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Microfacies Analysis of Limestones

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and 58 Tables

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Preface

Reviewers of the German edition of this book found that the text deals with facts and descriptions of limestones rather than with global speculations on facies models or large-scale sedimentation patterns. The book is neither a picture-book nor a recipe-book for facies interpretation of carbonates, but an attempt to summarize the present "state of the art" of a rather small but increasingly more important part of geology.

The book is written for advanced undergraduate and post-graduate students as well as for research workers and exploration geologists who need rapid and intensive training in modern methods of microfacies analysis. The book should facilitate decisions about which methods to use in one's own investigations, and where to look for comparative studies.

Microfacies interpretation of carbonate rocks can not rely solely on the investigation of sedimentological and paleontological thin-section data, but must also consider geological and palecological criteria. It is beyond the scope of this book to describe all of these aspects. However, broader applications are indicated in the chapters dealing with the relationships between geochemical as well as physical data and the depositional and diagenetic fabric of limestones.

The original German edition has been expanded and brought up to date. Changes have been made in the chapters on carbonate diagenesis, facies-controlled porosity, deeper-marine environments, and fossils in thin-sections. Case histories, taken from different depositional environments and based mainly on the author's own facies studies in Paleozoic and Mesozoic rocks, may illustrate the potential of microfacies analysis.

The modifications in the English edition reflect the growing interest in these fields, and also the need to put more stress on the practical applications of microfacies studies in applied geosciences and integrated facies research.

I wish to thank the technical staff of the Institut für Paläontologie der Universität Erlangen for their continuous help. Special thanks are extended to H. Hagn, München, R. Schröder, Frankfurt, and J. Remane, Neuchâtel who contributed thin-section photographs, and to all colleagues who offered suggestions for the improvement

of the book. I appreciate the help of all persons and institutions who gave permission to use their figures and tables.

I am especially grateful to Karen Christenson for the translation and for her constantly growing interest in microfacies problems.

Erlangen, February, 1982 ERIK FLÜGEL

Cover: Lower Permian limestone breccia, Southern Alps: Microfacies types of lithoclasts indicate erosion of different parts of a marine shallow-water carbonate platform. The bioclastic grainstone (left) with dasycladacean algae (*Connexia carniapulchra, Mizzia* sp., *Gyroporella* sp.) and fusulinid foraminifera (*Pseudofusulina* cf. *P. paragregaria*) was derived from protected, high-energy environments within the shelf-lagoon; primary high interparticle porosity was reduced by submarine cementation. The bioclastic packstone (right) yields poorly sorted skeletal grains (echinoderms, foraminifera) which have undergone selective dolomitization prior to the deposition of the lithoclasts. Fusulinids are represented by *Pseudoschwagerina* sp. (center) and *Pseudofusulina* cf. *P. paragregaria,* indicating a Lower Artinskian age (Zone with *Pseudofusulina lutugini*). Both lithoclasts were deposited together with quartz pebbles (center and upper right) within a lacustrine environment characterized by the homogeneous dark grey micritic matrix with dewatering structures. During burial diagenesis the breccia was affected by strong pressure-solution. – The sample comes from the Tarvis Breccia of the Sexten Dolomites. The lithoclasts of this Permian breccia were eroded from the Tresdorf Limestone of the Trogkofel Formation (Artinskian). Width of photograph 2 cm.

Preface to the German Edition

„The geological study of facies has been carried out scientifically in the strictest sense of the word since the 1840s, yet one finds even today that the methods used reveal a noticeable lack of clarity and order and that great gaps are present in the results of earlier work in this field . . . One finds side by side the most varied descriptions of the way in which certain sedimentary layers are formed and new views are expressed each day without those already in existence being refuted. . . . It is high time that the principles behind facies research were clearly laid down and that the extensive literature dealing with such questions were revised."

These introductory words from *Geologische Fazieskunde* by Laszlo Strauss (1928) are still valid today. They also hold true for the microfacies analysis of carbonate rocks in thin-sections. Here, too, there are methodological difficulties, for the range of possible interpretations is subject to continual change, owing to the rapid advances in the sciences of paleoecology and carbonate sedimentology, whilst a comprehensive overview of the extensive literature from the various fields of the geosciences does not exist.

The following work is not intended as a synthesis, but rather as a presentation of the current methods of microfacies research as well as a pointer to promising new developments. This applies to the exact description of microfacies types and the facies models based upon them as well as to the reciprocal relationships between biogenic and abiogenic factors in carbonate sedimentation. Important possibilities for development exist with regard to research into the connections between physical parameters of carbonate rocks and facies types, on the one hand, and on the other, between geochemical criteria and sedimentary as well as diagenetic characteristics found in microfacies. The paleontological description and ecological or stratigraphic evaluation of many "thin-section fossils" is just now beginning (e.g., reef associations), while in some cases new, more detailed studies are needed (e.g., dasycladaceans). Compounded with this is the fact that certain individual time periods, such as the Tertiary, have so far hardly been examined from a microfacies point of view.

