

PS Physical and Mechanical Characteristics of the Opal-A to Opal-CT Transition Zone: Enhanced Diatomite Permeability from Heterogeneous Diagenetic Embrittlement*

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Abstract

In terms of porosity, permeability, density, and other rock properties important to petroleum geologists, the opal-A to opal-CT transition zone is likely the most stratigraphically heterogeneous interval known to result from the burial diagenesis of fine-grained sediments. Investigation and quantification of rock properties within this zone is key to understanding of its potentially unique petroleum reservoir potential. In the western San Joaquin Basin, the upper Monterey Formation (Antelope, Belridge, Reef Ridge units) is originally composed of highly unstable diatomite or diatomaceous mudstone that is heterogeneously bedded or laminated. With burial, in situ transformation of biogenetic opal-A to diagenetic opal-CT occurs over an interval of 10s to 100s of meters with a relative timing that is largely controlled by the bulk composition of individual strata and maximum temperature reached. Particularly, smectitic clay content retards the transformation, resulting in diagenesis that occurs first in silica-rich lithologies and later in detrital-rich lithologies. Conversely, the presence of carbonate may accelerate the phase transformation. Both factors can lead to a complexly interbedded succession of opal-CT chert or porcelanite with opal-A diatomite or diatomaceous mudstone. The intercalation of highly fractured or fracturable opal-CT-phase beds with highly porous, moderately permeable diatomaceous beds could form an effective migration pathway or attractive reservoir for petroleum. We will complete a high-resolution study of this zone, relating the interstratified coexistence of opal-A and opal-CT-phase rocks with the resulting contrasting physical and mechanical properties and behaviors. Quantifying such contrast is important to understanding plastic-elastic deformation and fluid flow in natural or artificial hydraulic fracturing and the potential development of compartmentalization. Core samples from a transition interval in the western San Joaquin Basin will be evaluated for mineralogical content, porosity, and permeability. We intend to use this detailed lithologic and diagenetic stratigraphy to define the mechanical stratigraphy by performing laboratory rock strength/failure measurements of well-characterized samples. Correlation of these rock properties to well logs will be used to identify and evaluate the opal-A to opal-CT transition zone's character as a reservoir and provide a model for further log recognition and characterization.

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Physical and Mechanical Characteristics of the Opal-A to Opal-CT Transition Zone: Enhanced Diatomite Permeability from Heterogeneous Diagenetic Embrittlement



MARS Project
Monterey And Related
Sediments

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INTRODUCTION

In terms of porosity, permeability, density, brittleness, and other properties important to petroleum geology, the opal-A to opal-CT transition zone of the upper Monterey Formation is likely the most heterogeneous interval to exist from the diagenesis of fine grained sediments.

Unstable biogenic silica transforms from opal-A to metastable opal-CT with burial in a sequence dependent on composition. Primary compositional heterogeneity leads to a complexly interbedded diagenetic succession with gross physical properties unlike fully altered or unaltered bedding packages.

The physical properties and mechanical behaviors of the transition zone showcase a unique interval with a high matrix porosity enhanced by natural fractures.

