

Dolomite Reservoirs

Geochemical Techniques for Evaluating Origin and Distribution

by

J. R. Allan

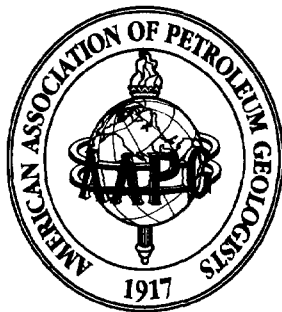
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PREFACE

Dolomite Reservoirs was written to address the need for a short, clear text that explains commonly used inorganic geochemical techniques and their application to dolomite petroleum reservoirs. It was written in order to transfer this useful geochemical technology to exploration and development geologists in a form that facilitates easy application of geochemical concepts.

Dolomitization results in unique reservoir geometries that bear directly on exploration strategy and field development. An understanding of the process that controlled dolomitization is helpful for predicting reservoir location, geometry, and continuity. Inorganic chemistry can often provide that understanding. Because no text is available to lead the petroleum geologist through the different geochemical techniques, earth scientists must go directly to the research literature to seek information. Unfortunately, the literature is full of studies in which geochemistry has been used improperly. This volume covers many state-of-the-art approaches to the study of dolomitization, and will help geoscientists to critically evaluate geochemical data and interpretations and to design their own geochemical studies of dolomite units.

Part I consists of chapters on different geochemical techniques, with guidelines on how best to apply them, interpret the data, and recognize and avoid the pitfalls and misconceptions that one commonly encounters. Many of the techniques described in Part I can be applied with equal success to limestone reservoir diagenesis.

Part II consists of case studies of dolomite petroleum reservoirs that formed in each of the major dolomitization environments. The examples were selected to illustrate the ways in which geochemistry can be used in conjunction with stratigraphic, structural, petrographic, and facies data to identify the origin of dolomite reservoirs. These case studies should serve as useful templates for the earth scientist who wishes to use geochemical data to evaluate dolomite reservoirs and to determine which dolomite model best fits his or her reservoir or play.

We hope that this book will help geoscientists understand better the many ways in which geochemistry can be used to address dolomite reservoir problems, and will encourage geologists to apply geochemical techniques to petroleum exploration and exploitation in carbonate provinces.

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Publisher's Note



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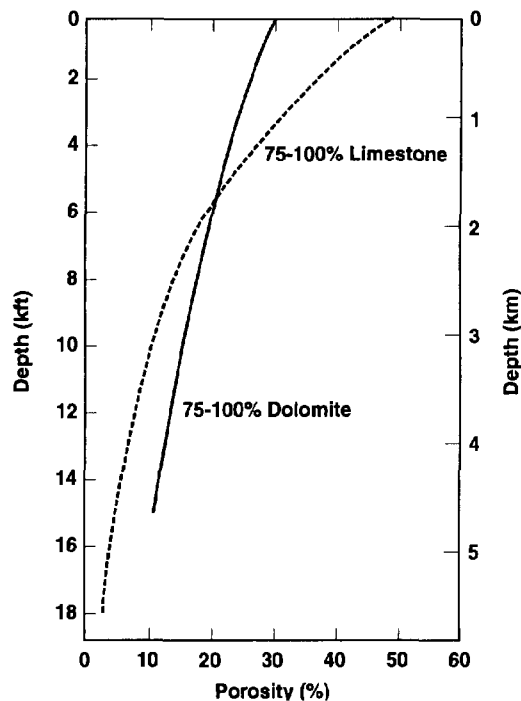
INTRODUCTION

INTRODUCTION

In carbonate systems, dolomite often forms the best reservoirs. The dolomitization of carbonate sediments and rocks increases crystal size and pore throat size, and decreases pore roughness. Without exception, the combination of these increases the permeability of the carbonate. In this way, dolomitization "makes" the reservoir, with dolomite serving as the reservoir and the surrounding limestone forming the seal. Porosity in the dolomitic facies is enhanced in such cases not so much as a result of dolomitization, but through leaching of skeletal grains or evaporites, or by fracturing.

Many environments of dolomitization have been identified. Some result in unique reservoir geometries that bear directly on exploration strategy. Therefore, it is important to gain a firm understanding of the process which controlled dolomitization early in the exploration history of a basin.

In addition, dolomite is less reactive than calcite, so dolomite units are more resistant to porosity loss with depth than limestone units (Fig. 1) and the depth to "economic basement" is commonly greater for dolomite than for limestone. Therefore, the spatial distribution of dolomitized intervals within



Modified after Schmoker and Halley, 1982

Figure 1. Plot of average porosity vs depth for limestones and dolomites of the South Florida basin. Porosity data are derived from borehole-gravity measurements and from acoustic, neutron, and density logs. Although the range of porosity values can be considerable at any given depth, the average porosity vs depth trends for limestone and dolomite are quite different. Above 5600 ft, limestones are, on the average, more porous than dolomites. Below 5600 ft, dolomites are, on the average, more porous than limestones, because they are less susceptible to porosity reduction by diagenesis and recrystallization than limestones.

a carbonate section often defines the limits of reservoir development. The hydrologic process that dolomitizes a limestone can control the morphology of the dolomite body as well (e.g., supratidal dolomitization can produce thin, stratified, laterally extensive reservoirs, whereas subsurface fault-controlled dolomitization can produce narrow, linear, vertically extensive reservoirs). Therefore, to predict the spatial distribution of a dolomite reservoir, it is advisable to first determine the process that produced the dolomite.

