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Recent Advances in GEOMATHEMATICS

An International Symposium

Edited by
D.F. Merriam
Syracuse University

Proceedings of papers presented at sessions sponsored by the International Association for Mathematical Geology at the 25th International Geological Congress in Sydney, Australia, August 1976.

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PREFACE

The Proceedings presented here, as the result of so many endeavors, are different than perceived. Some papers given orally at the Congress were not available for publication, other papers with appropriate subject matter were substituted, other contributions were extensively modified, etc., and so the final result has only little resemblance to the original program. No matter, as this volume is intended to give the reader an awareness and appreciation of "Recent Advances in Geomathematics."

Unfortunately only abstracts of papers presented at the 25th International Geological Congress in Sydney were published. The IAMG sponsored three sessions - 116.1 - Random Events in Geology; 116.2 - Quantitative Exploration Techniques; and 116.3 - Geomathematics (general session). This volume contains papers from session 116.3. The session was organized by Alan C. Cook of Wollongong University and Daniel F. Merriam of Syracuse University.

The collection of papers is varied. That is good as a potpourri will give a better idea of the level of overall involvement of geologists in the subject and give the reader a broad background in the subject. The contents are restrictive in that no depth in coverage is provided and no provision is made for supportive data. However the reader is encouraged to delve into any subject of interest through the list of references included in the papers, any of the many texts now available, and the leading journals on the subject - Journal of Mathematical Geology (Plenum Press) and Computers & Geosciences (Pergamon Press).

Papers included in these proceedings are concerned with stratigraphy, sedimentology, paleontology, petrology, structure, engineering geology, geochemistry, and geophysics. Most are oriented statistically and range in subject matter from multivariate statistics to simulation.

The first paper by Flood-Allen-Orme involves the recognition of Recent sediment types by compositional data using multivariate analysis. Denness-Cubitt-McCann-McQuillan report on mapping utilizing multivariate techniques of regional geotechnical parameters of engineering significance on the seafloor. Chyi-Elizalde-Smith-Ehmann use multivariate techniques to demonstrate that minor and trace elements are diagnostic and can be used for stratigraphic identification of Pennsylvanian limestones in Kentucky. And Merriam-Pena Daza classify and map limestones in Kansas by determining the vertical and horizontal distribution of contained chemical elements in the Permo-Pennsylvanian cyclic sequence. Brower-Clement-Veinus use principal components and factors derived from a covariance matrix of logs of original measures of fossils to characterize sources of allometry in the data.

Dienes proposes a formalized stratigraphic nomenclature and Jasko was able to determine quantitatively by Monte-Carlo methods that the error in stratigraphic correlation increases with distance in a given region. Reyment notes that statistical properties of polarity reversals can be correlated with major geological events.

The last papers are concerned with cartography, mapping, and simulation. Bell-Bickmore outline interactive cartography. Pauncz-Johnson have developed a gridding technique with finite difference operators for contouring 3-D data at selected sections. Tipper uses computer-aided design to create computerized models, which represent complex surfaces. Burns-Shepherd-Marshall have formulated a coding sequence of statements or relations which describes the field data as recorded. The technique can be used to detect errors and inconsistancies of an observer or between observers. Finally, Harvey-Ferguson give a computer simulation model for interpreting textures in crystalline rocks.

These papers are interesting and thought provoking. It is hoped they will stimulate additional work in these important areas and encourage work in others.

I would like to thank all of the contributors for without their cooperation it would have been impossible to complete this volume on schedule. Prof. A.C. Cook of Wollongong University cochaired the sessions and made all the technical arrangements at the Congress in Sydney. Mrs. Janice Potak of the Department of Geology, Syracuse University typed the manuscripts and assisted with the proofreading. Mr. Harry Holt and Mr. Peter Henn of Pergamon Press made arrangements for publication.

