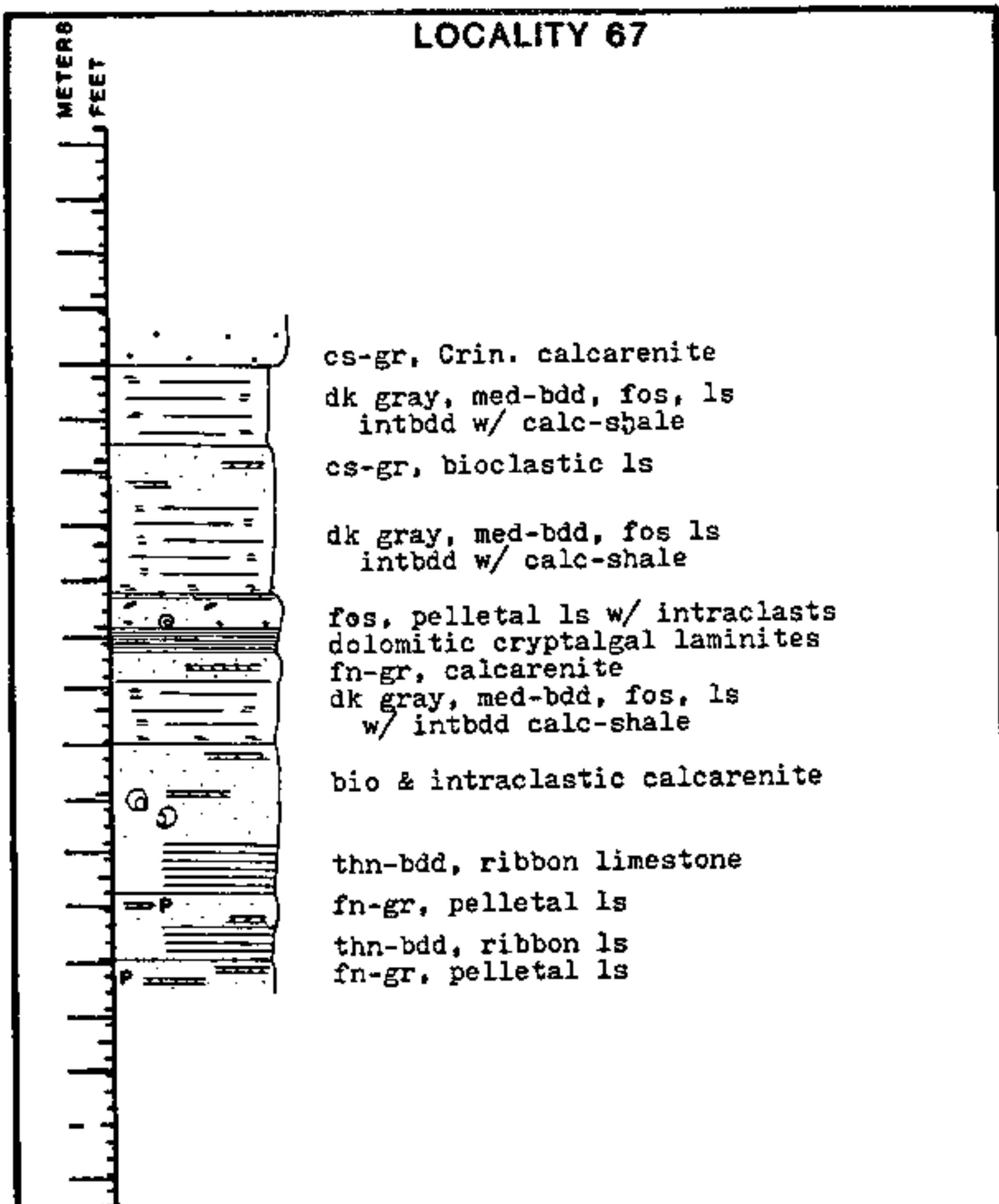


FIGURE 30: Outcrop description of Locality 67.

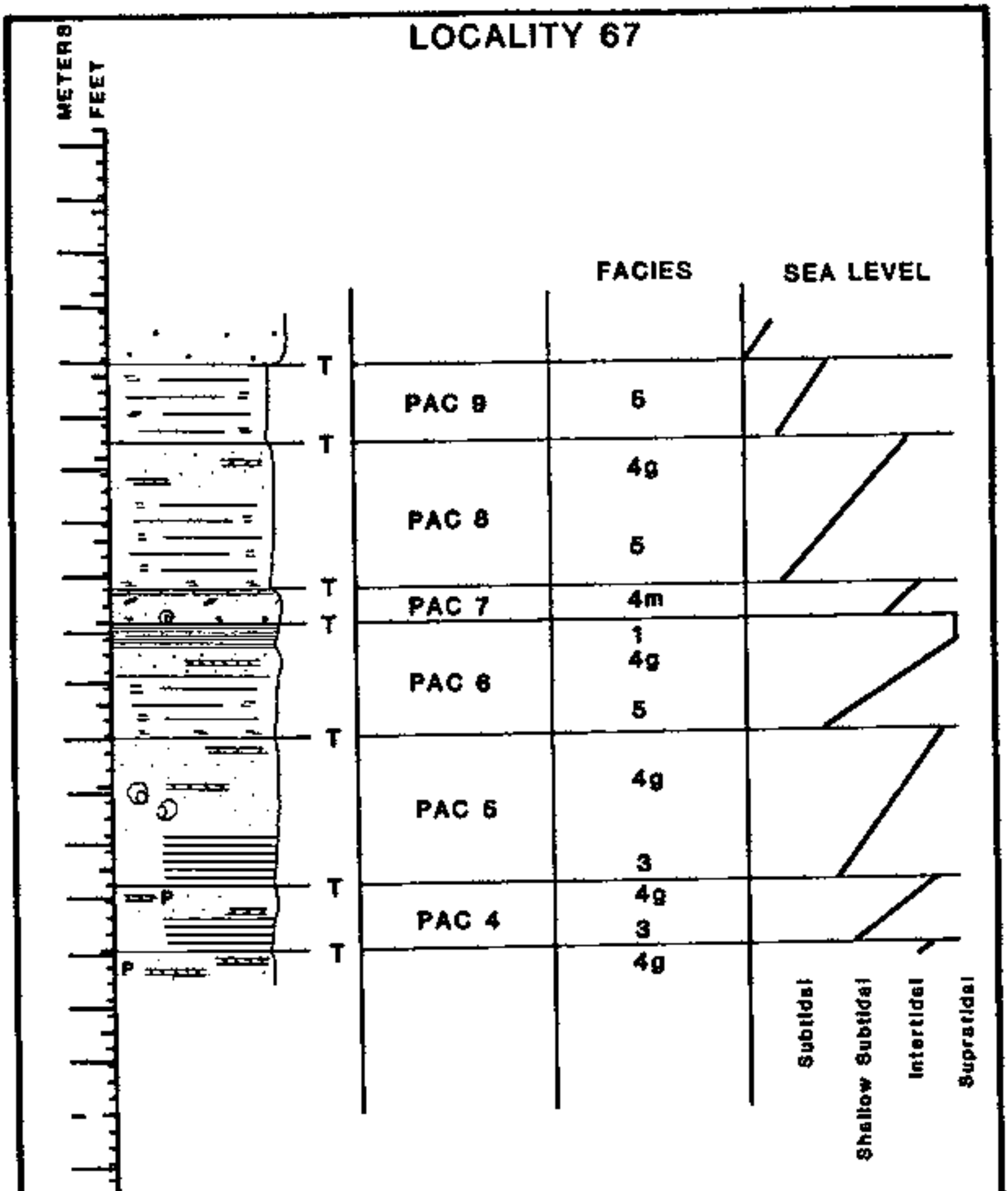


FIGURE 31: PAC interpretation of Locality 67.

from subtidal to shallow high energy environments.

PAC 6 - PAC 6 is 2 meters thick and begins at a sharp deepening surface. The basal portion of this cycle is composed of Facies 5 which grades upward into medium-bedded, gastropod containing, sparsely fossiliferous micrite. This is overlain by supratidally deposited Facies 1. PAC 6 represents deposition from subtidal to supratidal environments.

PAC 7 - PAC 7 is a thin (0.38 m thick) PAC at this locality as it is at localities 72-b and 74. It is composed of intraclastic and fossiliferous limestone which sharply overlies Facies 1 dolomites of PAC 6. This unit is in turn overlain by the faunally diverse Facies 5 which occurs in the base of PAC 8. It represents deepening over the underlying supratidal rocks and aggradation of limestone until deposition is interrupted by a deepening event and deposition of PAC 8.

PAC 8 - PAC 8 begins at a sharp transgressive surface over the thin PAC 7. Its basal portion contains Facies 5 which grades upward into current-washed strophomenid-containing calcarenites. As is evidenced by many other PACs, this facies transition represents a shallowing from periodically current-washed subtidal environments to more continuously current washed conditions.

PAC 9 - PAC 9 is 1.67 meters thick and is composed of medium-bedded pelmatozoan rich Facies 5. It overlies the current washed calcarenites at the top of PAC 8 and underlies the open subtidal Favosites and Gypidula bearing rocks of the Coeymans Formation. This PAC is entirely subtidal. The Manlius/Coeymans boundary is somewhat problematic at this locality as it is at localities 72-b and 74. It may be defined at the top of the strophomenid bearing bed at the top of PAC 8 where pelmatozoan rich rocks first begin to appear in abundance or or at the first occurrence of Favosities and Gypidula at the top of PAC 9.

PAC 10 - PAC 10 begins at the first occurrence of Favosities and Gypidula in the Coeymans Formation. The upper limit of this PAC has not been defined, since it requires a detailed anaysis of the Facies of the Coeymans Formation in order to delineate depth-sensitive facies and faunal characteristics. PAC 10 represents a deepening from micritic carbonate bank deposition of the Manlius Formation to agitated shelf deposition of the Coeymans Formation.

Locality 70

Locality 70 occurs at the base of the lowest exposure of Manlius Formation rocks in The Scoharie Quarry at Scoharie, New York (Rickard, 1962). Seven complete PACs have been identified within the Manlius Formation at this

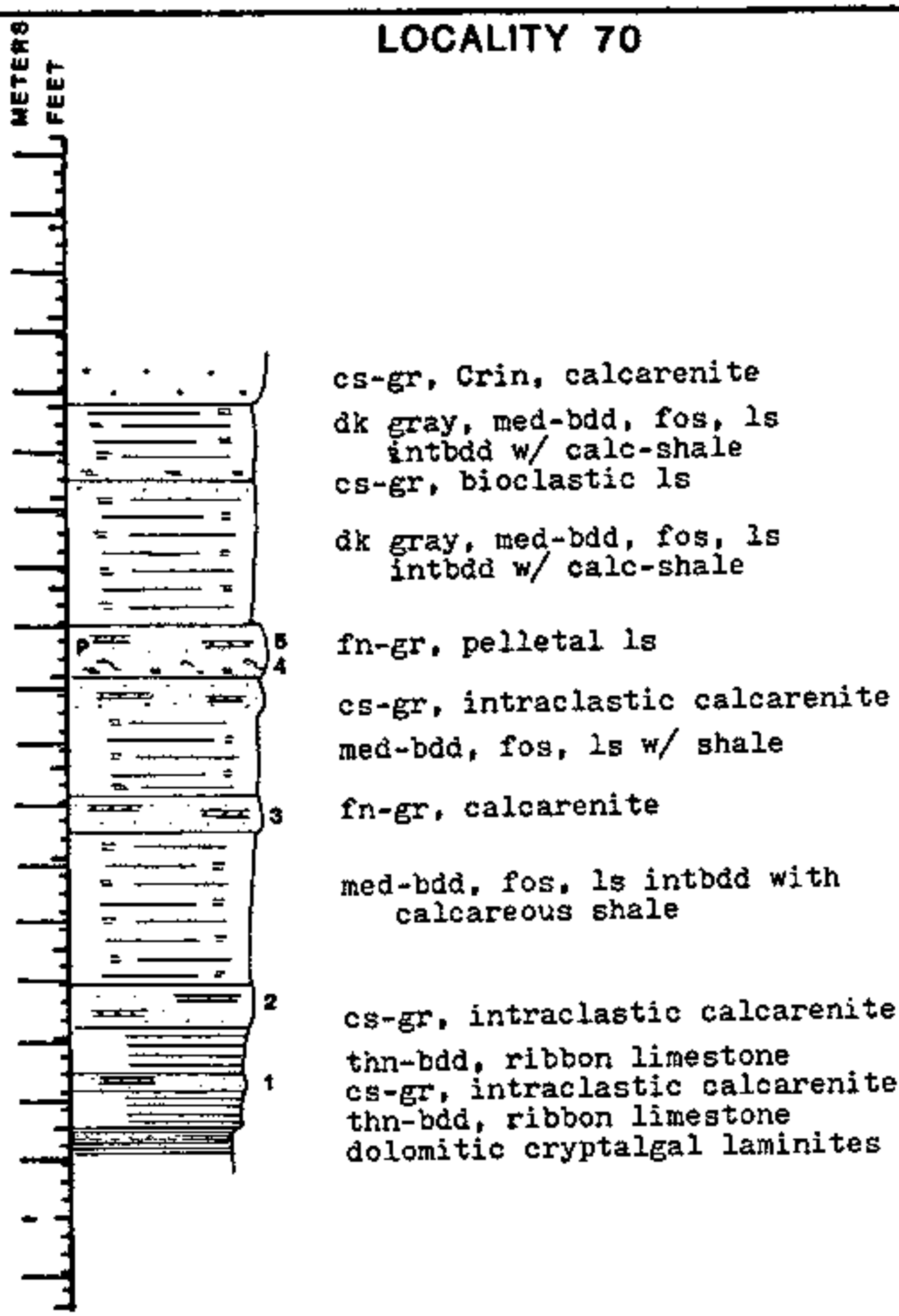


FIGURE 32: Outcrop description of Locality 70.