The structure of this book owes much to important questions that have arisen in the inter-university courses on microfacies held in Erlangen, Germany, over the last few years as well as to the author's own results from microfacies studies of the Permian and the Mesozoic in the Alps and the Malm (Upper Jurassic) found in Franconia, Germany. The literature which has been evaluated covers a broad range of stratigraphic problems, drawn from all over the world, and the same holds for the thin-section samples selected for the Plates.

The intent behind the book was not to produce a "thin-section picture book"; neither does it claim to provide quick and easy recipes for facies interpretation – even if the tables and the condensed presentation of the material may sometimes give this impression. The object of this book is to make possible independent study of carbonate rocks with regard to paleontological and sedimentological aspects, by clarifying definitions and compiling information (in the form of annotated bibliographies and reference tables). For this reason it seemed necessary to include a synopsis of Recent carbonates and carbonate diagenesis, despite the fact that Bathurst (1971) and Milliman (1974) have already published excellent surveys of these topics.

The "Key to Identification" and the exercises should facilitate the direct transfer of what has been read in theory to the practical application of microfacies techniques. This should not be limited to mere description and classification, but rather the attempt should be made to correlate critically one's own observations with standard Recent and Ancient values. It is only in this way and in close association with the various disciplines of the geosciences that microfacies analysis can contribute to facies studies.

I would like to thank the Deutsche Forschungsgemeinschaft for the support it has given my work, the staff at the Springer Verlag for its concern for my wishes, and all the colleagues and institutions who kindly gave me permission to use their illustrations and tables.

I am also very grateful to my co-workers at the Institut für Paläontologie der Universität Erlangen for their help in preparing this book, especially Frau U. Scholl, Frau Chr. Sporn and Herr F. Grimmer. The critical questions asked by students participating in the Erlangen microfacies courses played no small part in my decision to write the book.

Erlangen, January, 1978 ERIK FLÜGEL

Contents

1 Introduction to Facies Analysis

"Every facies of a deposition shows well-defined petrographic, geognostic and paleontological properties which can be clearly differentiated from the properties of other facies in the same geological period." The necessity for interdisciplinary studies is clearly expressed in this definition given by Amanz Gressly in 1838. In facies analysis paleontological, sedimentological, geological, and geochemical data provide the basic information about the sedimentary environment, the lithogenesis, and the biotopes of organisms preserved as fossils.

1.1 The Microfacies Concept

A. Name: The term "microfacies" was suggested by Brown (1943: 325): "In thin section the rock is seen to be composed of ... microfacies." In other words, microfacies refers to the criteria appearing in thin-sections under the microscope.

The various objections raised to the term microfacies have not gained a foothold: Calkins (1943 – a "microfacies" must be counterbalanced with a "megafacies"); Campbell (1944 – instead of "microfacies," simply "under the microscope"); Alling (1945 – "microfacies" is difficult to define, therefore preferably "microlithology" as a result of quantitative microscopic studies).

Apparently without any knowledge of Brown's suggestion, Cuvillier (1952, 1958, 1961) re-introduced the name microfacies to characterize paleontological and petrographic criteria in thin-sections. The *International Sedimentary Petrographical Series,* which first appeared, upon the request of Cuvillier, at the Third International World Petroleum Conference in Paris in 1951, contributed substantially to the rapid adoption of the term microfacies. The distinction between micro-lithofacies and micro-biofacies called for by Fairbridge (1954) has gained little support.

B. Definition: Microfacies is the total of all the paleontological and sedimentological criteria which can be classified in thin-sections, peels, and polished slabs.

C. Discussion: This definition assumes the following:

a. Study of thin-sections, peels, and polished slabs at magnifications of up to approximately ×200.

b. Equal consideration of paleontological and sedimentary criteria.

c. Classification of data, taking into account the qualitative and quantitative criteria (e.g., organic associations, limestone classification, and modal composition).

d. Testing of microfacies classifications by comparison with geological field data, paleoecological interpretations and, perhaps, geochemical criteria.

e. Application of small-scale observations to larger dimensions (outcrop: meter to kilometer range). The methodological relationship between thin-sections and outcrop areas comes from the use of limestone classifications based on textural and structural criteria (Dunham, 1962; see 6.2.2) and from the statistical evaluation of data (see 7.3).

