# DETRITAL MODE EVOLUTION OF THE RIFTED CONTINENTAL-MARGIN LONGOBUCCO SEQUENCE (JURASSIC), CALABRIAN ARC, ITALY[1]

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ABSTRACT: The Longobucco Sequence is a 1200-m-thick dominantly carbonate miogeoclinal wedge which accumulated in the Mediterranean area during Jurassic time. Sedimentary facies pass upward from continental (3% of the stratigraphic column) at the base, through shelf (6%), slope (14%), to deep-sea turbidites (77%) at the top. Sand framework grains had five sources, four are *noncarbonate extrabasinal* and one, the most abundant, is *carbonate intrabasinal* as follows:

1) reworked arenites (*quartzarenites*, petrofacies A);
2) low-rank metamorphic rocks (*litharenites*, petrofacies B);
3) eolian or beach arenites (*feldspathic-quartzarenites*, petrofacies C);
4) granitic and high-grade metamorphic rocks (*arkoses*, petrofacies D);
5) intrabasinal shelf sediments (*peloids, intraclasts, fossils* and *oolites*).

Quartzarenites, which form fluvial and shallow-marine deposits, gradually pass upward through shelf, siliciclast-rich limestone to marly slope deposits with minor interbedded litharenites. Deep-sea fan deposits are chiefly carbonate turbidites, but feldspathic quartzarenites are present in the lower part. Arkoses abruptly replace the feldspathic quartzarenites in the upper part of the section. The litharenitic source is represented throughout the stratigraphic column. Therefore, different terrigenous source areas simultaneously supplied detritus to the sedimentary basin.

The evolution of detrital modes and depositional systems suggests two major tectonic events: latest Early Jurassic and probably Late Jurassic, superimposed on a progressive sinking of the basins. Both the change in depositional systems and sand composition can be related to a complex interplay of microcontinents and oceans which determined local compressive or extensional regimes during Alpine rifting in the Tethys region.

## INTRODUCTION

Numerous analyses of sedimentary basins or source areas related to different plate tectonic regimes have been published during the last five years. Interesting syntheses on this topic are reported in Dickinson (1974), Sloss and Speed (1974), Fischer and Sheldoln (1975), Dott (1978), and Dickinson and Suczek (in press). Although numerous petrographic and sedimentological facies analyses have been carried out (e.g., Mansfield, 1971; Dickinson and Rich, 1972; Moore, 1973; Ingersoll, 1978; Ingersoll and Suczek, in press; Dickinson et al., 1979) for paleogeographic and paleotectonic "compressive margin" reconstructions, few of such analyses are yet available for "rifted margin" sedimentary sequences.

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Quantitative studies on modes of modern marine sands of the Atlantic, Pacific and Arctic North American margin (Hubert and Neal, 1967; McKinney and Friedman, 1970; Cleary and Conolly, 1974; van de Kamp et al., 1976; Campbell and Clark, 1977) generally concern quartzarenitic and subarkosic compositions. The compositional maturity of ancient sequences, which are believed to have been deposited in "trailing margin" regimes (Boggs, 1966; Schwab, 1970, 1971, 1974, 1975; Lobo and Osborne, 1976) roughly agree with data from modern sands, but less agreement exists when comparing the provenance of ancient and modern detrital particles.

Crook (1974) and Schwab (1975) accounted for detrital modes of quartzarenitic composition when the arenites are derived from passive margins according to the traditional Krynine (1942) model. Dickinson and Suczek (in press) pointed out a large-scale correlation

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among the principal plate tectonic settings and the composition of the detrital framework modes of arenites; for trailing margin regimes they extended Crook's (1974) and Schwab's (1975) data for distinguishing between "quartzarenitic" provenance types from interior cratonic areas and "arkosic" provenance types from locally uplifted basement areas.

The aim of this work is to study the stratigraphic composition of sandy terrigenous material from a key rifted continental-margin sequence in the Mediterranean area in order to make paleogeographic and paleotectonic reconstructions for the Jurassic.

