ORIGIN OF MEGAPHYTOCLAST CONCENTRATIONS IN COARSE-GRAINED TURBIDITES, CRETACEOUS OF NORTHERN CALIFORNIA

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ABSTRACT

Coarse-grained, medium- to thick-bedded turbidites in the Franciscan Complex contain carbonized plant debris concentrated in the upper parts of some of the beds. These concentrations typically occur at the top of a thick, graded to massive sand subdivision, and may be covered by a thin, parallel-laminated silt or silty sand subdivision. Plant fragments are usually angular, vary greatly in size and shape, and do not display obvious signs of current orientation. The largest fragments (≥ 1 cm in longest dimension) are here termed *megaphytoclasts*. Accumulations of plant debris in sandy turbidites suggest a complex interaction of water currents with heterogeneous sediment loads in high-concentration turbidity currents.

Phytoclast lamina probably are formed by *hydrofoil stripping*, in which plant fragments are wafted out of sediment gravity flows by currents moving forward and upward through the head regions of the flows, followed immediately by settling of the fragments directly onto newly deposited carpets of turbidite sand. Phytoclast concentrations formed in this way may be buried by fine-grained sediment in the last stage of turbidite emplacement, or plant material may accumulate without further clastic deposition resulting in lamina of deepsea terrigenous coal.

INTRODUCTION

Land-derived plant debris is a familiar component of modern and ancient turbidites (Bouma, 1962; Bouma and Brower, 1964; Griggs *et al.*, 1969; Bostnick, 1974; Bourgeois, 1980; Nilsen, 1984; Nelson and Nilsen, 1984; Bouma *et al.*, 1985; Miller, 1989; Einsele, 1991). In most instances, presence of plant material has been mentioned in descriptions of stratigraphic sections without any further explanation. In a few cases phytoclasts (transported plant material of varied size, shape, and origin) occurring in turbidite sandstone have been used to estimate thermal metamorphic grade (Bostnick, 1974) or to infer paleocurrent direction (Marschalko, 1964). Processes responsible for accumulation of phytoclasts in deepsea depositional environments, however, have never been documented.

Plant fragments also are well known from studies of the modern deep seafloor (see review of early literature in Knudsen, 1961, and Uchupi and Jones, 1967). The significance of plant debris is usually evaluated in ecologic terms: as food resources, special substrata, or as an aspect of disturbance regime (Menzies *et al.*, 1967; Menzies and Rowe, 1969; Keller *et al.*, 1973; Wiebe *et al.*, 1976; Hinga *et al.*, 1979; Rowe and Staresinic; 1979; Wolff, 1976, 1979; Carey, 1981; Stockton and DeLaca, 1982; Grassle and Morse-Porteous, 1987; Alongi, 1990; Gage and Tyler, 1991; Young and Eckelbarger, 1994). Because of the episodic nature of transport and deposition of coarse-grained material in the deep sea, delivery of land-derived plant debris is largely pulsed and linked to events on islands and continents that vary greatly in terms of recurrence interval. Depositional pulses that deliver phytoclasts to off-shelf settings vary from yearly floods at fluvial sources to debris flows originating at the shelf edge, on the slope apron, or within submarine canyons at intervals of $10\text{-}10^3$ yr. In general, the result of such processes is the spatially and temporally discontinuous accumulation of plant fragments. Ultimate sources of large, woody material are forested, emergent landscapes (Gage and Tyler, 1991).

Large plant fragments are mentioned in systematic surveys of components of the deepsea benthos requiring woody substrata (*e.g.*, Knudsen, 1961; Turner, 1973). These large land-derived fragments (referred to here as *megaphytoclasts*, or phytoclasts ≥1 cm in longest dimension) have not been described in studies of ancient deepsea sediments or fossils, so far as I can judge from a review of the literature. Yet the delivery of megaphytoclasts to the deep sea must have been an ongoing process at least since the appearance of forests containing large tracheophytes in the Pennsylvanian Period.