DIAGENESIS

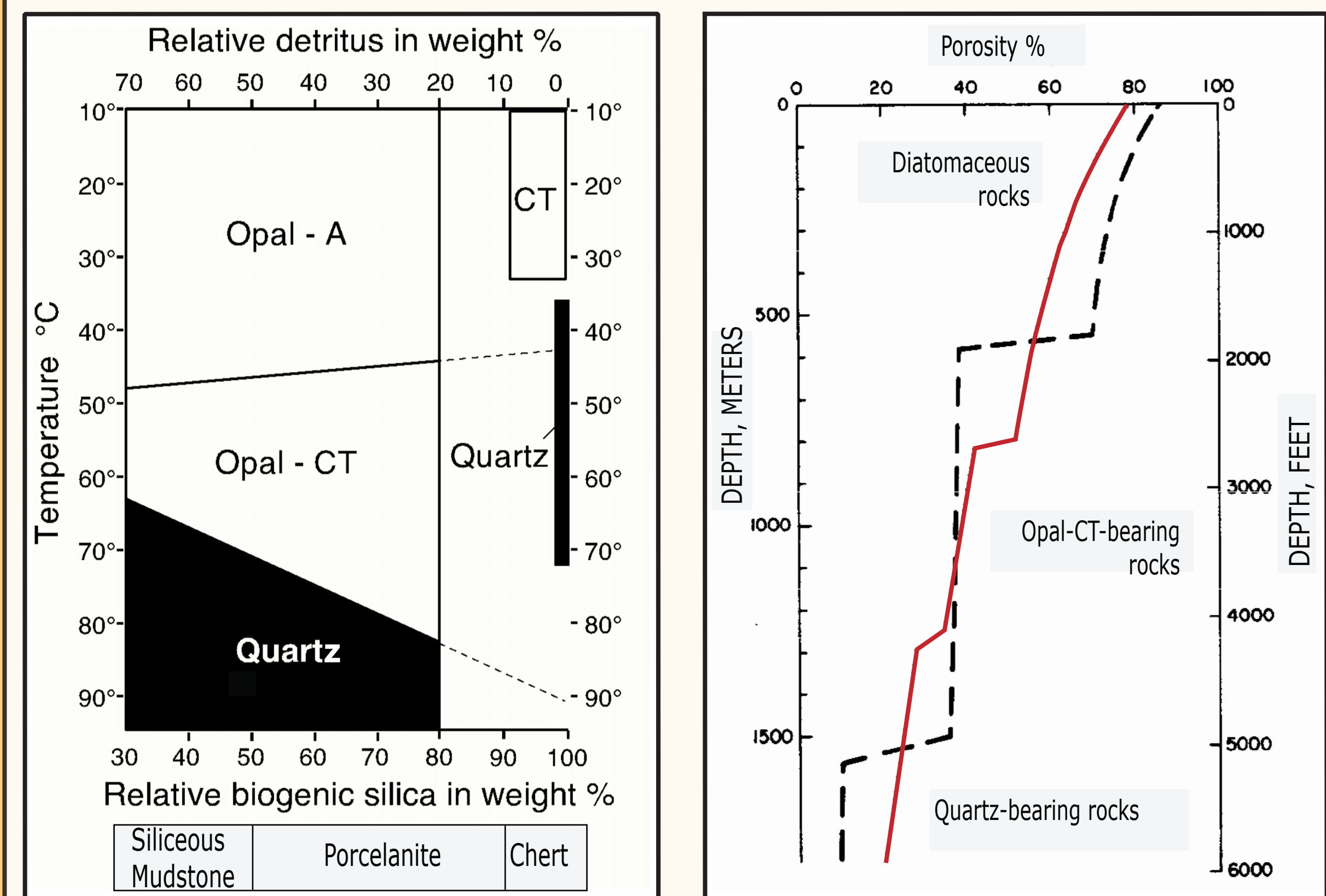


FIGURE 1: Three phase silica diagenesis with regard to temperature and compositional controls. Note cherts form much earlier than opal-CT porcelanite and siliceous mudstone (Behl, 1999).

Silica diagenesis is largely controlled by composition and maximum burial conditions (Figure 1). Opal-CT chert can form at very shallow intervals in the most siliceous beds. Clay content retards the transformation, requiring deeper burial for diagenesis.

Porosity reduction occurs during the in situ dissolution of opal-A and reprecipitation of opal-CT lithologies (Figure 2). Silica-rich rocks dramatically lose porosity at transitional steps, while clay-rich rocks are gradually affected by compaction with smaller steps in phase transformation.

Fluid expulsion from pore collapse and dehydration in diagenesis promotes fracture formation by reducing effective rock strength (Eichhubl and Behl, 1998).

Diagenetic embrittlement, porosity reduction, increased pore pressure, and resultant fractures are vividly expressed in the opal-A to opal-CT transition zone.

HETEROGENEITY AND INTERBEDDING

Heterogeneity in bedding is common to cyclic deposition and can lead to a complexly interbedded succession of opal-CT chert or porcelanite with opal-A diatomite or diatomaceous mudstone. By burying a compositionally complex sequence, a diagenetically interbedded interval of 10s to 100s of meters develops.

