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Upper Mississippian to Middle Pennsylvanian stratigraphic section Pottsville, Pennsylvania

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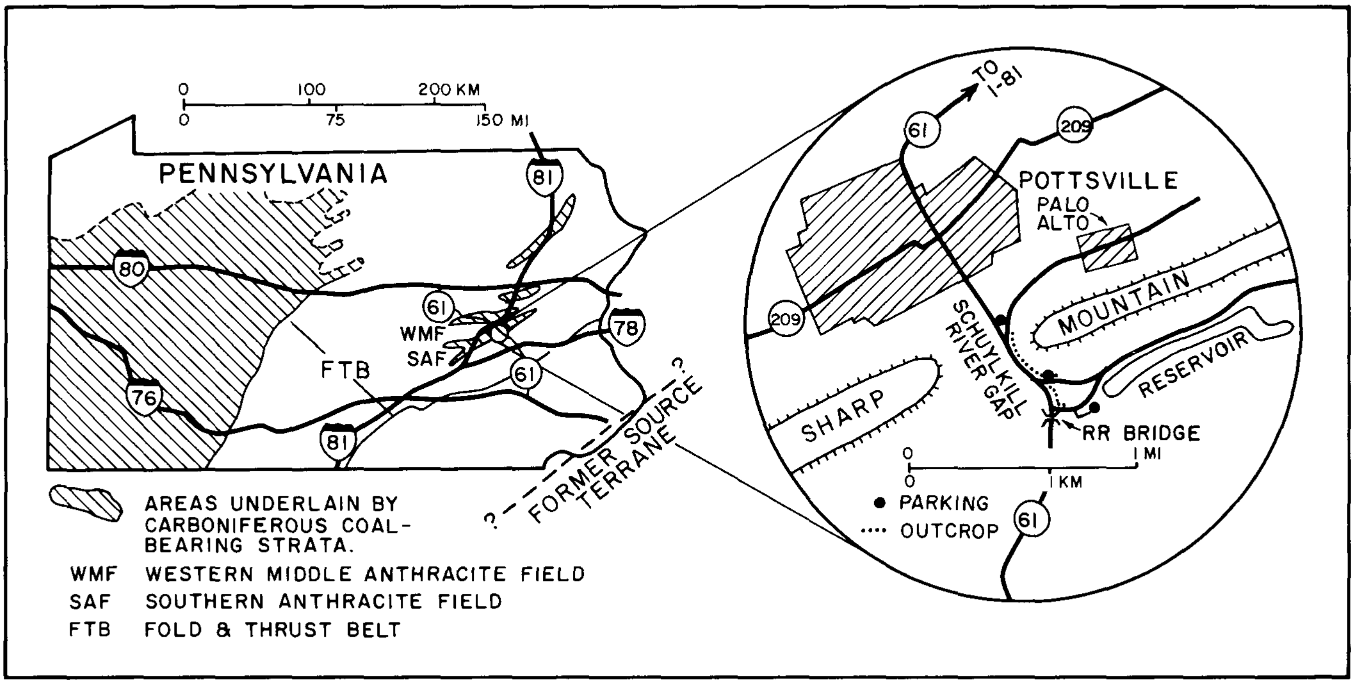

Figure 1. Key map of field locality.

LOCATION AND ACCESSIBILITY

The rocks at this site are exposed along a road cut on the eastern side of Pennsylvania 61, 0.3 to 0.5 mi (0.4 to 0.8 km) south of Pottsville, Pennsylvania (Fig. 1), on the southern margin of the Southern Anthracite field where the Schuylkill River has cut a deep gap in Sharp Mountain. Parking is available at several places, but it is advantageous to begin at the southern end of the outcrop and walk up section.

SIGNIFICANCE OF SITE

The outcrop exposes a 2,000-ft (600+-m)-thick section of upper Carboniferous molasse, representing the northwestward influx of elastic detritus into the Appalachian foreland basin from an erogenic source terrane formerly situated along the present Atlantic Coastal Plain. The alternation of facies (Fig. 2) reflects the gradual but progressive evolution of depositional environments from a semi-arid alluvial plain (Mauch Chunk Formation), to a semi-humid alluvial plain (Pottsville Formation), to a humid alluvial plain dominated by peat swamps (Llewellyn Formation).

