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Geology of the Oquirrh Mountains, Utah

by Edwin W. Tooker

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Abstract

The Oquirrh Mountains are located in north-central Utah, immediately south of the Great Salt Lake, in the easternmost part of the Basin and Range physiographic province. The range consists of northerly-trending aligned peaks 56 kilometers long flanked on the west by Tooele and Rush Valleys and on the east by Jordan and Cedar Valleys. The range hosts several of the more prominent base- and precious-metal and disseminated-gold mining areas in the western United States. The 130-year old Bingham porphyry copper mining district, which is of world-class magnitude in the central part of the range, is still active. The Mercur mining district, which has recently become inactive, was one of the first of the new-type disseminated gold deposits; the Ophir and Stockton base- and precious-metal mining districts are inactive at present. The newest active mining areas in the range are the Barneys Canyon and adjoining Melco disseminated gold deposits, considered to be part of the Bingham mining district by the operator. The Oquirrh Mountains and its flanks also contain a number of industrial mineral resources useful in the infrastructure construction and the smelting industries. Here-to-fore, much information about these mining areas is scattered in numerous publications and has not been placed in a current geologic framework that permits construction of a unified regional deposit model of use in further exploration in the range and elsewhere. This report summarizes regional geologic data as a basis for added resource perspective, identifies as yet unresolved controversial geological interpretations, and is a platform on which to frame future geologic research and exploration. A geologic map of the range (Tooker and Roberts, 1998) is available at a scale of 1:50,000 .

The present stratigraphic and structural regime, and the siting of the mineral deposits in the Oquirrh Mountains are the result of a long geologic history. An underlying Precambrian craton consists of a Proterozoic terrane believed to be accreted onto an Archean terrane along a basement suture zone called the Uinta trend. This zone is recognized by its Paleozoic stratigraphic features, evidence of intermittent local structural uplift and erosion, and an alignment of Tertiary intrusives and spatially related ore deposits.

Paleozoic sedimentary rocks were deposited in westernmost Utah and eastern Nevada on an irregular, broad, gradually-, and differentially-subsiding, shallowly-submerged craton shelf athwart the Uinta trend zone. Debris shed into two basins separated by the trend, the Oquirrh on the south and Sublette on the north, was from the craton to the east, the Antler orogenic zone on the west, and locally uplifted parts of the trend itself. The composition of the miogeoclinal sedimentary rocks varied during time as well as along the shelf, depending on the relative contributions of source sediments and structural events along the Uinta trend. In general the rocks now exposed in the Oquirrh Mountains are thick accumulations of clastic carbonaceous-quartz quartzite, shale, limestone, and dolomite of Lower and Upper Paleozoic ages. The carbonate rocks generally contain an abundant fauna of macro- and micro-fossils. A much thinner sequence of comparable rocks deposited on the craton shelf is exposed in the neighboring Wasatch Mountains to the east.

The anomalous juxtapositions of compositionally comparable thick and thin miogeosynclinal shelf rocks in the Oquirrh and Wasatch Mountains is recognized by Baker and others (1949) as the result of decollement thrust faulting during the Late Cretaceous Sevier orogeny. The Oquirrh Mountains were further deformed during the late Cenozoic extension of the area to form the Basin and Range region. The present topography of the range is the result of accelerated uplift and erosion during the Tertiary and Pleistocene.

Detailed mapping in the Oquirrh Mountains reveals that Sevier thrust faults delimit five distinct nappes, the Pass Canyon, Bingham, Rogers Canyon, South Mountain, and Fivemile Pass nappes, that moved sequentially along differing paths from a western hinterland to their foreland in the east . The nappes converged on a basement uplifted buttress along the Uinta trend, producing distinctive folds and imbricate thrusts. The nappes are roughly similar stratigraphically, but are composed of individually distinctive sedimentary rock sequences. Intrusive and extrusive rocks, and, in some cases, co-located base- and precious-metal ore deposits occur in the range along the trace of the Uinta trend.

The *Pass Canyon nappe,* located in the north central part of the Oquirrh Mountains, was the first nappe to arrive in the foreland. It moved generally eastward onto the buttress from a hinterland that was on or near the Uinta trend. The sole thrust is not exposed in the range because of overlap by the later emplacements of the Rogers Canyon nappe from the north and Bingham nappe from the south. The basal thrust of the Pass Canyon nappe may be an upper imbrication or peripheral part of the Nebo-Charleston nappe, identified in the Wasatch Mountains by Baker and others (1949), that was separated from the main part of the Nebo-Charleston nappe by a major tear fault. Two informal stratigraphic units composing the nappe are recognized as the older Dry Fork (Pennsylvanian and Permian) and younger Flood Canyon (Permian) units of Tooker and Roberts (1988). Detailed stratigraphic relations in the nappe are incomplete owing to its great structural complexity, local alteration, and the presence of only sparse Wolfcamp-age fossils. Joining contacts seem to be along imbricate thrust, tear, and normal faults. The Barneys Canyon and Melco disseminated gold deposits are located in the Pass Canyon nappe.

The *Bingham nappe*, located in the southern half of the range, is the largest thrust plate. It was the next nappe to move generally eastward on the Midas thrust from its Oquirrh basin hinterland to its foreland site to overlie the Uinta trend buttress and Pass Canyon nappe. The sole thrust also is not exposed in the Oquirrh Mountains, having been overridden by the Rogers Canyon nappe and concealed by normal faults. The nappe contains a 7,989 m-thick Paleozoic stratigraphic section, ranging from the Cambrian Tintic Quartzite to the Pennsylvanian Bingham Mine Formation of the Oquirrh Group. The rocks are predominantly clean, well-sorted clastic carbonates, argillaceous limestones, calcareous sandstones, and quartzites. They have been deformed into through-going *main* and more local *secondary* folds by the sole Midas and several imbricate thrusts in the upper part of the nappe. Tear faults segment the folds locally, and normal faults developed during the Cretaceous Sevier thrusts provided openings locally for the introduction of magma and hydrothermal solutions. Some of these faults were reactivated and enlarged during the period of Basin and Range extensional tectonics. The Bingham mining district ores are located in the locally structurally complex leading edges of the sole Midas thrust. The deposits are composed of base- and precious-metal disseminations in porphyritic intrusives and in veins and replacements in the adjoining Pennsylvanian Oquirrh Group's formations. Disseminated gold in the Mercur mining district is located in Upper Mississippian carbonate rocks overlying the imbricate Manning thrust. The vein and replacement deposits in the Ophir mining district are localized mainly along normal faults and in replaced carbonate rocks of lower Paleozoic formations, which are closely associated with local structures associated with the Manning main and related secondary thrusts.

The *Rogers Canyon nappe*, located in the northern end of the Oquirrh Mountains, was the third detached plate that moved on the North Oquirrh thrust southeastward from its Sublette basin hinterland onto the Uinta trend buttress. The nappe contains a 3,810 m-thick stratigraphic section beginning with the Mississippian Green Ravine Formation, overlain by the Oquirrh Group, and topped by the Grandeur Member of the Permian Park City Formation. The sedimentary rocks are mainly carbonate- and quartzite-rich, and are grossly similar to comparably-aged rocks in the Bingham nappe and in Oquirrh Group rocks in the nappes comprising neighboring ranges. The rocks are compressed into main and secondary folds on the western side of the range, and smaller-amplitude folds in the imbricate structures in the nappe on the eastern side. No ore deposits are found in the nappe.

The *South Mountain nappe*, located on the western side of the central part of the range, was next to be emplaced against the Uinta trend from its Oquirrh basin hinterland south-southwest of the range; it overlaps the Bingham nappe. The stratigraphic section is 4,087 m thick and includes the Pennsylvanian and Permian Oquirrh Group. It is divided into three informal formational units--the Rush Lake, Salvation, and South Peak units of Tooker and Roberts (1992). The structure of the eastern half of the nappe, which hosts the base- and precious-metal Stockton mining district, is on the upper plate of the Stockton thrust. The eastern half of the nappe is tightly folded, cut by imbricate thrusts and intruded by numerous monzonitic plugs, dikes and sills. The western half of the nappe on South Mountain is a main fold that is separated from the eastern half by the Rush Valley tear fault. The west part of the nappe is believed to lie on the TAD thrust, an imbricate fault that moved the plate northward, probably overlapping the eastern part of the nappe.

The *Fivemile Pass nappe* at the south end of the range is the smallest areally and probably the latest to be emplaced from its Oquirrh basin hinterland source area south-southwest of the range . The nappe contains folded and faulted Mississippian carbonate rocks of the Manning Canyon Shale and the upper part of the Great Blue Limestone formations whose true thicknesses could not be determined. The nappe represents a stratigraphic facies change in these formations that is intermediate between those that occur in the Bingham nappe in the Oquirrh Mountains and those found in the East Tintic Mountains to the south. The Mercur limestone member of Gordon, Tooker, and Dutro (2000) of the Great Blue Limestone hosts the unique variscite mineral locality at the south end of the Oquirrh Mountains. Extensive brick clay deposits, in clay-shale beds in the Mercur member of the Great Blue Limestone were mined in past years at the south end of the range.

INTRODUCTION

The Oquirrh Mountains are the site of one of the most prominent base- and precious-metal and disseminated gold mining areas of western United States (fig. 1); and through more than 130 years this range has been an area rich in the history of mining and in providing mineral resources that supported the growth of an expanding Nation. The Oquirrh Mountains continue to supply many of the metals and industrial minerals necessary for current and future local and national growth, mainly from five mining areas—the Bingham mining district, which includes the nearby Barneys Canyon and Melco mines, and the Mercur, Ophir, and Stockton mining districts. Much is known about the geology of the ore deposits in these districts and of the Oquirrh Mountains, but that information is dispersed individually in numerous places, and has not been fully integrated or brought up to date in terms of recent geologic theory. This summary and status of knowledge of the geology of the range provides a current perspective of the stratigraphy and structures of the host environments for the occurrence of these mineral resources, based on long-term investigations by the author and his many U.S. Geological Survey colleagues.

FIGURE 1, NEAR HERE.