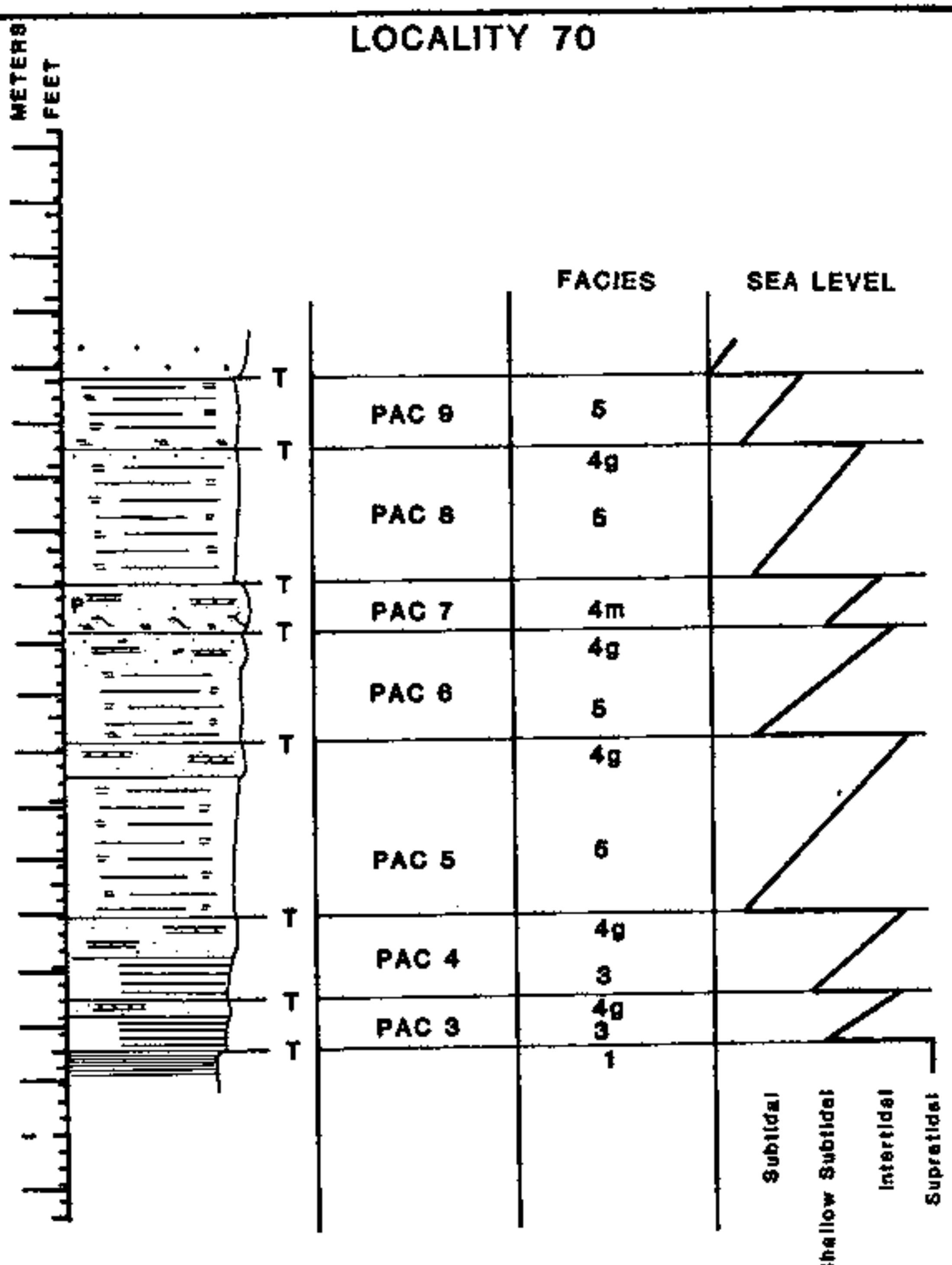


FIGURE 33: PAC interpretation of Locality 70.

Locality (Figures 32 & 33).

PAC 2 & 3 - PAC 2 is represented by 0.61 m of Facies 1 which occurs at the base of the exposure. PAC 3 is composed of Facies 4, ostracode bearing intrasparites and was deposited in a shallow subtidal environment after a deepening event over the supratidally deposited facies at the top of PAC 2.

PAC 4 - PAC 4 is 1.37 meters thick and is composed of Facies 3 ribbon limestones which grade upwards into Facies 4 intraclastic calcarenites. It represents aggradation of sediments from a restricted relatively quiet water environment (Facies 3) into a shoal environment (Facies 4) after a deepening event over the underlying shallow environment.

PACs 5 & 6 - PACs 5 and 6 are 3.2 & 1.8 meters thick (10.5 & 6 feet) and exhibit upward facies changes from Facies 5 fossiliferous limestones to Facies 4 calcarenites. These PACs represent aggradation from relatively open subtidal to more restricted shallow subtidal shoal environments.

PAC 7 - PAC 7 is a 1 meter thick PAC composed of bioturbated fossiliferous limestone which grades upward into a current washed, ostracode rich calcarenite of Facies 4. It represents deposition from quiet water subtidal to a shallow current agitated environments.

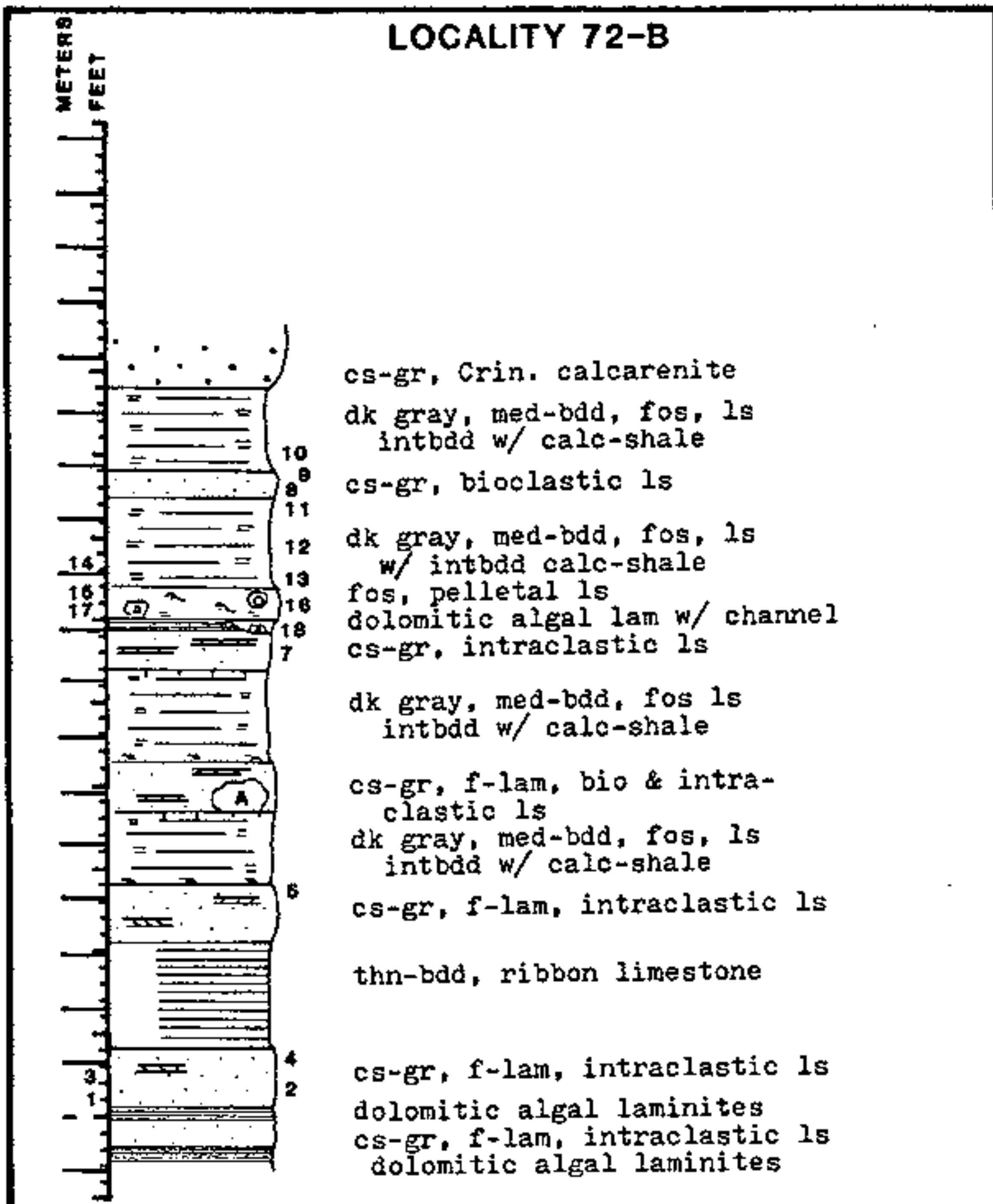
PAC 8 - PAC 8 is composed of Facies 5 medium-bedded limestone which grades upwards into a strophomenid bearing calcarenite. This PAC records aggradation from a relatively open subtidal environment to a shoal environment following a deepening event that initiated Facies 5 deposition.

PAC 9 - PAC 9 is composed of Facies 5 basally and grades upwards into an ostracode gastropod intraclastic calcarenite. This represents aggradation from an open, subtidal environment to a restricted and high energy shoal water environment after a deepening event over the deposits of PAC 8.

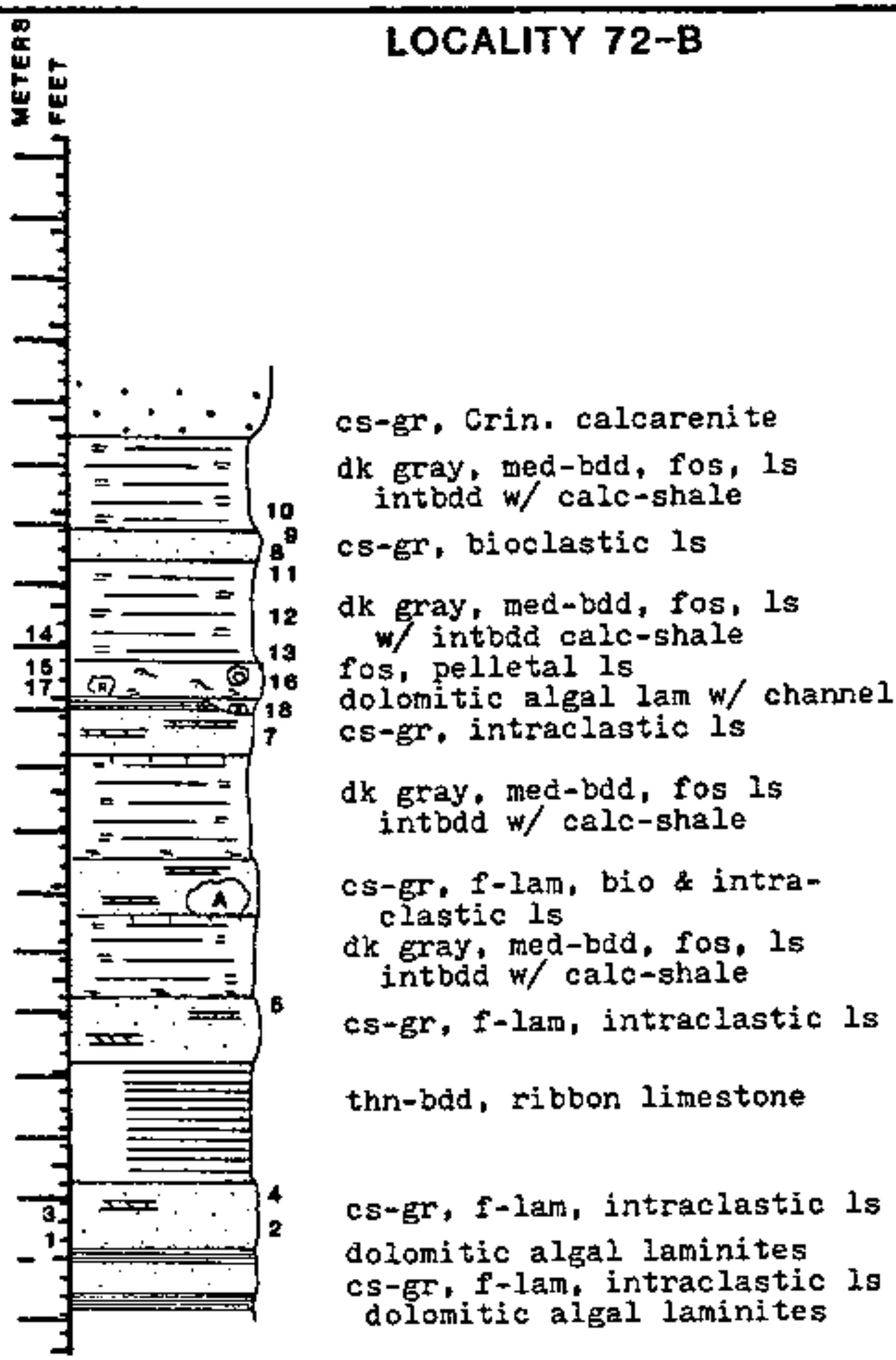
PAC 10 - PAC 10 is composed of Gypidula bearing, bioturbated, crinoidal calcarenites and occurs within the Coeymans Foprmation. This PAC is 6 feet thick and ends in current washed crinoidal calcarenites.

