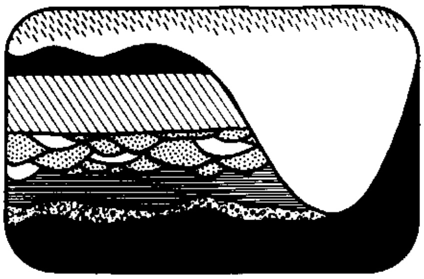

Facies Models 1. General Introduction

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Purpose of Series
This article is a general introduction to a proposed series of articles on sedimentary facies models. They will appear roughly one per issue in *Geoscience Canada*, and are intended to review specific sedimentary environments. The articles will be written for the non-specialist who wishes or needs to be aware of current ideas in environmental interpretation and prediction. There will be a minimum of text, a maximum of illustrations, and a bibliography so short that there is a reasonable chance for the non-specialist-sedimentologist to read a little farther and painlessly find his way into a maze of literature. Obviously, we will stress review papers and classic examples, using Canadian examples wherever possible.

Introduction
In the general field of stratigraphy and sedimentology, one of the most active areas is that concerned with the formulation of facies models for various sedimentary environments. This emphasis is not new; many of the ideas were embodied in Dunbar and Rodger's *Principles of Stratigraphy* in 1957, and were based upon studies dating back to Gressly and Walther in the 19th Century (Middleton, 1973). However, the importance of facies models at the present time is due to an increasing need for the models, and a rapidly increasing data base on which the models are formulated.

A facies model could be defined as a general summary of a specific sedimentary environment, written in terms that make the summary useable in at least four different ways. The basis of the summary consists of many studies in both ancient rocks and recent sediments; the rapidly increasing data base is due at least partly to the large number of recent sediment studies in the last 15 years. The increased need for the models is due to the increasing amount of prediction that geologists are making from a limited local data base. This prediction may concern subsurface sandstone geometry in hydrocarbon reservoirs, the association of mineral deposits with specific sedimentary environments (for example, uraniferous conglomerates), or the movement of modern sand bars in shallow water (Bay of Fundy, tidal power). In all cases, a limited amount of local information *plus* the guidance of a well-understood facies model results in potentially important predictions about that local environment.

Sedimentary Environments
The preparation of a series of review articles implies that there must be some agreement among sedimentologists as to how to subdivide up the depositional environments of the world into commonly recurring types. At a recent count (1972), there were 18 major environments, 40 sub-types, 14 sub-sub-types, and 20 sub-sub-sub-types. I deliberately do *not* cite this reference! Nevertheless, there is some agreement on a very basic subdivision based upon morphology, physical and chemical processes, and biological processes. The geologist involved with ancient environments would add the criteria of stratigraphic record and diagenesis to the above list. A typical set of environments that most sedimentologists would not object to is shown in Table I; many but perhaps not all of these will be covered in this series, and some others might be added. Sedimentologists might also wish to add aeolian and glacially-influenced environments to the list, and herein lies the beginning of confusion - some environments are being defined geomorphologically (e.g., alluvial fans) and others by process (e.g., aeolian). Aeolian sediments can exist on their own (in many deserts) or can be blown into alluvial fan and fluvial environments, yet still be identifiable as windblown.

Table I *Major environments of deposition of clastic rocks*

Terrestrial:	Alluvial fans
	Rivers and their floodplains
Marginal-Marine:	Deltas
	Alongshore sand bodies (beaches, cheniers, barriers)
Marine:	Shelf
	Submarine fans - Turbidites - Abyssal plains

The point to make here is that our aim as geologists is not only to recognize environments, but to understand the range of processes that can operate within them. We must also be sure of why we want to identify environments in the first place. Is it to provide a name showing that we have thought about the origin of the unit we have mapped ("the Ordovician Cloridorme Formation consists of deep water turbidites"), or is it to provide a framework for further thought? It is the latter - the framework for further thought - that in my mind separates the art of recognizing environments from the art of FACIES ANALYSIS and FACIES MODELLING. The meaning and implication of these terms will become apparent.