The Longobucco Sequence covers 100 $km^2$ along the northeastern Sila margin of the Calabrian Arc (Fig. 1); it transgressively overlies a Paleozoic basement of epimetamorphic rocks containing intruded granitic masses. Mapping by Magri et al. (1963–65) and a preliminary sedimentological and petrographic study by Zuffa (a, in press) permitted stratigraphic subdivision of the sequence. Lanzafame and Tortorici (in press) extended its age through the Early Cretaceous. Both the origin and tectonostratigraphic position of the "Longobucco Unit" (Paleozoic basement and sedimentary Mesozoic cover) within the Calabro-Peloritano Arc are still uncertain (Ogniben, 1973; Alvarez et al., 1974; D'Argenio, 1974; Amodio Morelli et al., 1979; Carrara and Zuffa, 1976; Scandone, 1979). Although this unit may occupy a base or a top position or may be emplaced on the Calabrian Arc from an African or European terrane, the sedimentary Mesozoic cover represents a miogeoclinal wedge deposited on a subsiding continental lithosphere related to the separation of Africa and Europe. The separation began in earliest Jurassic time (Dewey et al., 1973).

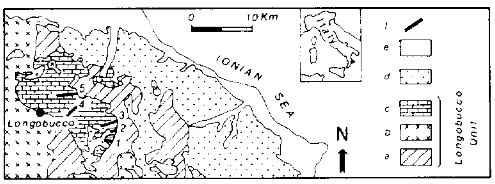


FIG. 1.—Geologic sketch map of northwestern Calabria. Longobucco Tectonic Unit: a) low-rank metamorphic rocks (Devonian), b) granite (Carboniferous-Permian), c) sedimentary sequences (Early Jurassic to Eocene); d) transgressive sequences overlying Alpine and Apenninic tectonic units (Late Miocene to Early Pliocene); e) postorogenic sequences (Pliocene to Holocene); f) measured stratigraphic sections, 1) Timpa della Gatta, 2) and 3) Vallone Santa Croce, 4) Fosso Petrone, and 5) Fiume Trionto.

## METHODS

Five stratigraphic sections were measured (Fig. 1) and 74 samples, mainly carbonate-poor arenites, were collected for petrographic study (sections 1–4, Fig. 2). Analytical results from the quantitative and qualitative studies concern:

1) quantitative analysis of carbonates by means of chemical determination of the total carbon dioxide, and by diffractometric evaluation of the ratio in weight between the carbonates present in the rock (Fabbri et al., 1973);

2) thin-section grain-size analyses using criteria proposed by Middleton (1962);

3) quantitative analysis on polycrystallinity and undulatory extinction of quartz grains according to suggestions by Basu et al. (1975);

4) the recognition of the rock fragments indicative of the source areas by the study of thin sections of coarse-grained impregnated sand fractions (Gazzi et al., 1973; Zuffa and DeRosa, 1978);

5) gross composition modal analyses according to the criteria proposed by Gazzi (1966), Zuffa (1969), Dickinson (1970), Gazzi et al. (1973). This approach to a quantitative analysis minimizes dependence of rock composition on grain size. The basic criterion for counting the detrital framework is separating coarse-grained lithic fragments (made up of single crystals more than 0.0625 mm in size) from fine-grained lithic fragments (made up of single crystals less than 0.0625 mm in size). Because of disintegration during dispersal, the former tend to break into individual crystals greater than the grain-matrix limit in size (i.e., 0.0625 mm), whereas the latter tend to break into still smaller fine-grained lithic fragments. Therefore, coarse-grained fragments are not counted as such but are instead assigned according to the mineral beneath the cross-hair. Thus it is possible to avoid tedious counting of different coarse, medium, and fine sand-size fractions (Zuffa, b, in press). An average