In this paper I describe the occurrence of megaphytoclasts in Cretaceous turbidites of the Franciscan Complex in northern coastal California. I will document the sedimentologic contexts of phytoclast concentrations in general, describe a particularly interesting occurrence of unusually large plant fragments, and propose a model to account for megaphytoclast accumulations in sandy turbidites.

STUDY SITES

Coarse-grained, medium- to thick-bedded turbidites were examined during the interval 1984-1988, as part of a larger effort to locate fossil assemblages of all types in different kinds of submarine fan facies of the Franciscan Complex. Three of the sites investigated at that time featured conspicuous phytoclast accumulations, and these localities provided the incentive and material for this study (Fig. 1)

The most carefully studied site (locality 1, Fig. 1) is the seacliff exposure of facies B and C turbidites (traditional facies classification of Mutti and Ricci Lucchi, 1978) at the southern end of Indian Beach, approximately 300 to 400 meters southeast of the village of Trinidad (Trinidad 7.5' quadrangle). At this locality, large bedding-plane exposures could be examined because in some parts of the outcrop beds dip at nearly 90° and strike more or less parallel to the cliffline. This locality is within the Central Melange terrane, as is a second, more remote site (locality 2, Fig. 1) 100 to 200 meters south of the mouth of McNeil Creek (Trinidad 7.5' quadrangle). This also is a seacliff exposure, but consists mostly of facies B deposits. The McNeil Creek site is remarkable because of the occurrence of soft-coal laminae at the tops of a few of the thick-bedded turbidites in lieu of the typical pelitic layers. The third site (locality 3, Fig. 1) is within the Yolla Bolly terrane at Point Saint George (Crescent City 7.5' quadrangle), and comprises a quarried cliffline and headland extending from 250 meters west to 450 meters south of the old Coast Guard Station. Facies A and B turbidites occur in these exposures. All turbidite beds examined were Cretaceous in age.

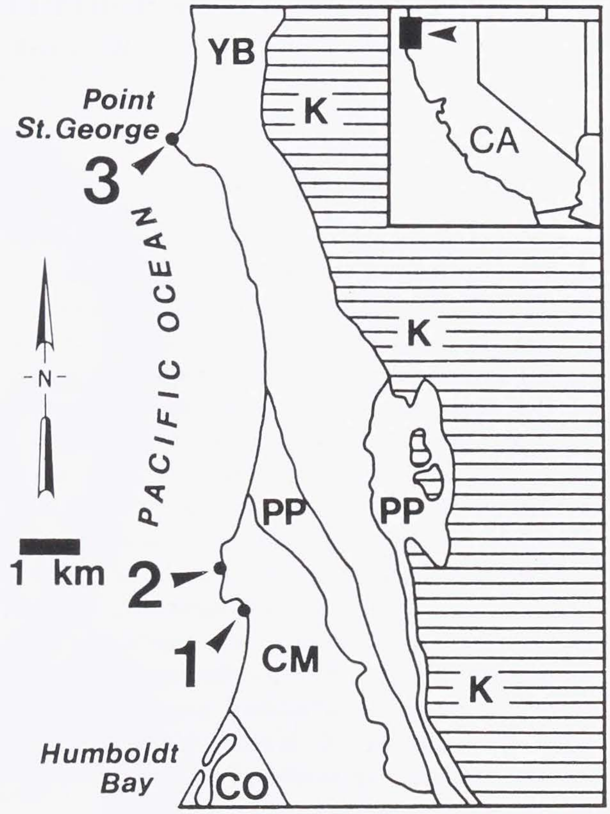

Figure 1. Location of study sites. Tectono-stratigraphic terranes include: *K*, Klamath Province undifferentiated; *PP*, Pickett Peak; *YB*, Yolla Bolly; *CM*, Central Melange; *CO*, Coastal. All but the first are within the Franciscan Complex. (After Aalto, 1989.) Sites are described in the text.

Structure and stratigraphy of Franciscan rocks in the vicinity of localities 1 and 2 have been described by Aalto (1976); the Franciscan geology at locality 3 has been documented by Aalto and Murphy (1984). Terrane terminology and sequence ages are reviewed in Aalto (1989) and Miller (1991, 1993), respectively.

