DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-1622-B

INTRODUCTION AND STRATIGRAPHIC SETTING

Turbidites are sediments deposited by turbid density currents. The turbidites described here are interpreted as prodelta deposits that formed in front of fan deltas and alluvial fans during the uplift of the ancestral Rocky Mountains in Pennsylvanian time. Laterally extensive, lenticular sand bodies deposited by turbidity flows crop out in the Middle Pennsylvanian Minturn Formation in the northern Sangre de Cristo Range, Custer and Saguache Counties, Colo. (figs. 1, 2). One of the turbidite-bearing intervals, informally designated the "main turbidite member," lies 906 m above the base of the Minturn; it reaches 150 m in thickness and extends more than 13 km along strike. The internal stratigraphy and sedimentary structures of the main turbidite member are described from the measured sections presented here.

The Middle Pennsylvanian Minturn Formation of the Spread Eagle Peak thrust plate (Lindsey, Johnson, and Andriessen, 1983) consists of about 2,000 m of interbedded conglomeratic sandstone, sandstone, siltstone, and lesser amounts of conglomerate, shale, and limestone. The lower 1,500 m of the Minturn is composed mainly of prograding deltaic-alluvial cycles that contain intervals of prodelta turbidites. The upper 500 m of the Minturn consists of deposits of small deltas and braided streams interbedded with shallow marine limestones interpreted as a fan-delta deposit (Clark, 1982). Above the Minturn Formation, the Pennsylvanian and Permian Sangre de Cristo Formation consists of more than 1,700 m of coarse conglomerate and sandstone interpreted as an alluvial-fan deposit (Lindsey and Schaefer, 1984).

The main turbidite member is the thickest and most extensive of the intervals of prodelta turbidites in the Minturn Formation. Each turbidite interval is part of a coarsening upward sequence interpreted as a prograding fan delta. A typical prograding cycle consists of prodelta marine shale and siltstone, prodelta turbidite sandstones, delta-front sandstone and conglomerate, and deltaic and alluvial-plain sandstone, siltstone, and shale. Fossils of land plants (mostly Calamites, including some in growth position) are locally abundant in deltaic and alluvial sediments of the prograding cycles. The turbidites are regarded as having been deposited offshore from alluvial systems.

LOCATION OF SECTIONS AND METHODS OF STUDY

Locations of the measured sections of the main turbidite member, from south to north, are as follows: A-3 at Venable Lakes, A-8 north of Goodwin Lakes, SC-126 below Eureka Lake, A-1 on Hermit Road, A-2 above Megan Lake, A-4 above Cotton Lake, and A-5 below Teacup Lake (fig. 1); these features are shown on the Electric Peak 15-minute topographic quadrangle map published by the U.S. Geological Survey. From sections A-3 to A-2, the main turbidite member crops out east of the crest of the range in west-dipping (about 50°) strata; north of section A-2, the turbidite crops out west of the crest of the range, on both flanks of the Cotton Lake anticline. The turbidite member is truncated by the Spread Eagle Peak thrust south of section A-3.

Data were collected on thickness of beds; lithology; grain size; nature of bedding contacts; presence and type of sole marks; type, sequence, and orientation of sedimentary structures; and occurrence of fossils. These data are summarized in this report.

STRATIGRAPHY OF MAIN TURBIDITE MEMBER

The main turbidite member ranges in thickness from about 45 m at section A-3 to about 150 m at section A-4. It underlies conglomeratic sandstone, 105-165 m in thickness, that forms a prominent ridge above the turbidite member, and it overlies approximately 30 m of thin-bedded sandstone, siltstone, and shale (fig. 2). The overlying conglomeratic sandstone member is characterized by abundant medium-scale (0.2-0.5 m) trough crossbedding and current ripple marks; it contains abundant lenses (less than 1 m thick) of sorted, stratified conglomerate and siltstone. Lenticular paleoplacers of magnetite, 0.1 m thick, occur locally. At some places turbidites overlie the conglomeratic sandstone member. Below the main turbidite member, sandstone, siltstone, and shale contain abundant current ripple marks and sparse fragmentary plant remains and pelecypods; these strata grade down into sandstone and conglomerate underlain locally by lenses of turbidites.

A bed of fissile black shale divides the main turbidite member into two parts southeast of section A-2. At the southern end of the line of sections (A-3), the marker shale lies directly beneath the conglomeratic sandstone member and the upper part of the main turbidite member is absent. In the northwestern sections (A-4 and A-5), the shale bed was not identified. Differences between the lower and upper parts of the main turbidite member are too subtle to be discerned in the field.

DESCRIPTION OF TURBIDITES

The turbidite member is composed entirely of fining-upward cycles of thin- to medium-bedded arkosic sandstone, siltstone, and shale; much of the sandstone contains abundant granule-size quartz and feldspar. These cycles contain the sequence of sedimentary structures diagnostic of turbidites (Bouma, 1962; 1972) and conform to the proximal turbidites of Walker (1967) and the C facies of Ricci-Lucchi (1975). Most are 0.2-1.0 m thick (10th and 90th percentiles) and average about 0.5-0.6 m in thickness, but a few range to more than 2 m in thickness (fig. 3). Some cycles amalgamate along strike. The thickness of cycles shows no discernible lateral or vertical trends (fig. 3); thinning-upward aggradational sequences (Ricci-Lucchi, 1975) characteristic of channel fill are not present. In general, sandstone and siltstone comprise most of the individual cycles; shale divisions at the tops of cycles are only 1-2 cm thick.

The base of each cycle is generally sharp and in some cases, slightly undulatory, reflecting slight erosion of underlying beds or draping over ripple forms. Erosional scours and small channels having 10-20 cm of relief occur locally. Sole marks are uncommon, but small flute and groove casts were seen on the bottoms of a few sandstone beds. Load casts and flame structures, resulting from settling of sand into underlying silt and mud, are common on bottoms of sandstone beds.

The interiors of cycles in the main turbidite member contain one or more of the following structures, in approximate order from base to top: graded bedding, massive bedding, parallel lamination, and ripple cross-lamination (seen also as ripple marks). Ball-and-pillow structure and convolute lamination occur in the sandy upper parts of some cycles. Low-angle crossbedding is present in a few cycles. Zoophycus, a trace fossil characteristic of, but not restricted to, turbidites deposited on continental slopes (Seilacher, 1978), was found in sandstone float at many places in the turbidite member. Fragmentary plant remains are also common.