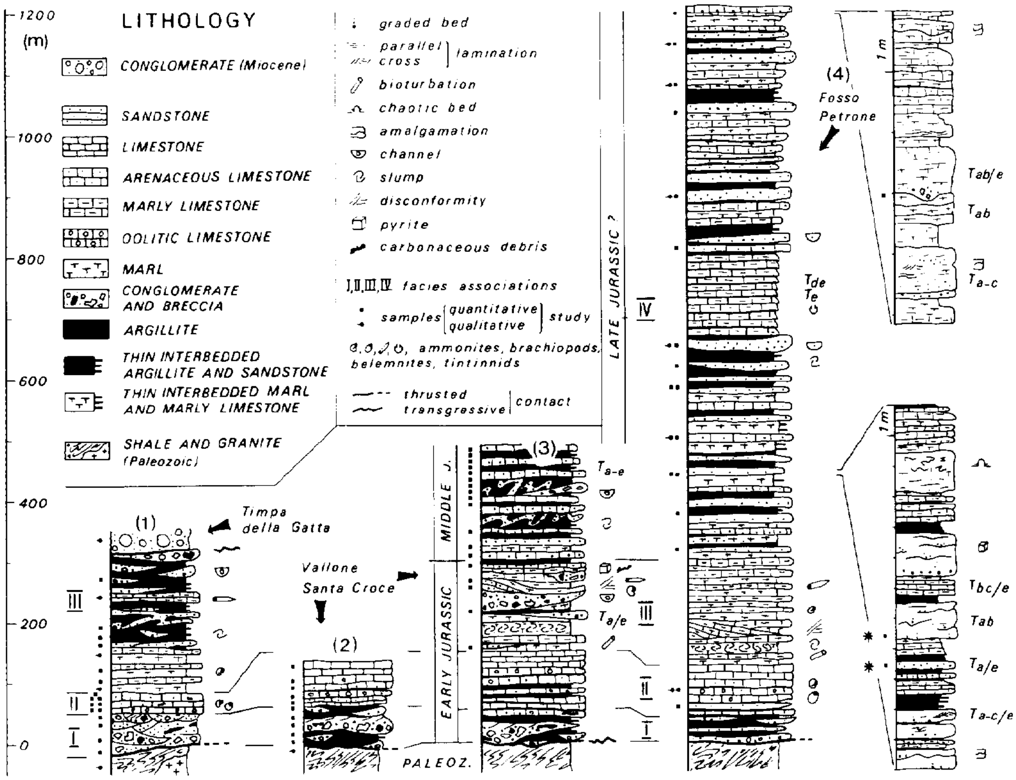


FIG. 2.—Measured stratigraphic sections and sedimentary facies of the Longobucco Sequence. Tabcde: Bouma sequence. Asterisks, in the detailed section (lower right) mark strata that have different sedimentary facies (Ta/e and Tab) and composition (litharenitic and quartzarenitic).

of 500 counts were made by all three authors on nonstained thin sections.

## STRATIGRAPHY

The Longobucco Sequence may be subdivided into four facies associations using models of Mutti and Ricci Lucchi (1972) and Ricci Lucchi (1978). Age, thickness, lithologic and sedimentologic characteristics for each facies association are summarized in Table 1 and Figure 2. These facies associations show a complete evolution from continental into turbidite depositional systems.

Continental deposits (Table 1, association I) are lithologically very similar to the "Verrucano" deposits of the Tuscany region (Tongiorgi et al., 1977). Shelf and slope deposits (associations II and III), recognized by Sturani (1968), may be directly correlated with the time-equivalent deposits of "Longi Unit" (Lentini and Vezzani, 1975) in western Sicily. Fewer correlations are possible between turbidite deposits (association IV) and other, possibly coeval, series cropping-out in the Apennines. Since the turbidite association appears to be continuous, the suggested Valanginian age (Lanzafame and Tortorici, in press) for a poorly preserved Calpionellid fauna in the middle part of the turbidite association (Fig. 2, section 4), implies that sedimentation continued throughout the Early Cretaceous. The 900-m-thick turbidite association consists mainly of siliciclast-rich limestone, minor sandstone and hemipelagite. Intrabasinal, mostly micritic, skeletal and oolitic shelf carbonate particles represent the main sediment supply. The sedimentation rate may have been very low, if one considers the sparse, mainly intrabasinal, particle delivery for carbonate turbidites, the interbedded hemipelagic deposits and the general tectonic

TABLE 1.—*Main sedimentary facies associations recognized in the Longobucco Sequence; facies after Mutti and Ricci Lucchi (1972) and Ricci Lucchi (1978)*