STRATAL PATTERNS

At the three study sites, phytoclast accumulations are restricted to the upper portions or tops of sandy turbidites. This recurrent pattern is a conspicuous feature at outcrops because the turbidite beds fracture readily parallel to bedding at the level of plant debris, revealing surfaces covered with dark-colored, carbonized fragments of varied size and shape (Fig. 2). Where bedding is perpendicular to the out-

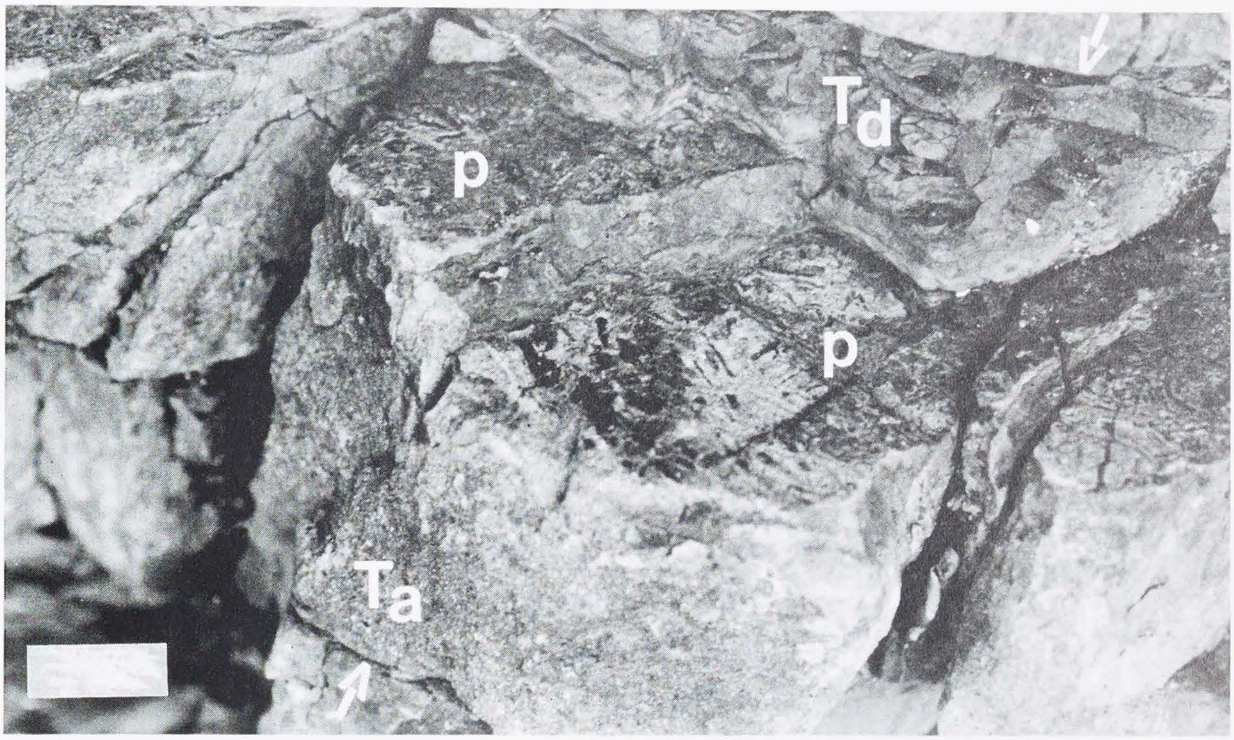

Figure 2. Typical phytoclast concentration (*p*) in Facies C turbidite bed at Indian Beach (locality 1, Fig. 1). Top and bottom of bed are indicated with arrows. Plant debris is concentrated at boundary between Bouma a and d subdivisions. Scale represents 5 cm.

crop surface, a thin, discontinuous black streak (weathering yellowish gray to light brown) denotes the phytoclast layer (Fig. 3a). Plant debris mostly consists of angular, mm- to cm-sized fragments showing no obvious preferred orientation (Fig. 3b), but larger phytoclasts and rounded fragments also were observed (Fig. 3c and e). By comparison, thin sections of sand subdivisions of turbidites from the Central Melange and Yolla Bolly terranes contain microscopic plant material distributed with mineral grains; and there is evidence from trace fossils produced by the benthos, which colonized newly-deposited turbidite sands, that these smaller particles were exploited as food (Miller, 1991). Patterns noted at the three study sites are described in more detail below.