The sequence of sedimentary structures contained in cycles of the main turbidite member is similar to the Bouma cycle (Bouma, 1962); such sequences are commonly incomplete, but are nevertheless diagnostic of deposition by density currents. Bouma's (1962; 1972) cycle and his notation are summarized as follows:

T_a--Graded or massive division; composed of either normally graded sandstone, in which the average and maximum grain size decreases upward, or massive sandstone having no discernible structure.

The T_a division overlies with sharp contact the shale or siltstone below. Inclusions of shale and fossils are common in this division. In the main turbidite member, it was possible to distinguish graded (T_{a1}) from massive (T_{a2}) divisions in most cycles, and to determine that the graded division generally precedes the massive division.

T_b--Lower division of parallel lamination; this division is dominated by distinct parallel lamination thought to have formed under upper-flow-regime conditions (Bouma, 1972, p. 209). It may occur in combination with normal grading of the underlying T_a division and may be transitional to it.

T_c--Division of current ripple lamination; this division is composed of ripple cross-laminated, fine- to medium-grained sandstone believed to have been deposited under lower flow-regime conditions (Bouma, 1972, p. 209). In addition to ripple cross-lamination, this division also contains deformed cross lamination and convolute lamination. The transition between divisions T_b and T_c can be distinct or gradational and commonly coincides with the transition from sandstone to shale.

T_d--Upper division of parallel lamination; characterized by faint parallel lamination and continued decrease in maximum and average grain size. Abundant sand enhances the visibility of these laminae.

T_e--Pelitic division; the top of the typical turbidite consists of silty or clayey sediment having no visible structure. The transition from division T_d is gradual and its distinction depends on the abundance of fine sediment and the degree of weathering.

The Bouma cycle is the result of deposition of sediment from density currents, which flow because of a density contrast between turbulently suspended sediment and the surrounding fluid and deposit sediment when their velocity decreases below a threshold.

Nine hundred thirteen cycles were measured and described from eight sections of the main turbidite member. Most of the beds of the main turbidite member do not contain complete Bouma cycles, but instead consist only of a graded (T_{a1e}) or massive (T_{a2e}) division followed by a thin pelitic division. The most common cycles consist of graded (T_{a1e}--24 percent) or massive (T_{a2e}--28 percent) sandstone divisions, and combinations beginning with graded (T_{a1-e}--15 percent) and massive (T_{a2-e}--19 percent) divisions followed by other divisions (fig. 4). These cycles are concluded by thin (1-2 cm) siltstone and shale of division T_e. Bouma cycles beginning with laminated divisions T_b are less common (8 percent), and cycles beginning with divisions T_c and T_d are rare. No noticeable variation in types of partial cycles was noted laterally or vertically within the main turbidite member.

Figure 5, taken from sections of the main turbidite member, shows the range of variability of the Bouma cycle in the Minturn turbidites. A and B of figure 5 depict nearly complete Bouma cycles (T_{a-e}) representing decreasing velocity and rate of deposition through upper and lower flow regimes. In figure 5B, the presence of shale clasts in the lower part of the graded division records the ripping loose of underlying mud during transportation and deposition; such fragile mud chips could not have endured distant transport before deposition.

In figure 5, C illustrates a less complete cycle than those of A and B. The cycle represented by figure 5C contains only a graded division (T_a) and a laminated and ripple cross-laminated division (T_{bc}) that probably records the transition from upper to lower flow regimes. Wavy outlines in the graded division may be bedforms--possibly standing waves or antidunes preserved by rapid deposition during upper flow-regime conditions. Figure 5D shows an amalgamated sequence of three graded divisions (T_a) stacked on top of one another, followed by a laminated siltstone (T_d) and another partial cycle (T_{ac}); the entire sequence is interpreted as indicating deposition, in rapid succession, from four density currents. Such rapid emplacement may be due either to lateral segmentation or to vertical stratification of a single density flow. No shale clasts, indicative of scouring of shale divisions (T_e) from the sequence, are present. Cycles shown in E and F of figure 5 begin with a reverse-graded division, generally followed by normal grading and other divisions; such cycles suggest an increasing rate of sedimentation in the early stages of deposition. Cycles shown in G and H of figure 5 contain ball-and-pillow structures, composed of masses of sandstone that have sunk into less cohesive silt and mud. Such structures were formed after deposition and before lithification; their formation may have been initiated by shocks such as earthquakes (Potter and Pettijohn, 1963, p. 148-162). In contrast, figure 5I shows asymmetric convolute structures in sandstone. These structures probably formed by sliding on a slope.

PALEOCURRENTS

Paleocurrent directions (Potter and Pettijohn, 1963, p. 252-268) were determined by measuring the orientation of rare scattered sole marks and low-angle crossbedding in the prodelta main turbidite member and of abundant trough crossbedding in the overlying delta-front conglomeratic sandstone member. Paleocurrent flow for both members was the same (fig. 6): toward 29° for the turbidite member (vector mean of 13 measurements) and toward 32° for the overlying sandstone member (vector mean of 134 measurements). These transport directions are in close agreement with those determined from 1,184 measurements by the authors of crossbedding in the entire section of marine and continental sediments in the Minturn and Sangre de Cristo Formations in the northern Sangre de Cristo Range. The coincidence of mean paleocurrent flow with that for continental alluvial sediments of the overlying Sangre de Cristo Formation indicates that the turbidite member was deposited by a well-established depositional system that originated on land. The paleocurrent directions indicate that the line of measured sections, striking about 320°, is inclined at an angle of only about 20° to the depositional strike (fig. 1). The lenticular shape of the main turbidite member, and of other turbidites noted in the Minturn but not described here, evidently represents facies changes that are nearly parallel to the shoreline. These relationships indicate that the lenticular turbidite member was probably deposited as a broad fan seaward from a continental alluvial and marine fan-delta system. The fan of the main turbidite member was at least as wide as the 13-km distance studied along strike.