| Age | Thickness (m) | | Facies Associations |
|---|---|---|---|
| Middle to Late Jurassic, through Early Cretaceous (Tortorici and Lanzafame, in press) | 900 | IV | DEEP-SEA FAN<br>*Turbidites and hemipelagites.* Carbonate turbidites (limestone, marly limestone, marl and arenaceous limestone) interbedded with minor noncarbonate turbidites (calcareous sandstone, sandstone and conglomerate) and clayey-marly hemipelagites.<br>Positive and negative sequences (the latter prevail in the upper part of the stratigraphic column); channelized bodies (phyllite pebbles in the lower part, granitic pebbles in the middle part of the stratigraphic column), slumpings (mostly in the Vallone S. Croce section); few bedforms.<br>Facies B, C and minor A. Interbedded carbonate turbidite of facies D and hemipelagites.<br>Calpionellid fauna in the middle part of the sequence. |
| Latest Early Jurassic (Sturani, 1968) | 100–230 | III | OUTER SHELF-SLOPE<br>*Marls and marly limestone.* Thin to medium-bedded (.1–.5 m), characteristic ochraceous coats, frequent disconformities and slumpings, significative amounts of interbedded lenticular coarse-grained sandstone (Ta/e Bouma Sequence) and some channelized conglomerates and breccias (phyllite pebbles). Carbonaceous organic debris and pyrite are common.<br>Facies G and minor A, E and F. In the upper part of the section 1 (Timpa della Gatta) siliciclast-turbidite of facies A and B are largely represented.<br>Ammonites and Belemnites. |
| | 35–95 | II | LITTORAL AND SHELF<br>*Gray limestone.* Pseudo and/or microspar limestone, distinct bedding (.1–1.0 m), some siliciclast-rich strata. Dominant facies in the upper part of the facies association.<br>*Oolitic limestone.* Oolitic bars (.2–2.0 m), fauna-rich probable storm layers (brachipods, ammonites, bryozoans, echinoids, etc., and coarse-sized siliciclasts), interbedded thin, gray pelites or light-color arenaceous and conglomerate lenticular strata.<br>Carbonaceous organic debris. |
| Early Jurassic (Hettangian) (Dubois, 1976) | 5–70 | I | TRANSITIONAL AND FLUVIAL<br>*Conglomerate, sandstone, siltstone and claystone.* Red-violet in the lower part, white-gray in the upper part of the association. Channel-fill, crevasse-splay, overbank deposits, flood plain soils, carbonaceous organic debris.<br>Lagoon deposits probably represent the transition to the upper marine association.<br>The deposits transgressively overlie Paleozoic low-rank metamorphic rocks (best contact: Vallone S. Croce, section 3). |

regime which existed during the time of deposition in the Tethys area. Thus, an age extension of the turbidite association through the Early Cretaceous is not in conflict with the sedimentological and petrographic data here obtained.

## PETROFACIES

### *Gross Composition*

The noncarbonate framework modes of 56 samples are plotted in Figure 3. Representative compositional points fall within well-defined small fields but they are not correlative with the four distinguishing facies associations. This implies the existence of different co-existing sources of supply within the same depositional system.

Taking into account seven integrated, compositional and textural parameters, four main petrofacies (term of Dickinson and Rich, 1972) were distinguished (Table 2, A, B, C, D). These distinctions can be achieved only by using the maturity index ($MI = 100 \cdot Q/Q + F + L$) versus the provenance index ($PI = 100 \cdot F/F + L$) as shown in Figure 4. Better characterized groups can be obtained by considering other parameters that are less sensitive to, but always coherent with the first separation (Table 2).

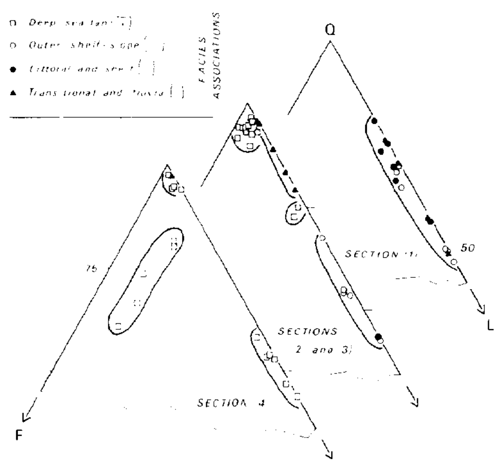


FIG. 3.—Composition of detrital modes. Q: quartz; F: feldspars; L: fine-grained lithic fragments.

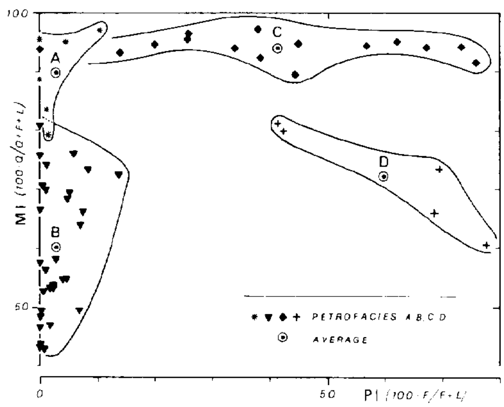


FIG. 4.—Petrofacies discrimination by maturity and provenance indices (MI and PI).

