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Molasse Facies: Records of Worldwide Crustal Stresses

Abstract. *Predominantly nonmarine molasse deposits in the Tethyan and Cordilleran mobile belts record major variations in orogenic activity in latest Cretaceous to earliest Cenozoic, mid-Cenozoic, and latest Cenozoic time. During the same intervals changes in activity also occurred on the sea floor. This coincidence suggests worldwide effects of movement of crustal plates.*

Current speculation about crustal-plate tectonics (Fig. 1) suggests that the major variations in linear magnetic patterns and in sequences of sediments on the sea floor may record periodic readjustment of movement of the plates (*1*). It is useful to inquire whether these variations correlate with marked changes in sedimentary sequences in mountain systems. Significantly, such sediments preserve abundant evidence of variations in activity.

The focus of this report is on sedimentary products of orogeny in some of those mountains deformed in the last 70 million years (Fig. 2), for that is the span of the most reliable information about the sea floor now available. The examples selected (Fig. 1) lie in the Cordilleran (*2*) and the Tethyan (*3, 4*) mobile belts.

These orogenic deposits are called molasse. As in its type area on the Swiss Plain (*3*), the term is applied here to thick, predominantly nonmarine sediments that followed marine geosynclinal deposition and accumulated in troughs (*5*) which encroached on stable cratons during completion of major deformation. Commonly, aggradation began in coastal lowlands, then alluvial plain and piedmont environments prevailed during most of the molasse phase.

Molasse began to accumulate along the continental side of the Cordilleran orogenic axes during the latest Cretaceous to earliest Cenozoic times. Uplifted crustal blocks and folded strata within the troughs and on adjacent cratons contributed considerable detritus, especially in the central Rocky Mountains where volcanism was widespread. In the Tethyan belt the marine geosynclinal phase continued.

Major deformation and the molasse phase ended in the central Rocky Mountains during the mid-Cenozoic, but volcanism persisted and thin nonmarine deposits spread across the craton. Molasse sedimentation also waned in the Colombian Andes. In the northern Alps molasse began to accumulate on the continental side of the range. In the Himalayas a molasse trough developed on the oceanic side of the mountains where it lay on the Indian continental block.

Volcanism and spread of the thin plains-mantle continued in the central Rocky Mountain region in the late Cenozoic. In the Colombian Andes renewed influx of molasse was accompanied by volcanism along the central axis. Thick molasse also accumulated in the Tethyan troughs, with only minor volcanism in the northern Alpine area.

During Pliocene and Pleistocene times deformation and regional uplift affected each of the molasse sequences as well as their source areas. In the central Rocky Mountain region, rift systems and wrench faults fragmented the orogenic axis, perhaps as a result of extension of the continental crust above the east flank of the overridden East Pacific Rise (*6*). The Colombian Andes were broken by high-angle displacements, both vertical and lateral, as volcanism reached its climax. In the Tethyan belt nappes were thrust over molasse bordering the mountain fronts.

Do these molasse records correlate with variations in activity found in the deep sea? Apparently there were three such episodes during the last 70 million years (Fig. 3)—in latest Cretaceous to earliest Cenozoic, in mid-Cenozoic, and in early Pliocene times (*7*). According to a sea-floor spreading hypothesis these intervals mark times of change in rate and direction of movement of crustal plates (*1*). Opening of the North Atlantic Basin (*8*) apparently was accomplished largely during the Mesozoic era. In the course of spreading during the Cenozoic, the rate diminished markedly in late Oligocene and early Miocene times, and again in the Pliocene epoch (*7, 8*).

Data from the eastern Pacific Basin and the adjacent coast of California suggest that during late Cretaceous and early Cenozoic drift toward the East Pacific Rise a west-facing coastal wedge accumulated along the continental margin (*9*). Then mid-Cenozoic block-faulting, volcanism, and nonmarine basin sedimentation predominated as the leading edge of the continent overran the crest of the rise (*9, 10*). Seaways flooded this setting in late Ceno-