CONCLUSIONS

The main turbidite member was deposited by turbid density currents, as shown by the predominance of graded bedding (Kuenen, 1953) and well-developed partial Bouma (1962) cycles. The predominance of thick (0.5-0.6 m) sand beds, coarse sand- and granule-size detritus, and partial Bouma cycles (T_{ae}) indicates that the Minturn turbidites are proximal in the sense of having been deposited near the source of the density current (Walker, 1967). The Minturn turbidites belong to facies C in the classification scheme of Ricci-Lucchi (1975).

The broad, lenticular cross section of the main turbidite member, as seen at a low angle to the depositional strike, demonstrates that the turbidites accumulated as a fan at least 13 km wide. The scarcity of channels and aggradational sequences that might be expected to fill channels (Ricci-Lucchi, 1975) is in accord with the fan-like geometry of the turbidites. These features, together with evidence for a deltaic to alluvial origin for overlying conglomeratic sandstone, indicate that the main turbidite was not deposited at the mouth of a submarine canyon like those described by Walker (1978). The turbidites are comparable to, but coarser, thicker, and more extensive than, prodelta turbidites deposited seaward from deltas in the Middle Pennsylvanian Sandia Formation of northern New Mexico (Casey, 1980) and the small delta distributary mouths of the Cretaceous Blackhawk Formation of Utah (Balsley, 1982). The main turbidite is directly overlain by crossbedded conglomeratic sandstone interpreted as a delta-front deposit, and thus is considered a prodelta turbidite deposit in the sense discussed briefly by Walker (1978).

The main turbidite member of the Minturn Formation probably accumulated seaward from a fan-delta complex somewhat like the modern Yallahs fan delta of Jamaica (Wescott and Ethridge, 1980), although the tectonic setting of the ancestral Rocky Mountains differed from that of present-day Jamaica. The turbidite-bearing interval of the Minturn is overlain by fan-delta deposits of alluvial conglomerate and sandstone interbedded with thin beds of marine limestone in the upper Minturn Formation (Clark, 1982). The fan-delta deposits in turn pass up into continental alluvial-fan conglomerate and sandstone of the Sangre de Cristo Formation (Lindsey and Schaefer, 1984). The Minturn turbidites may have formed in response to major influxes of sediment from the alluvial-deltaic system during floods, or in response to sliding off the front of the fan delta.

REFERENCES CITED

Balsley, J. K., 1982, Cretaceous wave-dominated delta systems: Book Cliffs, east-central Utah: American Association of Petroleum Geologists Guidebook, 219 p.

Bouma, A. H., 1962, Sedimentology of some flysch deposits--A graphic approach to facies interpretation: Amsterdam, Elsevier Publishing Company, 168 p.

______1972, Recent and ancient turbidites and contourites: Gulf Coast Association of Geological Societies Transactions, v. 22, p. 205-221.

Casey, J. M., 1980, Depositional systems and paleogeographical evolution of the late Paleozoic Taos trough, northern New Mexico, in Fouch, T. D., and Magathan, E. R., eds., Paleozoic paleogeography of west-central United States; Paleogeography Symposium I: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, p. 181-196.

Clark, R. F., 1982, Stratigraphy, sedimentology and copper-uranium occurrences of the upper part of the Middle Pennsylvanian Minturn Formation, Sangre de Cristo Mountains, Colorado: Golden, Colorado School of Mines M.S. thesis, 151 p.

Kuenen, Ph. H., 1953, Significant features of graded bedding: American Association of Petroleum Geologists Bulletin, v. 37, no. 5, p. 1044-1066.

Lindsey, D. A., Johnson, B. J., and Andriessen, P. A. M., 1983, Laramide and Neogene structure of the northern Sangre de Cristo Range, south-central Colorado, in Lowell, J. D., ed., Rocky Mountain foreland basins and uplifts: Rocky Mountain Association of Geologists Symposium, p. 219-228.

Lindsey, D. A., and Schaefer, R. A., 1984, Principal reference section for the Pennsylvanian and Permian Sangre de Cristo Formation, northern Sangre de Cristo Range, Saguache County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-1622-A.

Potter, P. E., and Pettijohn, F. J., 1963, Paleocurrents and basin analysis: New York, Academic Press, 296 p.

Ricci-Lucchi, R., 1975, Depositional cycles in two turbidite formations of northern Appennines (Italy): Journal of Sedimentary Petrology, v. 45, no. 1, p. 3-43.

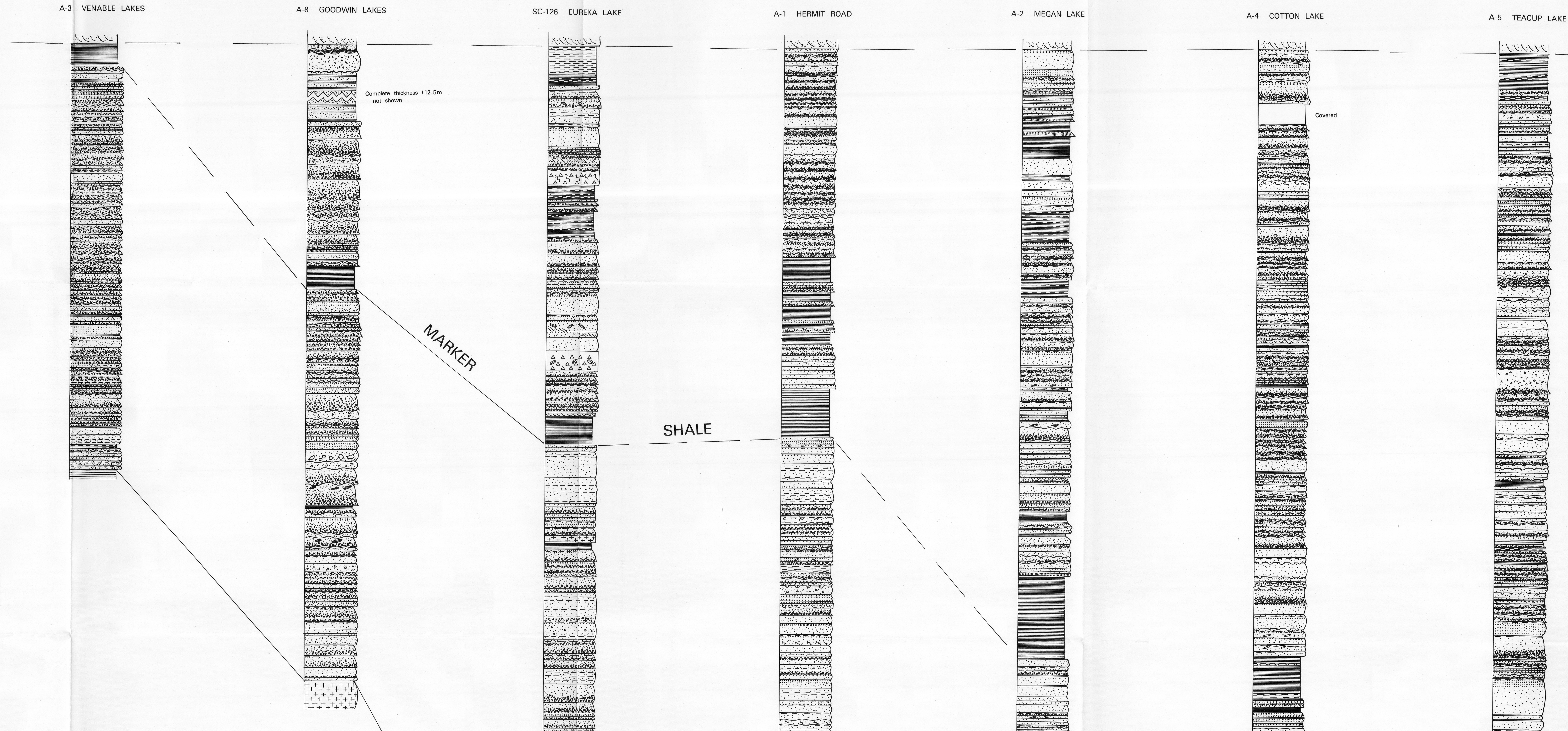
Scott, G. R., and Taylor, R. B., 1974, Reconnaissance geologic map of the Electric Peak quadrangle, Custer and Saguache Counties, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-628, scale 1:62,500.