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This transition, documented by dramatic changes in sedimentary facies, facies sequences, and maximum clast sizes, clearly reflects regional (perhaps even world-wide) climatic changes occurring near the end of the Mississippian; however, incipient Alleghanian tectonism and the evolution of many new plant groups occurring at this time may have played an influential role as well.

Subsequent to their deposition, the Carboniferous sediments were deeply buried, metamorphosed, tectonically deformed in the Alleghanian orogeny, uplifted, and largely eroded. The Southern Anthracite field now preserves the thickest, coarsest-grained, most proximal to the source, and most stratigraphically continuous occurrence of upper Carboniferous molasse in the central Appalachians.

STRATIGRAPHIC AND GEOMORPHIC OVERVIEW

Molasse sediments of the Anthracite region are stratigraphitally subdivided on the basis of grain size and predominant coloration (Wood and others, 1969). The fine-grained, red Mauch Chunk Formation (Middle to Upper Mississippian) intertongues with and is replaced by the coarse-grained, gray Pottsville Formation (Lower to Middle Pennsylvanian), which in turn gives way

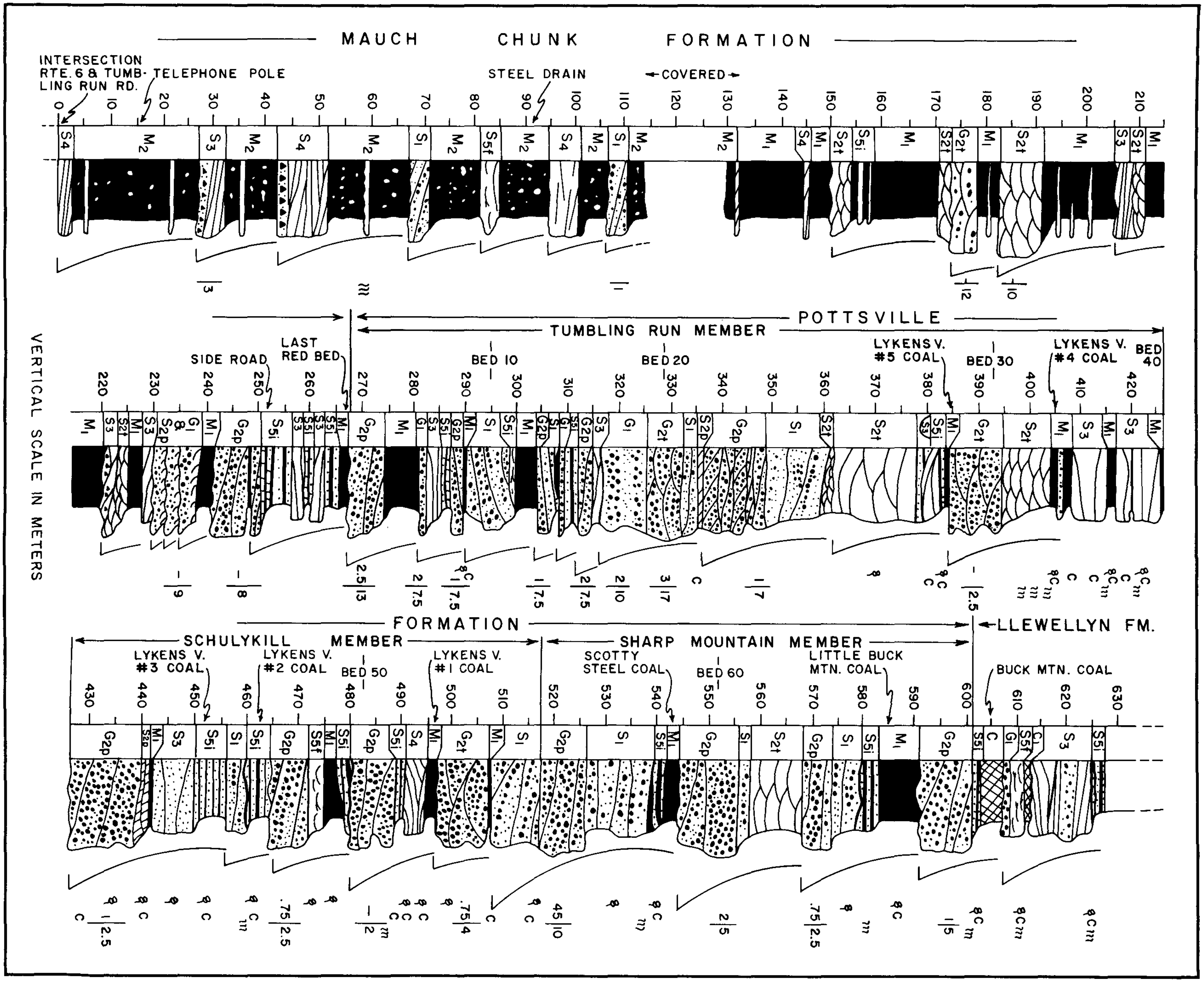
MAUCH CHUNK FORMATION
INTERSECTION RTE. 6 & TUMBLING RUN RD.
TELEPHONE POLE
STEEL DRAIN
←COVERED→
POTTSVILLE
SIDE ROAD
LAST RED BED
TUMBLING RUN MEMBER
BED 10
BED 20
LYKENS V. #5 COAL
BED 30
LYKENS V. #4 COAL
BED 40
FORMATION
LLEWELLYN FM.
SCHULYKILL MEMBER
LYKENS V. #3 COAL
LYKENS V. #2 COAL
BED 50
LYKENS V. #1 COAL
SHARP MOUNTAIN MEMBER
SCOTTY STEEL COAL
BED 60
LITTLE BUCK MTN. COAL
BUCK MTN. COAL
VERTICAL SCALE IN METERS

