (s)

The equations describing the

The equations describing the
relationship of water flow and sediment transport are a bit more complex. The complexity of sediment transport rates are due to a large number of unknowns (e.g. bed geometry, particle size, shape and concentration), as well as multiple forces acting upon the sediment (e.g. relative inertia, turbulent eddies, velocity fluctuations in speed and direction) [11]. The sediment transport rate in particular is difficult to measure, as any measurement method will disturb the flow and thus alter the reading. Most flow rate and sediment transport rate equations attempt to simplify the scenario by ignoring the effects of channel width, shape and curvature of a channel, sediment cohesion and non-uniform flows [11].

The two main flow factors in sediment transport are the settling rate and the boundary layer shear stress [27]. The settling rate (also called Stokes settling) is the rate at which sediment falls through a liquid and it is controlled by the drag force (keeping a particle suspended) and the gravitational force (a function of the particle size) [27]. Understanding this relationship helps to define some of the forces that sediment transport has to overcome relative to particle size.

$v_s = (g * (\rho_p - \rho_f) * D_p^2) / 18\mu$
v_s = settling velocity
g = gravitational constant
ρ_p = particle density
ρ_f = fluid density
D_p = particle diameter
μ= fluid viscosity [29]



Shear stresses in the boundary layer of a sediment bed explain how much force is required

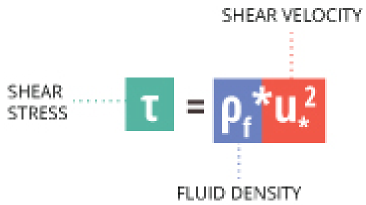
Shear stresses in the boundary layer of a sediment bed explain how much force is required for water flow to overcome relative inertia and begin sediment transport (through bedload or suspended load) [27].

$\tau = \rho_f * u_*^2$

τ = shear stress

ρ_f = fluid density

u_* = characteristic velocity of turbulent flow (shear velocity) (see following equations) [27]



In a basic freshwater river system, u_* can be calculated as:

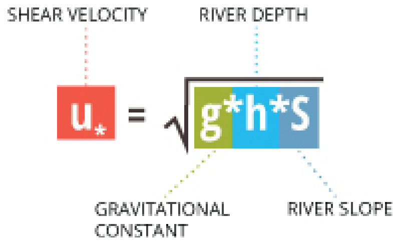
$u_* = Sqrt(g * h * S)$

u_* = shear velocity

g = gravitational constant

h = river depth

S = river slope [27]



In the ocean and in other more complex water systems,
this equation is inadequate. Instead, the Von Karman-Prandlt equation should be used. The shear stress is influenced not only by the viscosity of the liquid, but the roughness of the sediment [27]. The turbulent eddies created at the bottom by water flow must also be

In the ocean and in other more complex water systems,
this equation is inadequate. Instead, the Von Karman-Prandlt equation should be used. The shear stress is influenced not only by the viscosity of the liquid, but the roughness of the sediment [27]. The turbulent eddies created at the bottom by water flow must also be accounted for. This is also known as the Law of the Wall [30].

$u/u_* = (1/\kappa) * \ln(z/z_0)$

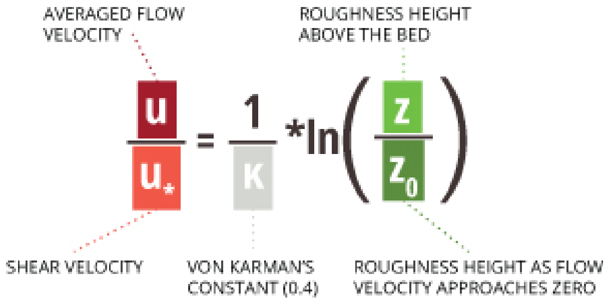
u = averaged flow velocity

u_* =shear velocity

κ = Von Karman's constant (0.4)

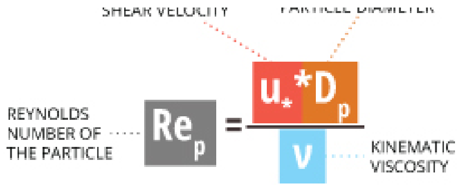
z = roughness height above the bed

z_0 = roughness height as flow velocity approaches zero [30]



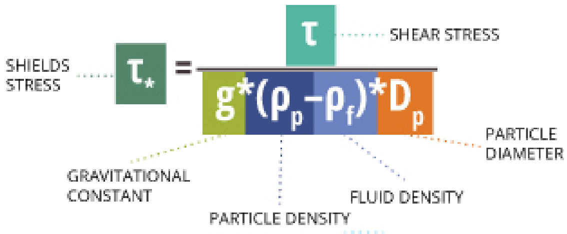
The above equations help to give a
basic understanding of some of the forces acting on sediment in the water. To further understand the conditions required for sediment transport, the Shields stress equation can be used. Shields stress, along with the particle Reynolds number, can be used to predict how much flow is required for substantial sediment transport [27]. The Reynolds number is an expression of a particle's resistance to viscous force [28]. In other words, the Reynolds number demonstrates whether or not a flow is viscous enough to overcome the relative inertia of sediment. For sediment transport, the Reynolds number for flow through a sediment bed can be calculated from the boundary layer shear stress equation:

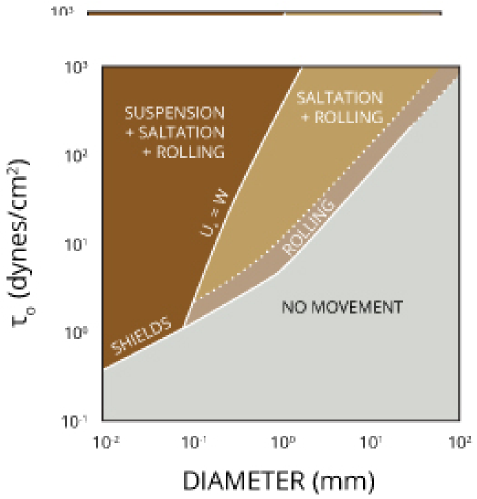
$Re_p = (u_* * D_p) / \nu$
Re_p = Reynolds number of the particle
u_* = characteristic velocity of turbulent flow (shear velocity)
D_p = particle diameter
ν = kinematic viscosity (viscosity/ fluid density, (μ/ρ_f))[27]



The point at which water flow begins to transport sediment is called the critical Shields stress [27]. This creates an empirical curve to approximate at what flow rate a sediment particle will move (based on particle size) [27].

$\tau_* = \tau /(g * (\rho_p - \rho_f) * D_p)$
τ_* = Shields stress
τ = shear stress
g = gravitational constant
ρ_p = particle density
ρ_f = density of fluid
D_p = particle diameter [13]



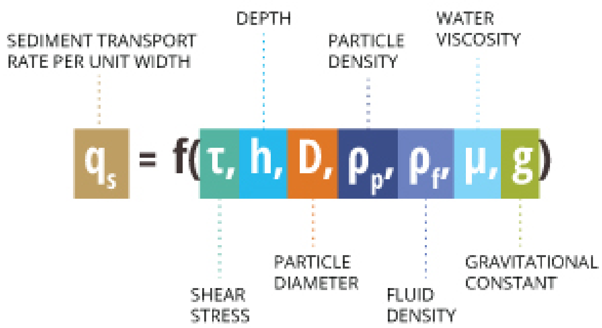


The critical Shields stress is the defining boundary between inertia and transport; when the flow rate is capable of moving particles of a specific size.

While these equations help define minimum flow rates for sediment transportation, they do not determine sediment load and sediment transport rates themselves. One sediment transport rate equation was developed by van Rijn, for the bedload transport of particles

$q_s = f(\tau, h, D, \rho_p, \rho_f, \mu, g)$

q_s = sediment transport rate per unit width
τ = shear stress
h = depth
D = particle diameter
ρ_p = particle density
ρ_f = fluid density
μ = water viscosity
g = gravitational constant

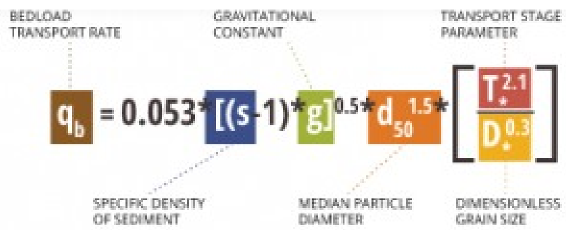


The sediment transport rate is a function of these seven variables, as well as the size-shape-density distribution (often assumed as a standard deviation of the particle diameter) of the suspended particles [31]. In addition, the largest river discharge does not automatically mean that a river will have the largest sediment load. The quantity and material of the sediment particles, as well as the geography of the local terrain will still play a contributing role in the sediment load [10].

The sediment load itself is calculated as a depth-integrated sediment mass above a unit area [11]. It is variable for multiple reasons, but can be estimated with a time-average collected sediment concentration [11]. While it is dependent on flow to initiate and continue transport, it is not calculated from flow rates, as the main variables in sediment load come from environment factors.

$q_b = 0.053 * [(s-1)*g]^{0.5} * d_{50}^{1.5} * [T_*^{2.1} / D_*^{0.3}]$

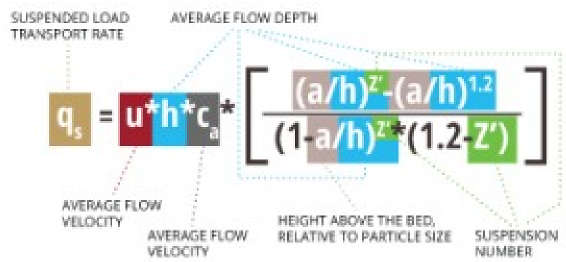
q_b = bedload transport rate
s= specific density of sediment
g = gravitational constant
d_{50} = median particle diameter
T_* = transport stage parameter
D_* = dimensionless grain size [18]



The suspended load transport rate (still assuming cohesionless sediment and a sediment size of 0.2-2mm) is even more complicated:

$q_s = u * h * c_a * [((a/h)^{Z'} - (a/h)^{1.2}) / ((1-a/h)^{Z'} * (1.2-Z'))]$

q_s= suspended load transport rate
u = average flow velocity
h = average flow depth
c_a= reference concentration
a = height above the bed, relative to particle size
Z' = suspension number [18]



Other sediment rating curves have been developed, but they cannot be equally applied to all water bodies [13]. This is because in any application, there are seven main variables that have an effect on sediment transport rates [11,31].

https://www.fondriest.com/environmental-measurements/parameters/hydrology/sediment-transport-deposition/

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