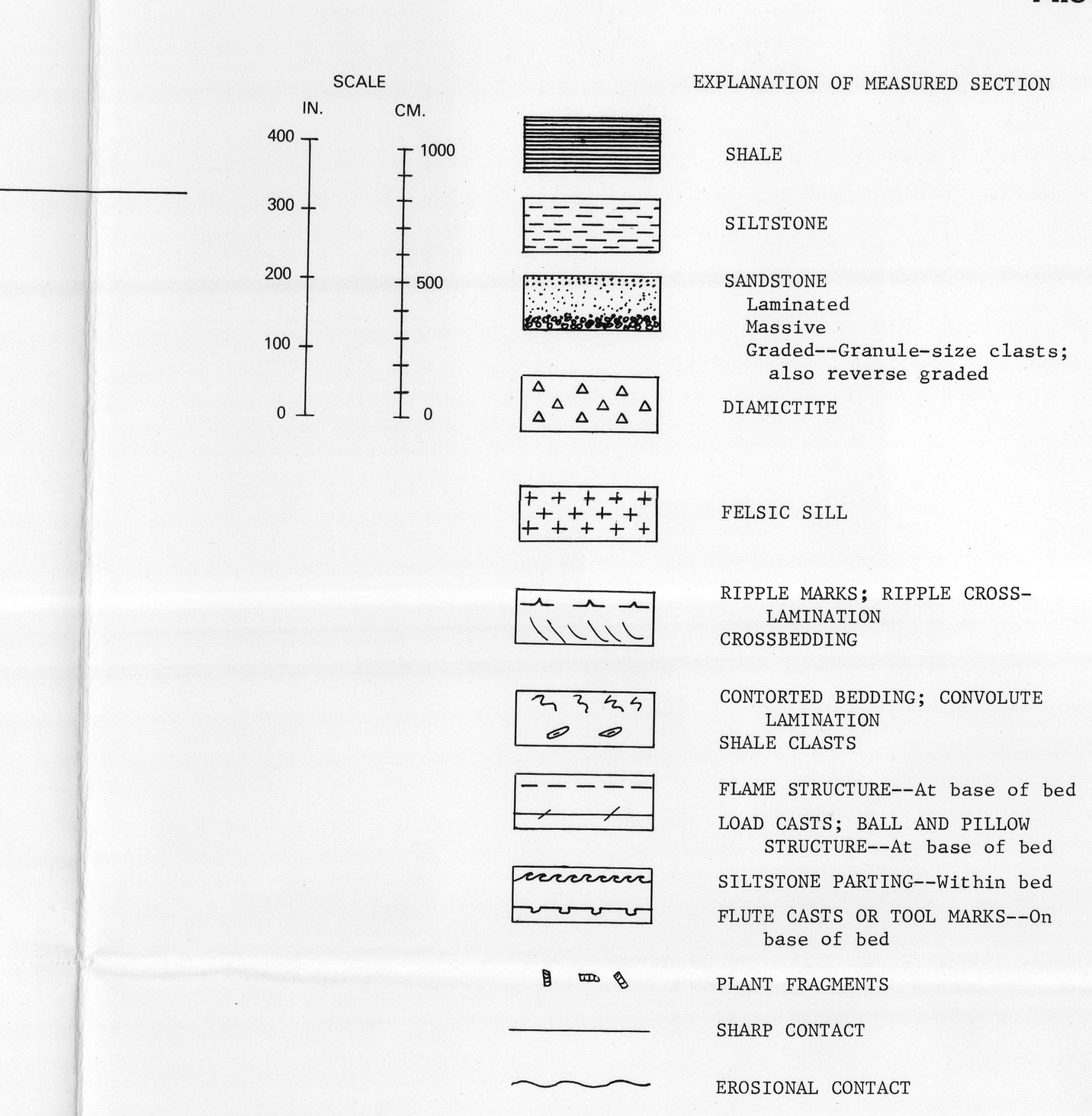
Seilacher, Adolph, 1978, Use of trace fossils for recognizing depositional environments, in Basan, P. B., ed., Trace fossil concepts: Society of Economic Paleontologists and Mineralogists Short Course, no. 5, p. 167-181.

Walker, R. G., 1967, Turbidite sedimentary structures and their relationship to proximal and distal depositional environments: Journal of Sedimentary Petrology, v. 37, no. 1, p. 25-43.