The definition presented here signifies a methodological refinement of Gressly's classical facies concept (see Teichert, 1958; Franke, 1963; Lützner et al., 1974). Because microfacies takes into consideration biological as well as lithological criteria, the arguments presented by W. Schäfer (1962: 546) opposing a "micro-biofacies" (third order biofacies) do not seem to be applicable.

D. Development of the concept: Even the earliest thin-section studies of carbonates aimed for genetic interpretations (Sorby, 1879; Bornemann, 1886) as well as for stratigraphic evaluation and ecological interpretations of fossils (Gümbel, 1873). Probably the oldest microfacies studies originated from K. Peters at the University of Graz, Austria, where in 1863 he published a paper entitled *Über Foraminiferen im Dachsteinkalk* (Foraminifera in Dachstein limestone); here thin-sections were evaluated to clarify paleoecological and paleogeographical questions. Hovelacque and Kilian (1900) published the first illustrated volume of thin-section photographs. The practical application of limestone structures in thin-sections was demonstrated by Udden and Waite (1927) for oil exploration in the Pennsylvanian of Texas.

Microscopic studies of carbonates were given substantial impetus by Bruno Sander (1936 – description of the depositional fabric; English translation 1951) and by Julius Pia (1933), who presented one of the first comprehensive general surveys of the Recent carbonates.

As illustrated in Fig. 1 by the Alpine Triassic, microfacies studies coupled with sedimentological and paleontological objectives did not begin in earnest until the 1960s. The rapid advances made in microfacies since then are a result of: (1) the exploration for oil in carbonate rocks (approximately 50% of the world's crude oil production); (2) creation of useful limestone classifications (Folk, 1959; Ham, 1962); and (3) paleontological problems (e.g., paleoecology of fossil reefs, biostratigraphy of "monotonous" limestone series by means of fossils in thin-sections). At the moment an increasing number of papers is available in which the multitude of microfacies criteria are compiled and interpreted in the form of "facies models" (J. L. Wilson, 1975, see Sects. 8 and 10). In addition, there are studies on the submicroscopic criteria of carbonate rocks (ultra-facies), on the possibilities offered by multivariate facies analyses, and on the mutual relationships between microfacies criteria and technological properties (see Sect. 9.2.3).

E. Divergent definitions: Gübler et al. (1967: 55) defined a "primary microfacies" on the basis of criteria observable in a sedimentation unit (= a rock lamina whose thickness does not exceed the largest diameter of the largest particle). According to this, the term is restricted to criteria which are determined in thin-sections parallel