Facies Models
The principles, methods and motives of facies analysis are shown in Figure 1, specifically for turbidites. This is to help link the general comments on facies models in this article with specific comments on the turbidite model discussed in the next article. In Figure 1, the local examples 1 through 6 are turbidite examples; however, I emphasize that the ideas embodied in Figure 1 can and should apply to facies models for all other environments. If enough examples of modern turbidites can be studied in cores, and if enough ancient turbidite formations are studied in the field, we may be able to make some general statements about turbidites, rather than statements about only one particular example. The process of extracting the general information is shown diagrammatically in Figure 1, where numbers 1 and 2 represent recent sediment studies (cores from, say, La Jolla fan and Hatteras abyssal plain) and numbers 3 through 6 represent studies of ancient

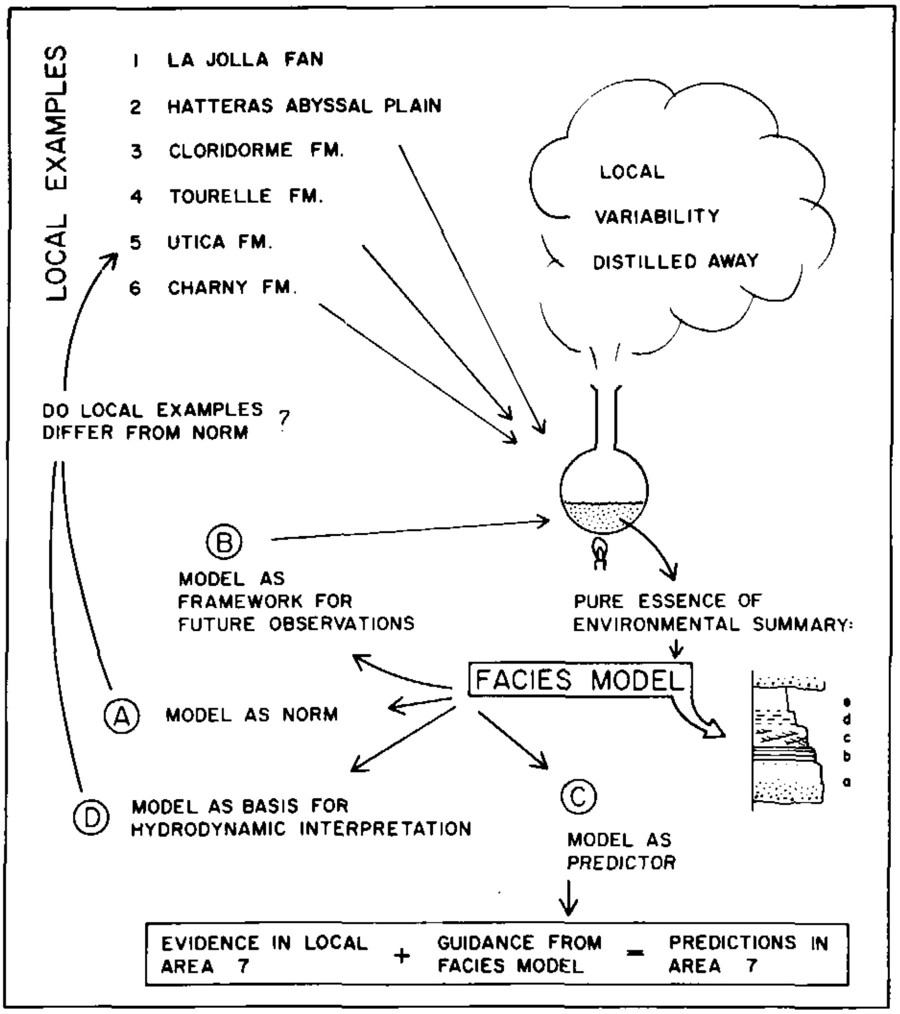

Figure 1
Distillation of a general facies model from various local examples, and its use as a norm, framework for observations, predictor, and basis for hydrodynamic interpretation. See text for details.

turbidites (for example, the Cloridorme and Tourelle Formations of Gaspé, the Utica Formation at Montmorency Falls, and the Charny Formation around Quebec City). The entire wealth of information on modern and ancient turbidites can then be distilled, boiling away the local details, but distilling and concentrating the important features that they have in common into a general summary of turbidites. If we distill enough individual turbidites, we can end up with a perfect "essence of turbidite" - now called the Bouma model (see next article in this issue). But what is the essence of any local example and what is its "noise"? Which aspects do we dismiss and which do we extract and consider important? Answering these questions involves experience, judgement, knowledge and argument among sedimentologists, and the answers also involve the ultimate purpose of the environmental synthesis and summary. We will not consider the process of distilling the information here, but will consider each environment at its present level of understanding - emphasizing its beauty but pointing out its warts.