______1978, Deep-water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps: American Association of Petroleum Geologists Bulletin, v. 62, no. 6, p. 932-966.

Wescott, W. A., and Ethridge, F. G., 1980, Fan-delta sedimentology and tectonic setting--Yallahs fan delta, southeast Jamica: American Association of Petroleum Geologists, v. 64, no. 3, p. 374-399.





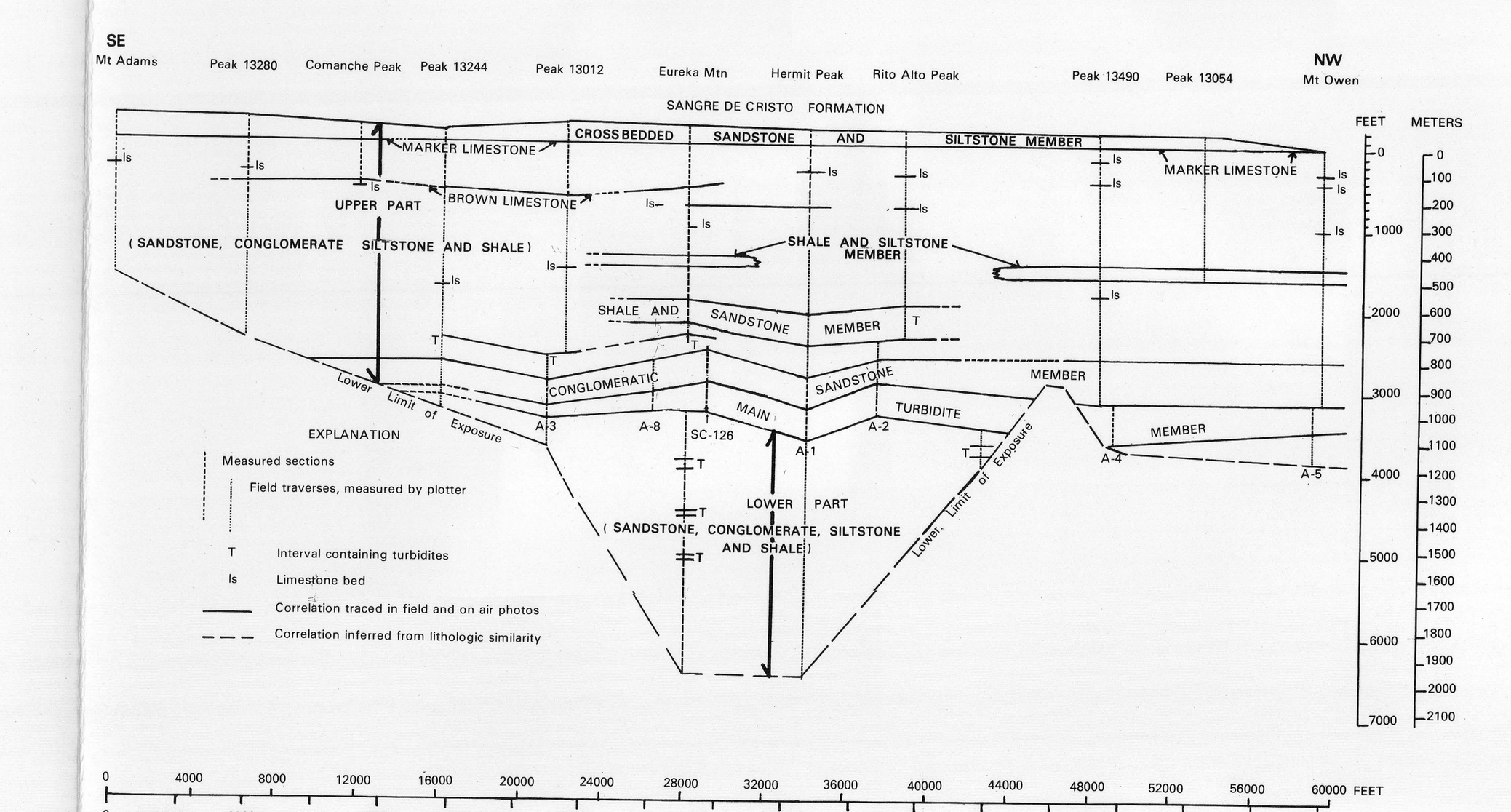
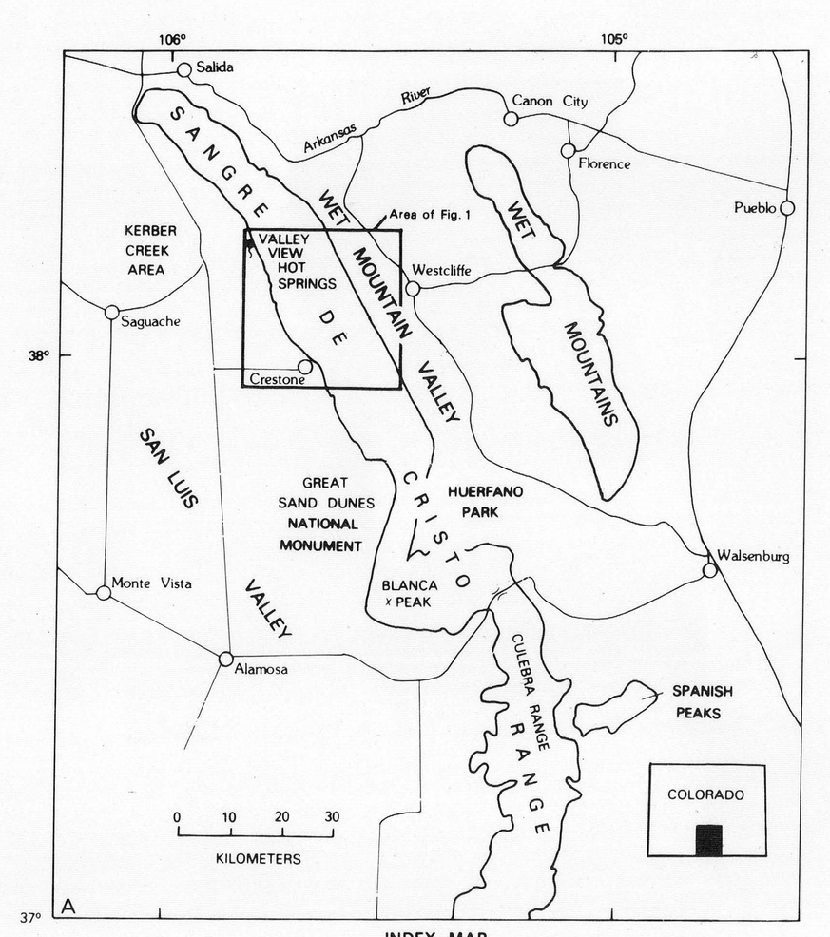


Figure 2.--Panel showing stratigraphy of the Minturn Formation in the Spread Eagle Peak thrust plate, northern Sangre de Cristo Range, Colo. Panel oriented southeast to northwest, as viewed from the east side of the range.