TABLE 1 — FACIES STATES, SEQUENCES, COMPOSITION, AND FEATURES OF POTTSVILLE SECTION.

CODE:	G_1	$G_{2T\&P}$	S_1	$S_{2T\&P}$	S_3	S_4	$S_{5F\&I}$	M_1	M_2	C
SYMBOL:		t, p		t, p			f, i			
NAME:	Crudely bedded sandy conglom.	Cross bedded sandy conglom.	Plane bedded pebbly sandst.	Cross bedded pebbly sandst.	Coarse, plane bedded sandst.	Fine, plane bedded sandst.	Flaser or interbedded sandst. & mudst.	Noncalcareous mudst.	Calcareous mudst.	Coal
COLOR:	Pale gray ss. with variegated conglom.	Dusky yellow conglom. with gray sandst.	Light olive gray	Grayish orange to pink	Pale red (Mauch Ch.) Pale olive (Pottsv.)	Grayish to pink	Gray red (Mauch Ch.) or dark gray (Pv.)	Ruddy (MC) to light brown to black (Pv.)	Ruddy to brown	Black as coal
GRAIN SIZE:	Coarse sand to pebble conglom.	Pebble conglom. to very coarse sand	Coarse to granule with pebbly stringers	Coarse to granule	Coarse to very coarse	Very fine to fine sand	Fine sand with interbed. mud	Fine clay to silt	Fine clay & silt with carbonate concretions	Finely macerated plant fragments
INTERNAL BED FORMS:	Subhoriz. interstat. coarse sand & pebble conglom. Lenticular medium - thick beds	Medium to very thick lensatic beds. Matrix supported conglom (Note 1.)	Low angle laterally contin. wedge sets Medium to thick, concave upward	Cross bedding Lg. scale trough (S_{2t}) or Sm. scale planar (S_{2p})	Decimeter - thick tabular or wedge sets. Lateral cont. to 10s of m. Mass. or par. laminated	Tab. or wedge - shape beds. Laterally extensive thin to thick parallel laminae	Small scale cross - strata with mud flasers (S_5f) or laminated w/ mud layers (S_5i)(Note 2.)	Finely laminated or rooted see Note 3.	Stratified or paleosol features (see Note 3.) M. C. only	Finely stratified but sheared during tectonic deform.
COMPOSITION MAUCH CHUNK TYPE:	(No specific data)		Maturity: mature	Monoxl quartz: 50%	Feldspar: <1%	Rock fragments plus mica. Avg. 15% Generally sedimentary or low - grade metamorphic origin; primarily zircon & tourmaline.		90% of M. C. Shales are red beds (org. - void) Relatively Fe - rich. Clays: 80% illite; 20% chlorite; $CaCO_3$ & SiO_2 concretions in M_1.		None
PV.—LLEWELL.— TYPE:	Vein qtz > sandstone, chert, conglom., silt, and shale > low to med grade metamorph. incl: phyllite, slate and schist.		more mature	60%	<1%	(3 - 38%) Med. to high - grade metamorphic minerals first appear in upper Mauch Chunk indicating unroofing of these rocks in source terrane.		All are grey to black org. - bearing Fe - poor, Al - rich. Primarily ill. & chlor. with →40% kaol. & pyro phyllite. No caliche.		> 92% fixed carbon, dry mineral matter - free.
TYPICAL BASE:	Undulatory, sharp	Undulatory, sharp, erosive	Undulatory, sharp, erosive	Gradational from S_1 or erosive from M_1	Gradational or sharp	Sharp, planar dips to 15°	Gradational from S_1 or S_3	Gradational from S_2 or S_5	Gradational	Gradational from M_1
TOP:	Gradational	Grades to S_{2t}	Sharp, undulatory, fine - gr.	Grad. to S_5i or M_1	Grad. to S_{2t} or S_{5i}	Grad. to M_2	Grad. to S_1 or M_2	Sharp or erosive	Sharp or erosive	Eros. to G_2 Grad. to M_1
NOTES:	1. G_2 bed continuity ranges from 3m to across outcrop. Lenses subparallel to 2nd - order truncation surfaces; either laterally extensive tangential low angle (<15°) planar cross - strata (G_{2p}) or large - scale (2 - 4 m) cut - and - fill troughs (G_{2t}) 2. S_5 unit contains abundant dark brown calcareous root traces, desiccation cracks, and raindrop impressions in Mauch Chunk or plant fragments in Pottsville. 3. Paleosol features of M_1 & M_2 : In Mauch Chunk, paleosols are "vertisols" with wetting/drying features, including wedge - shaped peds, blocky joints, mud cracks, raindrop impressions, pretectonic slickensides, & caliche. Paleosols in Pottsville Fm. are "underclays" with abundant root impressions, leached clay minerals, & no bedding.									
OTHER SYMBOLS:	▲▲ Intraformational conglomerate; Calcareous concretions; Root traces; Plant fragments; C Carbonaceous; Erosional contact; 3|10 average (3) and maximum (10) clast size in centimeters; Fining and thinning upward cycle; Disconformity									
TRANSITION MATRIX SUMMARY SEQUENCES:	Mauch Chunk No. 1 $S_4 \rightarrow M_2$; Mauch Chunk No. 2 S_3, S_{2t}, S_{5i}, M_1; Pottsville $G_{2p} \rightarrow S_1 \rightarrow S_{2t} \rightarrow M_1$, $S_3 \rightarrow S_{5i}$, S_{5f}									