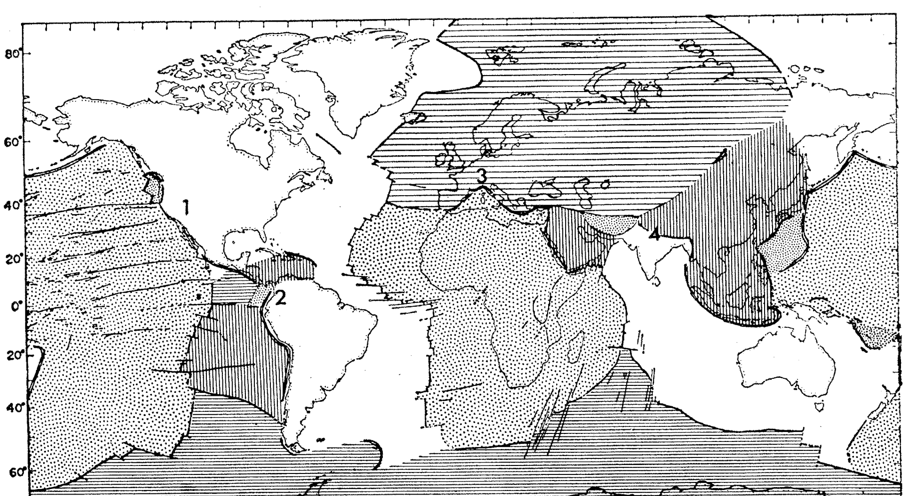

Fig. 1. Aseismic crustal plates outlined by belts of shallow-focus earthquakes (*17*). Cordilleran mobile belt along west side of American plate—1, central Rocky Mountains; 2, Colombian Andes. Tethyan mobile belt along southern margin of Eurasian and Indonesian plates—3, northern Alps; 4, southern Himalayas.

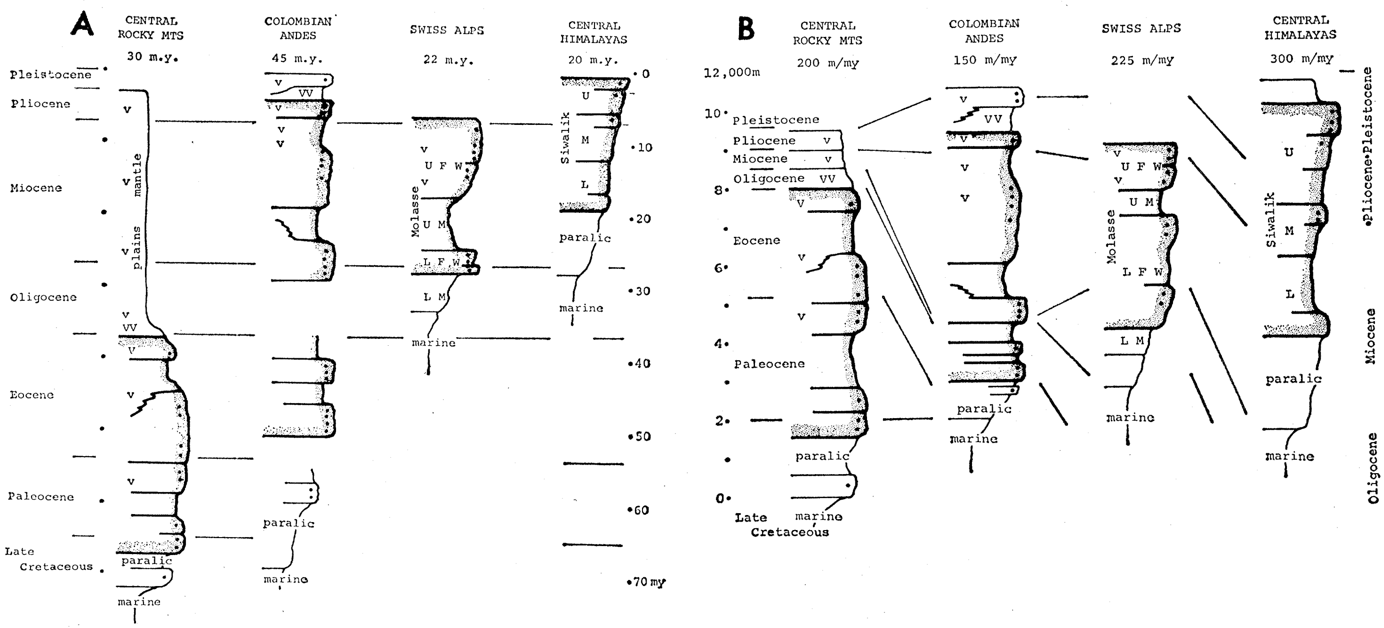

Fig. 2. (A) Stratigraphic sections of selected molasse sequences (shaded) and durations in millions of years. Dots, thick conglomeratic units; *V-v*, major and minor volcanic deposits. *LM* (Lower marine), *LFW* (Lower fresh water), *UM* (Upper marine), and *UFW* (Upper fresh water) Molasse. (B) Thickness of selected molasse sequences (shaded) and subsidence rates in meters per million years. Symbols as in Fig. 2A.