25 August 1976
Sydney, Australia

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CONTENTS

MULTIVARIATE ANALYSIS OF COMPOSITIONAL DATA OF BIOCLASTIC CARBONATE SEDIMENTS FROM LADY MUSGRAVE REEF, GREAT BARRIER REEF, AUSTRALIA

P.G. Flood, J. Allen, and G.R. Orme

University of Queensland

ABSTRACT

Multivariate techniques (cluster, discriminant, and factor analyses) display the interrelationships which exist between skeletal type, particle size, mineralogy, and trace-element data obtained from bioclastic carbonate sediments collected throughout the range of depositional environments present on the reef top of Lady Musgrave Reef. Two sediment types or facies can be recognized on the basis of skeletal-component composition and five sediment types or facies can be recognized using the particle-size data. Sediments in which coral particles dominate are typical of the lagoonal environment, whereas fragments of coralline algae dominate the sediments from the reef flat and reef rim. The particle-size types are arranged in a concentric-horizontal manner across the reef top and a size gradient is evident from gravel and very coarse sand on the reef rim to fine sand and silt in the lagoon. This gradient reflects the gradual decrease in the available energy of the factors (action of breaking waves, translatory waves, tidal currents) responsible for producing sediment transport. The various sediment types can be classified using the discriminant-analysis results and the numerical analysis confirms the observations and conclusions drawn by previous researchers.
KEY WORDS: *bioclastic carbonate sediments, Great Barrier Reef, sedimentology, geochemistry, cluster analysis, factor analysis, discriminant analysis, numerical analysis.*

INTRODUCTION

Petrological and geochemical analyses of sediment samples, and a graphical approach to the analysis and interpretation of granulometric data, were incorporated in an earlier study of the sediments and physiography of Lady Musgrave Reef (Orme, Flood, and Ewart, 1974). It was concluded that the distribution of sediment properties reflected a relationship between physiographic patterns, source, and water movement.

Multivariate techniques, sequentially employing cluster, discriminant, and factor analyses, were applied to the petrographic and geochemical data in order to examine possible interrelationships between skeletal type, particle size, mineralogy, and trace elements, and to define statistically recognizable sediment types or facies. The results presented here indicate the potential of multivariate techniques in studies of reef top biogenic sediments.

LADY MUSGRAVE REEF

Lady Musgrave Reef (25°54'S, 152°23'E), situated at the southern extremity of the Great Barrier Reef Province (Fig. 1), is a closed ring platform-reef type (Maxwell, 1968) resembling an atoll (Fig. 2). A summary account of its physiography and sediments is provided by Orme, Flood, and Ewart (1974).

Physiography

The reef top, that is the part of the reef mass which is enclosed by the outer edge of the encircling reef rim is divisible into three distinct depositional environments; supratidal, intertidal, and subtidal. The former includes the cay, the intertidal environment covers the reef rim and the reef flat (coral zone), and the latter includes the sanded zone and lagoon.

The reef rim, a narrow zone 70 to 200 m in width, surrounds the reef top. It is the highest intertidal portion of the reef, being a few centimeters above the upper level of coral growth. The rim slopes gently seaward, merging into the reef slope. Coral shingle (*Acropora* spp.) forms an extensive veneer over the coralline algal pavement. Benthonic foraminifers live attached to soft brown algae which also occur on the rim.

The reef flat extends inward from its junction with the reef rim as a series of radial lineations, consisting of living corals (mainly *Acropora* sp. on the growing margin) arranged normal to the refracted wave fronts. The upper surface of the corals within this zone may show extensive encrustations of coralline algae. The dominant sediment components are coral and coralline algae together with subordinate amounts of *Halimeda*, foraminifers, and molluscs.

The sanded zone represents a subtidal accumulation of sand-sized skeletal detritus which has been removed from the reef rim and reef flat but locally postmortem in situ additions of molluscan and *Halimeda* particles are important. This zone is broadest in the ESE sector, near the area of maximum wave energy which corresponds with the direction of maximum influence in the Southeast Trade Winds. In contrast to the interdigitating junction of this zone and the reef flat, its boundary with the lagoon is straight and is marked by a depth increase of about 3 m. The presence of lagoonal patch reefs studded across the latter boundary is indicative of its prograding nature.