Purpose of the Report

Continuing world-class mining activity and the great interest in gold exploration in the Oquirrh Mountains are primary bases for compiling the geologic information derived from recent geologic mapping and related research efforts by the USGS, mining companies, and university faculty and students. The science of geology has also grown during the 30 years or so with the advent of "plate tectonics," as well as of more sophisticated geologic field and laboratory technology. Some descriptions of the geology of individual parts of the range are as much as 10-12 decades old (Murphy, 1872; Spurr, 1895; Boutwell,1905a and 1905b; Wegg, 1915; Beeson, 1917 and 1925; Hunt, 1924 and 1933; Peterson, 1924; Gilluly, 1932; and Hammond, 1961); the most recent discussion of the geology of the whole Oquirrh Mountains is more than 75 years old (Butler, 1920). However, a number of individually cited more recent geologic descriptions of local (mining) areas within the range, many prepared as field trip guides that were published by the mining companies, university faculty and student thesis research, or by scientific societies, provide an additional growing source of data (Peacock, 1948; Field, 1966; James and others, 1961b; Cook 1961; Einaudi, 1975; James, 1978 and 1982, Wilson and Parry (1995) and Presnell and Parry, (1996).

This report is the author's perspective for a regional geologic description of the Oquirrh Mountains area including some controversial unresolved differences of geologic analysis. The report thus may become a platform of information on which to frame future geologic research and exploration activities. As such, this report primarily describes and summarizes the regional geologic relations observed by U.S. Geological Survey (USGS) maps of all or parts of fourteen—7 1/2-min. quadrangles (at a 1:24,000 scale)[1], which cover the Oquirrh Mountains (fig. 1). A compilation of these maps (Tooker, and Roberts, 1998) at 1:50,000 scale provides a modern geologic foundation on which to consider the geological aspects of ore deposits in the context of their local Oquirrh Mountains and broader regional settings.

Geophysical and geochemical studies have also been conducted by the USGS (Mabey, 1960; Cook and Berg, 1961; Mabey and others, 1963, 1964, 1978; Zietz and others, 1976; and Stein and others, 1989), mining companies (Kornze and others 1985), the Utah Geological Survey (Lenzi, 1971), and university students and instructors (Wilson and Parry, 1994). During this same period, several mining company exploration and development programs and a number of university faculty geologic research programs and student theses have been completed (Wilson, 1986, Wilson and Parry, 1995, and Presnell and Parry (1996); these results are added to an emerging complex regional geologic model.

More detailed geologic and geophysical studies completed within the mining districts, particularly by the mine staffs of Kennecott Corporation (Babcock and others, 1995) and Barrick

[1]Mills Junction, Farnsworth Peak (formerly Garfield), Magna, Tooele, Bingham Canyon, Lark, Stockton, Lowe Peak, Tickville Springs, South Mountain, Ophir, and Mercur.

Mercur Gold Mines, Inc. (Kornze and others, 1985) have continued since the completion of the USGS's regional mapping research. These resulting three-dimensional data amplify or modify some of the more generalized interpretations permitted by an original two-dimensional surface mapping examination .

One may expect that when geologists with dissimilar perspectives, objectives, and experiences examine an area, a number of differences in the interpretation of some geologic observations are apt to occur; the alternative interpretations developed by others in individual studies of the Oquirrh Mountains are noted in this report. The geologic descriptions and interpretations that follow are the author's responsibility. Such diversity of opinion eventually leads geologists to conceive the critical research that results in the resolution of these differences. Contribution to that resolution is the ultimate objective of this report.

Location, Geomorphic Features, and Access

The Oquirrh Mountains, which rise at the south end of the Great Salt Lake, about 25 km west of Salt Lake City, Utah, constitute the first of a series of north-trending mountain ranges in the eastern part of the Basin and Range province in west-central Utah, along its border with the Northern Rocky Mountains province (fig. 2). Stretching 56 km due south from the south end of the Great Salt Lake, the range ends at Fivemile Pass, which separates the Oquirrh Mountains from the Thorpe Hills. Antelope Island, which is aligned with the Oquirrh Mountains, lies 14 km to the north within the Great Salt Lake. The Wasatch fault, a prominent north-trending structure along the western margin of the Wasatch Range, is the boundary separating the northern Rocky Mountains province on the east and the Great Basin part of the Basin and Range province characterized by internal drainage.which is on the west. The Great Salt Lake at the eastern edge of the basin is the vestigial remnant of a large Pleistocene freshwater body, Lake Bonneville.
FIGURE 2, NEAR HERE.

The Oquirrh Mountains consist of a series of coalescing northerly-aligned peaks that rise abruptly from the shore of Great Salt Lake, at about 1,280 m (4,200 ft) and rises up to 2,852 m

(9,356 ft) elevation at Nelson Peak in the northern part of the range (fig. 2). The ridge line drops down to 2,499 m (8,200 ft) in the vicinity of the Bingham mine in the central part of the range, only to rise to its highest point at Lowe Peak, elevation 3,228 m (10,589 ft), in the southern part of the range, and thence descending gradually to Fivemile Pass at about 1,676 m (5,500 ft).

Two topographically lower-lying, east-west-trending ranges flank the central part of the Oquirrh Mountains. South Mountain, a separate narrow outlier, trends west from the western side of the Oquirrh Mountains; similarly, the western Traverse Mountains join the Oquirrh range directly on its east side. However, these lower mountain masses are integral and geologically compatible adjuncts to the Oquirrh Mountains. The highest and broadest part of the Oquirrh Mountains is aligned with the east-west crossing axis of the western Traverse Mountains and South Mountain. Jordan and Cedar Valleys, which flank the range on the east side, are separated by the Traverse Mountains, and Tooele and Rush Valleys, which lie on the western side, are separated by South Mountain.

The Oquirrh Mountains contain five base- and precious-metal mining districts. The Bingham mining district, which is located about 32 km southwest of Salt Lake City, in the central part of the range, is of world-class magnitude (fig. 2). The recently-developed Barneys Canyon and Melco mines lie about 6 km north of the Bingham mine. The Mercur (and the adjoining Sunshine mining area), Ophir, and Stockton mining districts are located on the west side in the southern half of the range. Mercur lies 59 km southwest of Salt Lake City, and the Ophir and Stockton districts are 7 and 18 km, respectively, north-northwest of Mercur.

The Oquirrh Mountains also contain industrial mineral resources in addition to extensive deposits of sand and gravel, which occur irregularly in alluvial fans and lake-shore bar and spit deposit about the range. Calcite oolite sands [for flux in smelting] were once mined about the southern shores of the Great Salt Lake and brick clay and limestone [also for flux] have been mined in the southern parts of the Oquirrh Mountains; a small deposit of the semi-precious mineral variscite also occurs in limestone at the south end of the range.

Access to the Oquirrh Mountains across its northern and eastern sides is by U.S. Interstate Highways 80 and 25. A number of Utah State Highways (36, 73, 111, 201, 48, 71, and 68) surround the eastern, southern, and western flanks of the Oquirrh Mountains. The Western Pacific Railroad mainline from Salt Lake City to San Francisco, California, passes the north end, and the Union Pacific Railroad mainline to Los Angeles California, also passes the north end and trends southward along the west side of the range. The Kennecott ore railroad along the eastern side connects the Bingham mine and mill installations with the copper smelting and refining complex at the north end of the range, and a spur line of the Denver and Rio Grande Railroad connects the mine with Salt Lake City.

Acknowledgments

Knowledge of the geology of the Oquirrh Mountains has evolved during more than 130 years, and each step along the way was made possible owing to the dedication, ingenuity, and persistent efforts of a long list of previous investigators. Earlier U.S. Geological Survey and mining company studies of the range and its mining districts by J.E. Spurr, J.M. Boutwell, J.J. Beeson, B.S. Butler, R.N. Hunt, and James Gilluly provide much of the historical background as well as early geological interpretations on which this survey is built. Growing recognition of the complexity of the subject still challenges us today. Ralph J. Roberts conceived and organized the Oquirrh Mountains studies reported here, but was called away midway to develop a USGS heavy metals program, entrusting me to complete our studies of the range. His keen scientific understanding and enthusiasm set the direction and tone for the project and this report. I also gratefully recognize the assistance and encouragement of U.S. Geological Survey colleagues W.J. Moore, J.A. Briskey, Jr., R.W. Kopf, T.L. Vercoutere, and D.B. Vander Meulen for their geologic mapping and structural and stratigraphic interpretations. W.J. Moore and E.H. McKee have classified and dated the igneous rocks. Mackenzie Gordon, Jr., R.C. Douglass, M.E. Taylor, E.L. Yochelson, H.M. Duncan, J.T. Dutro, Jr., K.S. Schindler, S.H. Mamay, and W. J. Sando made the paleontologic identifications, indicated the chronology of sedimentary rocks, and indicated regional stratigraphic correlations. D.R. Mabey conducted geophysical investigations in the range.

I also wish to acknowledge the recently published company-sponsored geologic studies in the greater Bingham mining district, in particular those of A.H. James, W. H. Smith, George Lanier, W.C. Peters, R.E. Bray, A. J. Swensen, B.F. Stringham, and J.E. Welsh of Kennecott; H.G. Peacock, M.T. Einaudi, W. W. Atkinson, Jr, and W.J. Garmoe of the former Anaconda Minerals Company; and R.N. Hunt, R. D. Rubright, and O.J. Hart of U.V. Industries (formerly the U.S. Smelting, Refining, and Mining Company). In similar fashion, I am indebted to L.D. Kornze, W.J. Tafuri, Tracy Shrier, T.B. Faddies, and R.G. Blair of American Barrick (formerly Getty Mining) for field visits, conferences, and published data on the geology of the Mercur mining district, and to F.W. Bauman, Touchstone Resources, for data on the Sunshine mining area. The report by W.L. Gunter, J.W. Hammitt, R.C. Babcock, Jr., and T.R. Gibson of the Kennecott Corporation and Kennecott Exploration Company., and R.D. Presnell, Univ. of Utah, and the recent summary by R.C. Babcock, Jr., G.H. Ballantyne, and C.H. Phillips of Kennecott are the main recent sources of information about the Bingham and Barneys Canyon mines.

Permission for entrance of U.S. Geological Survey personnel on privately controlled lands by the television transmission, livestock grazing, and mining companies is also acknowledged with appreciation. Other acknowledged contributions of data on the geology and ore deposits in the Oquirrh Mountains, which are derived from a number of university and individuals' studies, are summarized in this report and by Tooker (1998); Gordon, Tooker and Dutro, (2000) and Tooker and Roberts (1998). The geologic conclusions and interpretations in this report, derived from those listed above, remains the responsibility of the author.