Locality 72-b

Locality 72-b is a recently excavated roadcut along Interstate 88 approximately 2 miles northwest of Scoharie, N.Y.. Virtually the entire Helderberg Group is exposed in a series of outcrops along this highway. The easternmost exposure contains the upper portion of the Brayman Formation, the Cobleskill, the Chrysler and the Manlius Formations, plus the lower portion of the Coeymans Formation. The Lower contact of the Manlius Formation is taken to occur at the 1.07 meters thick, massive-bedded,



FACIES 34: Outcrop description of Locality 72-b.



FACIES 34: Outcrop description of Locality 72-b.

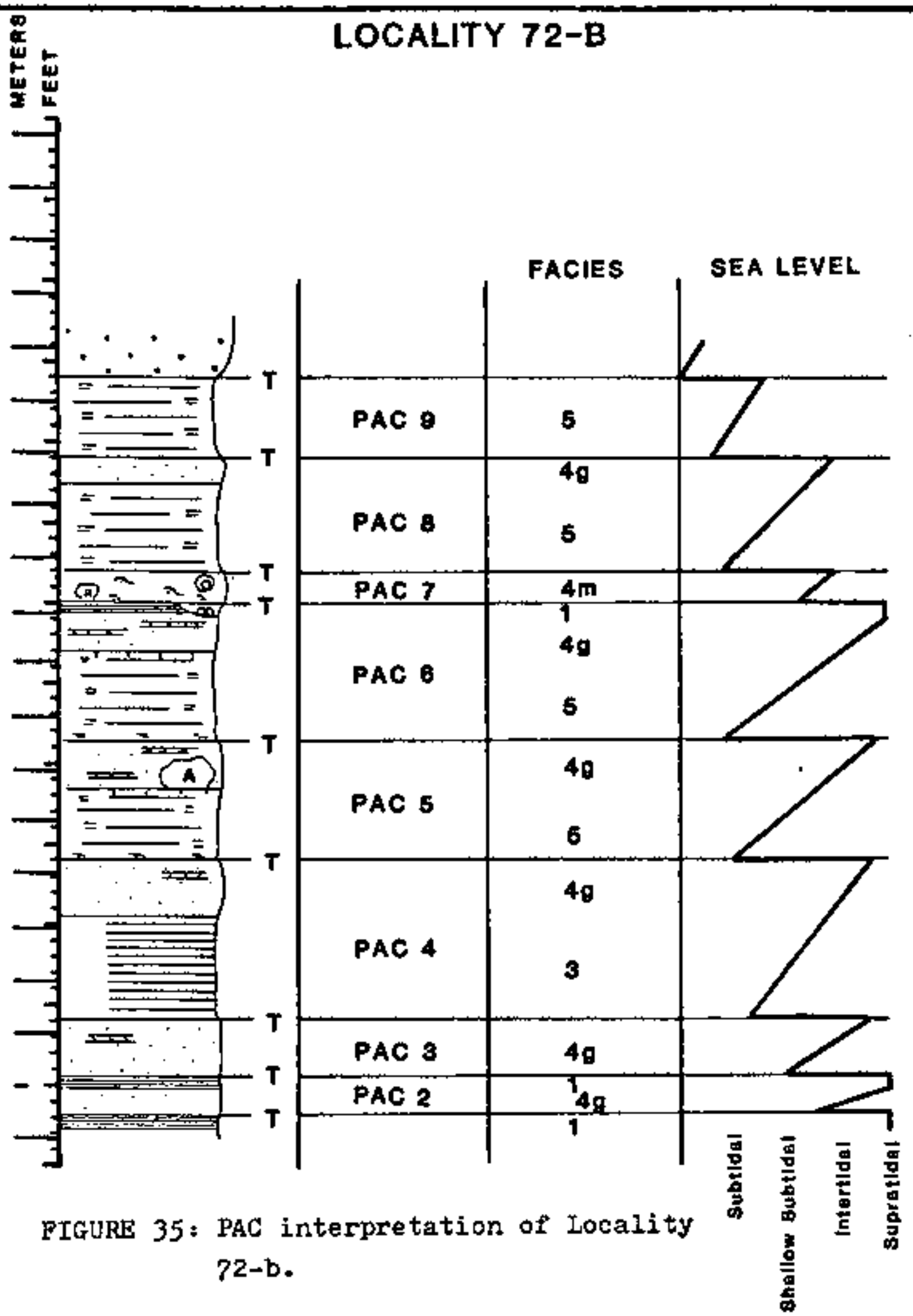


FIGURE 35: PAC interpretation of Locality 72-b.

current laminated, ostracode bearing, intraclastic calcarenite which occurs under the first occurrence of thin-bedded Tentaculities-bearing ribbon limestones (Figures 34 & 35). Using the criteria outlined above for the base of the Thacher Member, seven PACs have been defined from this rock unit as well as several small scale PACs from the upper portion of the Chrysler Formation. The Chrysler Formation PACs exhibit facies characteristics very similar to those of the lower PACs at locality 59 and to those defined by Busch (1981) and Lee (1981) from the Elmwood member of the Manlius Formation.

PACs 1, 2 & 3 - PAC 3 occurs at the base of the Manlius Formation here. It is 1.07 meters thick and is composed of the restricted endmember of Facies 4 (ostracode bearing, intraclastic and bioclastic calcarenites). At the base of this PAC, there is a dark shale. This PAC overlies dolomitic algal laminites which occur in the top of the underlying PAC, it represents depositon in a shallow subtidal, shoal environment which was deposited after a deepening over supratidally deposited Facies 1. PACs 1 & 2 (0.76 & 1.07 meters thick) each exhibit facies transitions from Facies 4 bioclastic and intraclastic calcarenites (containing digitate stromatolites and oncolites) to Facies 1. Each of these PACs represents shallowing from shoal environments to supratidal environments.

PAC 4 - PAC 4 is 3.05 meters thick and begins at a deepening surface over the underlying Facies 4. It grades upward from Facies 3 ribbon limestones to Facies 4 intraclastic and bioclastic coarse-grained calcarenites interbedded with limestones containing Tentaculities and spiriferid brachiopod. These facies transitions represent a shallowing from a restricted, subtidal environment to a shallow subtidal shoal water environment (possibly windward of a large shoal complex). This PAC is important because it suggests that Facies 3 is deeper than the shallow endmember of coarse-grained Facies 4 (due to their stratigraphic position within the PAC).

PACs 5 & 6 - PACs 5 & 6 are 2.44 and 3.05 meters thick, respectively, and exhibit similar facies transitions. Each PAC begins at a deepening surface and grades upward from Facies 5 into current laminated, massive-bedded, coarse-grained, intraclastic and bioclastic calcarenites of Facies 4 (containing clotted algal heads). The medium-bedded limestones of Facies 5 exhibit a fining upward trend to micrite and a loss of faunal diversity until all that is evident are infrequent occurrences of gastropods. Each PAC represents shallowing from open subtidal, to shallow subtidal, to shoal water environments.

PAC 7 - PAC 7 is 0.5 meters (1.5 feet) thick and is composed of various lithologies including biomicrite, biopelsparite and biointrasparite. The fauna of this PAC is diverse and includes virtually all the taxa that occur in the medium-bedded facies. This unit is defined as a PAC because it is separated above and below by deepening surfaces. It is underlain by more shallow deposits facies and overlain by facies indicating deeper paleoenvironments (Facies 5).

PAC 8 - PAC 8 is 2.13 meters thick and grades from Facies 5 (basally) to the micritic Facies 5, to a current-washed strophomenid rich calcarenite of Facies 4. This PAC represents a shallowing from subtidal environments to shoal water environments.

PAC 9 - PAC 9 is 1.6 meters thick and is composed of Facies 5. It is underlain by a deepening surface which separates it from the current-washed limestones at the top of PAC 8. It is overlain by a deepening surface which separates this PAC in the Manlius Formation from the Coeymans Formation. PAC 10 occurs within the Coeymans Formation but the thickness of PAC 10 has not been determined.

Locality 74

Locality 74 is located along a railroad cut approximately 0.3 miles west of Howes Cave, N.Y., next to an inactive limestone quarry (Rickard, 1962). The type section for the Cobleskill and Brayman Formations occurs along the road below the railroad cut. In the railroad cut there are 36 feet of the upper Thacher Member and approximately 60 feet of the Lower Coeymans Formation. Six PACs have been defined within the Thacher Member (Figures 36 & 37).

PAC 4 - PAC 4 is at least 2.1 meters thick. Its absolute base is concealed, but the lower portion of the PAC is composed of ribbon limestone. These rocks are overlain by coarse-grained bioclastic, current laminated, calcarenites of Facies 4. The unit containing the calcarenite ranges in thickness along the outcrop from 0.3 to 1 meters thick. This PAC represents shallowing from a restricted subtidal to a shallow shoal environment.

PACs 5 & 6 - PACs 5 and 6 exhibit similar upward-shallowing characteristics. They each begin at a deepening surface, which is overlain by Facies 5, and fine upward into a pure micrite (as occurs at locality 72-b). The only faunal elements within the micrite are gastropods, and their occurrence is infrequent. Facies 5 is overlain by Facies 4 coarse, bioclastic and intraclastic, bimodally, ripple cross stratified,

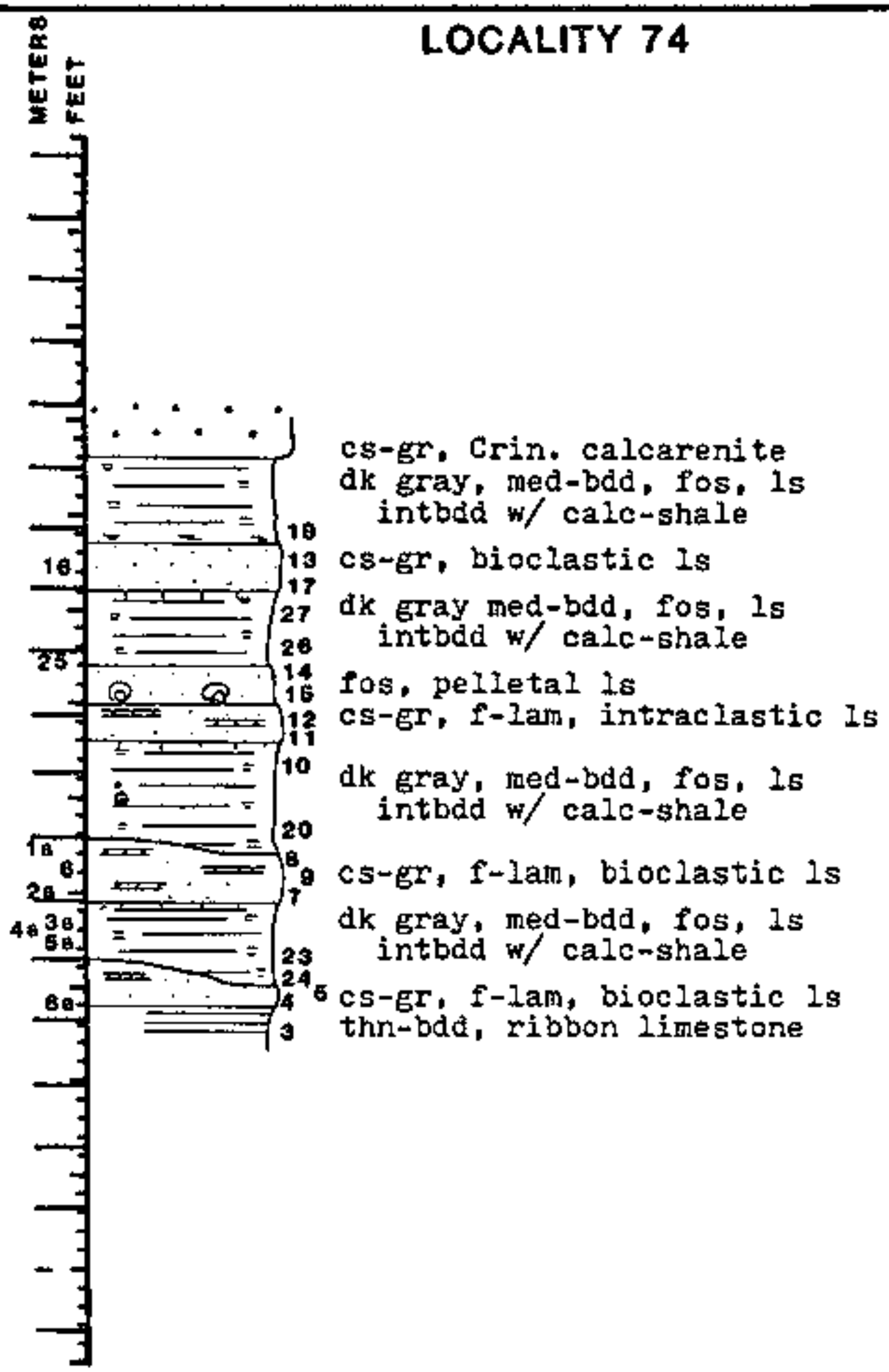


FIGURE 36: Outcrop description of Locality 74.