I pointed out earlier that the difference *between the summary of an* environment and a facies model perhaps depends mainly on the use to which the summary is put. As well as being a summary, a FACIES MODEL must fulfill four other important functions:

1) it must act as a *norm*, for purposes of comparison
2) it must act as a *framework* and *guide* for future observations
3) it must act as a *predictor* in new geological situations
4) it must act as a *basis for hydrodynamic interpretation* for the environment or system that it represents.

Figure 1 has been constructed to illustrate these various functions. Using the example of the turbidite model, the numbers 1 through 6 indicate various local studies of modern and ancient turbidites. There is a constant feedback between examples - in this way the sedimentologist exercises his judgement in defining the features in common and identifying "local irregularities". This is the "distillation" process that allows the environmental summary (that will act as a facies model) to be set up.

Having constructed the facies model, it must act first as a norm (Fig. 1, A) with *which individual examples can be* compared. Without a norm, we are unable to say whether example 5 of Figure 1 contains any unusual features. In this example, Utica Formation turbidites at Montmorency Falls are very thin, silty, and many beds do not begin with division A of the Bouma model (Fig. 1); they begin with division B or C. Because of the existence of the norm (Bouma model), we can ask questions about example 5 that we could not otherwise have asked, and whole new avenues of productive thought can be opened up this way. Thus there is a constant feedback between a model and its individual examples - the more examples and the more distillation, the better the norm will be, and the more we must be forced into explaining local variations.

The second function of the facies model is to set up a framework for future observations (Fig. 1, B). Inasmuch as the model summarizes the important information, geologists know that similar information must be sought in new situations. In our example, this would include the individual characteristics of *the five Bouma divisions. Although the* framework ensures that this information is recorded wherever possible, it can also act to blind the unwary, who might ignore some evidence because it is not clearly spelled out by the model. This leads to imprecise interpretations, and would cause a freeze on any further improvement of the facies model - hence the feedback arrow (Fig. 1, B) implying that all future observations must in turn be distilled to better define the general model.

The third function of the model is as a *predictor in new geological situations* (Fig. 1, C). In example 7 (for example, Archean rocks in the Manitou Lake area, N.W. Ontario) (Fig. 1, C) let us imagine that we have just enough evidence to suggest a turbidite interpretation. Because we have the turbidite model and (in an ideal world) understand its operation, we can take the combination of the model and the limited data from area 7 to make further predictions about area 7. This is obviously a vitally important aspect of facies modelling, and good surface or subsurface prediction from limited data can save unnecessary exploration guesswork and potentially vast sums of money.

The fourth major function of a facies model is to act as an integrated basis for hydrodynamic interpretations (Fig. 1, D). Again, it is important to eliminate the local "noise" before looking for a general hydrodynamic interpretation, and again, there can be a feedback between the hydrodynamic norm and local examples (Fig. 1, D). This is indicated by the feedback arrow to example 5 (Fig. 1), implying the question "does the interpretation of example 5 differ from the idealized hydrodynamic interpretation?" If there *is* a difference (and there is), we can again ask questions that could not be asked if we had not used the facies model to formulate a general interpretation. This usage of the facies model is demonstrated particularly well by the turbidite model, discussed in the following article.

The turbidite/submarine fan model has been selected as the first to discuss because it is reasonably well understood, and because it demonstrates particularly well the four functions of a model illustrated by Figure 1. Some of the other models to be discussed are less well understood - because the environmental summary is weaker, so the functioning of the model is weaker. I emphasize that the *construction and functioning of facies* models is essentially similar for all environments, and that the turbidite example was discussed above to make the general statements about facies models a little more specific.

Basic Sources of Information

The following bibliography is not intended to be complete, and my annotations apply *only* to the aspects of the books or papers relevant to environmental summary and facies modelling.

Books Containing General Environmental Syntheses

Selley, R. C., 1970, Ancient sedimentary environments: Ithaca, N.Y., Cornell University Press, 237 p.

Selley introduces the volume as "not a work for the specialist sedimentologist, but an introductory survey for readers with a basic knowledge of geology". The book achieves this end very well - it summarizes, it leans on classical examples, and it very briefly indicates the economic implications (oil, gas, minerals) of some of the environments. This volume is a good place to start.