GEOLOGIC SETTING OF NORTH-CENTRAL UTAH

The geologic features of the region are the result of a complex sequence of events beginning with the formation of a Precambrian craton and shelf on the western edge of the North American continent (Atwater, 1970, Christiansen and Lipman, 1972, Burchfield and Hickox, 1972; Coney, 1978; Link, 1993; and Reed and others, 1993). Paleozoic miogeoclinal sediments were deposited on a slowly subsiding craton shelf west of the Wasatch Mountains (Stewart and Poole, 1974). These strata were intruded in eastern Nevada and Western Utah by Jurassic plutons that metamorphosed the adjacent host sedimentary rocks and induced local thrust faulting (Allmendinger and others, 1984). The rocks subsequently were moved eastward during the late Cretaceous Sevier Orogeny on thrust faults to become folded and faulted nappes (Armstrong, 1968b; Tooker, 1970; Royse and others, 1975; Tooker, 1983; Price, 1989; and DeCelles and others, 1995). The structures and juxtaposed sedimentary rock sequences created became the core of the Oquirrh Mountains. Block faulting and erosion during a late Cenozoic period of extension formed the Basin and Range physiographic province (Gilbert, 1928, Stewart, 1978; Best and Hamblin, 1978, and Smith and Bruhn, 1984) and the Oquirrh Mountains. Tertiary igneous intrusive and extrusive rocks were introduced from crustal sources, and associated hydrothermal ore-bearing solutions formed the base- and precious-metal ore deposits (Peters and others, 1966). Uplift and accelerated erosion in the central Oquirrh Mountains during the early part of the Quaternary produced extensive local coarse clastic deposits. During the Pleistocene glacial episode Lake Bonneville covered much of the eastern part of the region, and lake currents redistributed much of the sand and gravel forming deposits at several levels of the lake (Crittenden, 1963, Morrison, 1966). Subsequent uplift and erosion continued to form the present topographic expression of the Oquirrh Mountains.

Precambrian Basement Terrane and the Uinta Trend

A structurally- and stratigraphically-complex Precambrian basement (cratonal) terrane, which extends westward into central Nevada, underlies north-central Utah (Eaton, 1982; Anderson and others, 1983; and Reed and others, 1993). This terrane is, in large part, concealed west of the Wasatch fault line in central Utah. However, the Precambrian terrane is known from outcrops in the Uinta and Wasatch Ranges (Crittenden and others, 1952; Condie, 1969; Crittenden (1976), Bryant and Nichols, 1988; and Bryant, 1993) and locally in west-central Utah (Levy and Christie-Blick, 1989). Geophysical data in the Great Basin indicate the presence of a basement terrane underlying the eastern Great Basin (Kistler and Peterman, 1978; Eaton and others 1978; Mabey and others, 1978; Bankey and Campbell, 1989; and Henstock and others, 1998). Where exposed in the Wasatch Mountains in the vicinity of Salt Lake City, the basement rocks consist of two Precambrian rock terranes (King and Beikman, 1974; Sears and others, 1982; and Bryant and Nichols, 1988). Crystalline basement rocks of the Archean Wyoming shield, described by King (1976) and Bryant (1979), lie north of a generally east-west-trending fault zone along the north flank of the Uinta Mountains (the Uinta trend in fig. 2). South of this zone a predominantly Proterozoic oceanic terrane forms the core of the Uinta Mountains (Blick, 1979).

The nature of geologic activity at this intersection over time is important for understanding the sequence of geologic events that eventually produced the Oquirrh Mountains. Crittenden and Wallace (1973) and Zoback (1983) consider that the Uinta Mountains were formed as a Proterozoic allocogen, which has undergone a number of subsequent uplifts. Beutner (1977) developed the concept that this uplifted "Salt Lake reentrant" is the site of a long-lived crustal flaw, the Cortez-Uinta axis or Uinta trend[2] , that originated from the allocogen and, at intervals during the Paleozoic, produced a linear transverse positive element westward across the adjoining miogeosyncline. The complex record of folding and uplift of the Uinta Mountains along the trend in terms of the interaction between the Uinta trend and the Sevier overthrust belt is considered in more detail by Osmond, (1964), Crosby, 1976), Bryant and Nichols (1988), Bradley and Bruhn (1988), and Bradley (1995) than is possible here. While most recent folding, northward thrusting and uplift of the Uinta Mountains (south of the Uinta trend) seems to postdate a Sevier overthrust

[2] *Uinta trend* is used in the remainder of this report for this basement structural element.

event (Bryant and Nichols, 1988; and Bradley and Bruhn, 1988), structural and stratigraphic differences along the northern and southern margins of the Uinta Mountains uplift strongly imply an earlier positive trend structure. Yonkee and Mitre (1993) demonstrate that the Precambrian basement rocks in the northern Wasatch Range are deformed by large-scale imbricate thrust faults.

An alternative interpretation for the origin of the Uinta trend as a zone of accretion of Proterozoic rocks from the south onto the Archean shield is supported by the geophysical evidence of Henstock and others (1998). This accretion produced an east-west trending fold system of the Uinta Mountains and adjoining basin to the south. The zone has undergone subsequent redeformation and uplift. Sims and others (1987) have identified comparable, possibly related accretion of a Proterozoic oceanic terrane to the shield in the midcontinent. The fault zone as traced along the northern border of the Uinta Mountains and across northern Colorado and southeastern Wyoming (Sears, and others, 1982) possibly may be regarded as a related westward extension of that midcontinent accretion zone. A projection of this suture zone, west-southwestward into western Utah, under the Oquirrh, Stansbury, and Cedar Mountains, and eastern Nevada, however, may be inferred from indirect evidence. Thus the Uinta trend seems to be part of a broad regional structural system .

There are a number of indicators for the existence of a Uinta trend. The inferred trace of it in figure 2 is located in a general way by Webb (1958), Roberts and others (1965), and Erickson (1976): (1) Along a number of linearly disposed intrusive and extrusive rocks of Tertiary age exposed in the Wasatch Mountains and in mountain ranges in the Great Basin west of the Wasatch fault (Armstrong and others, 1969, Moore and others, 1979, and Moore and McKee, 1983), (2) by local extensive uplift and erosion of sedimentary rocks overlying the Bingham plutons during a period of igneous activity in the Oligocene (Slentz, 1955), (3) sedimentational evidence of irregular, local uplifts elsewhere during the Paleozoic in western Utah and eastern Nevada (Webb, 1958, Coats, 1987, Brooks, 1956, and Roberts and Tooker, 1969), (4) and geophysical data (Bankey and Campbell, 1989).

Finally, Field and Moore (1971) reported an isotopic signature for the Bingham intrusives that indicated their derivation, in part at least, from crustal rocks. This infers access to a deep-reaching flaw zone structure in this area that tapped a crustal source of magma. However, the validity of their isotopic signature was recently challenged by Farmer and DePaolo (1983). In spite of this problem, the linear series of intrusions westward from the Wasatch is permissive evidence for believing that the Uinta trend is a deep-seated basement structure. There is also the suggestion from regional geochemical data that minor amounts of platinum occur in ore deposits along a zone overlying the Uinta trend from Ely, Nevada to southeastern Wyoming (Page and Tooker, 1979; Tooker 1979).

Geologic evidence seems to indicate that the Uinta trend was a structurally active zone that constituted an uplifted promontory in the basement during the Late Cretaceous forming a foreland buttress in the vicinity east of the Oquirrh Mountains against which the several nappes converged (Tooker, 1983). In contrast, nappes that moved into topographic lows in the craton, both north and south of the trend, permitted more eastward penetration and much less fragmentation of the Sevier thrust lobes in Wyoming, as shown by Oriel and Armstrong (1966), and in central Utah, as described by Morris (1983).

Paleozoic Depositional Basin

Phanerozoic sediments were deposited on an irregular, broad, gradually- and differentially- subsiding, shallowly submerged craton shelf (Stewart and Poole, 1974; Peterson, 1977), presumably located in what is now western Utah and eastern Nevada (fig. 3). The shelf orientation is interpreted to trend generally north-northeasterly, and occur an undetermined distance west of the autochthonous, nearer-shore, more slowly-subsiding part of the craton shelf zone now exposed in the present Wasatch Mountains, east of Salt Lake City (Baker and others, 1949; Armstrong, 1968a; Crittenden, 1976; Rose, 1976a, 1976b; and Jordan and Douglas, 1980). [This same hinterland zone is the site of later Jurassic plutons described by Miller and Hoisch (1995).] The east-west Uinta trend

(Webb, 1958; and Roberts and others, 1965) crosses the miogeocline in a west-southwest direction. It provided a persistent barrier, sometimes as an emergent ridge across the shelf separating deposition of sediments in an Oquirrh basin to the south and the Sublette basin on the northern side (Peterson, 1977), and intermittently contributing coarse clastic debris locally. The regional distribution of separate sedimentational regimes in the Oquirrh and Sublette basins, which is discussed later in more detail, is shown in figure 4. The differentiation in the pattern of sedimentation north of the trend from that south of the trend is observed in the Oquirrh Mountain in the Paleozoic rocks of the Rogers Canyon and Bingham nappes (Tooker and Roberts, 1970; and Morris and Lovering, 1961) and in the Paleozoic rocks in the Wasatch Range (Crittenden, 1959, 1976).

FIGURES 3 and 4, NEAR HERE

The miogeoclinal sediments present in the Oquirrh Mountains originally comprised an extensive, although locally compositionally variable and structurally attenuated, sedimentary record of the Paleozoic, Mesozoic, and Cenozoic eras (Armstrong 1968a; and Stewart and Poole, 1974). Overall, the Paleozoic rocks exposed in the Oquirrh Mountains are mainly thick accumulations of various amounts of carbonate-quartz clastics, orthoquartzite, shale, limestone, and dolomite (Tooker and Roberts, 1970) mostly of Paleozoic age that contain an abundant fauna of macro- and micro-fossils. These indicate deposition on a generally shallow, slowly-subsiding, miogeoclinal craton shelf (Gordon and Duncan, 1970). During the early Paleozoic, well-sized, clean sedimentary materials were derived from the rising and eroding continental craton to the east. Later, during mid- and upper-Paleozoic time, sedimentary debris originating in the northern part of the miogeocline also began to include less well-sized, mixed source materials from the erosion of a rising Antler belt to the west, which was composed of oceanic-derived rocks (Roberts, 1964; Poole, 1974; and Wilson and Laule, 1979). The composition of the resulting miogeoclinal sedimentary rocks varied during time as well as along the shelf depending on the proximity to and relative contributions of materials from these contrasting sources of sedimentary materials moving into the geosynclinal basins (Tooker and Roberts, 1988).