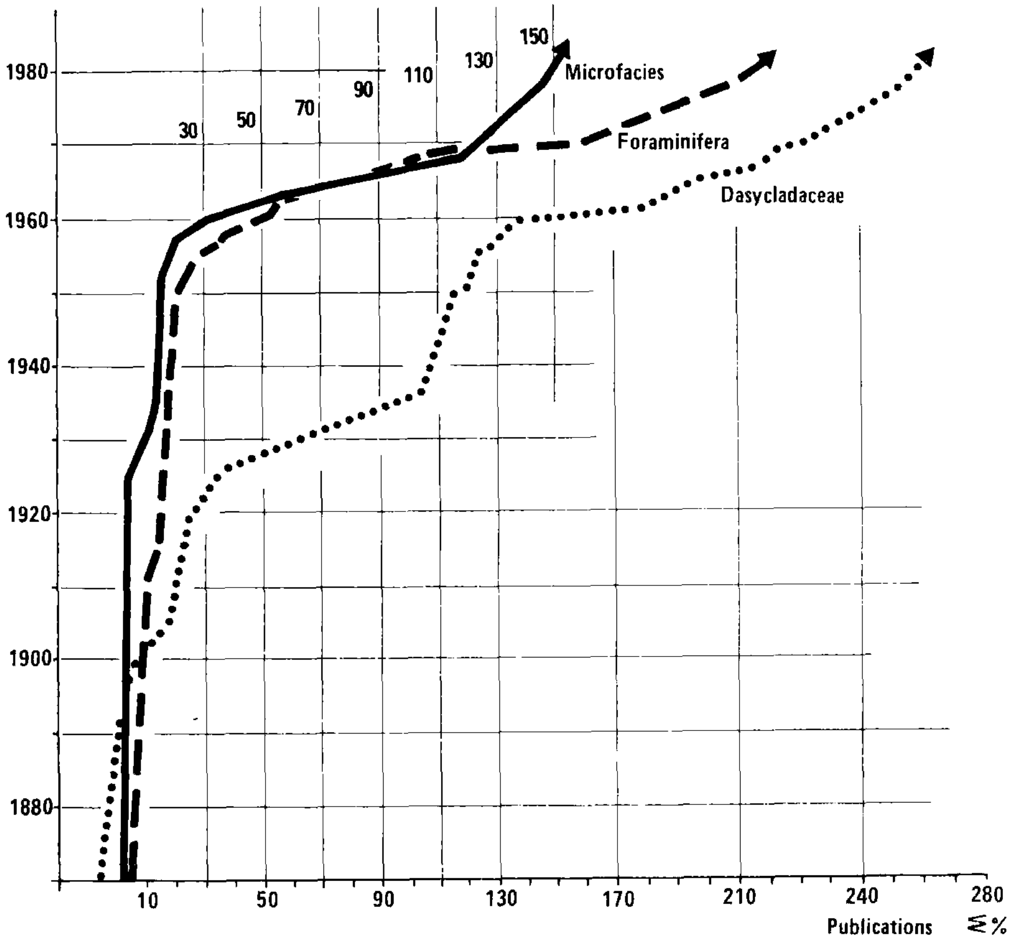

Fig. 1. The interest in microfacies analyses of Triassic sediments in the Calcareous Alps, expressed by the annual number of publications. Calcareous algae were studied relatively early because of their value for biostratigraphy. The number of papers on foraminifera studied in thin-sections and on microfacies characteristics do not begin to grow appreciably until about 1960, as a result of new micropaleontological and sedimentological problems

to bedding planes. "Microsequences" result from a vertical succession of primary microfacies types. These correspond to the microfacies types determined in vertical sections (perpendicular to the bedding plane) in the usual sense of the definition. Cloud and Barnes (1957) use the term microfacies to characterize minor or less important facies developments within larger facies environments. We cannot accept the use of the term microfacies to characterize certain mineral parageneses (e.g., "stress-controlled microfacies", Shaw and Walton, 1963) or to describe textures of sedimentary boulders ("microfacies analyses of till," Ostry and Deane, 1963).

1.2 Methods of Facies Analysis

Basically we can distinguish between studies carried out in the field and those carried out in the laboratory (Fig. 2).

1.2.1 Fieldwork

Prerequisites for microfacies analysis are geological field studies and profiles, with special consideration of facies criteria (lithology, rock colors, bedding and lamination. sedimentary structures and textures, fossil content, stratigraphic relationships and geometric shapes of rocks). Introductions to the methods of field studies are to be found in Krumbein and Sloss (1963), Geyer (1973), Falke (1975) and in Vossmerbäumer (1976).

The description of recognizable criteria for carbonate rocks both in hand specimens and outcrops can be made easier by using the following *check list:*

1. Mineralogical composition (calcite, dolomite) and rock name (limestone, calcareous dolomite, dolomite, dedolomite, limestone-marl cycles, etc.). Methods: HCl, staining with alizarin red S, etc. (see 1.2.3.3 and Bouma, 1969).

2. Rock colors (fresh fracture and weathering colors). Methods: standard color chart (e.g.. ROCK-COLOR-CHART, Geol. Soc. Amer. 1951 or MUNSELL SOIL COLOR CHART; see Folk, 1969).

3. Fracture patterns (conchoidal, subconchoidal, uneven, splintery, fracturing through particles, cleavage along particle boundaries).

4. Main constituents at $\times 10$ magnification (fine-grained carbonate matrix, sparite, particles, pores; see Leighton and Pendexter, 1962, Sect. 6.2.3):

- Matrix (grain size and color: homogeneous or non-homogeneous);
- Sparite (equant or non-equant grain sizes; cement fabric, see Sect. 3.3);
- Main particle types (ecological and systematic grouping of the skeletal grains; peloids, aggregate grains, oncoids, ooids, lithoclasts, terrigenous minerals, e.g. detrital quartz, see Sect. 4.1.3.8;
- Particle sizes (siltite up to 0.063 mm, arenite to 2 mm, rudite >2 mm; possible differentiation of fine, medium, and coarse arenite <0.25, <0.50 and >0.50 mm). Methods: Müller hand lens, G. Müller (1967);
- Particle shape (angular, subangular, rounded, etc.);
- Particle frequency and matrix/particle ratio;
- Particle orientation (not oriented, s-fabric, imbricate structures, graded bedding, etc.);
- Particle packing (open or closed fabric, see Sects. 6.2.2 and 4.2.3.1);
- Pores and open-space structures (see 4.2.3.1 and 9.2.1).

5. Bedding and sedimentary textures:

- Bedding types (horizontal bedding, cross-bedding, flaser and lenticular bedding, deformation bedding, biogenic bedding);
- Features of the bedding surface (even, uneven; marks – ripple marks, scour marks, pits and imprints; shrinkage cracks and injection cracks; traces and trails; films);