zoic time. During the Pliocene and Pleistocene epochs the West Coast was severely faulted and folded, and associated westward extension produced the Gulf of California Rift (*11*).

South America is believed to have drifted westward in early Cenozoic time as the Bolivar Geosyncline and its western borderland developed along the northwestern continental margin (*12*). The oceanic borderland foundered in mid-Cenozoic time, and somewhat later the trough encroached on the continent. Then, deformation and latest Cenozoic volcanism and uplift destroyed the geosyncline, and the west-trending Galapagos Rise off southwestern Colombia began to produce a linear pattern of magnetic anomalies (*13*).

Records from the Indian Basin suggest that a Gondwana block began its northward drift early in the Cenozoic era (*14*) and collided with an Asian plate (Fig. 1) in mid-Cenozoic time. With continued drift the Indian block was driven under the Asiatic continent, uplifting the Himalayan-Tibetan region (*15*).

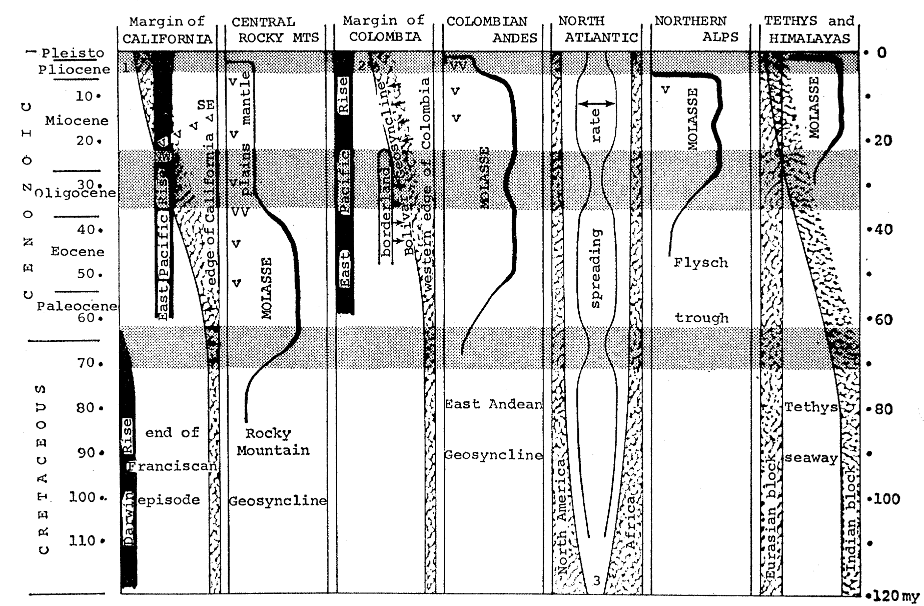

Fig. 3. Correlation of events in ocean basins and selected mountain systems. Three shaded bands mark major discontinuities in activity. Arrow, direction of dispersal of main supply of sediments. *V*, volcanism. 1, Gulf of California Rift; 2, Galapagos Rise; 3, South Atlantic spreading apparently began in mid-Cretaceous time.

This coincidence among changes of activity in mountain belts and on the sea floor during the last 70 million years (Fig. 3) supports, but does not prove, the proposition that readjustment of movement of crustal plates registers worldwide effects. An interpretation of molasse sequences as sedimentary products of crustal-plate movement is presented as a working hypothesis.

Regardless of the fate of the new global tectonics (*16*) the questions raised lead to renewed focus on records of mountain building. And now the basic concern is the sequence of events rather than specific similarity of structural style. Some of the differences among the molasse examples, such as when they began and the rates of subsidence, may be related to differences in the direction and kind of movement between crustal plates, to the nature of the leading edges of colliding plates, and to the role of the associated midoceanic rises and the trenches they generate.