Spearing, D. R., 1974, Summary sheets of sedimentary deposits: Geol. Soc. Am., Map and Charts Mc-8.

A series of 7 large sheets with many line drawings, minimal text, and useful references on selected sandstone depositional environments. This is a quick way to get a feeling for alluvial fan, alluvial valley, aeolian, regressive shoreline, barrier island, tidal, and turbidity current environments, and the series also provides a very good entry to the recent literature.

Blatt, H., G. V. Middleton and R. C. Murray, 1972, Origin of sedimentary rocks: Englewood Cliffs, N.J., Prentice Hall, 634 p.

Chapter six, on facies models, is only *29 pages long, but summarizes* concisely the general principles of facies and facies analysis, and briefly reviews alluvial fans, alluvial plains, deltas, barriers, offshore shoals and turbidites - deep basin environments.

Allen, J. R. L., 1970, Physical processes of sedimentation: New York, American Elsevier, 248 p.

Although slanted toward physical processes, the book contains chapters *on winds and their deposits, river flow* and alluvium, shallow marine deposits, turbidity currents and turbidites, and glaciers and glacial deposits. Each chapter begins with a discussion of processes, but ends with useful generalized descriptions of the environments. This volume would not be the place to start reading, but would be good follow-up material for readers wanting a better understanding of physical processes operating in various environments.

Pettijohn, F. J., P. E. Potter and R. Siever, 1972, Sand and Sandstone: New York, Springer-Verlag, 618 p.

Chapter 11 (p. 439-543) is a review of sand bodies and environment written at a fuller and more technical level than Selley, Spearing, or Blatt, Middleton and Murray. It considers Alluvial, Deltaic Estuarine, Tidal Flat, Beach and Barrier, Marine Shelf, Turbidite and Aeolian environments, with separate remarks on sand body prediction. Useful follow-up reading after Blatt, Middleton and Murray (1972), Spearing (1974) and Selley (1970) in that order.

Rigby, J. K., and W. K. Hamblin, eds., 1972, Recognition of ancient sedimentary environments: Soc. Econ. Paleont. Min., Spec. Pub. 16, 340 p.

Contains separate papers on many important environments written at a technical level. Many of the papers are disappointing as reviews but there are excellent contributions on Alluvial Fans, *Fluvial Paleochannels, Barrier* Coastlines and Shorelines. Most of the authors present their environmental summaries but do not attempt to use them as models.

Reineck, H. E., and I. B. Singh, 1973, Depositional sedimentary environments: New York, Springer-Verlag, 439 p.

Pages 160-439 are devoted to *summaries of many modern* environments. Coverage is at the graduate student - professional sedimentologist level, but is patchy and rather uncritical. Vast reference lists are given, but it is hard to single out the very important papers from the trivial. The emphasis on modern environments is useful, but the book should not be used until one is at least somewhat familiar with specific environments.

The formulation and use of facies models

Harms, J. C., D. R. Spearing, J. B. Southard and R. G. Walker, 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Soc. Econ. Paleont. Min., Short Course 2 (Dallas, 1975), 161 p.

These notes were intended for the general soft-rock geologist, not the expert sedimentologist. They review sedimentary structures and their formation, and they way in which sedimentary structures, in sequence, can be used to construct facies models. The emphasis is general and philosophical, although fluvial, shoreline (conglomeratic, sandy and muddy), and shelf facies models are discussed in detail. Problems of facies analysis of conglomerates are also discussed. Recommended to those who wish to explore the ideas behind facies models, how they are formulated, and the degree of gradation between various models. Classical summaries of specific environments are not attempted.

Cant, D. J. and R. G. Walker, 1976, Development of a braided-fluvial facies model for the Devonian Battery Point Sandstone, Quebec: Can. Jour. Earth Sci. (in press, to appear January, 1976).

Although this paper presents new research results, it discusses in general terms some of the methods of facies model construction, using the Battery Point Sandstone as an example. The gradation between meandering and braided stream models is also emphasized. Recommended to readers specifically concerned either with formulating new models, or with using various fluvial models.

Reference

Middleton, G. V., 1973, Johannes Walther's law of the correlation of facies: Geol. Soc. Am. Bull., v. 84, p. 979-988.

MS received November 24, 1975.