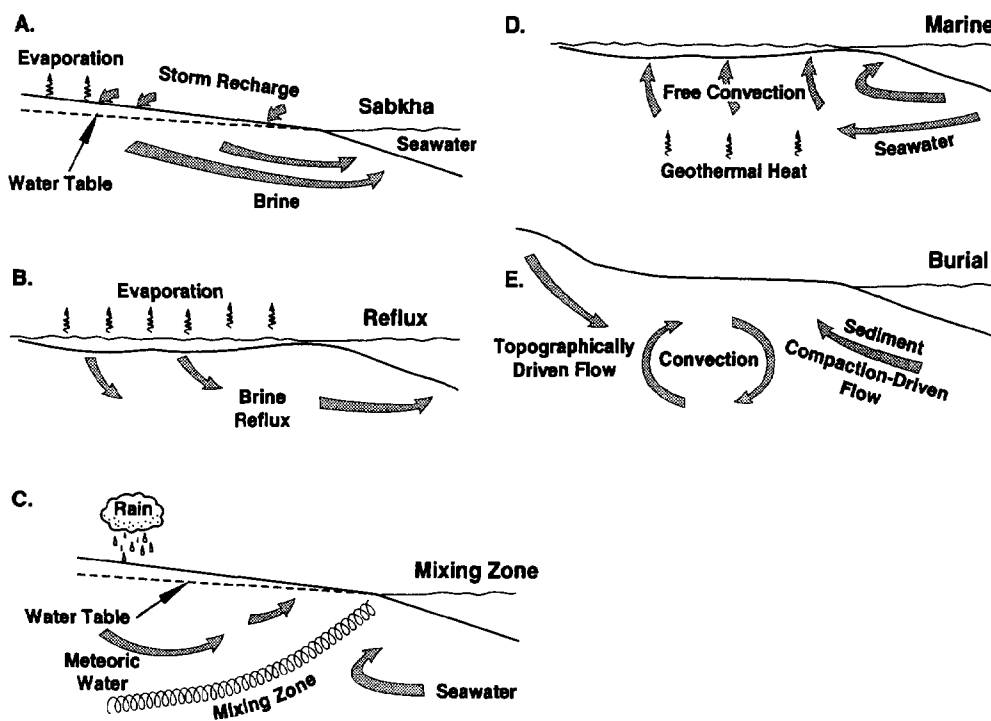
Our goal in inorganic geochemistry is to improve our understanding of the processes which formed a dolomite reservoir in a way which will aid reservoir delineation. For example, geochemical evidence for hydrothermal dolomite may increase the importance of recognizing deep subsurface faults, which can act as conduits for dolomitizing fluids and can be identified using seismic reflection profiles and well data. Evidence for low-temperature, hypersaline dolomite may focus attention on mapping sabkha depositional facies from core and identifying the positions of ancient strandlines. Geochemical techniques succeed when they improve our understanding of the origin of a dolomite reservoir and therefore favor a particular exploration model. Although geochemistry sometimes provides equivocal results, in our experience, failure most often occurs because of lack of integration of multiple types of evidence and an over-reliance on a single technique (e. g., stable isotopes). Inorganic geochemistry is most valuable when it constrains dolomitization models and helps to focus attention on probable reservoir targets. It should always be used in conjunction with other methods of investigation, which, when integrated, may provide information on where a geologist should spot a well.

This manual can be used as a guide by the geologist planning to start a geochemical study of dolomitization, or as an aid to interpreting geochemical data already collected. Because of the length of this manual and the complexity of the topics covered, it is *not* intended to be read from beginning to end as a treatise. Instead, it has been set up as a series of stand-alone chapters. Part I consists of chapters on each of the geochemical techniques commonly applied to dolomite problems. Part II consists of case studies of dolomite reservoirs that formed in each of the major dolomitization environments, and illustrates how each environment can be recognized using the techniques described in Part I in conjunction with other forms of data.

DOLOMITE MODELS

In order to dolomitize a limestone, two requirements must be met: (1) a source of Mg sufficient to dolomitize the limestone must exist; and (2) a transport mechanism must be available to carry the Mg to the site of dolomitization, because mass balance calculations indicate that hundreds of pore volumes of fluid must be exchanged in order to complete the dolomitization reaction. In most cases, the source of Mg is seawater or a seawater-derived formation water or brine. Thus, identifying the hydrologic system responsible for “pumping” the dolomitizing fluid through a limestone is the most important step in identifying the origin of a dolomite. Before commencing with our discussion of geochemical techniques, we will briefly introduce each of the basic dolomitization models. More complete discussions of these models can be found in Morrow (1982b), Land (1986), and Morse and Mackenzie (1990). Those most important to petroleum reservoir formation are described in greater detail in Part II of the manual.