Structural factors along the Uinta trend complicate the early Paleozoic miogeoclinal stratigraphic record. Uplift along the trend, beginning in early Ordovician time (Gilluly, 1932, Roberts and others, 1965; and Tooker, 1983) resulted in an absence of Ordovician, Silurian, and much of the Devonian sedimentary record in the Oquirrh Mountains' part of the Bingham nappe owing to non-deposition or erosion. The Stansbury disturbance in Late Devonian time, described by Brooks (1956), Rigby (1959), Morris and Lovering (1961), and Roberts and Tooker, (1969), also initiated arching, uplift, and faulting along parts of the Uinta trend. This resulted in local erosion of lower Paleozoic rocks down to the Precambrian level in western Uinta Mountains, and local formation of coarse clastic rocks immediately north and south of the axial region. Coats (1978) reported local conglomeratic lenses north of the trend in the Pennsylvanian-age rocks of Elko County. The Uinta trend can not be reliably inferred farther west than Eureka, Nevada, because of the overlap of thrust plates from the west during the Antler orogeny in Late Devonian or Early Mississippian time.

Thus stratigraphic and structural distinctions recognized in rocks previously thought to be indistinguishable now permits the identification of thrust-fault nappes joined in the Oquirrh Mountains that were derived from separate parts of the miogeocline (Tooker and Roberts, 1988). A much thinner sequence of comparable sedimentary rocks and their faunas were deposited on the craton shelf and are exposed in the Wasatch Mountains (Baker, and others, 1949; and Crittenden, and others, 1952 and Crittenden, 1976).

Jurassic Orogeny

Late Jurassic plutonism occurred in the eastern Nevada-northwestern Utah area, the probable hinterland of the Sevier-age thrusts. Miller and Hoisch (1995) reviewed the evidence of localized magma plutons and metamorphosed wallrocks accompanying modest local thrusts with minimal frontal breakout. K-Ar ages of illite-rich clays in argilically altered and mineralized limestone from the Mercur mining district are found to range from 98.4 to 226 Ma, according to Wilson and Parry (1995) who estimate that the main alteration-gold mineralization event occurred at about 152± 4 Ma and thus may be correlated with the Late Jurassic orogeny. Presnell and Parry (1996) propose that folds in the Oquirrh Mountains at the Barneys Canyon deposit in the Pass Canyon nappe were formed by this same Jurassic orogenic episode. However, there are no known Jurassic plutons to provide heat sources for metamorphism in the northern and southern Oquirrh Mountains. Further, I believe that stratigraphic and structural evidence and ore mineral zonation across the Uinta trend that the Jurassic-altered rocks indicate that they most probably were moved eastward on Sevier-age thrusts and folded during the Late Cretaceous. The ore deposits were formed or remobilized in Sevier-age structures during Tertiary intrusive activity.

Cretaceous Sevier Orogeny

An anomalous juxtaposition of the thick miogeoclinal shelf [the Mt. Timpanogos sequence of Tooker and Roberts, 1962] and thin platform shelf [the Mt. Raymond sequence of Tooker and Roberts, 1962] sequences of comparably-aged sedimentary rocks with distinctive lithologies were observed by Baker and others (1949) in the Wasatch Mountains. They concluded that this positioning was the result of irregular sequential eastward transport of thick stratigraphic plates of Paleozoic rocks by thrust faults during a compressional phase of the Late Cretaceous Sevier orogeny. This is now known to be part of an extensive decollement that extends discontinuously from Alaska to Mexico (Armstrong, 1968a; and Roberts and Crittenden, 1973), and trends south-southwest across central Utah (fig.5). Price (1989) proposed a useful model for its origin, but the geologic mechanism for producing decollement thrust faults is still warmly debated (Hamilton and Meyers, 1966; Armstrong, 1972; Roberts and Crittenden, 1973; Allmendinger, and others, 1983; and DeCelles and others, 1995). Parts of the thrust belt may have been transported eastward toward the present foreland zone as little as 10 km (Hintze, 1973) to as much 150 km (Crittenden, 1961). The movement of the thrust belt was irregular, both in time and space, and apparently its frontal edge was separated into individual lobes approaching the foreland zone in central Utah.

Segmentation of the Sevier thrust belt into individually recognizable distinctively deformed nappes[3] in the central-Utah part of the belt have been described by Morris (1983) and Tooker (1970, 1983). Five nappes, which were the result of the coalescing of sequentially-arriving individual lobes (fig. 6) are recognized in the Oquirrh Mountains by Tooker (1983) and Tooker and Roberts (1988), on the basis of structural and stratigraphic evidence.

FIGURES 5 and 6, NEAR HERE.

Further evidence of the Sevier orogeny observed in the late Mesozoic and Cenozoic strata on the craton platform east of ther Oquirrh Mountains are mainly clastic conglomerate, sandstone, shale, and lesser carbonate sediments that were derived from the erosion of the foreland of Sevier thrust plates (Spieker, 1946; Eardley, 1955; Lawton and others, 1993; and Heller and Paola, 1989).

Formation of the Basin and Range Province

The characteristic geologic features along the eastern edge of the Great Basin part of the Basin and Range province (Nolan, 1943) were initiated in the late Cenozoic as a result of crustal extension and accompanying magmatism (VonTIsh and others, 1985) following a period of profound plate convergence and crustal compression that had produced the Antler and Sevier orogenic events. The Basin and Range region is characterized by many normal faults, some of which are still active; physiographically it is an area of internal drainage. Eaton (1979) has enlarged the Basin and Range province to include some adjoining areas in what he has called a Cordilleran thermotectonic anomaly region, a geophysically consistent area of high heat flow, low seismic wave velocity, and thin crust and lithosphere.

The present topography is that of intermountane alluvial-filled basins and narrow block-faulted mountain ranges described by Stewart (1978). The mountain ranges in western Utah and in most of Nevada are surrounded by shallow- to deeply-filled basins containing clastic

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3 A nappe, as used here, is a sheetlike allochthonous structural unit formed by thrust faulting. The nappe in turn, may contain lesser imbricate overlying thrust faults.

sedimentary materials resulting from accelerated uplift and erosion. Some of the graben-like basins flanking the Oquirrh Mountains contain more than 3,600 m of poorly consolidated sediments (Cook and others, 1966). The faults bounding the mountains are believed to be listric, and ranges such as the Oquirrh Mountains along the eastern side of the Great Basin have been tilted as much as 25 degrees to the east (Stewart, 1978). The block faulting probably is the result of back-arc uplift and extension developed during the early and middle Cenozoic, and to result from diapiric rise and lateral spreading of the North American plate, which overlay and was heated by a subducted Farallon plate at depth (Davis, 1979; Stewart, 1978; Eaton, 1979; and Zobach, 1983). Thus, the Great Basin is a region characterized locally by later magmatic intrusion and extrusive deposits accompanied by hydrothermal circulation, and the deposition of metallic ore deposits (Eaton, 1979).

Tertiary Igneous Activity and Ore Deposits

Within the Sevier orogenic belt, major east-west transverse structural zones like the Uinta trend became sites for the localization of igneous intrusions and spatially-located clusters of important mineral districts (Butler, and others, 1920; Hilpert and Roberts, 1964; Jerome and Cook, 1967; Tooker, 1971; and Stewart, and others, 1977). Tooker (1971), Lipman and Christiansen (1972), and Shawe and Stewart (1976) correlate the location of such ore-forming zones in the Sevier belt with magmatism related to crustal lineaments, which may represent persistent structural zones in the Precambrian basement rocks.

Autochthonous and allochthonous sedimentary rocks on the craton platform and shelf were intruded locally during the Oligocene by subvolcanic quartz monzonitic porphyry stocks, sills, and dikes (Moore, 1973b; Lanier and others, 1978b; and John, 1978). Late stages of the Oligocene igneous activity were marked by the extrusion of andesitic to latitic volcanic and volcaniclastic rocks in Jordan Valley and the West Transverse Mountains (Smith, 1961; and Moore, 1973a). Late-stage hydrothermal solutions developed near the close of intrusive activity (Moore, 1973c) were introduced and ore and gangue minerals were precipitated locally in structurally prepared and stratigraphically favorable areas in and adjoining the intrusives.

Uplift of the Oquirrh Mountains along the Uinta Trend Axis during the Period of Igneous Activity

Several lines of evidence from the types of igneous rock suites and timing of their introduction permit the inference that the uplift of the sedimentary rocks overlying parts of the Uinta trend continued during the period of igneous activity. The sequence of intrusion along the northeast-trending fault system in the Bingham district developed by Waarnars and others (1978) implies that the faults were reopened successively, following deposition of the composite stocks, allowing the formation of cross-cutting dikes. Lateral movement along the faults is not pronounced, which suggests that the main reopening force along them was from vertical movement. The central part of the Oquirrh Mountains is also the apparent source area for the maximum thickness of deposits of Harkers Fanglomerate (Tooker and Roberts, 1971b) along the margins of the range. Although Tooker and Roberts consider that this unit is mainly of Quaternary age, its deposition most probably may, in part at least, be correlated with the Tertiary period of accelerated uplift in the central Oquirrh Mountains.

The relatively narrow zone of larger, nearly comparable-aged monzonite-type stock and dike intrusions in the range lie between the Bingham and Stockton intrusive centers. Volcanic rocks are concentrated along the eastern margin of the range and occur for short distances across the zone of uplift. In a general way, the intrusive and extrusive rocks farther from the main zone are progressively younger in age and less abundant. The Bingham and Last Chance stocks were emplaced early in the sequence. Moore's (1973b) estimate that the stocks were formed under a sedimentary cover of about 2,300 m is based on fluid inclusion data. Yet the associated volcanic units, which undoubtedly were formed at or close to the surface, presently lie adjacent to the stocks. One hypothesis is that uplift of the stocks and erosion of the original sedimentary rock cover brought the intrusives closer to the surface by the time of the formation of the younger volcanic rock south of the main intrusive zone. One problem with this analysis is that the age of andesite porphyry flow on the range front northeast of the Bingham district is comparable with that of the Bingham stock. This can only be explained by postulating a range-boundary fault that dropped the east side and protected the volcanic rocks while the west side containing the porphyry stocks subsequently rose and its original cover was eroded. Such an explanation can not be dismissed because the preservation of the klippen block containing Grandeur Member limestones at the mouth of Barneys Canyon (Tooker and Roberts 1988) can best be explained by a similar type of structural analysis (Tooker, 1992).