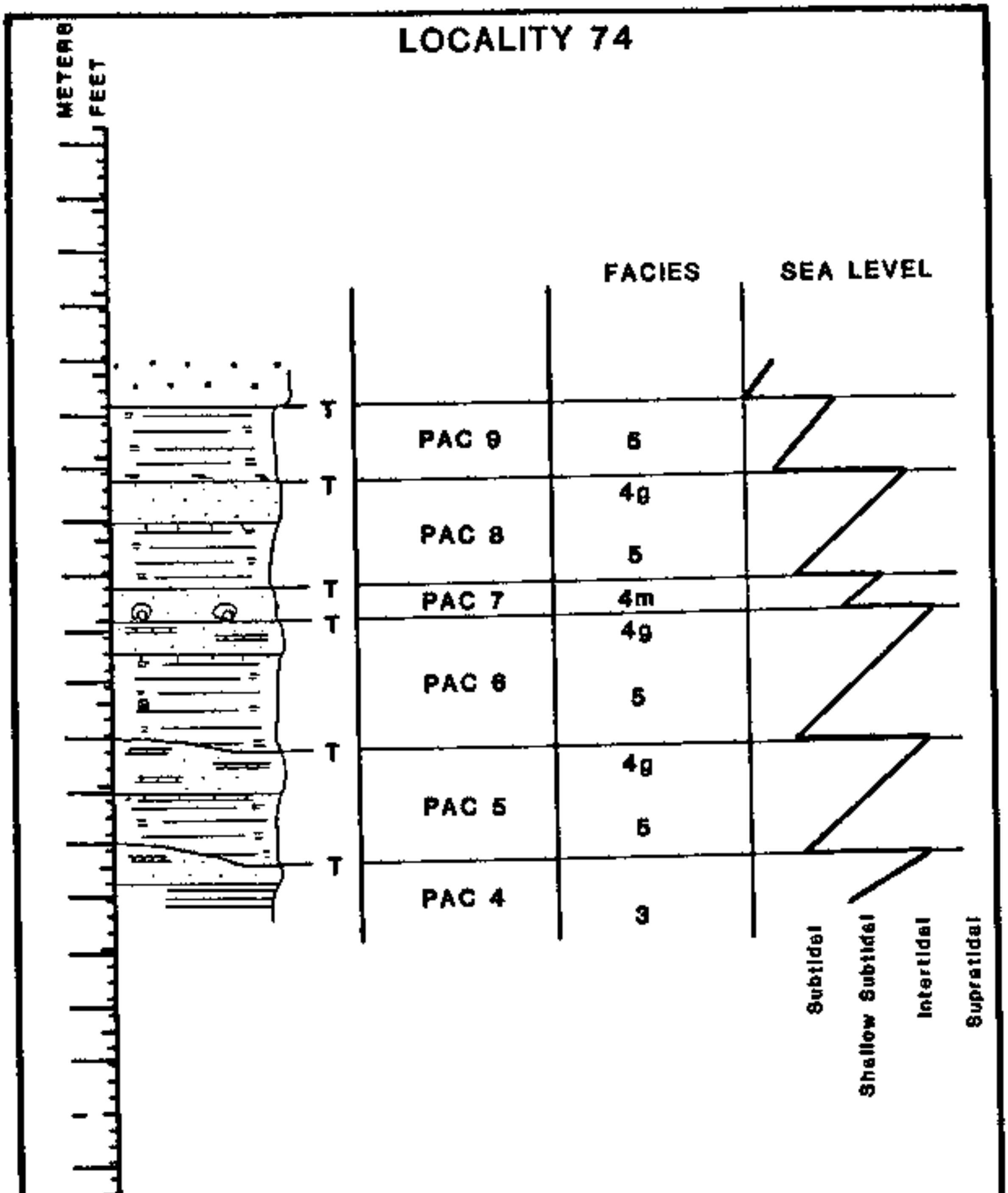


FIGURE 37: PAC interpretation of Locality 74.

calcarenites. The calcarenite bed at the top of PAC 5 exhibits up to 1 foot of thickness variation. Each of these PACs exhibits shallowing from relatively open subtidal environments to a restricted subtidal environment as is evidence by the micrite increase upward to a shoal water environment.

PAC 7 - PAC 7 is very thin and overlies PAC 6 at a sharp surface on which laminar stromatoporoids have grown. This unit contains a diverse faunal assemblage and is primarily composed of bioturbated biopelsparite and biopelmicrite. This unit is overlain by a sharp contact with up to 5 cm of relief above which occurs a shale rich Facies 5. This surface probably represents a deepening surface and it may have been a hardground due to the fact that it exhibits local relief. This PAC represents deposition and possible hardground development in a subtidal environment until deposition was interrupted by the deepening which initiated deposition of shale rich Facies 5 at the base of PAC 8.

PAC 8 - PAC 8 exhibits characteristics identical to PAC 8 at locality 72-b. It grades upward from fossiliferous Facies 5 to micritic Facies 5 overlain by a strophomenid bearing calcarenite. This PAC records shallowing from open subtidal to restricted subtidal similar to aggradation of modern Florida Bay (Enos & Perkins, 1977).

PAC 9 - PAC 9 is composed of Facies 5 rocks and is overlain by a deepening surface separating the medium-bedded fossiliferous limestones from Coeymans Formation crinoidal calcarenites. PAC 10 does not occur in the Manlius Formation but it is hypothesized to occur in the basal portion of the Coeymans Formation.

Locality 87

Locality 87 occurs in a series of abandoned quarries in which houses have been built along route 10 in Sharon Springs, N.Y.. Here, 9.9 meters (32.5 feet) of the Thacher Member are exposed as well as approximately 18 meters (60 feet) of the Coeymans Formation. Five PACs have been defined within the Thacher Member(Figures 38 & 39).

PAC 5 - PAC 5 occurs at the base of the lowest quarry and is at least 1.22 meters (4 feet) thick. It grades upward from Facies 3 to Facies 4 bioclastic and intraclastic calcarenites. This PAC represents shallowing from a restricted subtidal environment to a shoal water environment.

PAC 6 - PAC 6 begins at a deepening surface over the Facies 4 calcarenites of the underlying PAC. Facies 5 is the lowest facies and it grades upward into a fossiliferous biomicritic (open, low energy, subtidal environment). The biomicrite grades upward into bioclastic and intraclastic calcarenites of Facies 4 (high

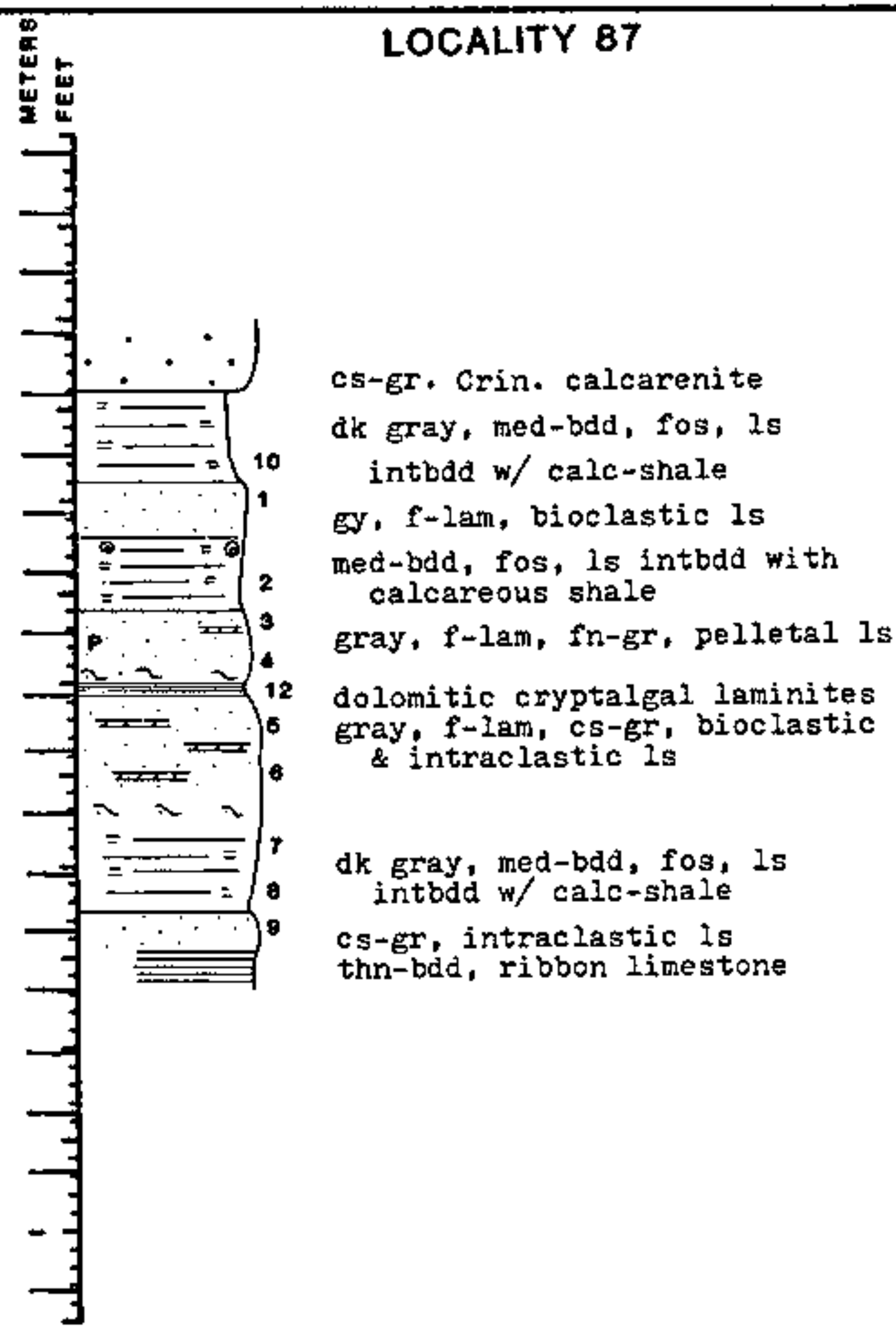


FIGURE 38: Outcrop description of Locality 87.

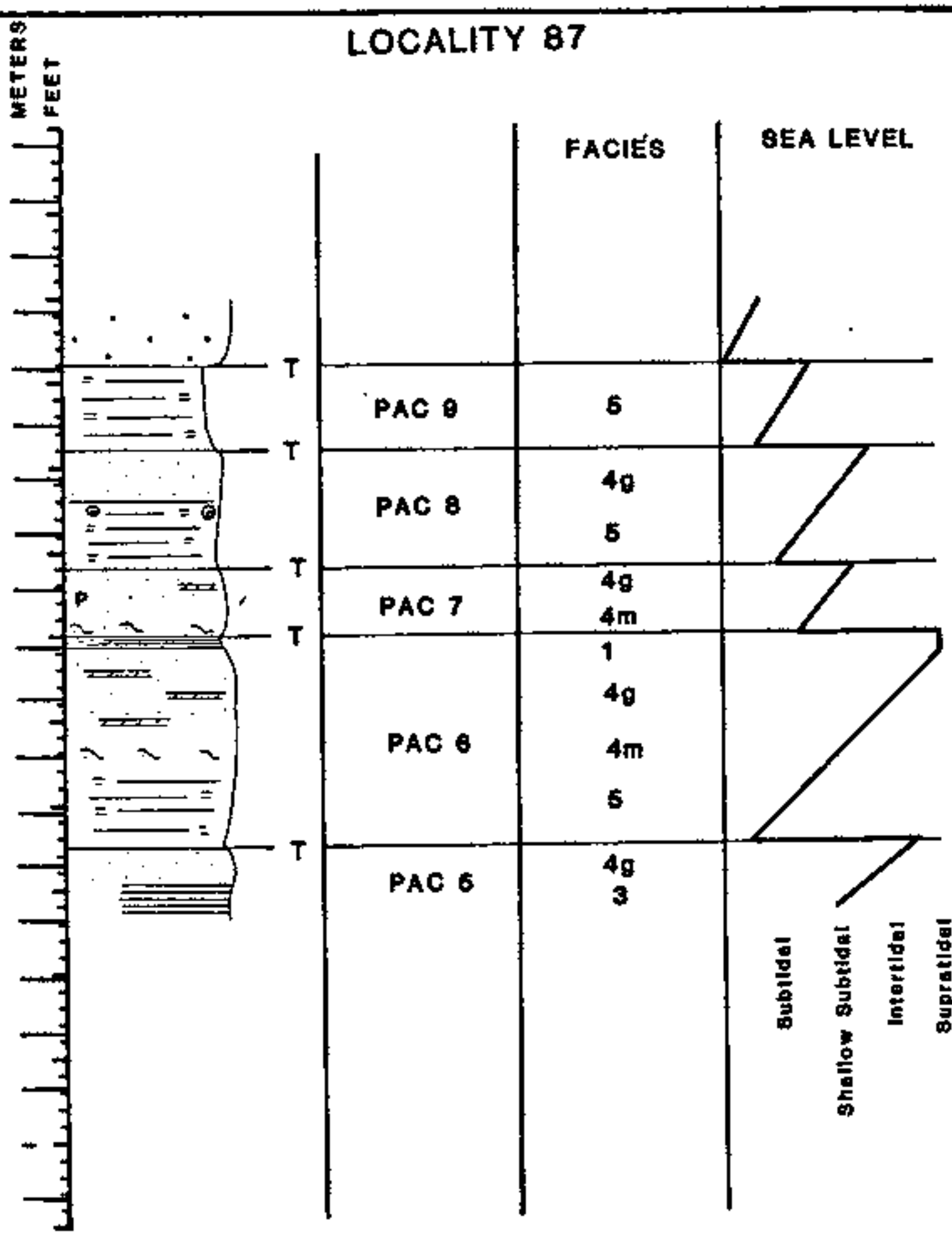


FIGURE 39: PAC interpretation of Locality 87.

energy, shallow subtidal environment). These rocks are overlain by a thin, 15 cm, occurrence of Facies 1 (supratidal environment). This PAC records the shallowing of environments from a relatively open, low energy, subtidal environment, to a shoal water environment, to a supratidal environment.

PAC 7 - PAC 7 is 1.22 meters thick (4 feet) and consists of the fine-grained pelletal calcarenites of Facies 4. This PAC begins at a deepening surface over supratidally deposited rocks of PAC 6. It grades upward from bioturbated pelmicrites (containing ostracodes and spiriferids) to a current laminated, ostracode bearing pelsparite. This PAC represents shallowing from a shallow or restricted environment to a shoal water environment.

PAC 8 - The base of PAC 8 contains fossiliferous, calcareous shale rich Facies 5 and grades upward into fine-grained pelletal Facies 4. This facies transition represents a shallowing from a low energy, subtidal to a current agitated shoal water environment.