(Compositional information from Meckel, 1967; Wood et al., 1969; Holbrook, 1970; Hosterman et al., 1970)

to the finer-grained, gray to black, coal-rich Llewellyn Formation (Middle Pennsylvanian), representing the youngest extant molasse in the region. The former presence of many miles (kilometers) of overlying rocks is implied by the high coal rank and compaction of the Llewellyn sediments (Paxton, 1983; Levine, 1986).

The Mauch Chunk Formation is informally subdivided into three members (Wood and others, 1969). The middle member represents the 'type' Mauch Chunk red bed lithofacies. The lower and upper members represent respectively the zones of intertonguing with the underlying Pocono Formation and the overlying Pottsville Formation. The upper contact of the Mauch Chunk is defined as the top of the uppermost Mauch Chunk-type red bed (Fig. 2).

The Pottsville Formation is formally subdivided into three members (Wood and others, 1956), each representing a crudely fining-upward megacycle. Of the three, the Tumbling Run and the Sharp Mountain members are the coarser-grained, while the intervening Schuylkill Member is finer-grained and contains a greater proportion of coal. The lower contacts of the Schuylkill and Sharp Mountain members are defined at the base of major conglomeratic units. The base of the Schuylkill Member is by no means obvious at the outcrop, but the "Great White Egg" quartz pebble conglomerate at the base of the Sharp Mountain Member is very distinctive. The contact between the Pottsville and Llewellyn Formations is placed at the base of the lowermost thick, stratigraphically persistent coal horizon, the Buck Mountain (#5), which has been correlated over large areas of the Anthracite fields (Wood and others, 1963).