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18 August 1969

Visual Pigment Density in Single Primate Foveal Cones

Abstract. *The feasibility is demonstrated of microspectrophotometric studies on primate photoreceptors aligned at right angles to the test beam, rather than axially illuminated. Pigment densities, and hence absorption per unit thickness, are approximately equal in primate rods and foveal cones. These pigment densities are similar to those reported for frog rods and fish cones.*

Microspectrophotometric studies demonstrated the existence of three visual pigments, isolated in separate cones, in both fish (*1–3*) and primates (*4–6*). These experiments elucidated the physiological basis for the trichromacy of vision and provided direct experimental confirmation of the Young-Helmholtz theory.

In the teleost experiments, teased preparations of receptors lying on their sides were employed, while the small size of primate cones dictated axial illumination to maximize the ratio of signal to noise. In addition to being the physiological orientation, the mosaic arrangement of receptors on end also simplifies differentiation of rods and cones and offers the possibility of studying the topographical relations among receptor types.

However, optical quality of the microscope objectives must be sacrificed to obtain the necessary long working distances. The preparation is also inconvenient both because suitable patches of retina are rarely located near an open area through which the reference beam of our microspectrophotometer can pass and because otherwise suitable receptors are usually observed leaning at an angle to the optical axis of the instrument.

Most serious of all, the intervening neural layers complicate the optical path, and scatter increases with clouding after death. This scatter causes the spectrum to be contaminated by the absorbtion of surrounding rods and is partially offset by the focusing effect of the inner segments of the cone. Estimates of pigment concentration in primate cones were thus complicated by the fact that the intensity of illumination of all points along the receptor outer segment was unknown.

On the other hand, the clearly defined optical geometry of the side-illuminated configuration permitted estimation of the absorption to be about 1.8 percent/μ of thickness (*1, 3*) in both frog rods and fish cones. Liebman's (*2*) absorptions are higher, probably because of less scatter. Calculations indicated that, under optimal conditions, it should also be possible to study primate receptors oriented at right angles to the optical axis. This method appears to be the only one applicable to the study of primate foveal cones since they are about 0.8 μ in diameter and densely packed. It does not appear feasible at this time to confine an axial beam of illumination to a single receptor of this type. However, the extinction of a cone lying on its side is far less than that of the same receptor on end, and the signal is further diluted by any light scattered around the outer segment. Consequently, ratios of signal to noise are critical (*7*), and further refinements were therefore made in the previously reported (*3*) instrument and technique.

Suitable field diaphragms were fabricated by milling slits in soft brass with a "flycutter." These slits were approximately 60 μ wide, and their length was adjusted by masking the ends with black tape. At the specimen plane they are projected at a width of about ⅔ μ (Fig. 1).

The geometric problems of superimposing the image of a slit (rather than a pinhole) on a cylindrical receptor necessitated installation of a "sliding-gliding" stage (Zeiss). This stage permits extremely fine adjustments as well as rotation to examine any receptor, regardless of its original orientation in the field of view.

Because of the orientation of the visual pigment molecules in the lamellae of photoreceptors, polarized light was used on primate cones, as described earlier for goldfish receptors (*1, 3*). The increase in the ratio of signal to noise was substantial and approximated the factor of $2^{\frac{1}{2}}$ predicted on theoretical grounds.

Alignment of the machine is critical. Virtually imperceptible adjustments in the focus of the monochromator filament on the back focal plane of the condenser can change the slope of the base line by a factor of 10.

Other efforts to refine the optical system concentrated on reducing longitudinal and lateral chromatic aberration to a minimum, and tests were run on more than 100 selected objectives (*8*).

Longitudinal chromatic aberration, the change in focal length with wavelength, can be easily observed in the spectrophotometer by scanning through the spectrum and watching the focus of the test and reference beams change. With paired optics for condenser and objective, measurements were made by refocusing at 25-nm intervals and recording adjustments from the fine-focus micrometer.

Lateral chromatic aberration, the change in magnification with wavelength, is manifested by lateral movements of the test beam so that the beam no longer passes through the receptor. This effect was evaluated by measurement of magnification changes on Polaroid photographs taken with different wavelengths and can be as much as 3 μ.

The effects of longitudinal chromatic