PAC 9 - PAC 9 is composed of 1.5 m of Facies 5. This PAC begins at a deepening surface between Facies 4 of PAC 8 and Facies 5 of PAC 9. PAC 9 is overlain by a transgressive surface and Favosities and Gypidula bearing crinoidal calcarenites of the Coeymans Formation. This PAC represents the deposition of calcareous sediment in a subtidal environment until sedimentation was interrupted by the deepening event at the base of the Coeyman Formation.

Locality 94

Locality 94 is located in a roadcut along the road to Cherry Valley, N.Y. just north of Route 20. Fourteen meters of the Thacher Member are exposed here. The member has been sub-divided into 8 PACs (Figures 40 & 41). At least 6 meters of the Coeymans Formation are also exposed.

PAC 2 & 3 - The upper portion of PAC 2 is exposed at the base of the outcrop, and it is composed of dolomitic algal laminites. These rocks are overlain by micritic rocks at the base of PAC 3 (0.8 meters) which grade upwards into Facies 1. This PAC represents shallowing from restricted subtidal to supratidal.

PAC 4 - PAC 4 is 2.3 meters thick (~ 7.5 feet) and is composed of Facies 4 calcarenites with abundant clotted algal heads. This PAC is capped by a thin (0 to 15 cm) discontinuous micrite bed. Overlying this bed are subtidally deposited, bioturbated biomicrites of Facies 4. This PAC records deposition in a shallow subtidal to intertidal environment.

PAC 5 - PAC 5 is 2.9 meters thick (9.5 feet) and begins at the contact (deepening surface) with the underlying PAC. The lower 1.5 meters is composed of fossiliferous, current-bedded limestone (5 cm thick beds)

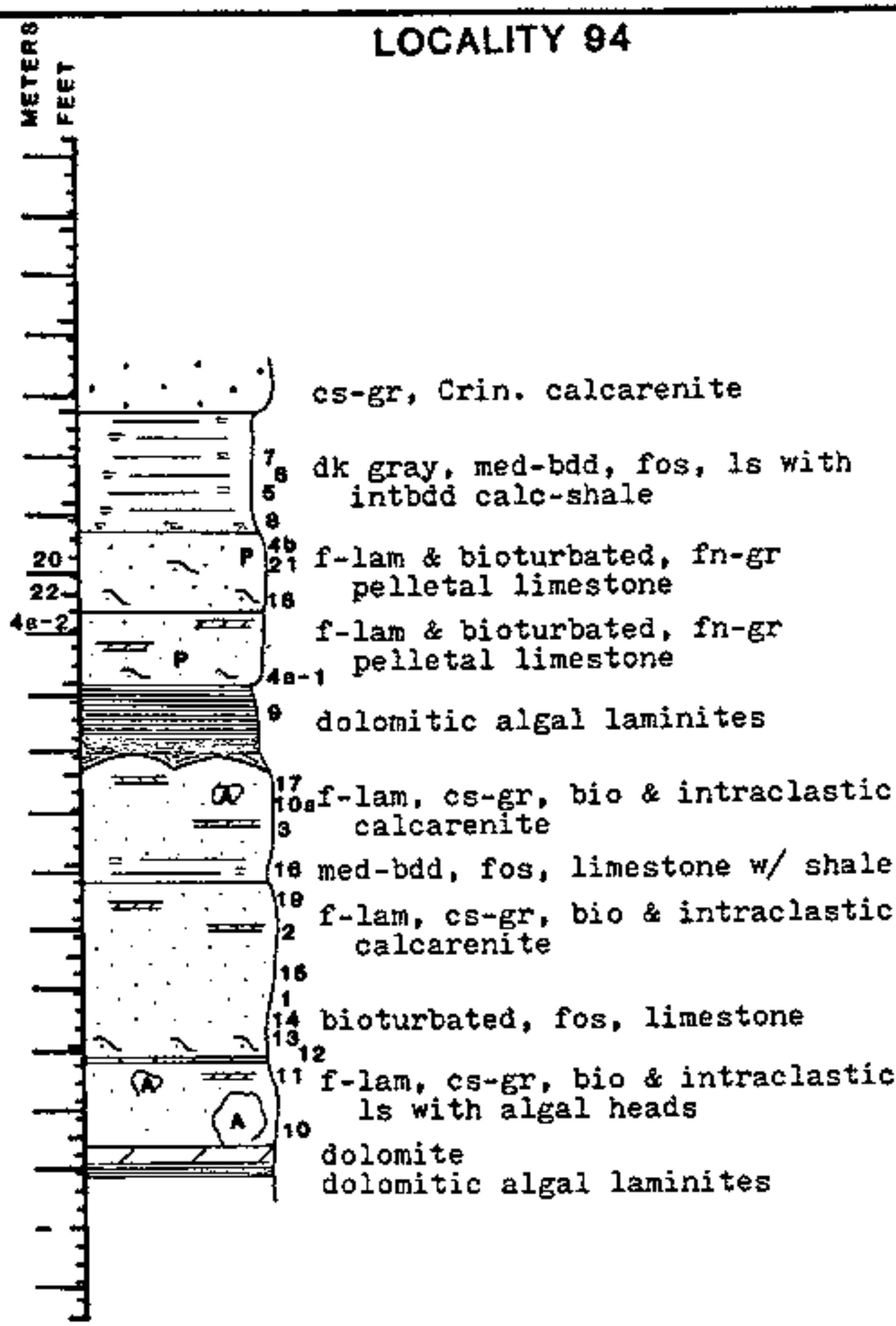


FIGURE 40: Outcrop description of Locality 94.

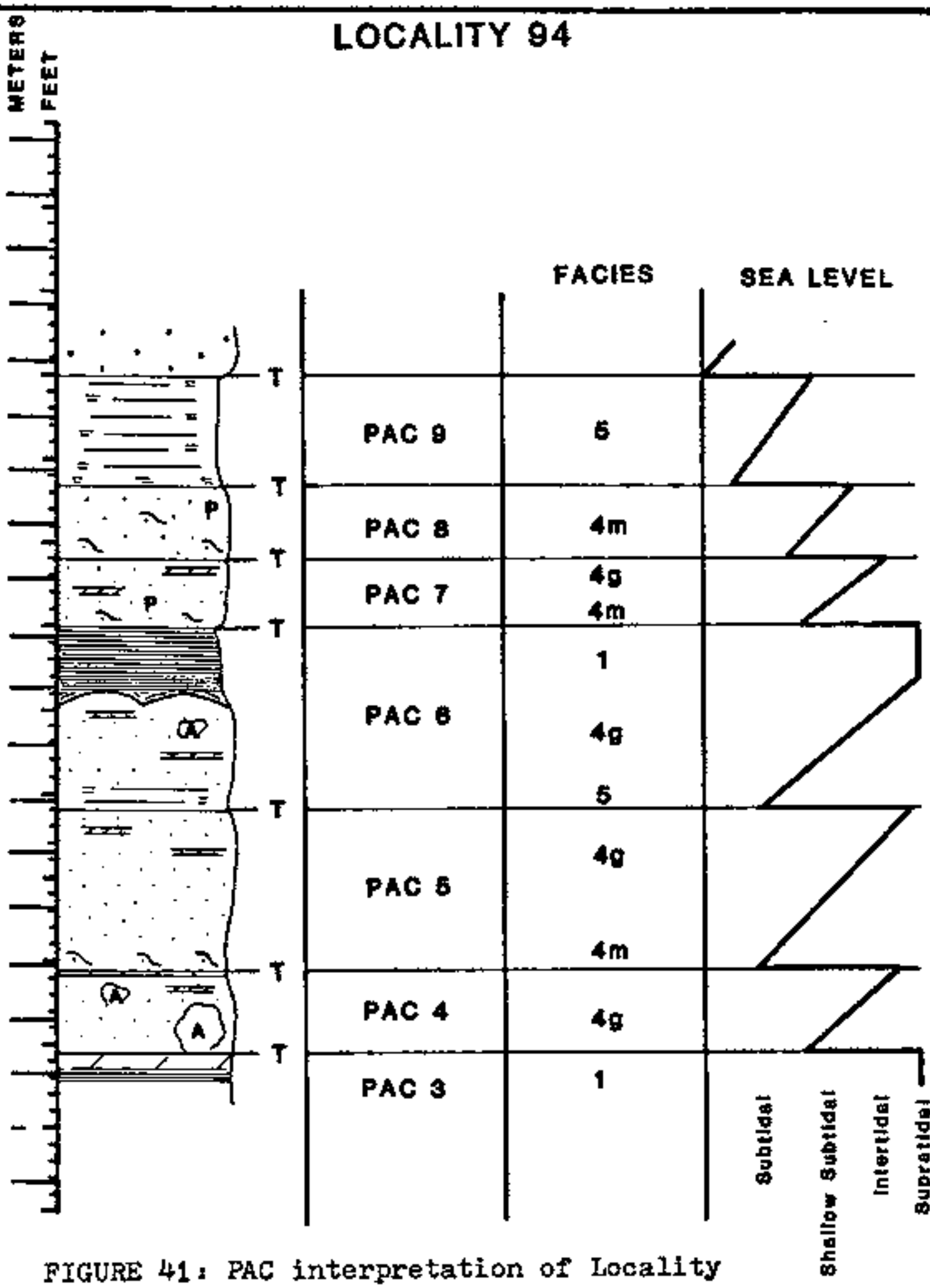


FIGURE 41: PAC interpretation of Locality 94.

containing Tentaculitids and spiriferid brachiopods which is overlain by 1.4 meters of current laminated, bioclastic and intraclastic limestones containing clotted algal heads and digitate stromatolites. This PAC records a shallowing from subtidal environments to shallow subtidal and intertidal environments.

PAC 6 - PAC 6 is 3.35 meters thick and is capped by a prominent, 1.37 meters thick, mudcracked, dolomitic, algal laminite bed. This PAC has been discussed in detail in the introduction to the Outcrop Analysis portion of this report (see Figure 18).

PACs 7 & 8 - PACs 7 and 8 are both dominated by the pelletal calcarenite subfacies. PAC 7 is about 1.2 meters thick (4 feet) and begins at a deepening surface over the supratidally deposited rocks at the top of PAC 6. Over the deepening surface there is bioturbated pelletal mudstone (pelmicrite) and wackestone (poorly washed pelsparite) that contains several ostracodes and high spired gastropods. These rocks grade upwards into parallel laminated, current washed, pelletal grainstone (pelsparite). These facies transitions represent a shallowing from a faunally restricted subtidal environment to a shallow subtidal or intertidal environment. PAC 8 is 1.37 meters thick (4.5 feet) and repeats the facies pattern exhibited by PAC 7.

PAC 9 - PAC 9 is ~ 2.1 meters thick and begins at a deepening surface which initiated the deposition of strophomenid rich Facies 5 limestones. The Facies 5 rocks grade upward into current washed,strophomenid/crinoidal calcarenites which are massively bedded. This represents a deepening over the restricted facies within the underlying PAC and a shallowing from a shale rich, relatively quiet water Facies 5 rock to current washed shoal facies exhibited by the strophomenid/crinoidal calcarenite.

Locality 106-b

Locality 106-b occurs in a farmers hillside quarry 1.1 miles north of Van Hornesville, N.Y. (Rickard, 1962). Approximately 9.5 meters (31 feet) of the Thacher Member are exposed at this locality and the Coeymans Formation is poorly exposed within the hillside pasture (Figures 42 & 43).

PACs 4, 5 & 6 - PACs 4, 5 and 6 exhibit similar internal characteristics. The upper portion of PAC 4 is exposed at the base of the quarry and it is composed of bioclastic and intraclastic coarse-grained calcarenites containing clotted algal heads. This calcarenite is overlain by PAC 5 (3 meters thick) which consists of fossiliferous micritic Facies 4 (faunally unrestricted endmember) grading upwards into bioclastic and intraclastic calcarenite with clotted algal heads and

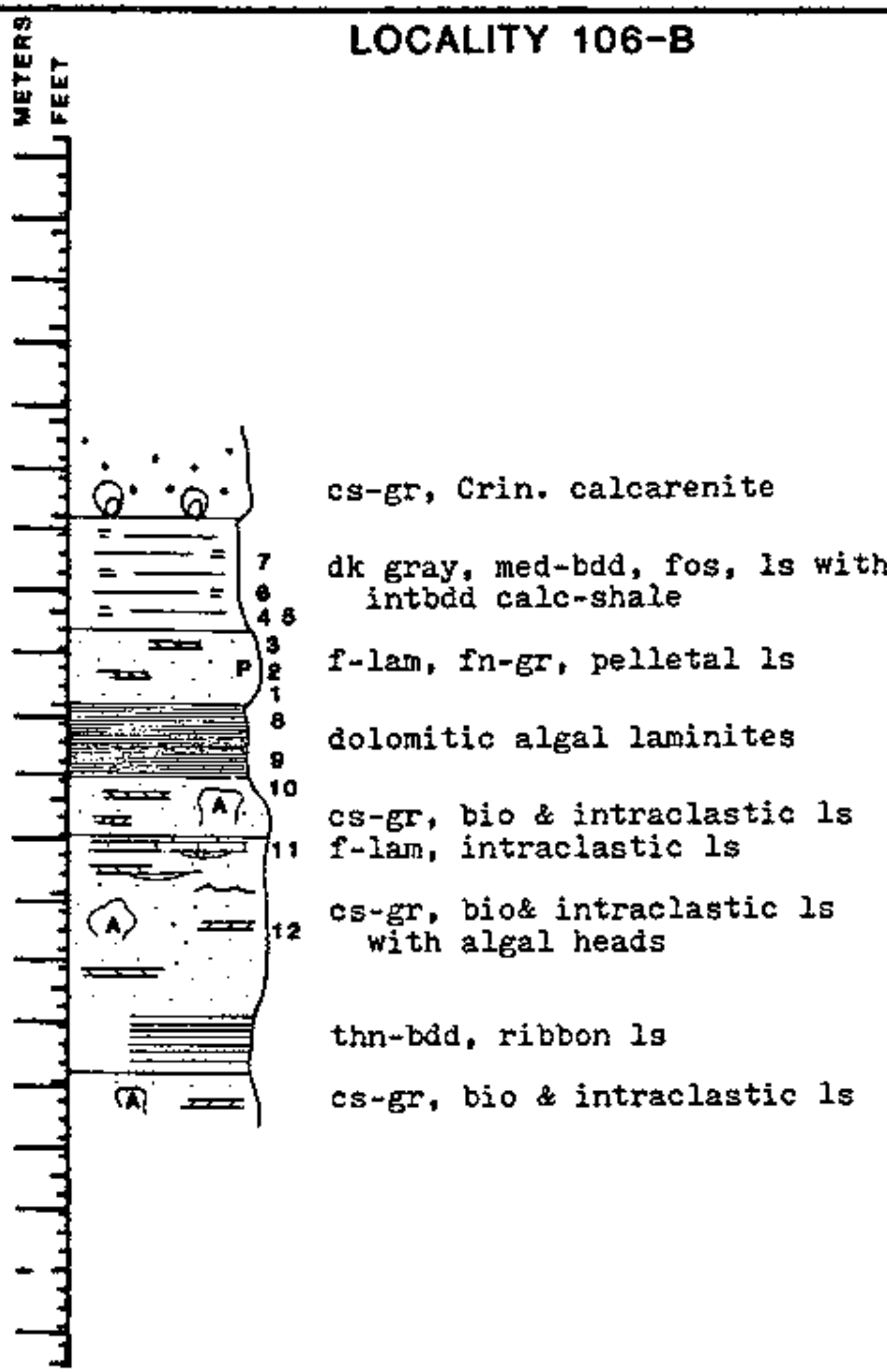


FIGURE 42: Outcrop description of Locality 106-b.