*Petrofacies A*.—Mostly quartzarenites, with argillite, shale and metarhyolite rock fragments; the groundmass of metarhyolites is generally silicified to a chert textural pattern, but euhedral-embayed quartz phenocrysts indicate their volcanic origin. Thin Fe-oxide films outline original grain margins, which tend to be obscured by quartz overgrowths.

*Petrofacies B*.—Litharenites with a variable maturity index, but very low provenance index (Fig. 4). Argillite and shale are the main rock fragments, but clasts of phyllite and very rare microgranite are also present. Calcite constitutes the most common cement, with fine-grained, deformed lithic fragments forming pseudomatrix (term of Dickinson, 1970).

*Petrofacies C*.—Feldspar-bearing quartzarenites with variable provenance index and small amounts of feldspar (generally K-feldspar). Rock fragments are similar to those of petrofacies B, but petrofacies C contains very rare granitic or possible gneissic rock fragments, which do not occur in conglomerate strata. Cements include quartz, ankerite, minor calcite and dolomite. Interstitial car-

TABLE 2.—*Petrofacies: synoptic table of distinctive parameters. Large case letters, small case letters, and parentheses indicate decreasing relative abundance*

| Petrofacies | Composition MI | Composition PI | Samples | Rock Fragments | Cementing Interstitial Materials | DI | Samples | Quartz I' | Quartz I'' | Samples |
|---|---|---|---|---|---|---|---|---|---|---|
| D | 72 | 60 | 5 | ARGILLITE, SHALE GRANITE | CALCITE | — | 5 | 10 | 55 | 5 |
| C | 94 | 41 | 15 | ARGILLITE, SHALE granite, gneiss | QUARTZ ANKERITE (calcite and/ or dolomite) | 51 | 15 | 3 | 61 | 15 |
| B | 60 | 3 | 30 | ARGILLITE, SHALE phyllite (microgranite) | CALCITE PSEUDOMATRIX | 17 | 26 | 1 | 18 | 28 |
| A | 90 | 3 | 6 | ARGILLITE, SHALE | QUARTZ Fe-OXIDES (pseudomatrix) | — | 5 | 13 | 40 | 6 |

MI(maturity index) = 100 · Q/Q + F + L.
PI(provenance index) = 100 · F/F + L.
DI = 100 · dolomite + ankerite/total carbonate.
$I' = 100 \cdot Q_{nu}/Q_{nu} + Q_u + Q_{px}$.
$I'' = 100 \cdot Q_u/Q_u + Q_{px}$.
Q = quartz; F = feldspars; L = fine-grained rock fragments (single crystals > 5φ).
$Q_{nu}$ = nonundulatory quartz; $Q_u$ = undulatory quartz; $Q_{px}$ = polycrystalline quartz.

bonate distribution is patchy. Euhedral ankerite rhombohedrons, which preceeded quartz overgrowths, are commonly present. Fe-oxide films on detrital grain surfaces are uncommon.

*Petrofacies D.*—Subarkoses (classification of McBride, 1963) with variable maturity and provenance indices (Fig. 4). Fine-grained rock fragments are similar to those of other petrofacies but coarse-grained rock fragments include significant amounts of granite and microgranite. Considerable quantities of intrabasinal shelf carbonate grains (mostly intraclasts, fossils and oolites) are intermixed with the terrigenous framework, and calcite is the only cement.

### *Quartz Type Analysis*

Quartz types (after Basu et al., 1975) also indicate four distinct terrigenous sources (Fig. 5). Identification of source rocks from quartz parameters is less clear; however this technique is important for quartzarenites because rock fragments are scarce or absent. Varying mechanical and chemical stabilities of quartz types (Harrell and Blatt, 1978) as well as strain-recrystallization phenomena (Bailey et al., 1958) modify the original quartz populations during weathering and transportation (Blatt and Christie, 1963).

The large amount of polycrystalline quartz (>3 crystal units per grain) present in petrofacies A and B correlates well with the abundance of low-rank metamorphic rock fragments (see Table 2).