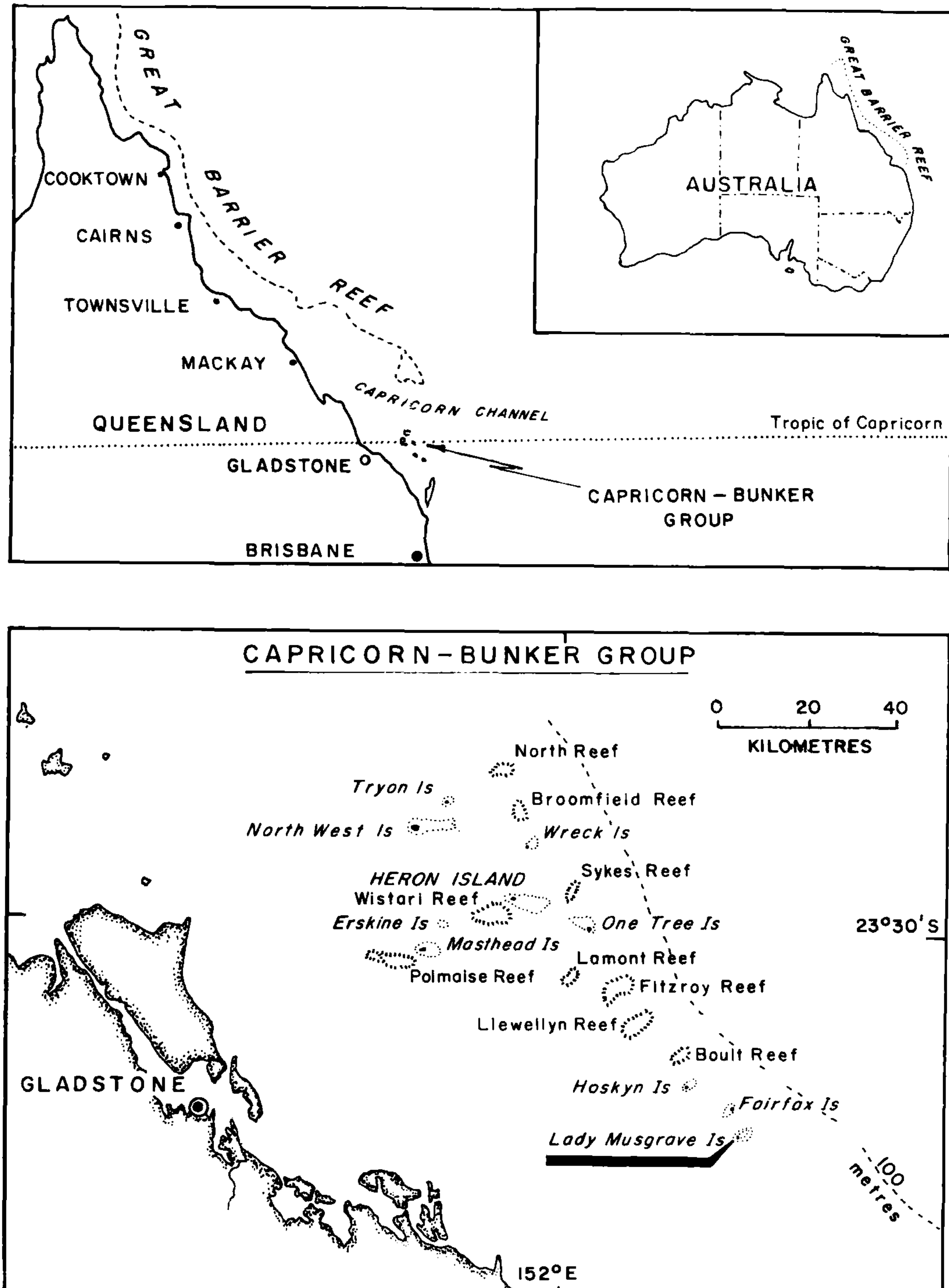

Figure 1. Location of Lady Musgrave Reef, southern region of Great Barrier Reef Province, Australia.