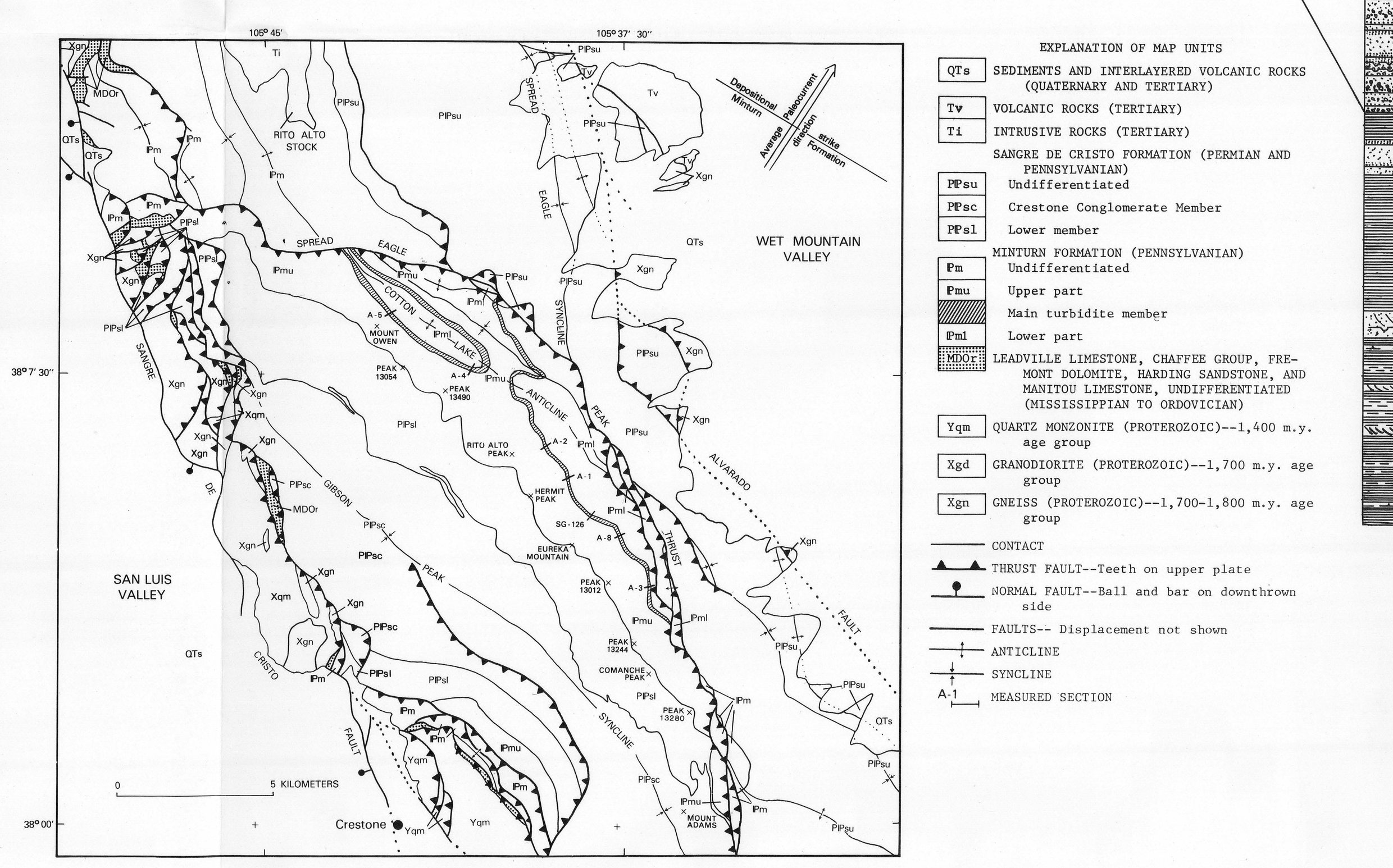


Figure 1.--Geologic map of part of the northern Sangre de Cristo Range, Colo., showing location of measured sections in the main turbidite member of Minturn Formation (from Lindsey and others, 1984). Paleocurrent direction and strike of depositional facies during deposition of the main turbidite member are shown also.