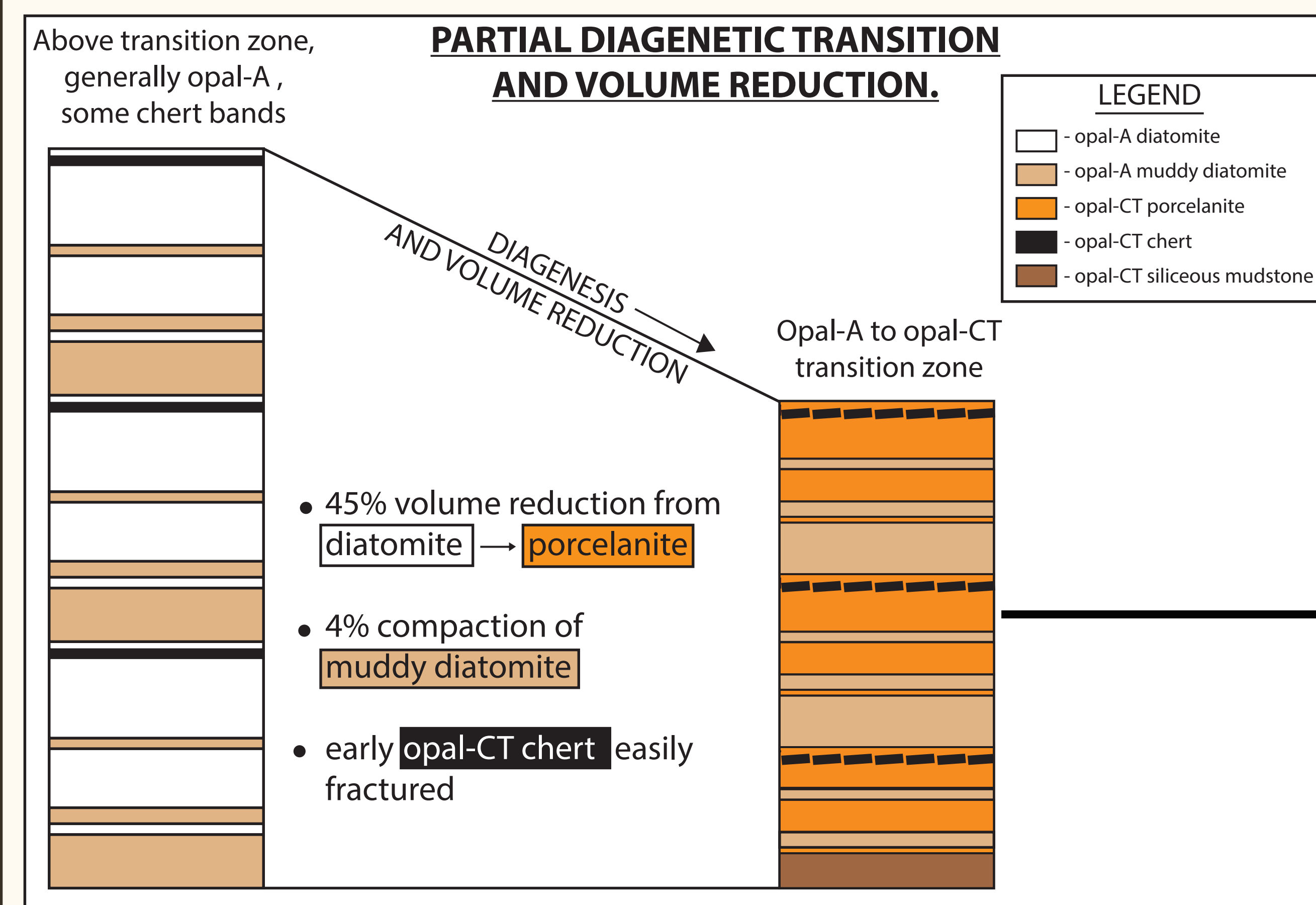


FIGURE 4: Approximate conceptualization of heterogeneous cleaning upward cycles resulting in diagenetically interbedded stratigraphy. Thin bands of opal-CT chert can be easily fractured from burial, tectonic stress, or natural hydraulic fracturing during dewatering.

ROCK PROPERTIES

The claim of extreme heterogeneity is substantiated by a doubling of coexisting lithology types each with measurable contrasts in deformational behavior. Diagenetically altered rocks are embrittled through a process of volume reduction and a greater silica ordering. This study will classify and test the relationships of silica phase, silica/detritus ratio, and bedding thickness to refine the generalizations of deformational behavior.