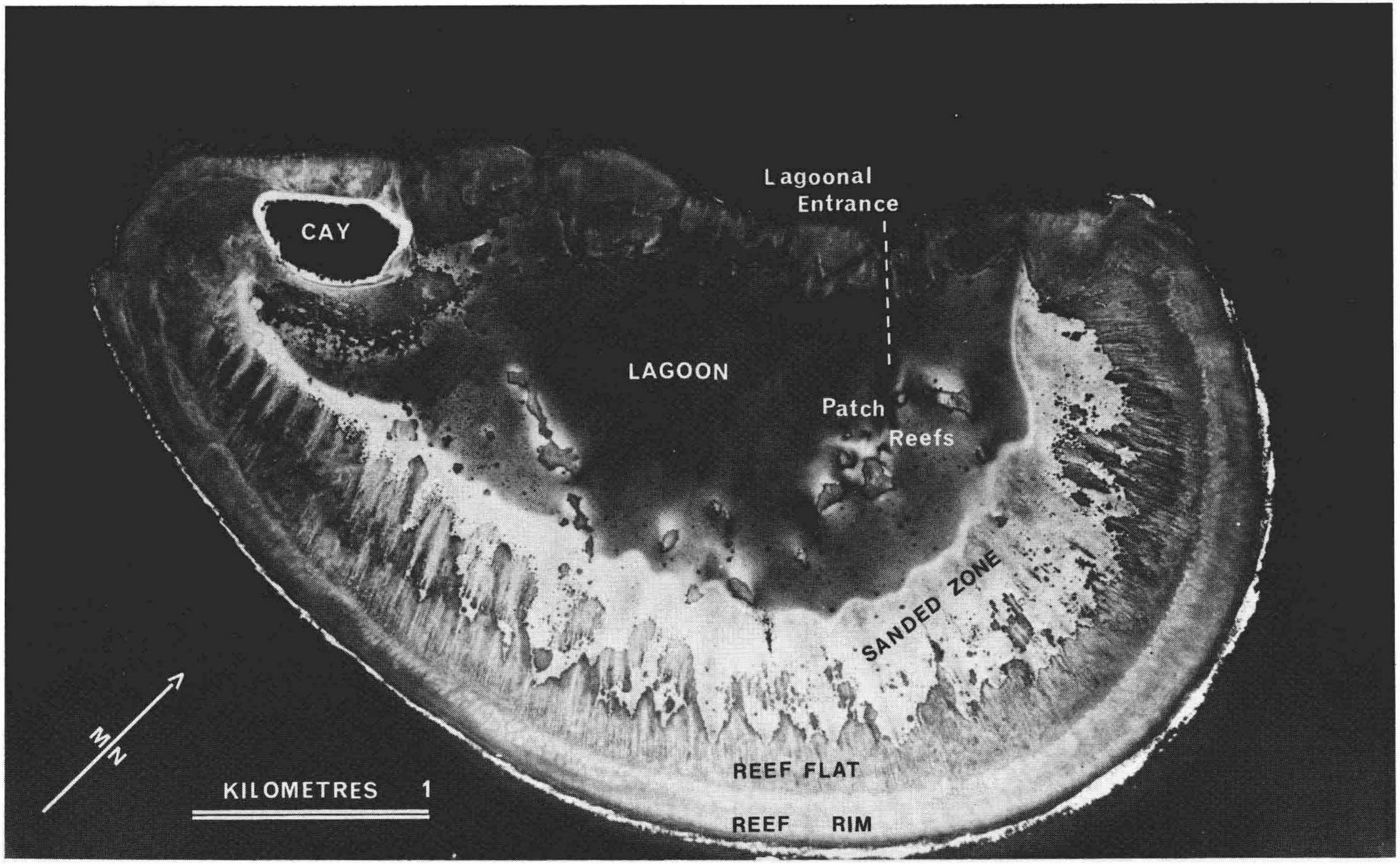

Figure 2. Vertical aerial photograph of Lady Musgrave Reef showing clear physiographic subdivision into intertidal reef rim and reef flat (coral zone), subtidal sanded zone and lagoon, and supratidal shingle cay.

The lagoon occupies the central portion of the reef top. Its depth is generally less than 6 m below low-water datum and the lagoonal floor is relatively flat except for several patch reefs which rise to the same level as the surrounding reef flat. A gap in the leeward reef rim provides a lagoonal entrance.

The island is a vegetated shingle cay consisting of coral shingle and sand-sized bioclastic particles, with beachrock which is exposed intertidally and near the western corner of island cemented cay shingle occurs.

Prevailing Physical Conditions

The Southeast Trade Wind blows at an average speed of 20 to 40 km/hr (Beaufort Scale 4 to 5) for approximately 70 percent of the year. The summer months experience calms or north-northwesterly winds and occasional cyclones. It is the small magnitude-high-frequency events influenced by the Southeast Trade Wind and not the large magnitude-low-frequency events caused by cyclones, which mold the reefal physiography. Ocean swells of 1 to 3 m in amplitude predominate from the east-southeast. Waves breaking on the reef rim can exceed 2 m and they refract around the reef producing lateral transport of sedimentary particles from windward to leeward. Sediment is deposited and may accumulate where wave sets converge for example the area of the cay. The water level on the intertidal portion is sufficiently shallow to allow wind shear to agitate sand-sized particles and to keep silt-sized particles in suspension.

The tidal range is 1.8 m (springs) and 0.8 m (neaps). Tidal currents which set westerly on the flood tide and easterly on the ebbtide rarely exceed 2 km/hr and as the water level falls drainage is crudely radial until the reef rim becomes exposed then it flows to leeward. A strong tidal current (up to 6 km/hr) flows through the lagoonal entrance. The lagoon experiences slack water for more than four hrs during each tidal cycle.