Chronostratigraphic age designations in the Anthracite region, based upon the 13 upper Paleozoic floral zones defined by Read and Mamay (1964; also see Edmunds and others, 1979, Fig. 11), indicate the Pottsville section is conformable, extending from Zone 3 in the upper Mauch Chunk Formation (Chesterian Series) to Zone 10 in the lower Llewellyn Formation (Des Moinesian/Missourian Series); however, Zones 7 and 8 have not been explicitly recognized at this site. The Mauch Chunk/Pottsville contact, occurring between Zones 3 and 4, corresponds roughly to the Mississippian/Pennsylvanian systemic boundary. In areas of the central Appalachians other than the Southern and

Middle Anthracite fields, Zones 4,5, and 6 are absent, suggesting the presence of a significant disconformity between the youngest Mississippian and oldest Pennsylvanian strata (see discussion in Edmunds and others, 1979).

The strata exposed at the site are slightly overturned and comprise part of the southern limb of the Minersville Synclinorium, forming the southern margin of the Southern Anthracite field. They attained their present attitude during the late Paleozoic Alleghanian orogeny when northwest-directed tectonic forces produced a progression of reformational phases that migrated northwestward across the foreland basin. At the Pottsville site all structural phases are superposed (Wood and Bergin, 1970; Nickelsen, 1979).

The structure and stratigraphy of the upper Paleozoic molasse sequence are revealed geomorphically by the relative resistance to erosion of the near-vertical component units. The Pocono sandstone, subjacent to the Mauch Chunk Formation, upholds Second Mountain, the major ridge visible to the south of the Pottsville section, The Mauch Chunk Formation underlies the valley between Second and Sharp mountains. The distinctive double ridge of Sharp Mountain is formed by the Tumbling Run and Sharp Mountain members of the Pottsville Formation. The Schuylkill River, which excavated the gap in Sharp Mountain, flows southeasterly across the Valley and Ridge Province on its course to the Chesapeake Bay, opposite to the streams that originally deposited the Pottsville sediments.

SEDIMENTOLOGY OF THE POTTSVILLE SECTION —FACIES STATES AND COMPOSITION

Sedimentary bed forms, sediment composition, facies sequences, and paleobotany reveal a significant alteration in paleoclimatic conditions across the Pottsville section, ranging from generally semi-arid, poorly vegetated conditions at the base to perennially humid, lush conditions at the top. Ten general facies have been defined at this site and are described in Table 1. Transition matrix analysis reveals two repeating motifs, one characteristic of the Mauch Chunk and one of the Pottsville. When compared to facies sequences from modern environments of deposition, the Mauch Chunk sequence is similar to that of Bijou Creek, Colorado, a sandy, braided, ephemeral stream subject to catastrophic floods (Miall, 1977). Facies S_3 and S_4 probably comprised sand flats or shallow channel deposits; S_{5i} and S_{2t} comprised waning flow deposits or overbank deposits more removed from the active channel. Ml represents intra-channel, slack water deposits and M_2 represents overbank soils.

The Pottsville sequence is similar to that produced by the Donjek River, Yukon Territory, a gravel-sand mixed bedload, perennial braided stream (Miall, 1977). Facies G_2, S_1, and S_3 formed in the lower parts of the active channels by longitudinal braid bar migration. Facies S_{2t} and S_{5t} formed in the upper parts of active channels or minor channels and on the tops of braid bars. Facies S_{5i} and Ml formed on bar tops, abandoned channels, and overbank areas, and facies C was deposited in inter-channel swamps. The channels forming the Pottsville Formation were deeper with greater cross-sectional areas, and lower width/depth ratios than those forming the Mauch Chunk Formation. In consequence, maximum clast size is greater as is the thickness of cross-bed sets.

Sandstone petrology, organic matter content, clay mineralogy, and features of the paleosols (Table 1) all show a progressive trend to more highly leaching, less oxidizing (i.e., more humid) conditions higher in the section. Sandstones are compositionally mature throughout the section but become even more mature up section. The Tumbling Run Member of the Pottsville Formation contains the highest variety and proportion of non-quartzose fragments while the Sharp Mountain Member contains the highest proportion of vein quartz (Meckel, 1967). Preservation of organic matter in the upper part of the section implies conditions of low Eh, maintained by continuous saturation by stagnant or slowly moving water. Clay minerals are enriched in alumina and depleted in iron higher in the section indicating a greater degree of chemical and biological leaching.