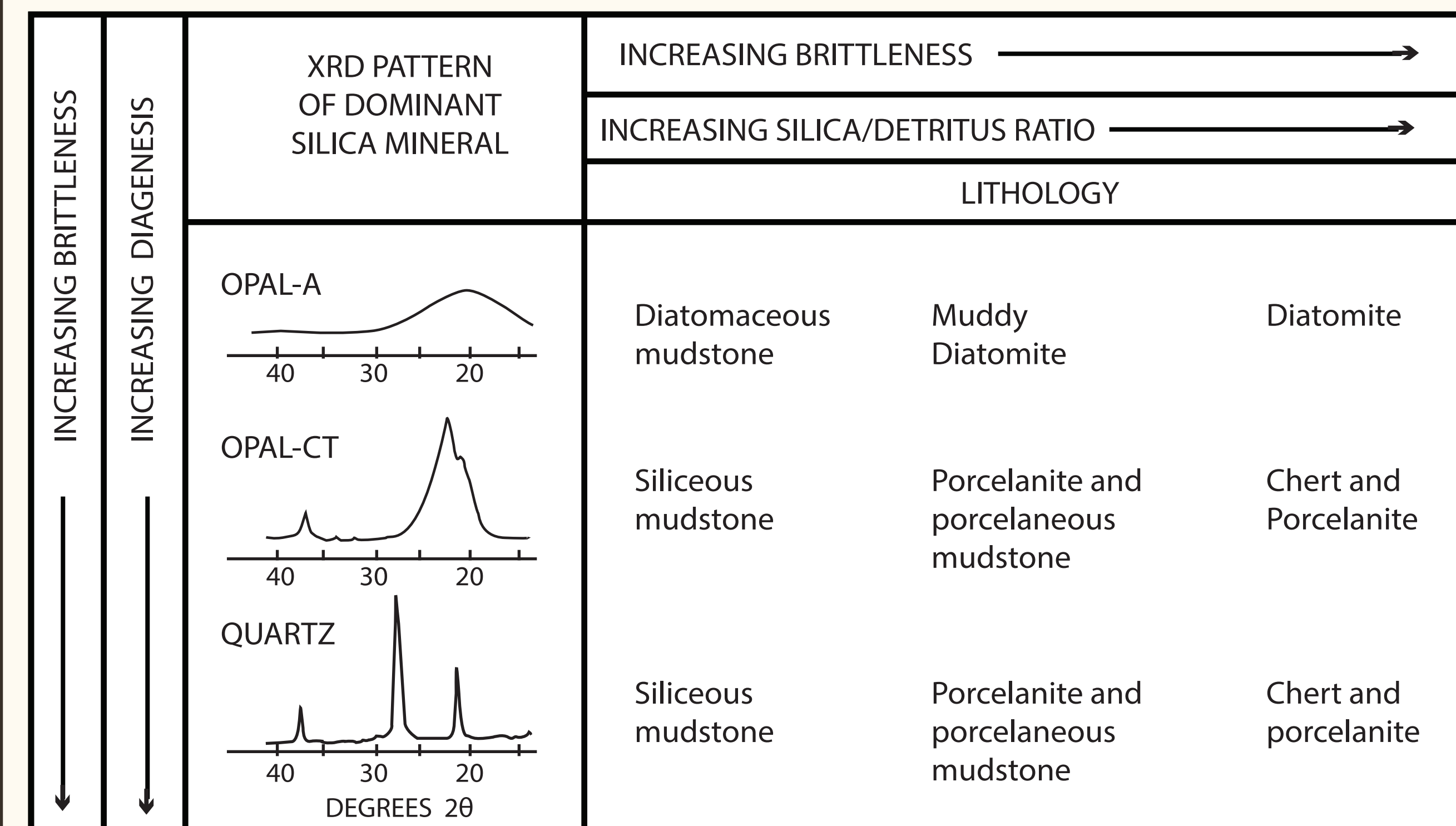


FIGURE 3: First order approximation of relative ductility comparative to silica phase identified by XRD. Silica-rich and diagenetically altered lithologies behave more rigidly.

MECHANICAL STRATIGRAPHY

While unaltered rocks have mechanically stratified layering due to difference in composition, partial diagenetic transformation adds dramatic rheological contrasts between diagenetically altered and non-altered rocks. Any deformational style is likely to greatly vary according to stress regime, structural position, timing, and bedding thickness.