Locality 1. – Facies C turbidites at Indian Beach (Fig. 1) feature a thick, lower, usually normally-graded subdivision overlain by one or more parallel-laminated silt or silty-sand subdivisions. In all beds containing phytoclast layers, the plant debris was concentrated between these two stratal divisions; or in the case of repeated silty units, at the base of each silty subdivision (Figs. 2, 3a, 4c and d). The pattern is indicative of some form of sorting and concentration of plant debris.

The largest megaphytoclasts were found at Indian Beach, apparently concentrated at tops of facies B deposits. The largest fragment observed was a rectangular piece, measuring approximately 23 x 22 cm, which appears to be a trunk or limb fragment displaying subparallel lineation that could be remnant fibrous tissue (Fig. 3c). Stem-like fragments up to 20 cm in length are more typical (Fig. 3e). The megaphytoclasts occur in layers consisting mostly of smaller debris.

Locality 2. – Most of the deposits at McNeil Creek (Fig. 1) are thick-bedded facies B turbidites. The same general stratal patterns were seen here, with the notable exception of coaly layers located at tops of some of the beds (Fig. 3f, 4b). Coal laminae are only a few mm thick and form flat lenses. The laminae apparently represent concentrations of plant debris to the exclusion of mineral clasts following emplacement of coarse, thick turbidite