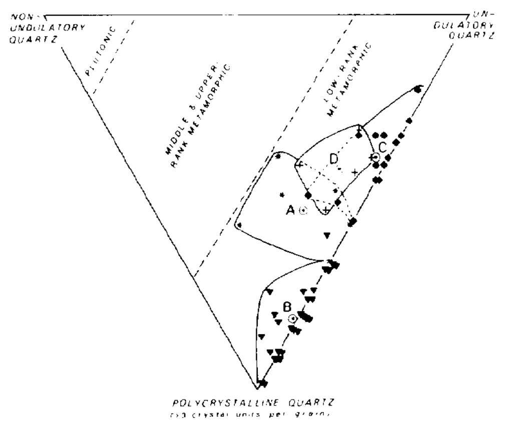


FIG. 5.—Quartz grain populations of sandy detrital modes (quartz types and field distinctions after Basu et al., 1975). A, B, C, and D: petrofacies. For explanation of symbols, see Figure 4.

Quartz from petrofacies C (quartzarenites) plots in the low-rank metamorphic field (Fig. 5), which seems unreliable because (i) plutonic-gneiss rock fragments are present (Table 2), (ii) quartz types plot in areas not covered by the original data of Basu et al. (1975), and (iii) to determine the undulatory or nonundulatory nature of the quartz, monocrystalline quartz grains are estimated only if the birefringence is less than 0.005 whereas polycrystalline grains are always counted. This procedure results in underestimation of monocrystalline quartz types and shifts the provenance indication toward low-rank metamorphic field. In a preliminary note on the Longobucco Sequence, Zuffa (a, in press) proposed an eolian or beach origin for the quartz of petrofacies C because of the high maturity and surface textural characteristics of quartz grain assemblages. The evolution of undulatory/polycrystalline quartz-ratio occurring from petrofacies B to petrofacies C (Table 2, Fig. 5) cannot be ascribed to a different grain size that controls this ratio (Conolly, 1965); in fact, graphic grain-size parameters for samples studied are quite similar (Fig. 6). Therefore, all of the compositional and textural evidence indicate that the supply for petrofacies C was at first both from low to high-rank metamorphic terrain and from plutonic rocks and possibly was later reworked in a high-energy environment.

Petrofacies D can be interpreted as similar to petrofacies C, but with the inclusion of first-cycle plutonic material and with minor

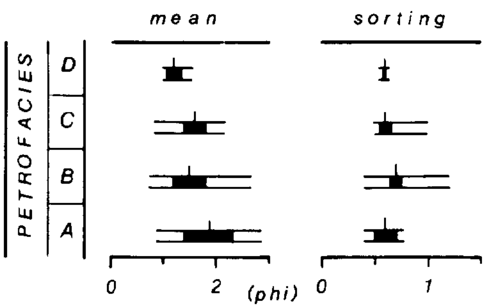


FIG. 6.—Graphic grain-size parameters (Folk, 1974) of the distinguished petrofacies. Vertical light lines: arithmetic mean; horizontal heavy bars: standard deviation; horizontal empty bars: range of values.

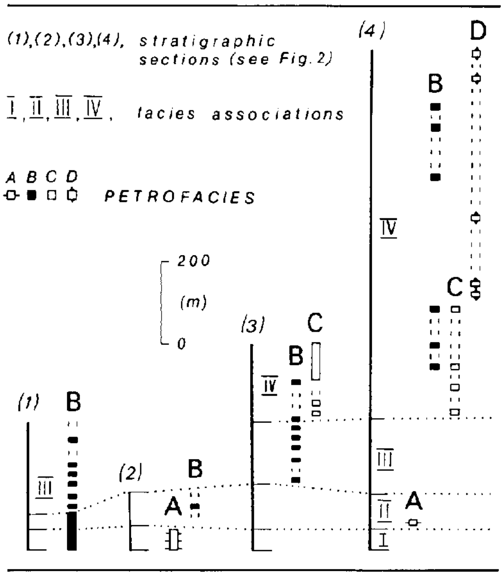

FIG. 7.—Sketch showing relation between petrofacies and petrological intervals in the stratigraphic sections. Symbols for the various petrofacies are shown at the stratigraphic level of the sample. Dashed lines indicate the probable petrological intervals.

environmental control of maturity.

The method of quartz analysis used for source rock identification seems equivocal for mature arenites and multiple-source provenances as indicated by Basu et al. (1975). Where the provenance is first-cycle, monogenic, and fine-grained source (volcanic, low-rank metamorphic rocks, etc.) quartz analysis seems unnecessary because of the first-level information that rock fragments can furnish. Thus, quartz analysis is best restricted to a first-cycle, monogenic arenites having a coarse-grained source.