Quaternary Uplift and Pleistocene Glaciation

Uplift and intense erosion during the early Quaternary unroofed the mineralized areas in the Oquirrh Mountains and elsewhere in the region, producing extensive alluvial fans and pediments along the range fronts, particularly in the central part of the range overlying the Uinta trend zone. These are the Harker Fanglomerate deposits (Slentz, 1955).

During the Pleistocene glacial interval, a very extensive body of freshwater, Lake Bonneville, formed in the valleys between the ranges (Gilbert, 1886; Eardley and others, 1957; and Crittenden, 1963). The multi-level shorelines representing fluctuating levels of this lake are the sites of widespread, locally well-preserved bars, spits, and other coarse clastic shoreline features.

RECOGNITION OF NAPPES IN THE OQUIRRH MOUNTAINS

Regional-scale thrust faulting during the Sevier orogeny, which created nappe structures in the Oquirrh Mountains, was recognized elsewhere by Baker, and others, (1949), Armstrong and Oriel (1965), Armstrong (1968b), and its significance in Utah was developed further by Roberts, and others (1965), Roberts and Crittenden (1973), and Beutner (1977). Detailed mapping of the foreland of the thrust belt in the Oquirrh Mountains provides additional information about thrust movement, the stratigraphic and structural characteristics of Paleozoic sedimentary rocks, and the location and geologic setting of the indigenous mining districts. Identification of five juxtaposed nappes in the Oquirrh Mountains is based on observations of distinctively different stratigraphic and structural features in the nappes (Tooker, 1983). The inference here is that strata now constituting these contiguous nappes were deposited originally in more widely separated sites on the miogeoclinal shelf than their present location would suggest, shown in fig. 3, and moved sequentially as individual lobes to converge and become joined in the present Oquirrh Mountains.

Location of the Oquirrh Mountains Nappes

The five Oquirrh Mountains nappes include the Pass Canyon, Bingham, Rogers Canyon, South Mountain, and Fivemile Pass nappes (fig. 7), whose geologic features were mapped originally in the 7 1/2-minute topographic quadrangles, as noted below, and located in figure l. The Pass Canyon nappe is exposed across the central part of the range north of the Bingham Canyon mine and south of Nelson Peak in the Bingham Canyon 7 1/2-min. quadrangle (Tooker and Roberts, 1988). The Bingham nappe occurs in the southern two thirds of the range, south of the Bingham Canyon mine and crops out in the Tooele (Tooker, 1980), Bingham Canyon (Tooker and Roberts, 1988), Lark (Tooker, unpubl. data), Stockton (Tooker and Roberts, 1992), Lowe Peak (Tooker, (1992), Tickville Springs (Moore, 1973a), Ophir and Mercur (Tooker, 1987), and Cedar Fort (Tooker, unpubl. data) 7 1/2-min. quadrangles. The Rogers Canyon nappe at the north end of the range occurs in the Mills Junction (Tooker and Roberts, 1971a), Farnsworth Peak [formerly Garfield] (Tooker and Roberts, 1971b), Magna (Tooker and Roberts, 1971c) and Bingham Canyon (Tooker and Roberts, 1988) 7 1/2-min. quadrangles. The South Mountain nappe occurs in the Stockton (Tooker and Roberts, 1992) and South Mountain (Tooker, unpubl. data) 7 1/2-min. quadrangles. The Fivemile Pass nappe is located north of Fivemile Pass at the very south end of the range in the Mercur 7 1/2-min. quadrangle (Tooker 1987).

FIGURE 7, NEAR HERE.

Hinterland Source of the Nappes

The location of a depositional site and hinterland source of sedimentary rocks comprising the nappes, inferred in figure 3 as possibly near or west of the Utah-Nevada State line area, remains uncertain in spite of past intense geologic research. The geology of this area is very complex both structurally and lithologically (Cook, and others 1964; Armstrong, 1972; Wenicke, 1981; Todd, 1983; Miller, 1983; Jordan, 1983; Camilleri and others, 1994, and Miller and Hoisch,1995. According to Camllleri and others (1994), the Sevier hinterland in northeast Nevada experienced two Mesozoic metamorphic event. A Late Jurassic event was characterized by contact metamorphism about sparse upper- to mid-crustal syntectonic plutons and synchronous crustal shortening and thickening. A Late Cretaceous regional metamorphism of the crust resulted in major crustal thickening and provided a mechanism for producing the Sevier-age decollement thrust in Utah. The hinterland area is a subject of continuing research and speculation in the attempt to identify a source for the nappes, a subject that is beyond the scope of this report.

Movement of the Nappes

A mechanism for initiating and facilitating nappe movement on the Sevier thrust faults also is not fully understood. Some investigators (Roberts and Crittenden, 1973; and Todd, 1983) call upon the gravity model of Ruby and Hubbard (1959). A detachment model described by Allmendinger and Jordan (1981, 1984) envisions a process of upthrusting initiated by an expanding magma chamber in the crust. None were able to pinpoint where the sediments were actually laid down (presumably somewhere in central or eastern Nevada) because of the overlap of subsequent thrusts and the formation of intervening uplifted core complexes (Compton, 1983). Cross (1986) proposed a tectonic model for the development of the Sevier foreland basin. The timing of thrusting in the Sevier belt was discussed by Heller and others (1986) and Gillespie and Heller (1995). However formed originally, the resulting structures observed in the Oquirrh Mountains part of the foreland, which represent only the final burst in movement of the thrust plates, seem to have the characteristics of or mimic gravity emplacement in their accretion onto the foreland craton platform (Tooker, 1970).

Generally eastward movement of Oquirrh Mountains nappes on sole thrusts is inferred from the regional deployment of thrust terranes (fig. 3) and the pattern and magnitude of folded foreland sedimentary strata (Morris, 1983; and Tooker, 1983). Morris and Tooker indicated that there are regional structural differences in the Utah nappes depending on whether the thrust plates impinged on a foreland craton area that was a low, downwarped basinal, or on an elevated promontory. It is not known whether the thrust belt moved initially as a single unit, and, at some point in its eastward journey, separated into distinct lobes. It is known that as these lobes approached the foreland, they moved separately and were structurally modified much as lobes in a glacier (Tooker, 1970). Eastward movement along the Sevier thrust belt seems to have progressed sequentially, timewise, from Wyoming and northern Utah southward (Oriel and Armstrong, 1966). The actual distances of nappe movement on the sole thrust faults in Utah are not known, but have been estimated at somewhere between 10 and 150 km (Hintze, 1973; Crittenden, 1961). The final directions of movement by the nappes (fig. 6) are inferred to be normal to the trend of the folds produced. In addition, movement on imbricate thrusts in the Oquirrh Mountain nappes is less extensive than on the main sole thrust. Movement on the imbricate thrusts probably ranges from tens of meters to possibly as much as one kilometer and may have occurred as pick-a-back structures before the nappe's sole thrust reached the foreland.

Convergence of Nappes in the area of the future Oquirrh Mountains

The Oquirrh Mountain nappes are inferred to have converged about a basement promontory or buttress (figs. 6 and 7), coming to rest sequentially (Tooker and Roberts, 1988). The Pass Canyon nappe was the first to arrive, followed, successively, by the Bingham, Rogers Canyon, South Mountain nappes, and last, the Fivemile Pass nappe. This order of arrival is determined by several lines of evidence. Their disposition over a basement high or promontory along the upwarped Uinta trend or reentrant of Beutner (1977) was based on permissive interpretation of the structural, stratigraphic, and geophysical features observed in the Salt Lake recess (Tooker, 1983). The relative ages of nappe emplacements in the Oquirrh Mountains are determined by such factors as their stratigraphic composition, structural positions, fold structures, degree of refolding, and alteration.

Assuming that the directions of fold axes are nearly normal to the last direction of nappe movement, the mapped fold systems, shown diagrammatically in figure 6 (from Tooker, 1998), permit speculating that the Pass Canyon nappe (or lobe) moved generally east-northeast to eastward where it was folded as it overran the Uinta trend basement buttress. The northern part of the Bingham nappe, whose folded sedimentary rocks are bent to the northwest, moved northeastward overlapping the Pass Canyon plate and the south side of the buttress. However, the main direction of nappe movement in the southern part of the range is nearly due eastward. The Rogers Canyon lobe subsequently approached its foreland destination from the northwest, overlapping the Pass Canyon and Bingham nappes as it moved generally southeastward over the buttress. The bent South Mountain nappe moved generally north and north-northeast on the Stockton thrust onto the Oquirrh Mountains, where it overlaps the Bingham plate. Subsequently, the Fivemile Pass nappe also docked on the Bingham nappe at the south end of the range, having moved in from the south-southwest.

Stratigraphic Features of the Main Nappes

Stratigraphic studies and geologic mapping in the Oquirrh Mountains at the 1:24,000 scale provide lithologic and structural data for distinguishing the nappes. The following brief summary of the salient stratigraphic features of the areally more prominent Pass Canyon, Bingham, and Rogers Canyon nappes highlights distinctions in rocks of Pennsylvanian and Early Permian ages, both locally in the Oquirrh Mountains and more regionally. More detailed examination of the stratigraphy of individual nappes follows in discussions of the geology. Consideration of the South Mountain and Fivemile Pass nappes, which are small areally, and are composed of very limited parts of the stratigraphic section, is deferred until the later discussion of lithologies in individual nappes.