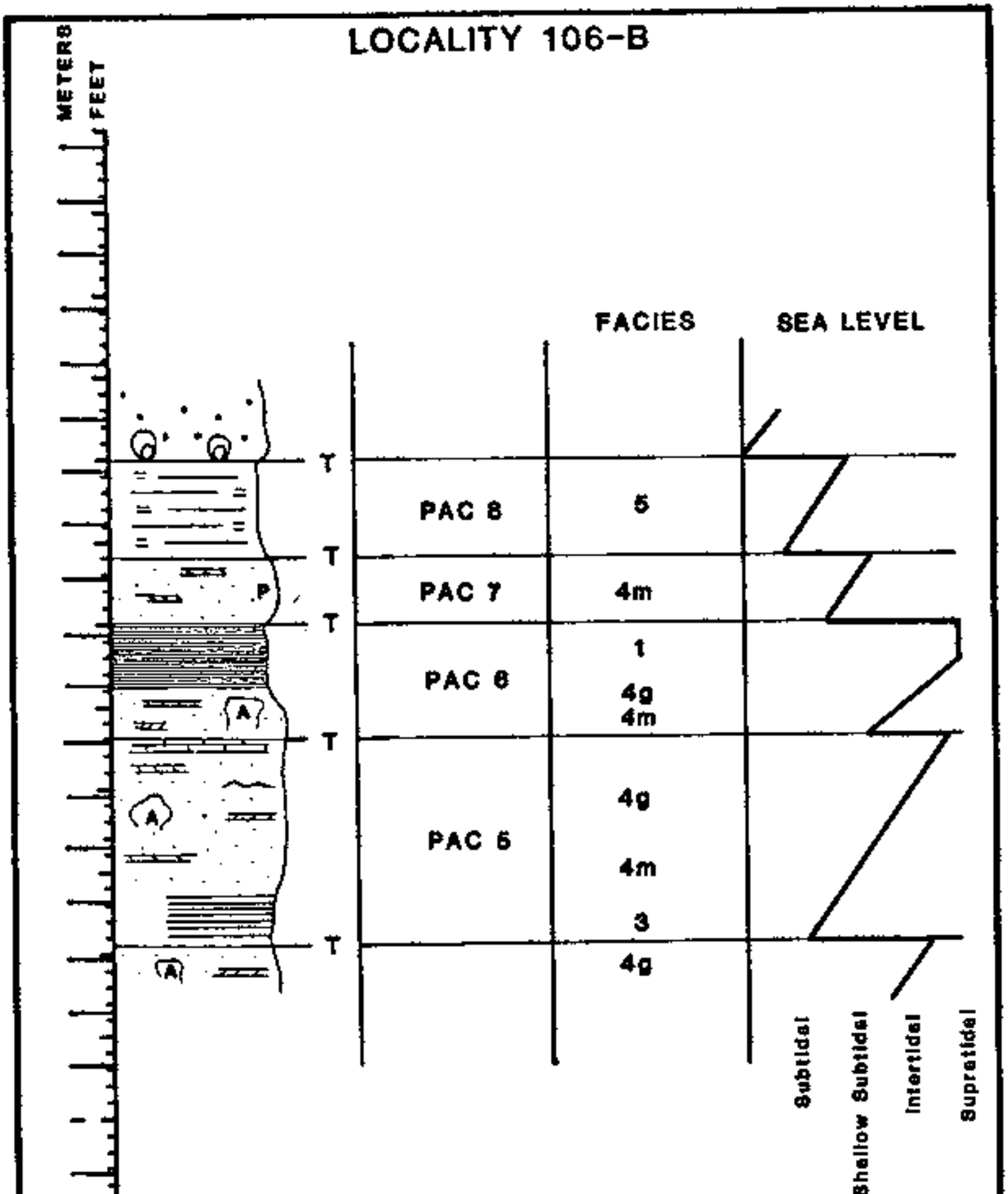


FIGURE 43: PAC interpretation of Locality 106-b.

digitate stomatolites. PAC 6 has identical facies transitions, except that the top of PAC 6 consists of 1 meter of dolomitic algal laminites. These PACs all record a shallowing pattern of deposition after nondepositional deepening events. Each PAC aggrades from subtidal to shallow subtidal or intertidal environments, and in the case of PAC 6, aggradation continued into the supratidal environment.

PAC 7 - PAC 7 is composed of ostracode bearing pelletal calcarenites of the faunally restricted endmember of Facies 4. Overlying PAC 7 are stromatoporoid bearing, fossiliferous, medium-bedded limestones of Facies 5. The pelletal calcarenites are bounded above and below by deepening contacts. PAC 7 records restricted subtidal deposition after a deepening event and continued deposition of pelletal lime mud (until the deepening event which initiated the deposition of Facies 5).

PAC 8 - PAC 8 is composed of stromatoporoid bearing, medium-bedded rocks of Facies 5 and is 1.7 meters thick. PAC 8 is overlain by coarse-grained stromatoporoid bearing crinoidal calcarenites of the Coeymans Formation. PACs 9 and 10 occur within the Coeymans Formation at this locality. PAC 8 records deposition within a relatively unrestricted subtidal environment until the deepening event which initiated Coeymans facies deposition.

Outcrop Analysis Summary

Punctuated Aggradational Cycles have been defined at each locality of the Thacher Member. Unlike the upward-shallowing cycles described by Read (1973), Aitken (1966) and James (1979) the Manlius Formation cycles cannot be defined by a unique, ideal cycle. The cycles vary in character,laterally across the outcrop belt. For example the cycles of the Schoharie Valley (Localities 70, 72-b & 74) are dominated by Facies 5 and the shallow subtidal shoal endmember of Facies 4, while the cycles of eastern sections are dominated by Facies 1, 2 and 3. The cycles also vary in character vertically. For example the PACs lower in each section are dominated by Facies 1 and 3 while PACs higher in each section are dominated by Facies 2, 4 and 5.

CORRELATION

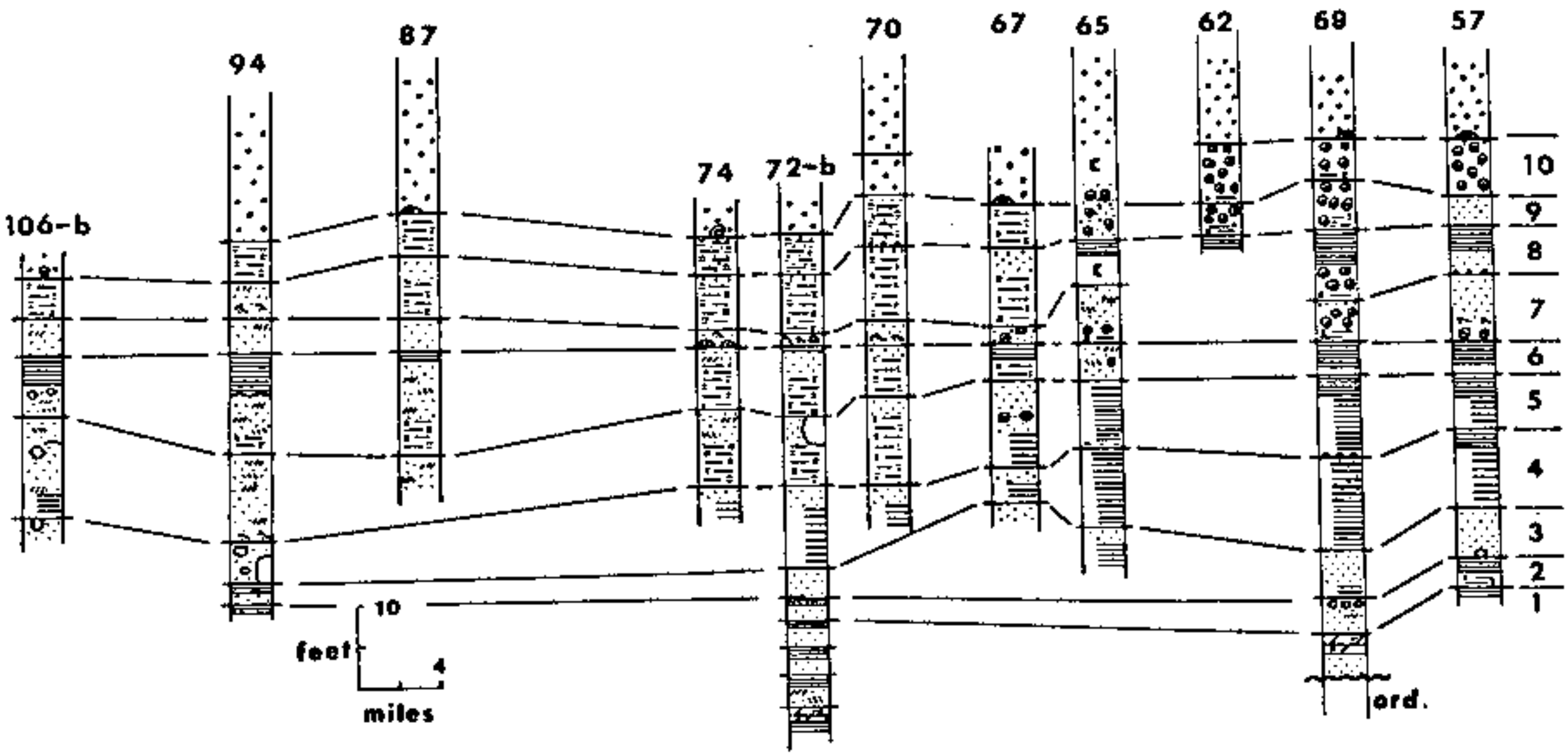
Punctuated Aggradational Cycles are lithologically defined, time-stratigraphic units bounded by isochronous deepening surfaces of at least basin-wide extent (Goodwin & Anderson, 1980). As such, these units should be correlatable across the sedimentary basin in which they occur. In this study I have established detailed correlations of 8 PACs of the Thacher Member over a distance of 80 kilometers (Figure 44). From Figure 44 it may be seen that 8 PACs (PACs 2-9) can be correlated from localities 57 to 94. Only PACs 3 through 8 occur entirely within the Manlius Formation. PAC 2 grades laterally from the Manlius Formation into the Chrysler Formation. PACs 9 and 10 grade from the Manlius Formation into the Coeymans Formation.

Several criteria were employed to derive these correlations:

1) Stratigraphic marker beds were traced between outcrops. The matching of similar lithologies indicates that these facies were deposited under similar environmental conditions. Although facies may be laterally persistent, it does not necessarily indicate that the rocks were synchronously deposited. The dolomitic algal laminite, tentaculitid-bearing ribbon limestone, coarse-grained calcarenites, and medium-bedded limestone lithosomes were used as stratigraphic markers.

Figure 44: Correlation of Thacher Member PACs.

Correlation of PACs



2) Individual PACs were traced between outcrops by matching similar PAC characteristics (e.g. thickness, internal facies type, internal facies transitions, and the relative magnitude of the deepening event which bounds the PAC). Since PACs are bounded by isochronous surfaces, a PAC then represents deposition within a definite period of time. Hence, a PAC is a time-stratigraphic unit.
3) Correlation was also attained by matching of deepening and shallowing trends in groups of PACs. It has been shown that a stratigraphic column made up of a series of PACs exhibits deepening and shallowing trends (Anderson & Goodwin, 1983). This is evidenced in the Manlius Formation by the shallowing trend from the Olney Member into the Elmwood Member (Lee, 1981 and Busch 1981) and the deepening trend from the Clark Reservation to the Jamesville Member of the Manlius Formation to the Deansboro Member of the Coeymans Formation (Goodwin & Anderson, 1980b).
4) Major vertical facies changes at PAC transgressive surfaces indicate major deepening events. These major deepening events can be recognized throughout the basin and serve as horizons for correlation.