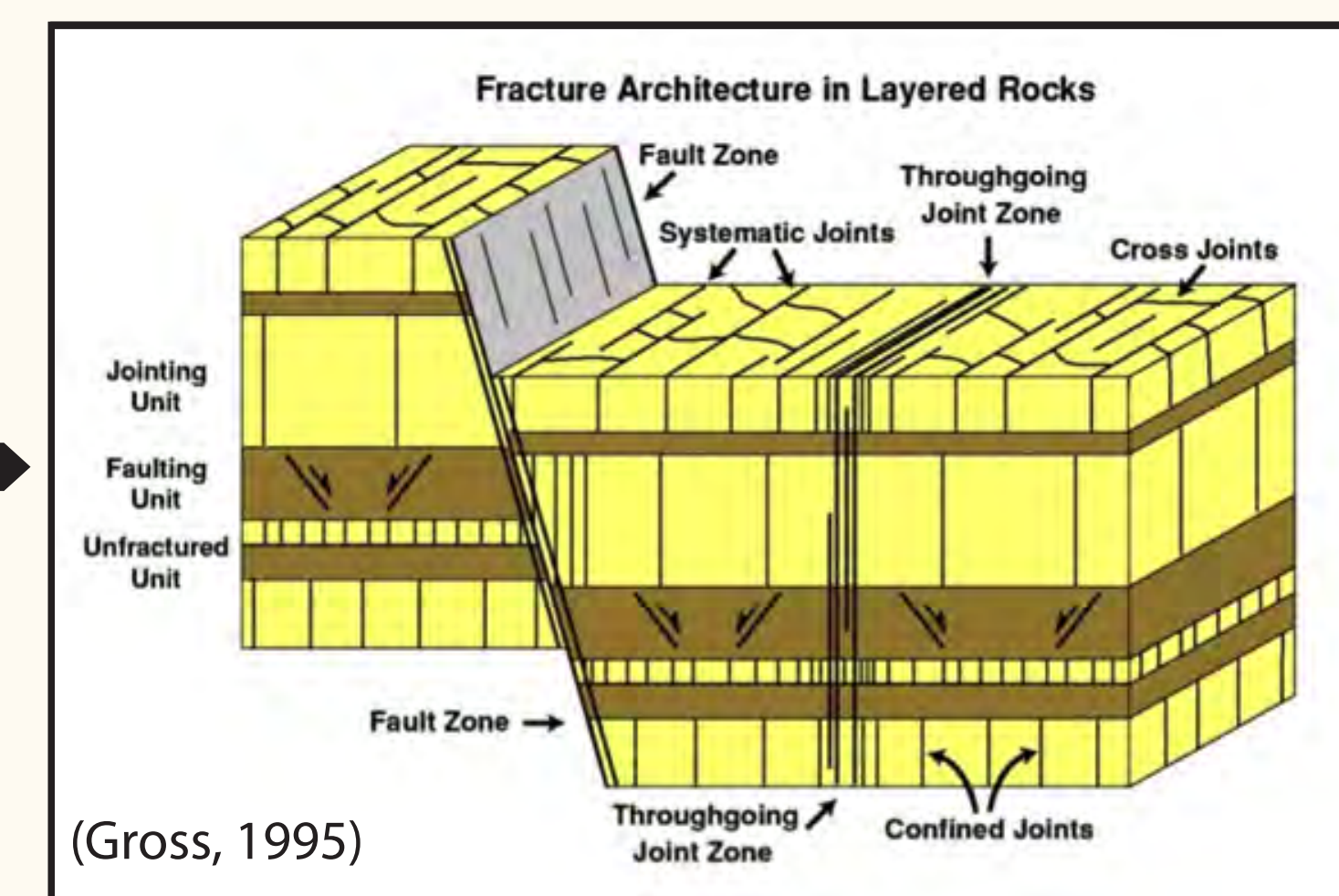


FIGURE 5: Fracture architecture in mechanically layered rocks.

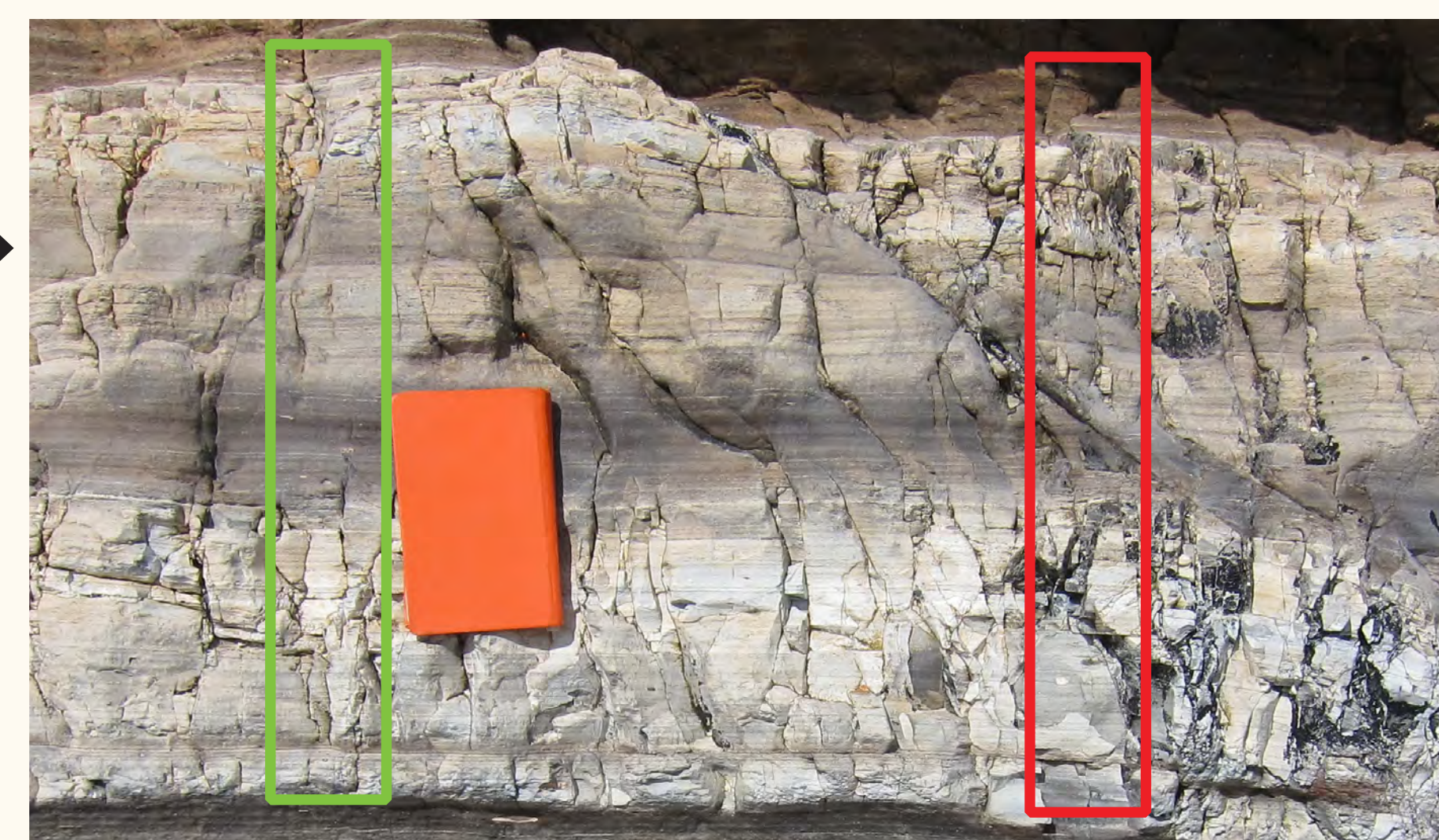


FIGURE 6: Brittle opal-CT lithologies readily fracture providing porosity and permeability while opal-A diatomaceous mudstone have lower fracture density and do not maintain open fractures. Core samples from green and red boxes would give different results due to structural position.