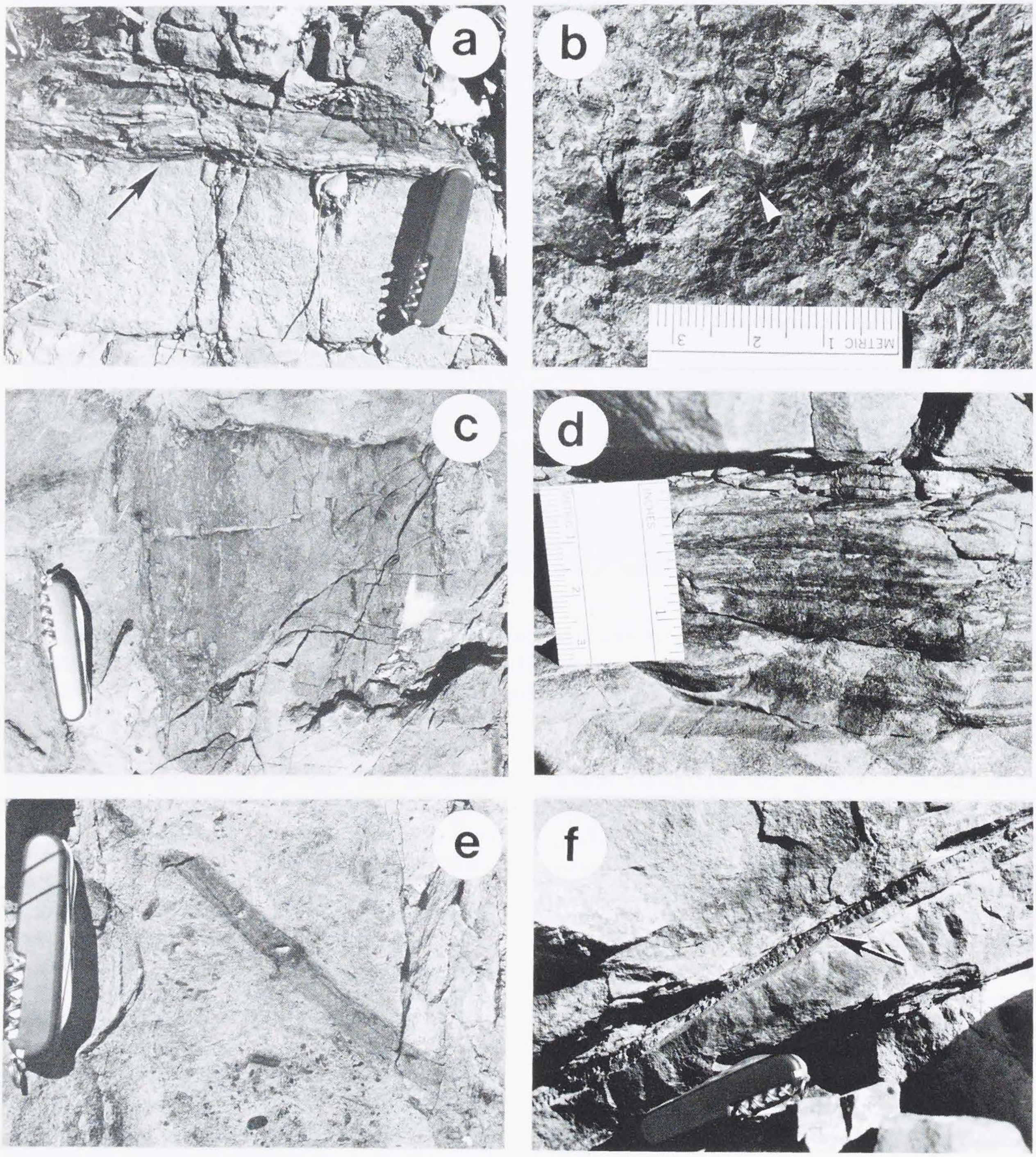

Figure 3. Examples of phytoclast concentrations: *a*, plant debris layer (arrow) at boundary between Bouma a and d subdivisions, Indian Beach near Trinidad (locality 1, Fig. 1); *b*, fracture surface covered with carbonized plant fragments, Indian Beach; *c*, large rectangular phytoclast, Indian Beach; *d*, repeated phytolast laminae at the top of thick sand subdivision, Point Saint George (locality 3); *e*, stem-like megaphytoclast, Indian Beach; *f*, soft coal lamina (arrow), near McNeil Creek (locality 2). Knife in a, c, e and f is 9 cm long.

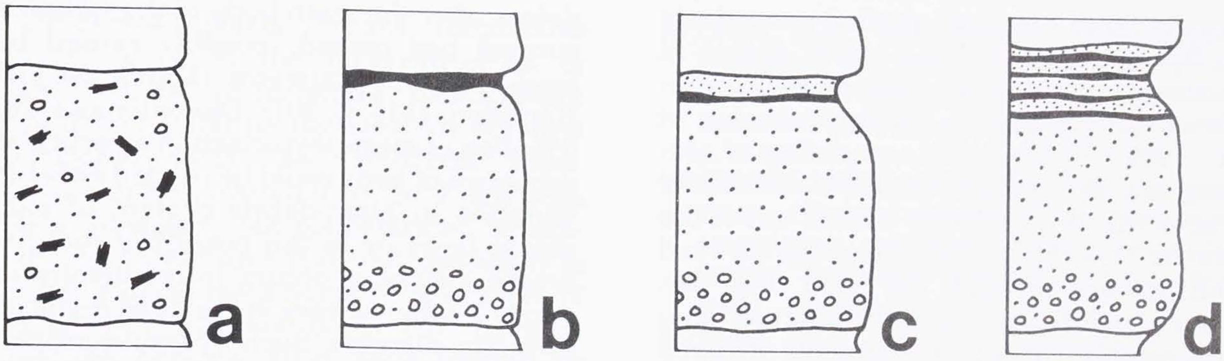

Figure 4. Occurrence of phytoclasts in Franciscan turbidites: *a*, distributed throughout bed (typically as microscopic particles); *b*, coaly lamina at top of thick, coarse-grained subdivision; *c*, concentration between coarse sand and silty subdivisions near top of bed; *d*, multiple concentrations near top of bed. Not drawn to scale.

sand layers. To my knowledge, this is the first record of *deepsea terrigenous coal*.