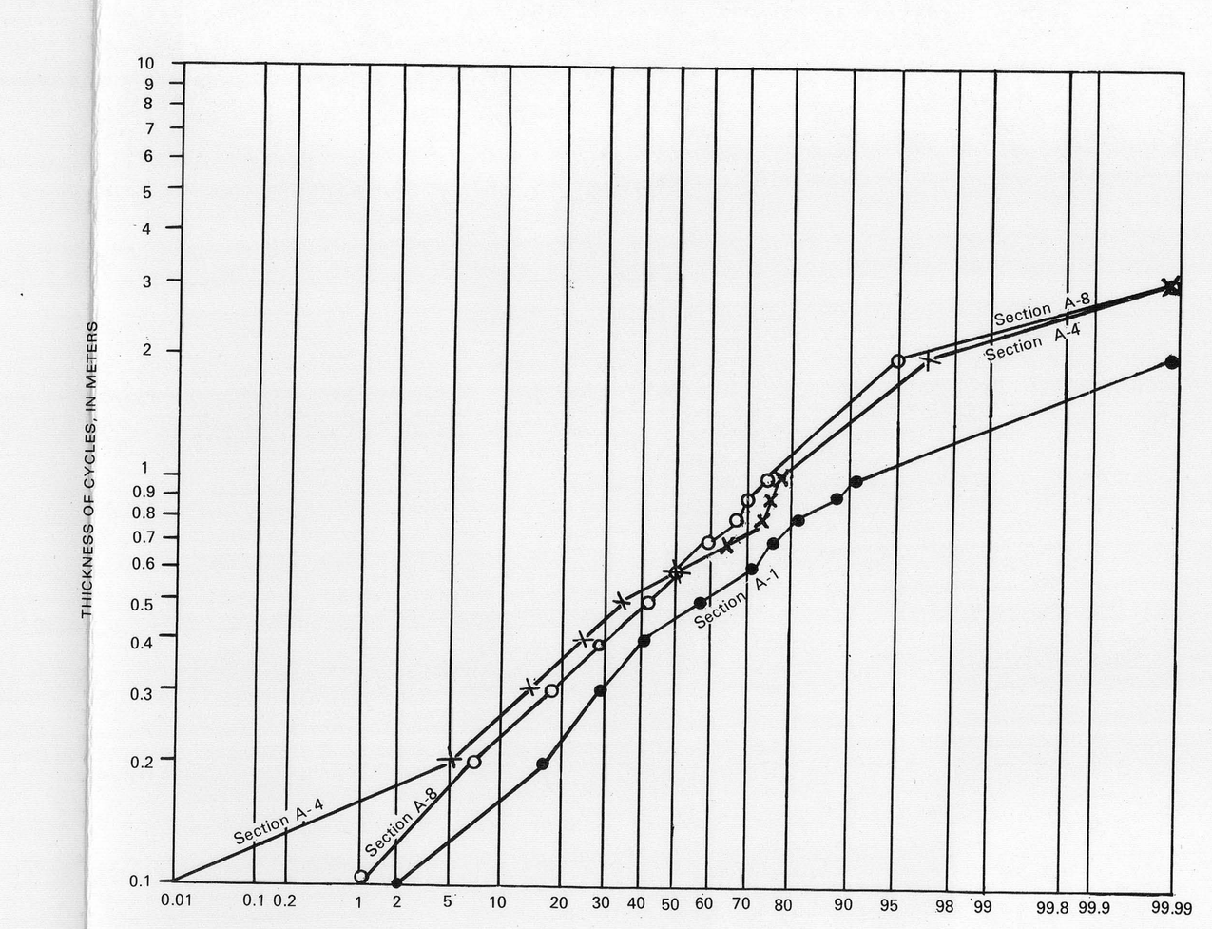


Figure 3.--Cumulative frequency plots, on log-probability scale, of thickness of Bouma cycles in three sections measured through the main turbidite member; sections A-8, A-1, and A-4 are representative of cycle thicknesses in the southern, central and northern parts of the line of sections, respectively.

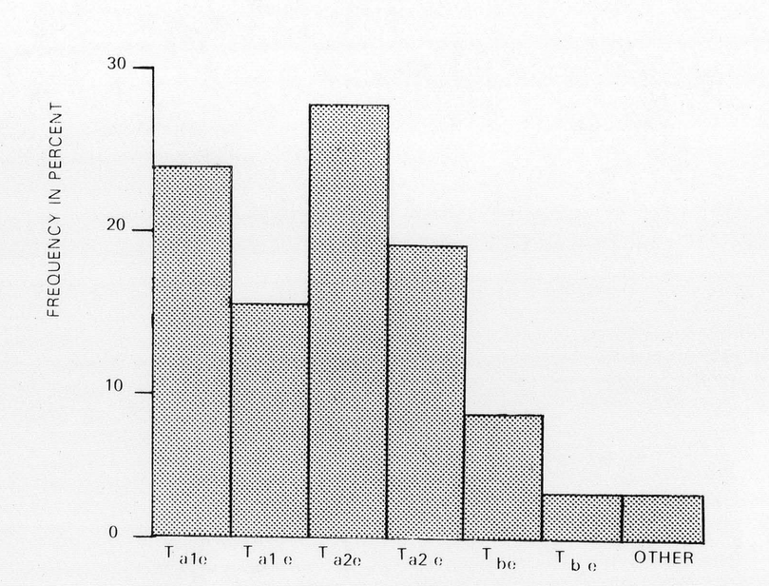


Figure 4.--Histogram showing the frequency of various Bouma cycles in the main turbidite member of the Minturn Formation. T_{a1e} = a graded and a pelitic division; T_{a1-e} = graded division followed by other divisions and generally ending with a pelitic division; T_{a2e} = a massive and a pelitic division; T_{a2-e} = massive division followed by other divisions and generally ending with a pelitic division; T_{be} = a laminated sand division and a pelitic division; T_{b-e} = laminated sand division followed by other divisions and ending with a pelitic division; and other = divisions containing reverse grading and low-angle crossbedding.