*Stratigraphic Evolution of Detrital Modes*

Four main noncarbonate detrital suites succeed one another in stratigraphic order with some lateral overlap (Figs. 7, 8).

Quartzarenites of petrofacies A characterize the lower part of the stratigraphic column. Petrofacies C and D respectively mark the lower and upper part of the deep-sea fan association. The litharenitic source (petrofacies B) persistently contributed terrigenous particles throughout the stratigraphic sequence. In the lower part of the deep-sea fan, terrigenous noncarbonate turbidites with Ta/e Bouma-sequences are from source B (litharenitic) and Tab sequences from C (quartzarenitic). They are separated only by thin, intrabasinal-carbonate Te-turbidites (Fig. 2, samples with asterisk). In the middle of the stratigraphic column, channelized sandy and conglomeratic bodies with granitic pebbles (Fig. 2, section 4) mark a new plutonic source (petrofacies D). Changes in basin geometry may be inferred from a sharp

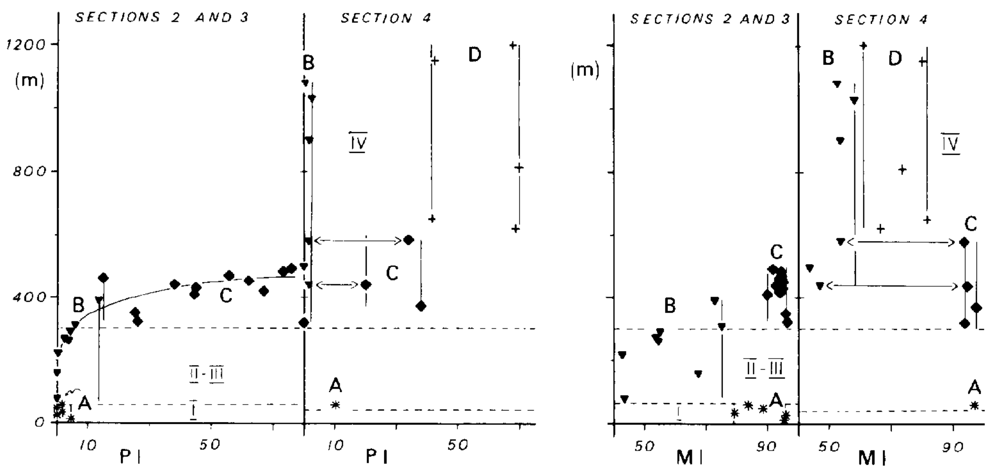

FIG. 8.—Stratigraphic evolution of detrital modes. MI: maturity index; PI: provenance index; A, B, C, D: petrofacies; vertical lines define petrofacies fields; horizontal dashed lines define facies association fields (I, II, III, and IV); arrows indicate samples from vertically adjacent beds belonging to different petrofacies.

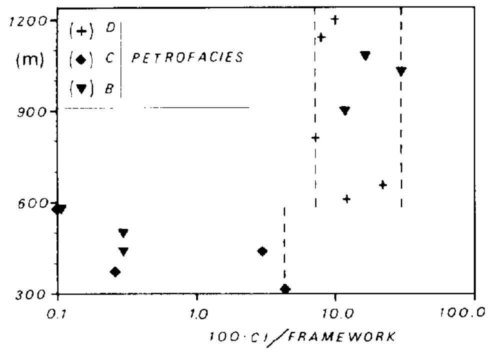


FIG. 9.—Stratigraphic evolution of carbonate intrabasinal grain-content (CI) in sandstone lithotypes of the turbidite facies association (Fig. 2, section 4). Dashed lines define two different fields of carbonate intrabasinal grain-content.

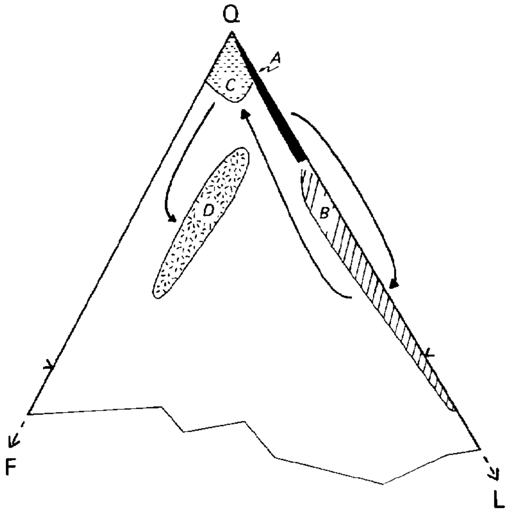


FIG. 10.—Evolution of detrital modes in the Mesozoic Longobucco Sequence. Arrows show the evolution through time of petrofacies from A to D.

increase in the amount of intrabasinal carbonate particles (from 1% to 10%, Fig. 9) mixed with terrigenous noncarbonate materials by turbidite sedimentation. Fossils, intraclasts and terrigenous nuclei-bearing oolites form the intrabasinal carbonate component.