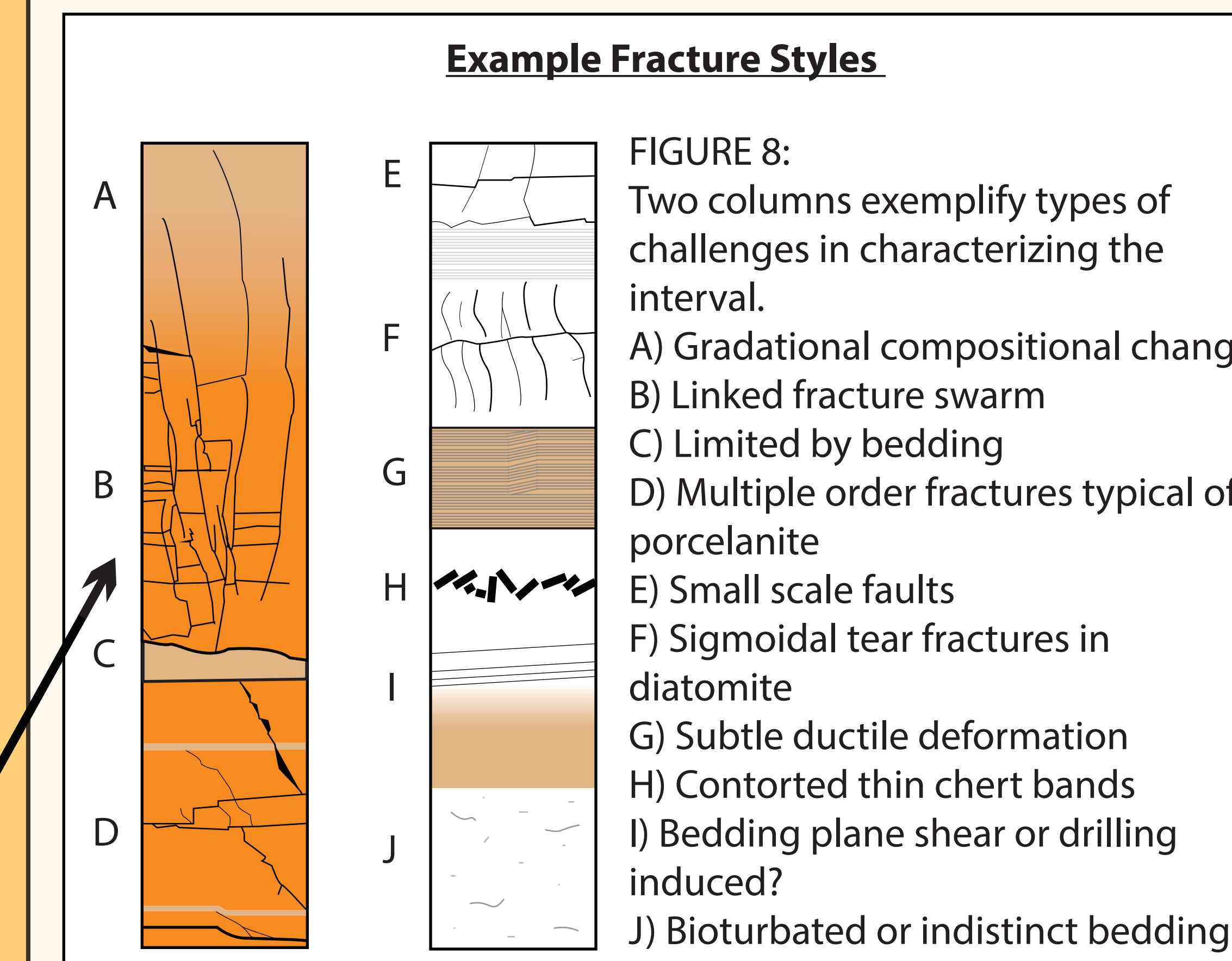
METHODS

The intent of this study is to sample at a high spatial resolution and develop relationships significant to precise geological constraints. The steps to do this are:

- Select a cored diatomaceous interval of low complexity.
- Describe lithology and test mineral types with XRD.
- Characterize type and quantify natural fractures in core.
- Correlate mechanical behavior by lithology and mineral percent. Normalize to bedding thickness.
- Test strength and brittleness properties of core. Tri-axial compressional strength testing is ideal to simulate in situ conditions, but likely unachievable. Point load and Schmidt hammer tests should provide reasonable strength and hardness estimates of broken or thinly bedded samples.
- Predict the deformational style of a rock unit.
- Determine access of fractures to storage capacity.
- Observe unorthodox diagenetic processes created by dewatering and silica mobility and search for evidence of compartmentalization.