Dolomite can form in or near hypersaline environments from seawater with a Mg/Ca ratio which has been greatly elevated by evaporite precipitation. Precipitation of gypsum and anhydrite, in particular, can preferentially remove Ca from seawater while leaving Mg unchanged. **Sabkha** dolomite (Fig. 2A) forms when storm surges force seawater landward over peritidal sediments in arid regions. Evaporation results in the precipitation of evaporite minerals. The increased density of the evaporation-concentrated brine causes it to flow downward and dolomitize underlying lime sediments. Thus, hydrodynamic head provides the hydrologic “pump.” Sabkha dolomite is usually easy to identify, because it is always associated with supratidal sediments and contains many distinctive associated features, such as algal stromatolites, nodular anhydrites, and eolian interbeds. **Reflux** dolomite (Fig. 2B) forms beneath restricted lagoons and basins, where evaporation is intense and leads to brine concentration and evaporite precipitation. Downward and seaward density-driven flow of brine once again leads to dolomitization of underlying sediment. However, in this case, the underlying sediment need not be supratidal, but can represent any depositional facies.



Modified after Land (1986) and Morse and Mackenzie (1990)

Figure 2. Illustration of the hydrologic environments which produce (A) sabkha, (B) reflux, (C) marine-meteoritic mixing zone, (D) marine, and (E) burial dolomite. The hydrology of the dolomitizing environment controls the shape, size, and location of the dolomite body produced. See text for discussion.

The marine-meteoric **mixing zone** model (Fig. 2C) is based on the idea that mixing meteoric water with seawater can produce a fluid that is undersaturated with respect to calcite and aragonite and supersaturated with respect to dolomite. The Mg is supplied by seawater and hydrodynamic head provides the hydrologic pump. Although the model has been widely invoked to explain ancient dolomitized sequences which lack evaporites, it is flawed in several ways. The absence of dolomite in all but a few modern mixing zones and the fact that seawater alone is more supersaturated with respect to dolomite than any meteoric water - seawater mixture are the two most commonly cited problems. As a result, increasing attention has been given to dolomitization by normal seawater.

Strong evidence for dolomitization by seawater has been presented in many recent papers. **Marine dolomite** (Fig. 2D) derives its Mg directly from seawater. The Mg is delivered either by tidal pumping or by inflow and buoyant rise of geothermally heated seawater at continental margins. **Burial dolomite** (Fig. 2E) forms in the subsurface after lithification of lime sediments. As temperature increases, the Mg/Ca ratio required to produce dolomite decreases and many subsurface waters can become dolomitizing solutions. The most-cited fluid sources for burial dolomitization are: (1) Mg-rich residual evaporite brines, (2) modified seawater, and (3) shale compaction waters. The water can be delivered to the site of dolomitization through porous aquifers or along faults by a number of transport mechanisms, including sediment compaction, thermal convection, and topographically or tectonically driven flow.

DOLOMITE PETROGRAPHY

Although often critical to reservoir development and porosity distribution, dolomite crystal size and texture are rarely definitive of dolomitizing environment. Nonetheless, crystal size and texture can be helpful in identifying a few specific types of occurrence. Therefore, before moving on to the geochemistry section of this manual, we will briefly examine dolomite petrography.

Microcrystalline texture in dolomite (particularly crystal size $<10\mu\text{m}$) is believed to be caused by a high degree of supersaturation with respect to dolomite, which overcomes kinetic barriers to nucleation and results in rapid precipitation of dolomite at many nucleation sites (Sibley, 1991). Microcrystalline textures are most commonly associated with sabkha dolomites (Moore, 1989) and rarely reported for other dolomitizing environments. Thus microcrystalline texture, particularly when associated with supratidal evaporites, is commonly indicative of early, nearsurface dolomitization.

Saddle dolomite (sometimes called baroque dolomite) is characterized by coarse crystallinity (crystal size from $\sim 150\mu\text{m}$ to several mm), curved crystal faces and cleavage, undulose extinction, and abundant fluid inclusions which give it a milky white to brown color. It occurs both as a void-filling cement in fractures and vugs and as a replacement of limestone (Radke and Mathis, 1980). Because saddle dolomite is commonly associated with hydrocarbons and hydrothermal minerals, has a "high temperature" geochemical signature, and, when replacive, transects bedding, stylolites, and formation boundaries, it is considered to be a late, high temperature phase.

Fluorescence microscopy can sometimes be used to visually recognize grain types and depositional textures in pervasively dolomitized carbonate rocks (Dravis and Yurewicz, 1985). Incident light fluorescence with a blue-light excitation filter apparently causes residual organic matter preserved in grains to fluoresce, allowing one to identify the depositional facies of the precursor sediment, even when dolomitization has nearly obliterated all textures. When successful, this technique provides information useful for interpreting dolomitization environment (e.g., open marine grainstones which are not likely to have been dolomitized by supratidal processes may be recognized). Unfortunately, fluorescence microscopy only works well in a minority of cases.