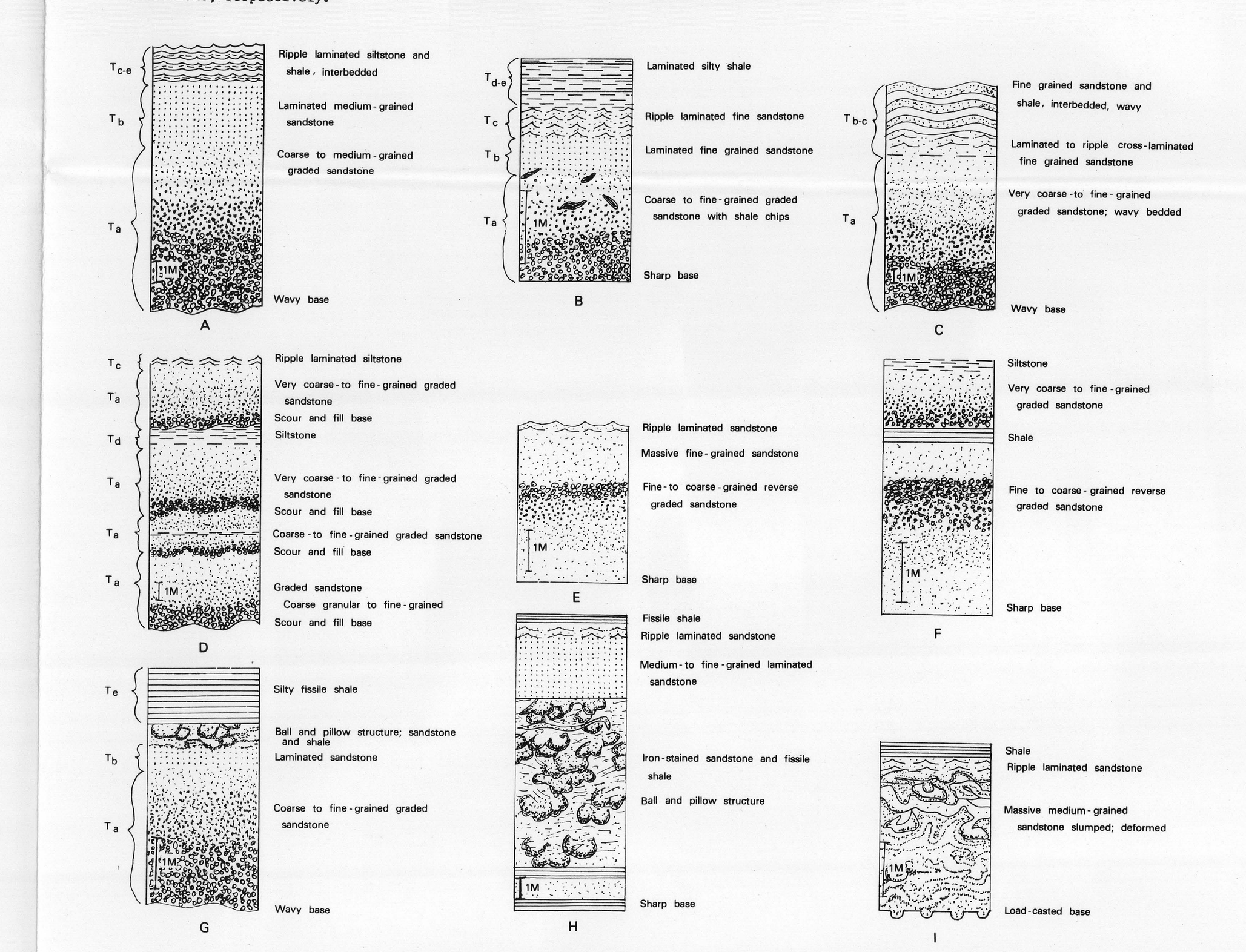


Figure 5.--Variations of the Bouma cycle seen in the main turbidite member of the Minturn Formation. Each variation is discussed in the text.

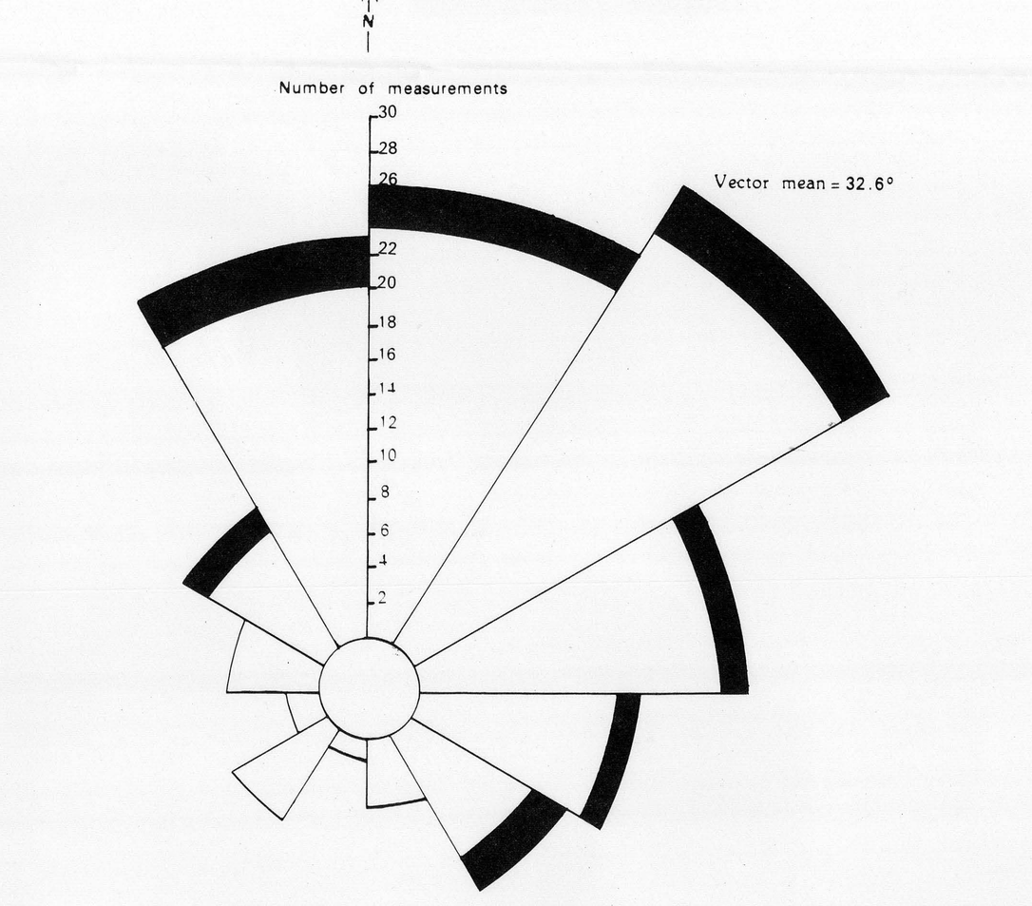


Figure 6.--Rose diagram showing paleocurrent directions of the main turbidite member (black) and the overlying conglomeratic sandstone member (white). Paleocurrent directions for main turbidite member determined from rare sole marks and low-angle crossbedding (N=13); for the conglomeratic sandstone member, from trough crossbedding (N=134).

MEASURED SECTIONS AND DISCUSSION OF THE MAIN TURBIDITE MEMBER, MIDDLE PENNSYLVANIAN MINTURN FORMATION, NORTHERN SANGRE DE CRISTO RANGE, CUSTER AND SAGUACHE COUNTIES, COLORADO

By

Sandra J. Soulliere, Barbara L. DeAngelis, and David A. Lindsey

1984

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1984

For sale by Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225