Pass Canyon nappe

Sedimentary rocks in the Pass Canyon nappe apparently were deposited in the vicinity of the Uinta trend, presumably on the southern edge of the Sublette basin, on that part of the shelf west-southwest of the Oquirrh Mountains between the deposition sites of the Bingham and Rogers Canyon nappes (fig. 3). There are no lower Paleozoic sedimentary rocks in the nappe, possibly because of non deposition, erosion, or, more probably, their non-selection by the nappe's (unexposed) Pass Canyon sole thrust fault, which may be an upper imbrication of the main Nebo-Charleston thrust in the Wasatch Mountains. The main Early Permian sedimentary rock units of the Pass Canyon nappe are believed to have been derived predominantly from the Antler uplift. The lowest Pass Canyon strata are composed of interbedded, thinly layered, sheared, cyclicly repeated, clastic limestones, shales, and quartzites, which superficially resemble sedimentary rocks of Missouri-age in the Bingham nappe. No identifiable fossils were found. These rocks are overlain by prominent calcareous quartzite and orthoquartzite with minor interbedded limestone that tentatively are dated by sparse and poorly preserved fossils. The quartzites characteristically weather dark brown in contrast to the clean, light-tan weathering, well-sorted quartzites of comparable age rocks in the Bingham nappe. Pebble conglomerates and intraformational breccias occur locally in the middle part of the Pass Canyon nappe. These features suggest that local uplift occurred intermittently along the part of the shelf that overlay the Uinta trend during the deposition of these sedimentary rocks. Coarse clastic materials were developed as the result of local reworking of previously consolidated sediments as well as slumping and brecciation of incompletely consolidated layers off of the uplifted zone during deposition of the sedimentary units. The uppermost sedimentary rocks of the nappe comprise prominent thin-bedded limestones, which are comparable lithologically to the Kirkman Limestone of Early Permian age in the Wasatch Range (Welsh and James 1961), and, like the Furner Valley Limestone in the East Tintic Mountains (Morris and others, 1977), seem to have been derived mainly from an eastern craton source. Thus, during Late Pennsylvanian-Early Permian time, larger contributions of carbonate and quartzose sediments to the Pass Canyon nappe are inferred to be derived from oceanic crustal sedimentary and igneous rocks composing the Antler uplift. During later Early Permian time, a larger contribution of carbonate sedimentary materials is best explained as their derivation from the east, mainly from erosion on the craton.

Bingham nappe

The Bingham nappe, which extends from the Oquirrh Mountains southward to the East Tintic Mountains, contains a thick Paleozoic stratigraphic section (Sandberg and others, 1982). It ranges from the Cambrian Tintic Quartzite to the Upper Pennsylvanian Bingham Mine Formation in the Oquirrh Mountains (Gilluly, 1932; Tooker and Roberts, 1988). However, Ordovician, Silurian, and Devonian sedimentary rocks, which are amply exposed at the south end of the Bingham nappe in the East Tintic Mountains, Utah (fig.4), are not present in the Oquirrh Mountains (Harris, 1959). The depositional area of the Timpanogos nappe, which moved eastward on the Nebo-Charleston thrust (Crittenden, 1976), must have been similarly located with respect to the Uinta trend as the same formational units are missing in it. This missing stratigraphic interval undoubtedly was the result of local uplift along the Uinta trend, as observed by Webb (1958). The depositional site of the part of the Bingham nappe that now is located at Tintic, Utah, apparently was located farther south in the Oquirrh basin from the uplifted Uinta trend. A thick stratigraphic section of Mississippian and Pennsylvanian fossil- and carbonate-rich sedimentary rocks present in the Bingham nappe seems to have been the result of deposition in a more rapidly subsiding part of the basin south of the Uinta trend (Tooker and Roberts, 1970). Based on the sorting and cleanness of detrital materials, the source of these sediments is believed to have been primarily from the craton. The absence of Permian strata in the northern part of the nappe may be explained by nondeposition along the Uinta trend or erosion during later uplift along the trend.

Permian-age sedimentary rocks, which are absent or were eroded in the southern Oquirrh Mountains, are present in the Bingham nappe in the southern-most East Tintic Mountains (Morris and others, 1977). The Upper Pennsylvanian Bingham Mine Formation in this area is, in large part, stratigraphically comparable with its age counterpart in the central and southern Oquirrh Mountains. The formation contains interbedded well-sorted, clean, clastic siliceous and carbonate strata, in which quartzites generally predominate over the interbedded limestone and shale. On the basis of its reworked and clean sedimentary debris and prominent cross-bedding structures, the Bingham Mine Formation apparently was derived mostly from the erosion of the craton and deposited on the craton platform in a relatively shallow sea. Morris and others (1977) showed that in the Bingham nappe at Tintic, Utah, the Bingham Mine Formation is succeeded by the more than 90 percent carbonate-bearing beds of the Late Pennsylvanian and Early Permian Furner Valley Limestone, which are also presumed to be of cratonal origin.

Rogers Canyon nappe

The Upper Pennsylvanian sedimentary rocks in the Rogers Canyon nappe are believed to have originated in the Sublette basin and contrast with those in the Bingham nappe in terms of thickness, age, characteristic sedimentary units, and missing parts of the section even though there is an overall similarity in the types of deposits of carbonate- and silica-rich sedimentary rocks. The Upper Mississippian Green Ravine Formation at the base of the exposed stratigraphic section is composed predominantly of fossiliferous limestones, correlative in age with the Mercur limestone member of the Great Blue Limestone. These sedimentary rocks grade into the mostly Pennsylvanian Lake Point Limestone without an intervening shale (eg., the Manning Canyon Shale) sequence that is present throughout the Bingham and Timpanogos nappes. The sedimentary rocks of the Early Pennsylvanian Oquirrh Group in the Rogers Canyon nappe apparently were deposited on the shelf in the Sublette basin in the hinterland farther north of the Uinta trend than those of the Pass Canyon or Bingham nappes. The rocks consist predominantly of well-sorted, thin-to medium-bedded, craton-derived clastic carbonate and quartzite components. Although the stratigraphic units of Late Pennsylvanian age are massive, generally weather dark brown, and are composed mainly of arenaceous orthoquartzites and calcareous quartzites interbedded with very sparse thin-bedded limestone and shale (Tooker and Roberts, 1970), their thickness is less than that of comparably-aged strata in the Bingham nappe. The Rogers Canyon strata are inferred to have been deposited in the less rapidly subsiding Sublette basin on the north side of the Uinta trend. Nearer-shore basin deposits north of the trend, now exposed on Mount Raymond in the Wasatch Mountains, contain closely similar but much thinned stratigraphic assemblages (fig. 4), according to Crittenden (1976).

No Wolfcamp-age (Early Permian) sediments are identified in the Rogers Canyon nappe. Gordon and Duncan (1970) concluded that an unconformity occurs at the base of the conformably overlying fossiliferous limestones of the Grandeur Member of the Park City Formation (Late Leonard to Early Permian age). Sedimentary rocks in the upper part of the Rogers Canyon nappe seem to include some oceanic-derived, often poorly-sorted sedimentary components from the Antler highland in central Nevada, which was an active highland area from Late Devonian to Early Pennsylvanian time (Roberts, 1964).

Significance of variations in nappe sedimentary rocks

The variations in sedimentary rocks in Oquirrh Mountain nappes, and including the East Tintic Mountains part of the Bingham nappe, are compatible with a model of transitional sedimentation southward along the miogeoclinal shelf. This conclusion is based on the relative proportions and types of source materials input, the development or absence of coarse clastics from local uplift along the Uinta trend, and in some cases, possibly, the absence of sedimentary materials available for deposit in an uplift area or their bypass of the deposit area.

Structural Features of Nappes

Structural dislocations along fold and fault systems in the Oquirrh Mountains provide additional clues to the recognition of individual nappes. The general characteristics of these structural elements are summarized below, but the details of their occurrences in individual nappes are described later. These data support a geologic model consisting of individual lobes developed along a decollement thrust front that were diversely deflected in the Salt Lake recess in sequence before they came to rest in the Oquirrh Mountains (Tooker, 1970).

Main and Secondary Folds

The principal sizes and types of folds that characterize the Oquirrh Mountains nappes include large-amplitude *main* folds and more numerous low-amplitude *secondary* folds. Main folds formed as the result of movement of a competent thick stratigraphic section on a sole thrust fault generally are broad, nearly symmetrical, and of high-amplitude such as the Kessler and Pole Canyon folds in the Rogers Canyon and Bingham nappes (Tooker and Roberts, cross sections in 1971b and 1988). When thin-bedded, less-competent, or a thinner stack of sedimentary rocks are moved, such as locally along the lead edges of thrusts, possibly on imbricate thrusts, tighter, low-amplitude folds result. Where the leading edges of nappes overrode the Uinta trend buttress, the broad folds became asymmetrical-to-slightly overturned, as seen in the Bingham syncline on the Bingham nappe in the Bingham mining district (Tooker and Roberts, 1988). The amplitude of some isoclinal folds that occur above the Uinta trend buttress may be large. Examples are found in the eastern half of the Rogers Canyon nappe (Tooker and Roberts, 1971b); and in the Pass Canyon nappe west of Nelson Peak (Tooker and Roberts, 1988).

A system of narrow, *secondary*, closely-spaced, symmetrical, low-amplitude, and locally asymmetrical-to-overturned folds were also developed in the thinned upper plate above imbricate thrusts in the nappe, and generally occur as subparallel overprinted folds of a main fold. Such secondary folds are observed on the upper plates of the Manning and Butterfield Pass imbricate thrusts in the Bingham nappe (Tooker, 1987, 1992).

Variations in the types and magnitudes of fold structures in the Oquirrh Mountain nappes may provide an indication of the distances travelled and the relative directions and timing of final nappe movement, assuming that the direction of final plate movement was normal to the general trend of fold axes and represents the approximate direction of final plate motion. Unfolding the folds provides a minimum distance of transport (Hintze, 1973). However, this does not take into account the overlap of numerous imbricate thrusts on the upper plate of sole thrusts. A maximum distance has been inferred by projection (Baker, and others, 1949; and Crittenden, 1961). The timing or sequence of emplacement of the nappes is inferred, in some cases, from the refolding of earlier folded nappes comprising the lower plate. For example, tightly-deformed isoclinal folds in the upper unit of the Pass Canyon nappe in Flood Canyon are overturned to the east at the base of the canyon. On the ridge to the south, these same folds are overturned to the west as the result of later overthrusting by the Rogers Canyon nappe.