In the deep-sea fan, terrigenous materials from different source areas occasionally reached the basin to yield single turbidite units of distinct composition interbedded with the more common intrabasinal carbonate turbidites and hemipelagites.

## PALEOGEOGRAPHIC AND PALEOTECTONIC EVOLUTION

Framework modes of Longobucco Sequence arenites were derived from five main sources, four noncarbonate extrabasinal sources (Fig. 10) and one carbonate intrabasinal: 1) reworked arenites (quartzarenites); 2) low-rank metamorphic rocks (litharenites); 3) eolian or beach arenites (feldspathic-quartzarenites); 4) granite and high-grade metamorphic rocks (arkoses), and 5) intrabasinal shelf sediments (peloids, intraclasts, fossils and oolites). Recognized terrigenous sources present good lithological analogies in respect to the Paleozoic basement which underlies the transgressive Mesozoic sedimentary sequence (see Fig. 1). Therefore, a paleogeographic reconstruction of the extrabasinal sources may consider only different sediment supplies from more or less dissected zones of the basement overlain by old highly-reworked sedimentary covers.

The Early Jurassic transgression records the Tethys rifting. As areas of the continental block began to sink because of block faulting, fluvial quartzarenite deposits graded upward into shallow-marine deposits, and the first-cycle detrital particles derived from dissected low-rank metamorphic sources were mixed with the former multicycle arenaceous materials. Basin sinking continued through the Liassic with deposition of carbonate shelf and marly outer shelf-slope deposits. This dominantly carbonate sequence contains both interbedded and scattered grains of litharenitic debris indicating a progressive increase of first-cycle material and a decrease in the amount of multicycle debris.

Near the Lias-Dogger time boundary, mostly carbonate intrabasinal turbidites formed a deep-sea fan, which, as it became active, also received a new terrigenous material of feldspathic-quartzarenitic character probably originating from eolian or beach deposits. Three different kinds of materials contributed to this new depositional system: litharenitic, feldspathic-quartzarenitic and intrabasinal-shelf-carbonate particles.

Stratigraphically higher in the section the deposition of the feldspathic-quartzarenite ceased and a new source area began to supply arkosic detritus. Concurrently, sandy-conglomerate channelized bodies of terrigenous turbidites containing significant amounts of intrabasinal carbonate particles were deposited.

The "quartzarenitic" and "feldspathic-quartzarenitic" detrital modes (Fig. 10) are consistent with a passive continental margin provenance (Crook, 1974; Schwab, 1975). The "arkosic" supply suggests an uplifted basement provenance (Dickinson and Suczek, in press) however the "litharenites" are not considered as typical of a continental rifted margin provenance. Thus data from Mesozoic arenites of southern Italy introduces complications in the use of detrital framework modes of sandstone suites as unequivocal indicators of plate tectonic setting.

Sedimentological and compositional data suggest two main Jurassic tectonic events during Longobucco Sequence deposition. The first event near the Lias-Dogger time boundary (Zuffa, a, in press) coincides with the development of a deep-sea fan and the appearance of a new terrigenous source area. The second and perhaps more important event of probable Late Jurassic age, is indicated by 1) the elimination of the previously activated source, and 2) the initiation of an arkosic supply accompanied by the development of sandy-conglomerate channelized bodies. The timing of these two tectonic events generally correlates with the compressive and extensional events in the Middle and Late Jurassic (as suggested by Folk, Folk and McBride, 1978), a conclusion previously reached on the basis of paleogeographic and tectonic considerations by Abbate et al. (1972).

Although paleogeographic configuration of the Mediterranean area during the Middle and Late Jurassic is uncertain (Bernoulli and Jenkyns, 1972), the model of a complex interplay of small microcontinents and oceans (Hsu, 1971; Smith, 1971; Alvarez et al., 1974) which caused local compressive and extensional tectonic regimes within the general framework of Tethys rifting, is consistent with the data obtained from this study.

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