Specifically, the first two methods of correlation by tracing key beds, similar facies and similar PACs were used between localities 57, 59, 62, 65 and 67 (Figure 33). Correlation of PACs 5, 6 and 8 was accomplished by matching the occurrences of dolomitic algal laminite beds, thin-bedded ribbon limestones (PACs 4 and 5) and by matching PACs with similar internal facies transitions (e.g. PACs 3, 4 and 6). A similar method of correlation was applied to the closely spaced outcrops in the Schoharie Valley (localities 70, 72-b and 74). In this case occurrences of ribbon limestone (PAC 4), massive-bedded, coarse grained calcarenites and medium-bedded limestones were matched (PACs 4, 5, 6, 8 and 9). Localities 87 through 106-b were correlated on the algal laminite lithosome which is present in the western Helderberg sections (Rickard, 1962). Other factors used in the correlation of these outcrops were the lithologic similarity and internal facies consistency between PACs 5, 6, and 7. In all of these localities the number of PACs is identical and the position of facies within them matches precisely.

The larger scale correlations necessary to correlate across the entire study interval were accomplished by matching major deepening events and defining deepening and shallowing trends. PACs 1 & 2 are the uppermost portion of a shallowing trend which started in the Chrysler Formation. PACs 3 to 6 record a deepening (PACs 3 & 4) and shallowing trend (PACs 5 & 6). PACs 7 to 10 record a deepening trend into the Coeymans Formation. This trend was interrupted by westward progradation of supratidal facies at the top of PAC 8 in the area east of Locality 65.

The deepening event which initiated PAC 4 was a major event. Prior to the deposition of PAC 4 the facies were dominated by the stromatolitic, coarse-grained calcarenites of Facies 4 and dolomitic cryptalgal laminites of Facies 1. Low-diversity faunas prior to PAC 4 consisted almost entirely of Hermannina alta and blue green algae (stromatolites, algal heads and algal laminites). The deepening event at the base of PAC 4 initiated the first occurrence of ribbon limestones (Facies 3). This was deposited at localities 57 to 74. Only at locality 94 does PAC 4 contain facies typical of earlier deposition as is evidenced by the occurrence of Facies 4 intraclastic and bioclastic grainstones with algal heads in PAC 4 at Locality 94. A major faunal change accompanied this event. A diverse assemblage which includes tentaculitids, a spiriferid brachiopod, bryozoans, and several ostracodes was established over the whole study area except at the westernmost localities.

A shallowing sequence of PACs is recognized at each locality after the deepening trend beginning in PAC 3. This shallowing trend encompasses PACs 5 and 6. The presence of a nearly continuous lithosome of dolomitic cryptalgal laminites at the top of PAC 6 indicates that the basin of deposition along the outcrop belt aggraded to the supratidal environment by the time the upper portion of PAC 6 was deposited.

A second major deepening event which occurs at the base of PAC 7 begins a deepening trend which continues into the Coeymans Formation. This deepening event initiated subtidal deposits over the entire study area. Significant stromatoporoid accumulations appear for the first time in the eastern area of the Helderberg basin. All Manlius Formation deposition occurred in subtidal environments after this deepening event except above the stromatoporoid buildups at localities 57, 59 and 65 in PAC 8. Over Facies 2 rocks of PAC 8, supratidal Facies 1 deposits formed indicating that the sediments aggraded to sea level quickly. Otherwise all post-PAC 6 Manlius Formation deposition occurred in the subtidal environment, and the facies indicate that a deepening trend continued into the Coeymans Formation.

The correlations proposed in this study would change Rickards (1962) correlations by moving the rocks east of the Schoharie Valley upward approximately 15 feet relative to the rocks along the remainder of the Helderberg cross section. Rickard (1962) correlated the uppermost occurrence of Facies 1 in the east with the only Facies 1 occurrence in the west. This study correlates the next lower occurrence of Facies 1 rocks in the east with the Facies 1 lithosome in the west.

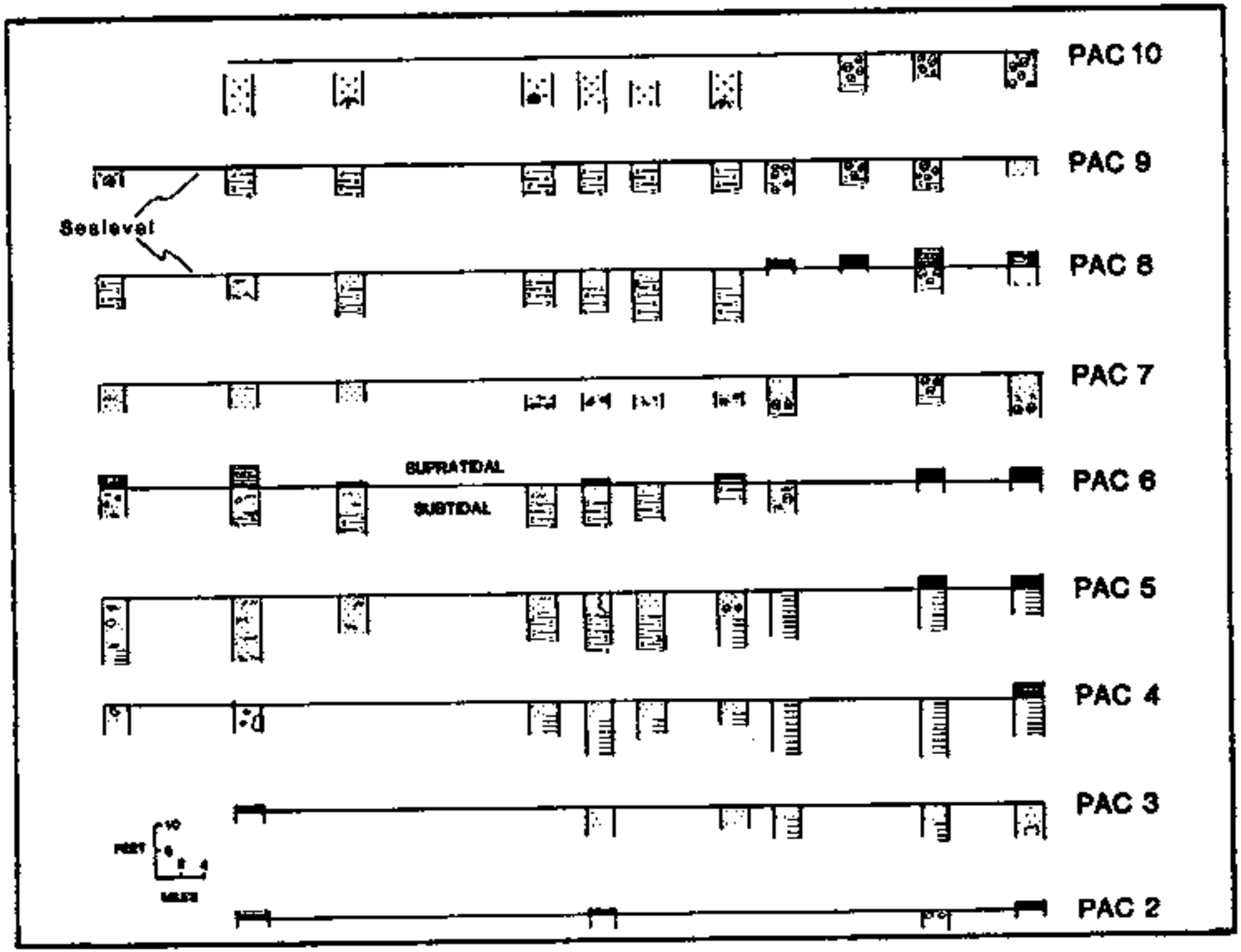
In summary it is possible to correlate a series of 8 PACs (PACs 2-9) within the Thacher Member throughout the study area. It is also possible to recognize and correlate two major deepening events and a shallowing trend of PACs. It is also possible to trace PAC 2 laterally from the Thacher Member of the Manlius Formation into the Chrysler Formation. PACs 9 and 10 can be traced from the Manlius Formation into the Coeymans Formation. These correlations form the basis for interpreting the detailed paleoenvironments and paleogeography and for understanding basin dynamics.

PALEOGEOGRAPHY

A corollary to the PAC Hypothesis is that each PAC represents a distinct paleogeographic pattern which developed following a rapid deepening event. Each of these rock units consists of a facies mosaic representing the paleoenvironmental patterns which developed and evolved by aggradation during a period of relative base-level stability. Therefore a paleogeographic analysis of the facies mosaic within each PAC may yield information about water depth, topography and specific paleoenvironments. For instance, the thickness of rock below the lowest occurrence of supratidal deposits should be an indication of the depth of deposition for that rock not including factors for mechanical compaction, pressure solution and superimposed subsidence during deposition of a PAC. The paleogeography of the facies mosaic of each PAC may be inferred from Figure 45 which shows each PAC separated from the other cycles at each locality.

PACs 1 and 2 are dominated by the supratidally deposited dolomitic cryptalgal laminite facies. PACs 1 and 2 occur within the upper portion of the Chrysler Formation. Based on the facies of the Chrysler and Cobleskill Formations these PACs appear to be the top of a shallowing trend of PACs which was initiated at the time

Figure 45: Paleogeography of Thacher Member PACs.


PAC 10
PAC 9
Sealevel
PAC 8
PAC 7
SUPRATIDAL
SUBTIDAL
PAC 6
PAC 5
PAC 4
PAC 3
PAC 2

of Cobleskill deposition. PACs 1 and 2 both record aggradation to the supratidal environment from shallow subtidal facies. At the end of deposition for each PAC (PAC 1 and 2) the entire study area was covered by a broad low relief (< 1 m) supratidal flat. Only in the vicinity of Locality 59 did PAC 2 remain under more continuous influence by marine waters as is evidenced by the presence of stromatolites and clotted algal heads.

PAC 3 is generally characterized by stromatolitic, shallow subtidal deposits (Facies 4) except in the western sections in the vicinity of Locality 94 where it exhibits Facies 1 rocks. The paleogeography at the end of PAC 3 deposition along the outcrop belt includes a supratidal flat in the west which grades eastward into shallow subtidal deposition as is evidenced by the bioclastic, ostracode, oncolitic and stromatolitic Facies 4 rocks.

The base of PAC 4 is generally characterized by the restricted subtidal Ribbqn Limestones Facies (Facies 3) east of Locality 87 and by fossiliferous biomicrites of the most subtidal endmember of Facies 4. PAC 4 at Localities 59 and 65 are entirely characterized by the restricted subtidal Ribbon Limestone facies. While the Facies 3 rocks grade upward to the supratidal facies at Locality 57 and to shallow subtidal, shoal water, facies at Localities 67, 70, 72-b, 74. PAC 4 at Locality 94 exhibits shallow subtidal deposition as is evidenced by the presence of algal heads in the coarse-grained, bioclastic and intraclastic endmember of Facies 4. The paleogeography at the base of PAC 4 included relatively restricted marine conditions east of Cherry Valley and shallow subtidal deposits west of there. The paleogeography at the time of the top of PAC 4 included a supratidal flat in the vicinity of Locality 57 grading westward into restricted marine conditions (Localities 59 & 65) into shoal water conditions west of Locality 65.

Laterally PAC 5 is characterized by facies which grade from open subtidal or restricted subtidal to shoal water and supratidal deposits. The lower portion of PAC 5 indicates that the entire area along the outcrop belt was subtidal with the eastern sections recording restricted subtidal deposits (Facies 4) while the western sections (70 to 94) exhibit more open marine subtidal environments except at Locality 106-b which also records restricted marine conditions. The top of PAC 5 indicates that an eastern supratidal flat (Localities 57 & 59) graded westward into a restricted subtidal environment (Locality 65) and into then shallow subtidal, sand shoal deposits (Localities 67 to 106-b).

Laterally the facies at the base of PAC 6 grade westward from shallow subtidal to open subtidal at the base of the PAC. The top of PAC 6 grades westward and eastward from supratidal to shallow subtidal environments in the Scoharie Valley vicinity (Localities 70 to 74). The paleogeography at the base of PAC 6 was characterized by relatively open bank conditions from localities 94 to 67. These deposits graded to shallow sand shoals at Localities 106-b and 67 to thin very shallow deposits at Locality 59 & 57. At the time of the end of PAC 6 much of the study area was covered with supratidal flats. The pattern of the supratidal facies indicates island development or an irregular shoreline separated by littoral or sublittoral sand shoals.

PAC 7 is characterized by subtidal deposition everywhere. In the eastern sections stromatoporoid accumulations are present at Localities 65, 59 and 57. These grade upwards into bioclastic sand shoal deposits. In the Schoharie Valley thin accumulations of fossiliferous, micrite and pelmicrite occur indicating deposition in a normal marine, carbonate bank, subtidal environment. At Localities 87, 94 and 106-b the faunally restricted fine-grained pelletal calcarenites of Facies 4 exist indicating deposition in a restricted subtidal environment. From west to east, PAC 7 exhibits a restricted marine environment to a subtidal environment with low accumulation rates to a normal marine subtidal environment with stromatoporoid patch reef accumulations.

PAC 8 is generally characterized by subtidal deposition except in the eastern sections (Localities 57, 59, 62 and 65) where dolomitic algal laminites occur at the tops of the cycles. The base of PAC 8 is characterized by normal marine subtidal environments (Facies 2 and 5) everywhere except at Locality 94 where PAC 8 is composed of fine-grained pelletal calcarenites. At the top of PAC 8 a supratidal flat developed from Locality 57 to 65 and the rest of the study area was characterized by shallow subtidal shoal deposition.

PAC 9 is entirely subtidal grading from fine-grained pelletal calcarenites with a limited fauna at locality 57 to stromatoporoid bearing limestones (Localities 59, 62 and 65) to Facies 5 fossiliferous limestones (Localities 70 to 94) to stromatoporoid-containing crinoidal calcarenites of the Coeymans Formation at Locality 106-b. These lateral facies transitions represent gradational environments from a restricted bank (Loc. 57) to patch reefs (Loc. 59-65) to an open muddy bank (Loc. 67- 94) to agitated normal marine conditions (Coeymans Formation at Locality 106-b).