Faults

Four principal types of faults predominate in the Oquirrh Mountain nappes: (1) sole and imbricate thrust and/or reverse faults, (2) tear or transcurrent faults, (3) tensional normal faults that were formed locally during the process of nappe emplacement, and later, (4) the extensional, probably listric, Basin and Range (normal) faults. Some generalizations about their prominent trend directions, length of segments, their spacing, dip, and relative displacement are important characteristics for distinguishing nappes; more detailed discussion of these faults is deferred to considerations of the individual nappes.

Sole and imbricate thrust faults—The basal plane of thrust fault motion in a nappe is considered a sole thrust fault. These faults commonly are not exposed due to later normal faulting, and must be inferred. To a much lesser extent, forward motion may also be generated along imbricate thrusts within the body of the nappe. Sole thrusts generally are shallow- to steep-dipping and may or may not follow along favorable stratigraphic horizons. The sole faults may steepen and cross stratigraphic horizons where the fault ramps up against an obstruction in the lower plate. The best example of this can be observed west of Nelson Peak in the central Oquirrh Mountains at the mouth of Bates Canyon (Tooker and Roberts, 1988). Here the North Oquirrh thrust dips at a low angle to the north, but higher up in the canyon the dip steepens as the sole thrust rises to overlap the Pass Canyon nappe. There seems to be little evidence of alteration or fracturing of sedimentary rocks on either the upper or lower plates associated with the movement of the sole thrust. The main Midas (sole) thrust underlying the Bingham nappe, is concealed north of the Bingham mine by normal faults that drop the Pass Canyon nappe down against the Bingham nappe. On the basis of subsurface information developed by mining companies (Shrier, 1987, oral commun.) and surface data by Tooker and Roberts (1988), the Midas thrust, as mapped at the surface, is now believed to be one of several upper plate imbricate thrust-faults of variable lateral extent that developed locally along the lead edge of the nappe. The amount of movement on Oquirrh Mountain's sole thrusts, which may be hundreds of kilometers, can not be measured in the Oquirrh Mountains.

Where the sole thrust ramps onto the craton-shelf buttress, a number of thrust-fault imbrications were formed within the upper plate. Thus, to the southeast the North Oquirrh thrust flattens and splays into a series of imbrications where it passes over the Pass Canyon-Bingham nappes and basement structural ridge. Tight, asymmetrical to overturned folds commonly developed along the lead edges of the now-thinned imbricate thrust plates, and, where overturned, the strata commonly are sheared along steep border tear faults. Imbricate thrusts may be shallow dipping, as is the Markham thrust on Markham Peak, or steeply dipping (reverse faults) as are those in the Pass Canyon nappe on the ridge west of Nelson Peak. Movement on the imbricate upper plate thrusts seems to be limited to a few tens of kilometers at most

Transcurrent or tear faults—Transcurrent or tear faults are modest to large-scale, steep strike-slip faults that bound thrust-fault segments, thereby facilitating irregular forward movement of the thrust fault front and constraining the lateral extent of thrust-fault segments. The displacement of tear faults in the Oquirrh Mountains is small in contrast to the moderate displacement along the Soldier tear fault that bounds the South Mountain nappe or large displacement along the Leamington, Inez, and Tintic Prince tear faults in the southern part of the East Tintic Mountains. These facilitated movement of the nappe across the Uinta basin low at the south end of the Bingham nappe (Morris, 1983). Tear faults in the Oquirrh Mountains are developed mostly within the individual nappes and offset strata and formational units within the sole and imbricate thrust plates. The tear faults may be close spaced, as in the Pass Canyon nappe, or more widely spaced as along Butterfield imbricate thrust (Tooker and Roberts, 1988). Some tear faults subsequently seem to have been reactivated as normal faults.

Tensional and other normal faults of thrust origin—Arching of locally-overturned broad folds formed in the leading edge of the Midas thrust in the Bingham syncline and adjoining anticlines during thrusting, resulted in the formation of steep-dipping tension faults normal to the fold axes (Tooker and Roberts, 1988) Where the bending is tightest, the faults are closer spaced. In some cases the pull-apart was filled by later igneous dikes and mineralized vein fissures. There may be little or no apparent horizontal or vertical displacement; some of these faults developed into tear faults, as one part of a lobe was pushed farther forward than its neighbor, or as normal faults with vertical displacement as a result of the Basin and Range extension in the region. Normal faults in which the hanging wall has been displaced downward fall into classes based largely on their prominent directional trends. In most areas the fault trends are conjugate systems; one directional system seems to predominate in each nappe. These faults seem mainly to be the result of the emplacement of the nappes and their later uplift.

Basin and Range normal faults—Steep-dipping, west side generally displaced down, northeast, northwest, and north-south trending, often intersecting normal faults define the western range-front margin of the Oquirrh Mountains. These were formed by the extensional tectonic regime that produced the Basin and Range region during the early and late Cenozoic. Many of the steep-dipping normal and tear faults within the range apparently were also reactivated during uplift and extension of the Basin and Range terrane. The amount of displacement along the range-front faults is uncertain, but geophysical data of Cook and others (1964, 1966), which define the Tooele Valley graben, indicatee large-scale displacement of consolidated rocks and substantial filling of unconsolidated materials. However, within the range, the displacement along normal faults is relatively small, judging from the offset of formation contacts. Faults bounding the ranges are commonly listric and aided the eastward tilting of the Oquirrh Mountains (Stewart, 1978). Those along the western side of the range are propagated in short segments, giving an saw-tooth pattern along the west range front (Tooker and Roberts, 1971b, 1971c). The disposition of range-front faults on the east side of the range is obscured by the eastward tilting of the range and by overlap Tertiary volcanic and Quaternary basin-fill deposits.

Some of the fault structures undoubtedly were deep-reaching enough to be able to provide access channels from the Uinta trend basement crustal zone for the movement of Tertiary magma and hydrothermal ore-bearing solutions into favorable nappe host rocks (Tooker and Roberts, 1988, p. 7-8). Map data indicate that most, if not all of the mining districts in the Oquirrh Mountains occur in stressed folds at or close to the lead edges of thrust structures (Tooker, 1998).

Igneous Rocks Associated with the Nappes

Intrusive and extrusive igneous rocks occur in various amounts in most of the nappes; the Bingham nappe, however, hosts the major intrusive and extrusive center in the Oquirrh Mountains (Tooker and Roberts, 1988). The Rogers Canyon and Fivemile Pass nappes, which are at the extreme ends of the range, contain the least igneous activity. The distribution of intrusive (Ti) and extrusive (Tv) rocks is shown later on the summary map of recent investigations in the Oquirrh Mountains compiled by Tooker and Roberts (1998). The petrology and petrography of these rocks were described by Moore (1973b). Additional published studies of these rocks are by Smith (1961), Lanier and others (1978a), Warnaars and others (1978), and Wilson (1978). Descriptions of them are not repeated here, but their general characteristics and ages are summarized in Table 1 The original authors' classifications of rock types are used in this report.

TABLE 1, NEAR HERE.

A complete understanding of intrusive rocks and their interrelationships throughout the Oquirrh Mountains requires further, more comprehensive investigation. Nevertheless, during the stratigraphic and structural studies it became clear that the distribution and types of igneous rocks provide evidence of continuing uplift and erosional activities along the Uinta trend during the approximately 8-million-year interval of igneous activity. The juxtaposition of coarse-grained porphyry plutons and adjoining metamorphosed skarns, fine-grained dikes and volcanic and lahar-type flows implies rapid uplift and erosion over the area of the Uinta trend during the intrusive-extrusive period. This concept is further supported by the local presence of thick, coarse, early Quaternary deposits containing intrusive rock clastics along the flanks of the range underlain by the Uinta trend. The relation of igneous dikes and sills on the distal flanks of the Uinta trend to the apparently spatially-associated disseminated gold deposits is not yet well understood.

GEOLOGY, CORRELATION, AND ECONOMIC IMPORTANCE OF TYPICAL NAPPE ROCKS IN THE OQUIRRH MOUNTAINS

Stratigraphic and structural data from the Oquirrh Mountains are advanced sufficiently to be important bases for identifying and interpreting the geologic evolution of the Pass Canyon, Bingham, Rogers Canyon, South Mountain, and Fivemile Pass nappes, their formations and accompanying igneous rocks. Where present, particular emphasis is placed on Upper Paleozoic stratigraphy (Upper Mississippian Chester to Lower Permian Leonard ages). The general physical similarity of Upper Paleozoic stratigraphic units in the central Oquirrh Mountains has, until recently, hindered differentiation of the nappes in the range. Brief summary statements about the associated igneous intrusive and extrusive rocks also follow. The characteristic associated ore deposits are reported from more detailed cited data.

Informal stratigraphic units are used where the requirements of the Code of Stratigraphic Nomenclature for naming formations in the Pass Canyon and South Mountain nappes have not yet been met. New names for some units identified earlier are required by the Code because of geologic-name preemptions elsewhere; in such cases, the previously assigned names are identified for clarity in making comparisons with information published here. Unpublished stratigraphic data developed during these studies are included in an appendix. Finally, incompletely-known or unresolved stratigraphic relations are indicated where more data are required to resolve remaining current conflicting geologic interpretations.

Diverse and complex fold and fault structures in the Oquirrh Mountains are interpreted primarily to be the result of the emplacement of nappes that converged in the Salt Lake recess (Tooker, 1983; Tooker and Roberts, 1988). These nappes are characterized individually by their characteristic fold geometry, thrust faults, associated transcurrent or tear faults, and the distribution of steep-dipping normal faults. The location of igneous intrusives and the spatially-associated ore deposits are directly related to the pattern of fault structures in the host rocks (Tooker, 1998). Finally, Basin and Range extensional faulting, local uplift in the range, and accelerated erosion determined the present topography of the range and the shape and filling of the adjoining intermontane valleys. Sketch maps that highlight or focus attention on specific structural features in the five nappes in the following sections are derived principally from 1:24,000-scale maps by the author and his collaborators, which are summarized by Tooker and Roberts (1998).