Sediments

The sediments are entirely biogenic and five organic groups account for more than 90 percent of the constituent particle composition of the reef top sediments (Orme, Flood, and Ewart, 1974; cf. Heron Reef, Maxwell, 1973, p. 229-354). These groups are in decreasing order of quantitative importance; coral, coralline algae, foraminifers, molluscs, and *Halimeda*. The distribution patterns of the skeletal detritus constituting the sediments are controlled by:

(1) the distribution of the living organisms,
(2) the susceptibility of the skeletons to mechanical breakdown,
(3) the production of specific size ranges upon breakdown, and

(4) the movement of skeletal detritus from growth areas to depositional areas under the action of
   (a) breaking waves
   (b) translatory waves
   (c) tidal currents.

These factors jointly influence the particle size and degree of sorting exhibited by the sediments.

Coralline algae which are relatively resistant to abrasion and mechanical breakdown contribute to the very coarse sands and gravels on the reef rim. Corals (especially *Acropora* spp.) are rapidly broken down into distinct size modes (shingle sticks, very coarse sand, fine to very fine sand) under the influence of the Sorby Principle (see Folk and Robles, 1964). The winnowing action of the breaking waves and translatory waves leaves the gravel-sized shingle as a lag deposit (shingle banks) on the reef rim and outer reef flat, and transports the coarse sand sizes as bedload into the sanded zone. Very fine sand and silt are carried in suspension to the lagoon where it settles out during periods of slack water. Consequently there is a size gradient from gravel and coarse sand to fine sand from the windward reef rim to the centrally located lagoon.