Paleosols occurring throughout the section are particularly useful in revealing paleo-environmental conditions. Most paleosols of the Pottsville and Llewellyn Formations formed as underclass beneath peat swamps and, therefore, must have been water-saturated during most of their development. In contrast, paleosols of the Mauch Chunk Formation, classified as vertisols by Holbrook (1970), exhibit a variety of features indicating episodic wetting/drying cycles (Table 1).

Caliche, occurring as thin, bed-parallel laminae or in nodular layers less than 3 ft (1 m) in thickness is common in the middle member of the Mauch Chunk (Fig. 2) and occurs occasionally in the upper member. Caliche forms in seasonally arid conditions when surface evaporation produces supersaturation of dissolved salts, especially calcium carbonate and silica. The laminar caliche is interpreted to have formed at the sediment surface in shallow ponds during evaporative cycles (Holbrook, 1970). A surface or near-surface origin is indicated for the nodular caliche as well (Holbrook, 1970) based on: (1) sedimentary laminations that pass from the surrounding sediment into the concretions, (2) nodules occurring as intraformational clasts in conglomerates, (3) the presence of carbonate as nodules in the shales but not as cement in the adjacent sandstones, and (4) ball and pillow structures occurring between the nodules and the underlying (but not the overlying) sediments.

The composition of the organic matter and clay minerals has been strongly influenced by diagenetic conditions during burial. The coal has been elevated to anthracite rank. Expandable layer clays are not present and illite is of the highly ordered 2-M form, representing “anchizone” alteration. Pyrophyllite is an anchizone alteration product of kaolinite that forms only in Fe-depleted rocks (cf., Hosterman and others, 1970, Table 1). Ammonium illite is thought to form at high coal rank in organic matter–rich sediments by nitrogen released during late stages of coalification (Paxton, 1983). These transformations imply temperatures of ca. 225-275°C and 4 to 6 mi (6 to 9 km) of burial.

TECTONIC SIGNIFICANCE OF THE POTTSVILLE SECTION

During deposition of the Pottsville section the depositional margin of the basin lay in the vicinity of Philadelphia as indicated by paleocurrent directions and regional trends in maximum grain size (Pelletier, 1958; Meckel, 1967; Wood and others, 1969). Northeast-flowing streams carried sediments toward the basin axis, which trended northeast-southwest across western Pennsylvania. Time equivalent upper Carboniferous rocks are alluvial in eastern Pennsylvania and deltaic and shallow marine to the west (Edmunds and others, 1979). The Mauch Chunk Formation documents a relatively quiescent interval represented variously by fine-grained sedimentation and soil development in the east, an erosional disconformity toward the west, and shallow marine carbonate sedimentation along the basin axis. The influx of coarse elastics in the Pottsville interval has traditionally been ascribed to tectonic uplift in the source (e.g., Meckel, 1967), but while this might be partly true, it is neither a necessary nor sufficient explanation. The simplest explanation is that the change to more humid climatic conditions in the Pennsylvanian produced larger sediment yields and stream discharges. The continued influx of elastic sediments would represent isostatic unloading of the Acadian source terrane.

An additional factor influencing the stratigraphic succession may have been the diversification and proliferation of terrestrial plants during the middle Carboniferous. Plant evolution could have helped to stabilize stream banks, allowed peat accumulation rates to equal or exceed basin subsidence, and influenced climatic patterns.

The intertonguing of Mauch Chunk and Pottsville facies in the upper member of the Mauch Chunk clearly indicates an alternation of depositional environments, but it is problematical whether this represents the lateral migration of two co-existing subenvironments in the sense of Walther's Law, or the sedimentological adjustment of an entire depositional system to cyclic climatic changes. In the former case, the Pottsville Formation would represent a higher elevation, proximal, more humid facies and the Mauch Chunk a more distal, flood basin facies, subject to wetting more by flooding than by rainfall.

The interpreted tectonic and paleoenvironmental setting during Mauch Chunk deposition would have resembled in many respects the current alluvial plain extending from the Zagros Mountains to the Persian Gulf where arid conditions produce little clastic influx from the tectonically active mountain belt. The adjacent foreland basin axis—lying parallel to the mountain belt—receives primarily carbonate sedimentation. Were a future global climatic change to transform the Middle East into a humid region, the margins of the Persian Gulf could perhaps evolve into a broad peat-forming environment such as existed in the Appalachian basin during Pottsville and Llewellyn times.

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