Locality 3. – Because the seacliffs and headlands at Point Saint George (Fig. 1) were quarried to repair the harbor at Crescent City following the 1964 tsunamis, good exposures of facies A and B turbidites can be seen at this site. Phytoclasts occur as scattered dark grains in a few of the conglomeratic facies A beds (Fig. 4a). Where plant debris occurs in the facies B deposits, it is usually concentrated at bases of repeated sandy laminae/thin beds located at tops of the thick massive to graded sandstones (Fig. 3d). This material consists of mm-sized plant fragments. Megaphytoclasts were uncommon in these beds. Size differences in plant debris between otherwise similar turbidite beds, as between here and Indian Beach, could have more to do with the characteristics of supply of plant fragments than with hydraulic processes at ths site of deposition.

ORIGIN OF PLANT DEBRIS CONCENTRATIONS IN FRANCISCAN TURBIDITES

An explanation for the origin of megaphytoclast or coaly layers in sandy turbidites must account for the following patterns:

1) Concentrations occur in facies B and C turbidites.

2) Coarse plant debris is concentrated in one or more laminae/thin beds at tops of graded to massive sand divisions of the turbidite beds.

3) Only microscopic plant material occurs *within* the thick sand divisions.

4) In facies B and C, large plant fragments tend to be concentrated at the boundary between Bouma a and d subdivisions.

5) Within the phytoclast concentrations, size sorting is poor, and the plant fragments are mostly angular and range from mm-sized to 10's-of-cm's in longest dimension.

6) Plant fragments have varied shapes and typically are not current oriented.

Most turbidite sandstones represent essentially single surges of turbulent flow originating from single point-sources or source zones on adjacent slopes or within submarine canyons (Middleton and Hampton, 1976; Nelson and Nilsen, 1984; Einsele, 1991). Merely invoking differential settling velocities to explain sorting and concentration of large phytoclasts is too simplistic. It fails to consider interaction of hydraulic processes of high-concentration turbidity currents with the complex mixture of sediments carried in the flow, including plant material of varied size and shape. Concentration must involve removal of the plant material from the turbidity current before deposition of the heaviest mineral grains. Such plant debris layers mark a level of change in the local hydraulic environment as the turbidity current passes over a patch of seafloor.

I propose that the megaphytoclast layers result from *hydrofoil stripping* of plant material in the turbulent head region of turbidity currents. Behavior of subaqueous gravity flows has been studied extensively in flume models and to a lesser degree in modern environments (reviewed in Middleton and Hampton, 1976; Pickering *et al.*, 1989). Plant debris, consisting of rectangular, disc-shaped and flat cylindrical fragments, are probably wafted out of the gravity flow by currents moving forward and upward through the head (Fig. 5a). After rapid deposition of the coarsest mineral component, plant fragments stripped from the turbidity current fall immediately from turbulent suspension onto the newly deposited sand blanket (Fig. 5b), followed by accumulation of fine-grained mineral clasts either deposited from suspension or entrained by the remnant boundary currents (Fig. 5c). Separation of grains, then, represents an internal sorting process that depends on: 1) physical properties of plant fragments (*i.e.*, shape and possibly size) that permit wafting; 2) the pattern of water currents within the head and neck areas of flows; and 3) the fact that sediment within the flow initially was a heterogeneous mixture of sand (and possibly granules), mud and plant debris.

The basic stratal pattern resulting from hydrofoil stripping is shown in Figure 4c. Variations include the coal laminae seen at McNeil Creek, which seem to result from the same process in the absence of fine-grained mineral clasts capping the bed (Fig. 4b). Cyclic phytoclast layers at tops of turbidites (Fig. 4d) could represent repeated resuspension and settling of plant debris after the main body of the turbidity current has passed, possibly caused by boundary layer currents (Middleton and Hampton, 1976, p. 201). Discontinuous distribution of megaphytoclasts in a particular sequence of beds could be related either to variation in plant-debris content of individual flows or to the possibility that hydrofoil stripping occurs intermittently as current patterns vary in the head region of turbidity currents. Such hydraulic properties are expected to change with varying sediment concentration and slope of the seafloor, that is with density and velocity.