COMPOSITION AND FRACTURE STYLE

Fracture style and length are highly influenced by composition and bedding. We intend to select samples from the silica rich Upper Monterey Formation in the western San Joaquin Basin (Belridge Diatomite) to reduce compositional differences. However, fracture complexity will require pragmatic and systematic quantification.



FRACTURE ACCESS

Fractures are critical to the storage and movement of fluids. In a heterogeneous reservoir, fractures are expected to cross cut, to marginally tear, or to be strictly limited by contrasting lithologies. In any case there will be an increase in local permeability. The effectiveness of fracture to penetrate and transmit fluids from highly porous opal-A lithologies may be variably dependent on bedding thickness, spacing, and matrix diffusion.

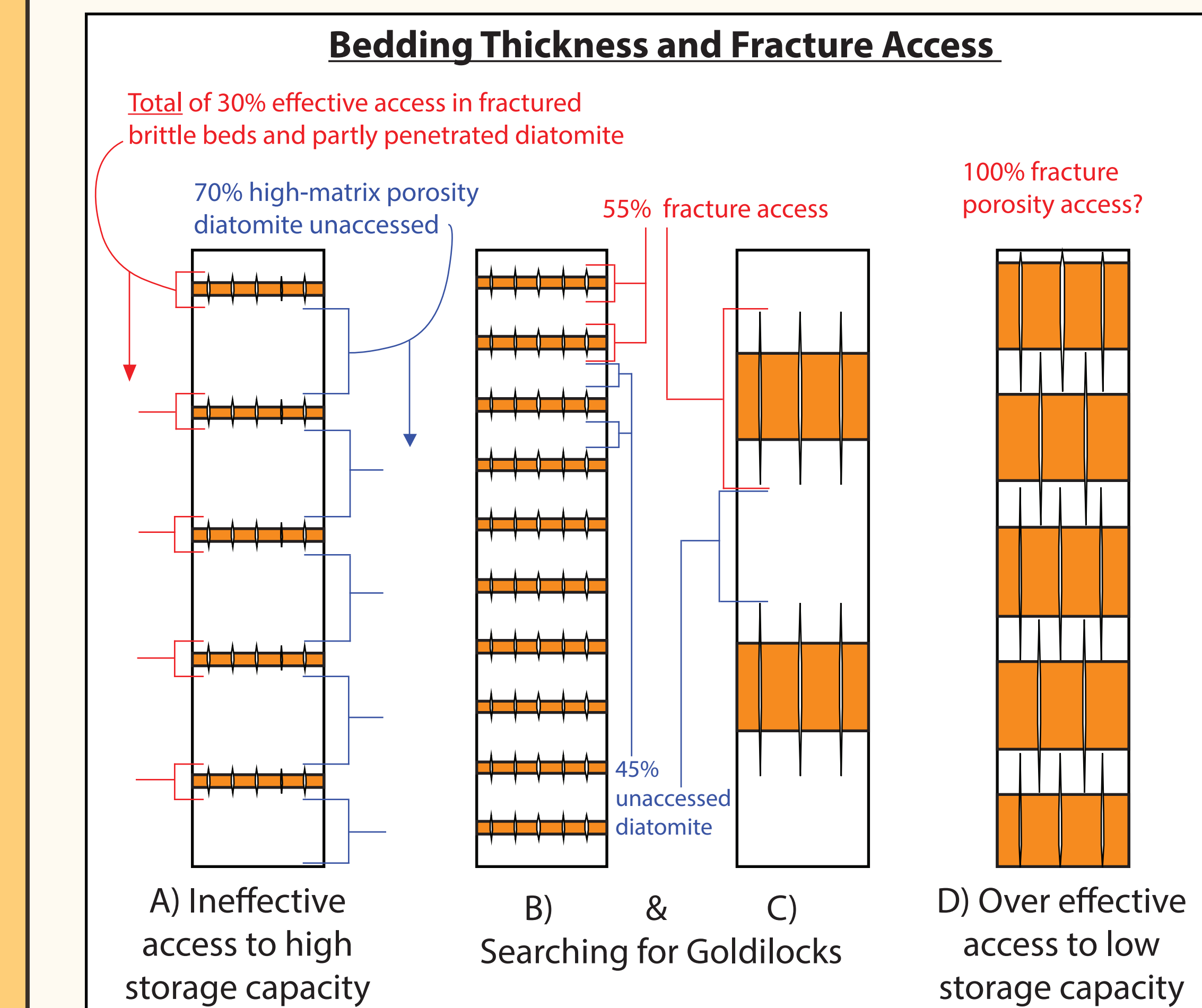


FIGURE 7: Hypothetical bedding ratios that suggest access by density of fractures in brittle opal-CT or chert lithologies (orange) to adjacent diatomaceous lithologies (white). B and C have similar fracture access by assuming a 50% reach of fracture length into adjacent lithologies.