PAC 10 is entirely subtidal and grades from stromatoporoid patch reefs at Localities 57 through 62 to crinoidal mounds as is evidenced by the crinoidal calcarenites of The Coeymans Formation at Localities 65 through 106-b.

By analyzing the lateral facies and vertical patterns of facies within the PACs defined in this study several conclusions can be drawn as to basin dynamics. The general pattern of the facies within the Thacher Member indicates an overall deepening of the Lower Devonian basin as was previously noted by Rickard (1962) and Laporte (1967). Also during the time of deposition for most of the Thacher Member the Schoharie Valley area generally remained deeper as is evidenced by the preponderance of Facies 5 rocks and lack of Facies 1 rocks in vertical sequence. By defining Punctuated Aggradational Cycles within the Thacher Member it has been shown that the Basin deepened episodically rather than gradually as implied by Laporte (1967). Also by analyzing each PAC facies mosaic it is possible to interpret paleogeography, to observe depositional topography, and estimate water depth and the magnitude of the deepening events.

CONCLUSIONS

The principal conclusion which can be drawn from this study is that the Thacher Member of the Manlius Formation can be totally subdivided into a sequence of Punctuated Aggradational Cycles. Each of these PACs is characterized by a sharp basal surface which is overlain by a facies which indicates a deeper environment of deposition than the underlying lithology. Within each PAC facies grade upwards into shallower facies until deposition is interrupted by another deepening event which gives rise to a non-depositional transgressive surface marking the basal portion of the next PAC. Since each PAC is bounded by isochronous surfaces, each is a lithologically defined time stratigraphic unit (chronostratigraphic unit).

Five facies have been defined in this study. They are the Dolomitic Cryptalgal Laminite facies, the Stromatoporoid facies, the Ribbon Limestone facies, the Massive-Bedded Calcarenite facies, and the Medium-Bedded Limestone facies. These facies represent deposition in environments ranging from a supratidal algal flat environment, intertidal environments, a faunally diverse patch reef environment, a restricted subtidal environment, a sand shoal fringe to sand shoal environment, and a faunally diverse subtidal environment.

Eight Punctuated Aggradational Cycles can be traced laterally throughout the study area. Three of these PACs cross formation boundaries indicating that the environments which deposited the dolomitic Chrysler Formation coexisted with the Lower Manlius Formation environments during deposition of PAC 2 and 3. Similarly, the environments indicated by the Upper Thacher Member coexisted with the

Coeymans Formation environments (PACs 9 & 10). By applying the PAC model to these units on a wider scale, it may be possible to make precise correlations across formation boundaries.

Detailed PAC correlations indicate that the overall transgressive nature of the Thacher Member was accomplished episodically not gradually as previously interpreted by Laporte (1969). The transgressive interpretation for the Thacher Member (Laporte, 1969) implies that the accumulation of these rocks was entirely a consequence of gradually superimposing adjacent environments with time. The fact that 10 PACs have been described within the Thacher Member indicates that this overall deepening was accomplished by periodic events of deepening and stasis. Hence the gradual superposition of facies did not occur at the scale of the entire Helderberg Group (50 to 100 meters) but at the scale of PACs (1 to 3 meters).

Finally, each PAC facies mosaic exhibits an evolving paleogeography from deeper environments to shallower ones. From a paleogeographic analysis of each PAC reasonable inferences may be drawn concerning depositional topography, water depth, and areal distribution of paleo-environments. This information might prove to be very useful for petroleum reservoir prediction and analysis, especially in light of paleo-hydrologic information which can be gleaned from this information.

REFERENCES

Ahr, W.M. (1971) Paleoenvironment, Algal Structures, and Fossil Algae in the Upper Cambrian of Central Texas. J.S.P. 41:205-216.

Aitken, J.D. (1966) Middle Cambrian to Middle Ordovician Cyclic Sedimentation, Southern Rocky Mountains of Alberta. Bull. Can. Pet. Geol. 14:405-441.

Anderson, E.J. (1978) Punctuated Aggradational Cycles: The Helderberg Group Lower Devonian of New York. (Abstract) G.S.A. Abstracts with Programs, p30, N.E. Section Meeting, Boston, Mass.

Anderson, E.J. & Goodwin, P. (1980) Application of the PAC Hypothesis to Limestones of the Helderberg Group, SEPM Eastern Section Guidebook., 32p.

Bathurst, R.G.C. (1975) Carbonate Sediments and Their Diagenesis, Elsevier, New York, 658p.

Busch, R.M. (1981) Detailed Lithostratigraphy and Faunal Distribution Through a Sequence of Punctuated Aggradational Cycles (PACs) in the Manlius Fm. of Central New York State. M.A. Thesis, Temple University, Phila. Pa.

Busch, R.M. (1983) Sea Level Correlation of Punctuated Aggradational Cycles (PACs) of the Manlius Formation, Central New York. Northeastern Geology 5:82-91.

Cameron, B. & Newman, E. (1980) Punctuated Aggradational Cycles: Reinterpretation of Black River-Trenton

Stratigraphy of the Lower Mohawk Valley, N.Y. (Abs) G.S.A. Abstracts with Programs, p.28, N.E. Section Meeting, Philadelphia, Pa.

Davies, G.R. (1970) Carbonate Bank Sedimentation, Eastern Shark Bay, Western Australia. in Carbonate Sedimentation and Environments, Shark Bay, Western Australia by Logan, B.W., Davies, G.R., Read,J.F. & Cebulski, D.E. p.85-168.

Demicco, R.V. (1983) Wavy and Lenticular-Bedded Carbonate Rocks of the Upper Cambrian Conoccheague Limestone, Central Appalachians. J.S.P., 53:1121-1132.

Dunham, R.J. (1962) Classification of Carbonate Rocks According to Depositional Texture. in W.E. Ham, ed., Classification of Carbonate Rocks. Tulsa, Okla., AAPG Memoir 1, 279p.

Enos, P. & Perkins R.D. (1977) Quaternary Sedimentation in South Florida. Geol. Soc. Am. Memoir 147.

Enos, P & Perkins, R.D. (1979) Evolution of Florida Bay from Island Stratigraphy. G.S.A.Bull. 90:59-83.

Fischer, A.G. (1964) The Lofer Cyclothems of the Alpine Triassic. in Symposium on Cyclic Sedimentation. D.F. Merrian, Eds., Bull. Geol. Surv. Kansas 169:107-149.

Fisher, D.W. (1979) Devonian Stratigraphy and Paleoecology in the Cherry Valley, New York Region. New York State Geological Assoc. Guidebook, p.20-46.

Flugel, E. (1982) Microfacies Analysis of Limestone.

translated by K. Christenson, Sperlag-Verlag, New York, 633p.

Folk, R.L. (1959) Practical Petrographic Classification of Limestones. AAPG 43:1-38.

Folk, R.L. (1974) The Natural History of Crystalline Calcium Carbonate: Effect of Magnesium Content and Salinity.J.S.P. 44:40-53.

Freidman, G.M. (1959) Identification of Carbonate Minerals by Staining Methods. J.S.P. 29:87-97.

Ginsburg, R.N. (1975) Tidal Deposits: a Casebook of Recent Examples and Fossil Counterparts. Springer-Verlag, Berlin.

Goodwin, P. & Anderson, E.J. (1974) Associated Physical and Biogenic Structures in Environmental Subdivision of a Cambrian Tidal Sand Body. Jour Geol 82:7 79-794.

Goodwin, P. & Anderson, E.J. (1978) The Middle Ordovician of Penna. A Test of the Hypothesis that all Deposition Occurs as Punctuated Aggradational Cycles. (Abstract) G.S.A. Abstracts with Programs, p.45 N.E. Section Meeting, Boston, Mass.

Goodwin, P., Anderson, E.J., Busch, R.M., Rush, P. (1980) The PAC Approach to Outcrop Analysis. (Abs) N.E.GSA Abstracts with Programs., p.39, Philadelphia, Pa.

Heckel, P.H. (1974) Carbonate Buildups in the Geologic Record: A Review. in Reefs in Time And Space, Selected Examples from the Recent and Ancient.

L.F. LaPorte ed., SEPM Spec. Publ. 18, pp. 90-154.

Illing, L.V. (1954) Bahaman Calcareous Sands, A.A.P.G. 38:1-95.

Illing, L.V., Wells, A.J. & Taylor, J.C.M. (1965) Peneconteporary Dolomite in the Persian Gulf, in L.C. Pray & R.C. Murry, eds. Dolomitization and Limestone Diagenesis SEPM Spec. Publ. #13, pp. 89-112.

Irwin, M.L. (1965) General Theory of Epeiric Clear Water Sedimentation. A.A.P.G., 49:445-459.

James, N.P. (1979) Facies Models 10. Shallowing-Upward Sequences in Carbonates. in R.G. Walker, eds., Facies Models, Geoscience Canada Reprint Series #1 . p. 109-119.

Kendall, C.St.C. & Schlager, W. (1981) Carbonates and Relative Changes in Sea Level. Marine Geology 4:181-212.

Laporte, L.F. (1963) Codiacean Algae and Algal Stromatolites of the Manlius Formation (Devonian) of New York. Jour. Paleo. 37:643-647.

Laporte, L.F. (1967) Carbonate Deposition Near Mean Sea-Level and Resultant Facies Mosaic: Manlius Formation (Lower Devonian) of New York State. AAPG 51:73-101.

Laporte, L.F. (1969) Recognition of a Transgressive Carbonate Sequence within an Epiric Sea: Helderberg Group (Lower Devonian) of New York State. in G.M.

Friedman, ed., Depositional Environments in Carbonate Rocks. SEPM Spec. Publ. 14, 98-118.

Lee, R.R. (1981) Upward Shallowing Cycles (PACs) of the Olney and Elmwood Members, Manlius Formation New York. M.A. Thesis, Temple University, Phila. Pa.

Lindsay, R,F, Kendall, C.G.St.C. (1980) Depositional Facies, Diagenesis and Reservoir Character of the Mission Canyon Formation of the Williston Basin at Little Knife Field, Billings, Dunn and McKenzie Counties, North Dakota. in Halley, R.B. & Loucks, R.B. eds., Carbonate Reservoir Rocks. SEPM Core Workshop No.1. p79-104.

Logan, B.W., Rezak, R., Ginsburg, R.N. (1964) Classification and Environmental Significance of Algal Stromatolites. Jour. Geol. 72:68-83.

Logan, B.W., Davies, G.R., Read, J.F., Celbulski, D.E. (1970) Carbonate Sedimentation and Environments, Shark Bay, Western Australia, AAPG Memoir 13, 223p.

Loucks, R.G. & Anderson, J.H. (1980) Depositional Facies and Porosity Development in Lower Ordovician Ellenberger Dolomite, Puckett Field, Pecos County, Texas: in Halley, R.B. and Loucks, R.G. eds., Carbonate Reservoir Rocks. SEPM Core Workshop No. 1 p 1-31.

Middleton, G.V. (1973) Johannes Walthers Law of the Correlation of Facies. G.S.A. Bull. 84:979-988.

Meissner, F.F. (1972) Cyclic Sedimentation in Middle Permian Strata of the Permian Basin, West Texas and New Mexico; in Cyclic Sedimentation in the Permian Basin, p.203-232.

Mesolella, K.J., Robinson, J.D., McCormick, L.M., & Ormiston, A.R. (1974) Cyclic Deposition of Silurian Carbonates and Evaporites in the Michigan Basin. AAPG 58:34-62.

Perkins, R.D. & Enos, P. (1968) Hurricane Betsy in the Florida-Bahama area - Geologic Effects and Comparison with Hurricane Donna. Jour. Geol. 76:710-717.

Purdy, E.G. (1963) Recent Carbonate Facies of the Great Bahama Bank. 2. Sedimentary Facies. Jour. Geol. 71:472:497.

Read, J.F. (1973) Carbonate Cycles, Pillara Fm. (Devonian) Canning Basin, Western Australia. Bull. Can. Pet. Geol. 21:38-51.

Rickard, L.V. (1962) Late Cayugan (Upper Silurian) and Helderbergian (Lower Devonian) Stratigraphy in New York. New York State Museum and Science Service Bulletin Number 386, Albany, N.Y.

Rose, P.R. (1972) Edwards Group, Surface and Subsurface, Central Texas: Austin, Univ. Texas, Bureau Econ. Geol. Rept. Invest. 74, 198p.

Seilacker, A. (1964) Biogenic Sedimentary Structures, in J. Imbrie & N.D. Newell, eds., Approaches to

Paleoecology, New York; John Wiley, Inc. p296-315.

Shaw, A.B. (1964) Time in Stratigraphy. McGraw-Hill, Inc. New York, N.Y., 365p.

Shinn, E., Ginsburg, R.N. & Lloyd, R.M. (1965) Recent Supratidal Dolomite from Andros Island. in L. Pray & R.C. Murray, eds; Dolomitization and Limestone Diagenesis. SEPM Spec. Pub. 13, p.112-123.

Turmel, R.J. & Swanson, R.G. (1976) The Development of Rodriquez Bank, a Holocene Mudbank in the Florida Reef Tract. J.S.P. 46:497-518.

Wanless, H.R. (1981) Fining-Upwards Sedimentary Sequences Generated in Seagrass Beds. J.S.P. 51:445-454.

Wilson, J.L. (1967) Carbonate-Evaporite Cycles in the Lower Duperow Formation of the Williston Basin, Bull. Can. Pet. Geol. 15:230-312.

Wilson, J.L. (1975) Carbonate Facies in Geologic History. Springer-Verlag, Publ., New York 471p.