SIGNIFICANCE

The obvious point to make here is that megaphytoclast concentrations indicate the complexity of water current-sediment particle interactions within turbidity currents. The process of hydrofoil stripping, as it seems to be reflected in the Franciscan turbidite sandstones, only operates in relatively high-density turbidity flows containing plant fragments together with abundant sand and mud. The plant debris can be concentrated only when currents circulating through the head of the flow are able to strip out this material, which is permitted by physical properties of the plant fragments such as shape. These ideas need to be tested in flume experiments.

From a paleontologic perspective, there are two important implications that deserve further study. First, if identifiable

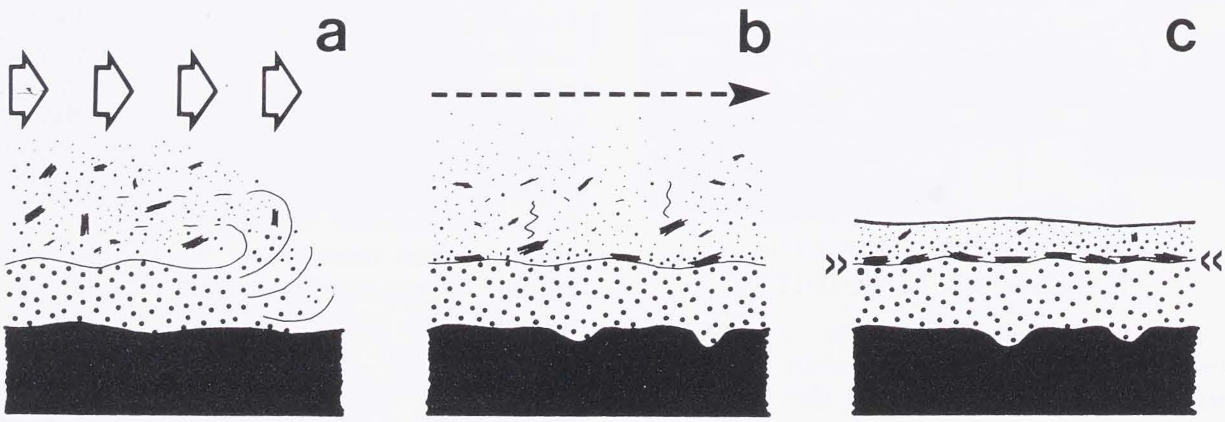

Figure 5. Concentration of megaphytoclasts by means of *hydrofoil stripping: a,* separation of plant debris by currents circulating through head region of turbidity current; *b,* immediate fall out from suspension onto surface of newly deposited turbidite sand; *c,* burial of plant debris beneath silt/silty sand from suspension or entrained in boundary current, completing deposition of the turbidite bed.

land-derived plants (organs, identifiable tissue) occur in the megaphytoclast or coaly laminae of turbidites, paleoclimatic conditions could be deduced for adjacent terrestrial areas. No identifiable specimens were recovered from the Franciscan beds, however, but concentrated searching might yield such material (especially in areas where metamorphic alteration of sandstones has not occurred). Second, deepsea benthos must have utilized or manipulated the windfall of organic material, even though rapid burial presumably would have prevented exploitation by epibenthos such as wood-boring clams. Megaphytoclast concentrations in Franciscan turbidites appear to be undisturbed by burrowers. Perhaps such layers are difficult to penetrate by endobenthic animals, or plant material was too coarse to digest even if laced with labile bacteria and fungi (Wolff, 1979; Gage and Tyler, 1991). Here again, concentrated prospecting might produce evidence of plant debris utilization by burrowing organisms that colonized newly deposited turbidite sand blankets.

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