The factors responsible for the particle-size differentiation also promote a segregation of calcitic detritus (coralline algae and Foraminifera) and aragonitic detritus (corals and *Halimeda*). The former which constitutes the coarser sediments remains near to the source whereas the latter, finer material, is transported towards the lagoon. This segregation also produces marked differences in the trace-element distribution throughout the reef top (see Orme, 1977, Chapt. 5). Magnesium is closely associated with the calcitic detritus; iron manganese and strontium is associated with the aragonitic detritus. The distribution patterns of six variables are shown in Figures 3 and 4. Orme, Flood, and Ewart (1974) were unable to determine any systematic variation in in the distribution patterns of copper, barium, or zinc.

NUMERICAL ANALYSIS

Forty variables were measured by Orme, Flood, and Ewart (1974) for the majority of the 89 samples in their sediment collection which was made in 1972. The variables included the percentage component of coral, coralline algae, *Halimeda*, foraminifers, molluscs, and unidentified constituents (closed array); four textural parameters (graphic mean size, inclusive graphic standard deviation, inclusive graphic skewness, kurtosis); calcite, magnesium, manganese, iron, strontium, copper, barium, and zinc content; 22 sieve fractions (weight percent gravel, sand at quarter phi intervals and mud-closed array). Statistics for the data set are give in Table 1.[1]

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[1]Data listings are available free of charge from P.G. Flood.

The cluster, discriminant, and factor analysis programs of Davis (1973), Nie and others (1975), and Klovan and Imbrie (1971) respectively, were employed sequentially to determine interrela-