POTENTIAL VALUE

This study will create a geologically realistic model of this anisotropic and complex interval in order to improve reservoir quality evaluation. Resolving lithologic and mineralogic controls on mechanics in a geological context should allow for well log correlation and the power to anticipate transition zone behavior.

We hope to determine an ideal setting for the combination of maximum matrix porosity and fracture permeability early in the opal-A to opal-CT transition zone (Figure 7, 9).

Mechanical strength and hardness testing will provide new information on the brittleness and the ability of a rock unit to withstand a fracture. Additional insight may be linked to proponent effectiveness for hydraulic fracturing.

Furthermore this study may observe dewatering and compartmentalized pressurization evidence that is not fully understood. We will additionally be able to study fracture mineralization, progressive silica ordering, and fluid expulsion.

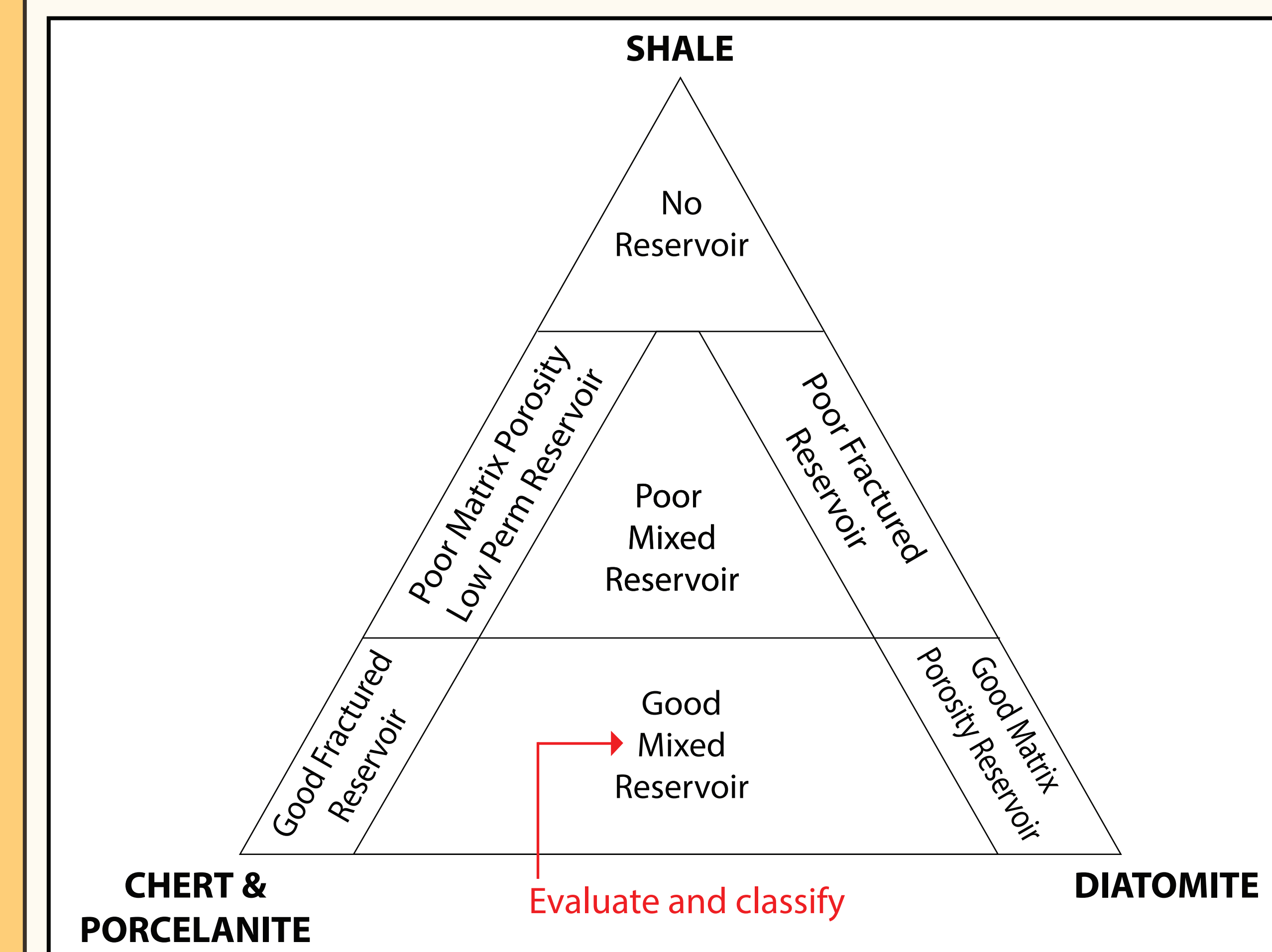


FIGURE 9: Conceptualized ternary diagrams of reservoir potential of unaltered and embrittled lithologies; from Williams (1988).

ACKNOWLEDGMENTS AND REFERENCES

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