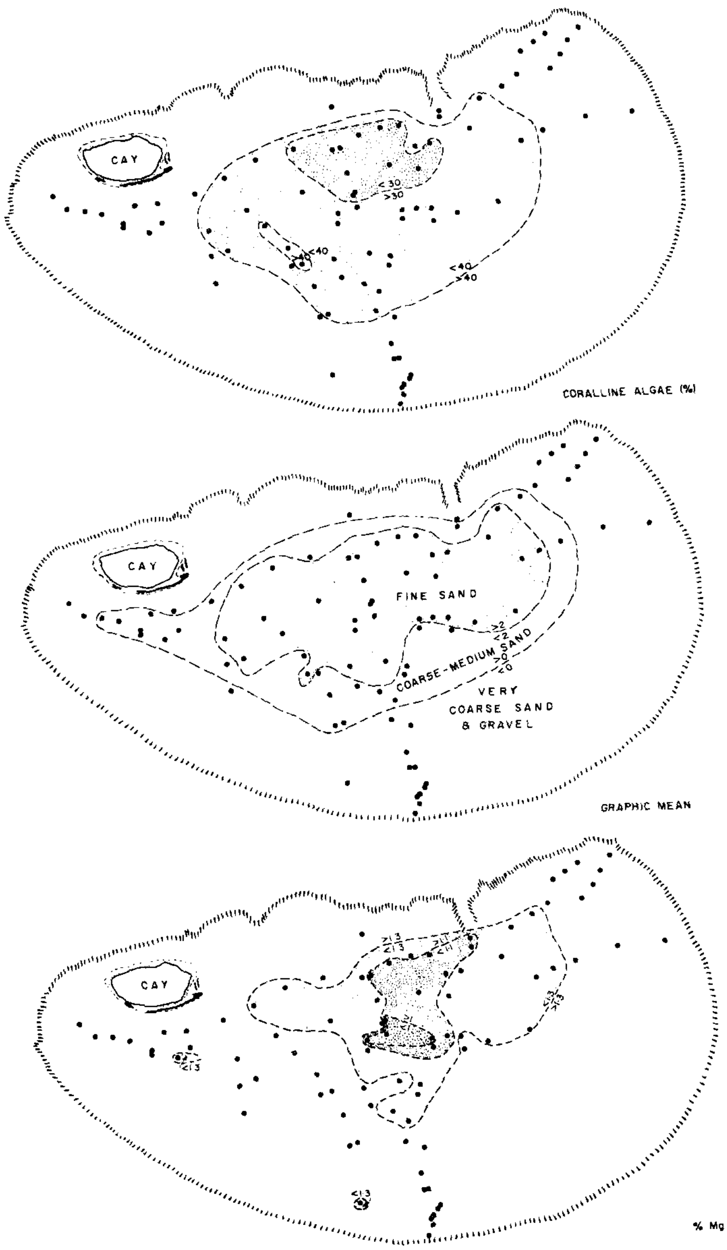

Figure 3. Spatial distribution of coralline algae, graphic mean size (phi units), and magnesium content. Sample locations are shown as dot.

tionship between skeletal-component types, particle size, mineralogy, and trace-element data, and to determine the number and nature of statistically recognizable sediment types.

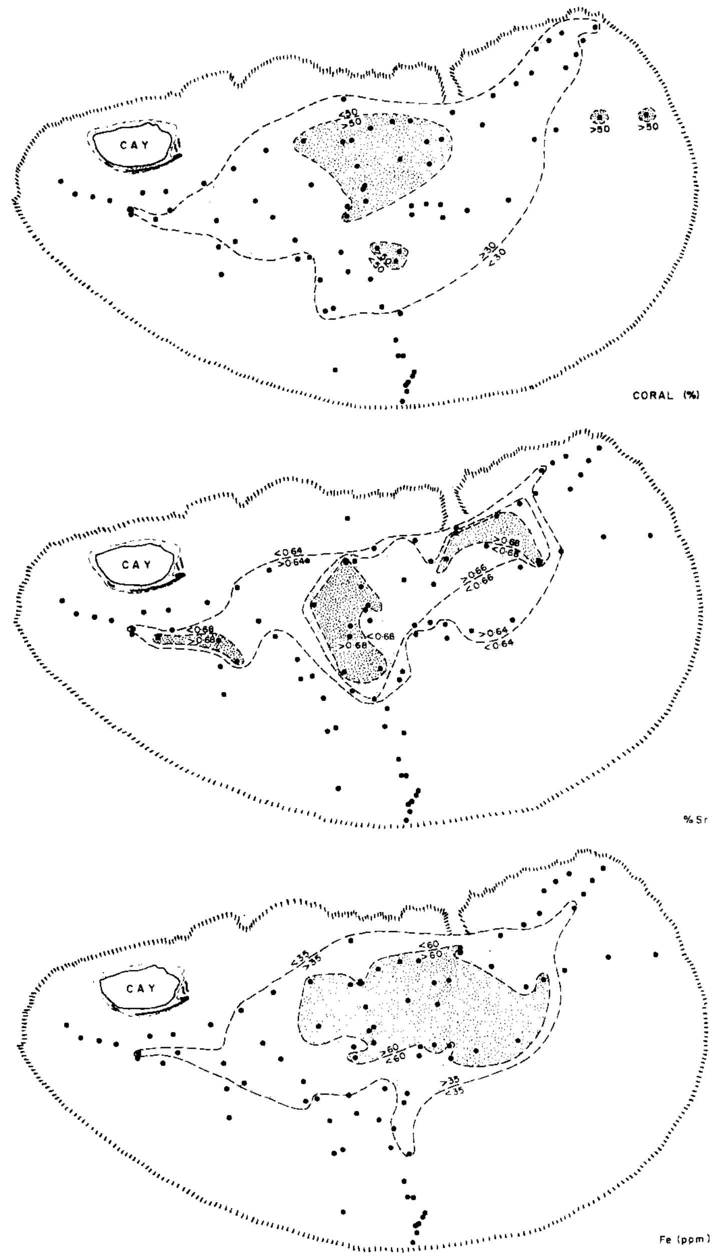

Figure 4. Spatial distribution of coral, strontium, and iron content. Sample locations are shown as dot.