Pass Canyon Nappe

The Pass Canyon nappe, is located in the north-central part of the Oquirrh Mountains north and northwest of the Bingham mining district (figs. 7 and 8). On the basis of its stacking position, stratigraphy, and fold and fault structures, the Pass Canyon thrust fault,may be a detached imbricate thrust above the sole Nebo-Charleston thrust that underlies the Timpanogos nappe of Baker and others (1949) and Tooker and Roberts (1962) in the Wasatch Mountains. The Pass Canyon nappe apparently was stranded in the area of the Oquirrh Mountains where it crossed the Uinta trend buttress and now is separated from the Timpanogos nappe by an inferred major east-trending tear fault. The north side of the Pass Canyon nappe is delimited by its contact with the overriding Rogers Canyon nappe (Tooker and Roberts, 1988); the boundary lies partly along the North Oquirrh thrust, which underlies the Rogers Canyon nappe, and partly along the down-dropped, steeply-dipping Nelson and Tooele tear or normal faults (fig. 8). The southern boundary of the Pass Canyon nappe is along its join with the overriding Bingham nappe, which is underlain by the unexposed sole Midas thrust. This boundary is constrained by the Pine Canyon, AJ , and Bingham Canyon faults, which are steep-dipping normal (south side down) and (or) tear faults. The west side of the Pass Canyon nappe is bounded by range-front normal faults and overlapping Quaternary deposits. The east side is overlapped by Tertiary volcanic rocks, Quaternary alluvial deposits, and Holocene mine-waste dumps.

FIGURE 8, NEAR HERE.

Two informal stratigraphic formational units were recognized by Tooker and Roberts (1988) in the nappe and named for typical outcrops in Dry Fork and Flood Canyons. Interpretation of the geology in this part of the range is contested, in large part, because detailed stratigraphy and geologic mapping are as yet incomplete owing to the lack of a complete measured section and sufficient fossil dating, the great structural complexity of the nappe, local alteration of the sedimentary rocks, the presence of only Wolfcamp-age units (Tooker and Roberts, 1988), and the fact that an orderly sequence of sedimentary rock units across the bases and tops of the two formational units is not exposed. All of their joining contacts seem to be along imbricate thrust, tear, and normal faults. The differences in interpretation of the geology and stratigraphic relations between Welsh and James (1961), Swensen (1975a and 1975b), and Babcock and others (1995) and this report are primarily due to the recognition here of structurally distinct regional nappe structures in the Oquirrh Mountains. Enough is now known to delineate the areal extent and general sedimentary and structural characteristics of the rocks exposed in the Pass Canyon nappe. Until more detailed mapping is done, however, measurement of the characteristic sedimentary rocks and their thicknesses in a stratigraphic section is not practicable.

Stratigraphic characteristics and correlation of sedimentary rocks

Stratigraphic features and structural discontinuities that facilitate the definition of the Pass Canyon nappe were the bases for proposing two informal formational units, the older Dry Fork Pennsylvanian and Permian(?) and younger Flood Canyon Permian(?) units of Tooker and Roberts

(1988). Their distribution in the range is shown in figure 8, which, with only minor reinterpretation here, is based on the map of the Bingham Canyon quadrangle by Tooker and Roberts (1988). General descriptions of these units follow; no measured sections of the rocks are available in this report.

Welsh and James (1961) and Swensen (1975a) considered these rocks to be the continuing upper part of the strata exposed in the Bingham mining district. A generalized columnar section of their Curry, Clinker, and Kirkman formational units is shown, in part, in App. 1. This section indicates their concept of the general nature of the sedimentary rock succession, and provides their interpretation of the succession of sedimentary rocks of Permian age that occur above an unconformity marked by an initial conglomerate in a thick quartzite portion of that measured section. More recently, Babcock and others (1995, p. 317) interpreted these rocks as comprising a folded thrust plate resulting from the Late Jurassic Elko orogeny. However, they still believe that the Curry, Clinker, and Kirkman formational units of Welsh and James (1961) overlie the Bingham Mine Formation (emplaced, according to them, by the Late Cretaceous Sevier orogeny) above a "slight disconformity."

The stratigraphic section observed in exposures on Freeman and Curry Peaks is believed to be part of a stratigraphic and structural domain distinct from that of the Bingham nappe on Markham Peak (Tooker and Roberts, 1988). The Flood Canyon unit apparently is younger in paleontologic age than the Dry Fork unit, and overlaps it southwest of Nelson Peak as the upper plate of an imbricate thrust within the Pass Canyon nappe (fig 8). However, more detailed geologic mapping is needed to resolve remaining stratigraphic and structural uncertainties of the Pass Canyon nappe.

Dry Fork unit of Tooker and Roberts (1988)—The unit is a broadly folded sequence of sedimentary rocks generally surrounding the Flood Canyon unit that occurs on the west-trending spur of Nelson Peak, on the range-front ridge south of Flood Canyon, and on Freeman and Curry Peaks in the Dry Fork area (fig.8). The lower part of the unit exposed on Freeman Peak is characterized by massive medium- to thick-bedded, dark-brown and tan quartzite and sandstone beds, that weather dark-brown and black. The upper part consists of interbedded thin- to medium-bedded, cross-laminated, light-brown to tan calcareous sandstone, siltstone, and local limestone and chert pebble conglomerates that weather light-gray -to tan . The thick-bedded quartzites generally consist of poorly-sorted grains and dark silty materials that characteristically weather dark brown to black in contrast to craton-derived, well-sorted, clean quartzites and carbonate units that occur in the Bingham nappe. The presence of conglomerates and poorly-sorted hinterland sediments suggest their derivation primarily from the erosion of an oceanic-derived source area and/or periodic local uplift along the Uinta trend.

The thickness of the Dry Fork unit as mapped by Tooker and Roberts (1988), is not known because of its complex internal fault structures and because its basal and upper contacts are faults. However, Swensen (1975a) reported that his Freeman Peak and Curry Peak formational units [the Clinker and Curry formational units of Welsh and James (1961)], which may in part be comparable with the Dry Fork unit, are about 1,480 m thick. This uncertainty requires a more definitive geologic-map and stratigraphic data in this well-faulted terrane in order to determine the true thickness of the Dry Fork unit.

The age of the rocks in the Dry Fork unit is based on poorly-preserved Pennsylvanian-age brachiopods, bryozoans, and corals in conglomerate pebbles that occur in the upper part of of the unit reported by Welsh and James (1961), . Typical Wolfcamp fusulinids were found in the upper part of the lower part of the Curry formational unit of Welsh and James (1961). Wolfcamp-age fusulinids were found locally also in thin siliceous sandstones and black chert layers in the upper part of the unit [their Clinker formational unit]. Adjoining Missouri-Virgil age Bingham nappe rocks are older than the Permian Pass Canyon formations. Rocks of Wolfcamp age were not identified in the adjoining Rogers Canyon nappe, but the massive unfossiliferous Oquirrh Group quartzites that underlie the Permian-age (Leonard) Grandeur Member of the Park City Formation superficially resemble rocks in the lower part of the Dry Fork unit, although as far as is now known, they may not be strict age equivalents.

Flood Canyon unit of Tooker and Roberts (1988)—This unit is named from tightly folded rocks exposed mainly in Flood Canyon, which empties into Tooele Valley in sec. 8, T.3 S., R. 3 W. (fig. 8). The unit is in the upper plate of a concealed unnamed imbricate thrust fault (Tooker and Roberts, 1988) and includes a thick basal series of thin- to medium-bedded yellow-brown- to reddish-brown-weathering calcareous sandstone, sandy limestone, and calcareous quartzite beds. These are succeeded by a series of cliff-forming interbedded medium- to thick-bedded, light-gray to brownish-tan calcareous sandstones, interformational breccias, and arenaceous limestone, dolomitic limestone, and white calcareous sandstone. The thick interformational breccias are believed to result from the sloughing of partially lithified fragments coincident with continuing sedimentation that cemented the sloughed fragments during a local limited uplift episode along the Uinta trend. These sedimentary rocks are the lower part of Swensen's (1975a) "Kirkman-Diamond Creek Formation." The upper part grades into thinly-laminated dark-gray limestone and arenaceous limestone that weathers bluish-gray, and superficially resembles Kirkman Limestone strata in the Wasatch Mountains (Baker and others, 1949). This stratigraphic similarity is the basis for believing that the Pass Canyon nappe may be a distal detached imbrication from the upper part of the Timpanogos nappe, which seems to predate the arrival of the Bingham nappe.

The original thickness of the Flood Canyon unit also is very problematical because of structural uncertainties. The unit is inferred to occur on an imbricate thrust that itself is composed of several imbricate thrust slices overlapping the Dry Fork unit and in fault contact with the Rogers Canyon nappe rocks, which are downdropped. The Flood Canyon unit is also dropped down along its southeastern border, forming a fault contact with the Dry Fork unit. Possibly only a minimal thickness of the formational unit is exposed owing to the overlap of its several imbricate thrusts and the presence of complex folds within the unit. More definitive mapping, the development of a cross section, age dating, measurement of a stratigraphic section, and development of a cross section of the Flood Canyon unit in the Oquirrh Mountains also will be required before its formal naming is practicable.

The Flood Canyon unit is assumed to be younger than the Dry Fork unit, as also maintained by Swensen (1975a), and on the basis of regional stratigraphic correlations with comparable rock sequences elsewhere in the Oquirrh and Wasatch Mountains (Tooker and Roberts, 1962). Few reliably dated fossils were found in these rocks, but Welsh and James (1961) report fusulinids of Early Permian (Wolfcamp) age.

Structural features

A complexly faulted system of arcuate folds in the Dry Fork and Flood Canyon formational units (fig. 8) are distributed across the projection of the Uinta trend buttress. The nappe moved an unknown distance more or less directly from a west or west-southwest basin source area (fig. 3). In the process of overriding Uinta trend structure, the distinctive clastic Oquirrh Group sedimentary rocks in the nappe were folded, locally sheared, and imbricate thrusts, tear, and normal faults formed. The structural regimes in the two formations are distinctive in part because of their characteristic lithologic compositions. The Dry Fork strata are generally thicker and massive, and their fold structures are more open. On the other hand, the thinner-bedded, more calcareous strata in the Flood Canyon unit southwest of Nelson Peak are intensely folded and fragmented by faults (fig. 8). The overlying thicker-bedded intraformational breccias in the unit originally were considered to be a chaos terrane (Schurer, 1979). The intensity of folding in these formational units depends on their location in the foreland, whether on or near the uplifted Uinta trend. In addition, the upper parts of some Flood Canyon isoclinal folds were redeformed locally where they were restressed successively later by the overriding Bingham and Rogers Canyon nappes.

Folds—Massive quartzites, sandstones, and interbedded limestones of the unit seem to be wrapped around an inferred basement ridge in tight asymmetrical folds that are exposed on the northwest side of the upper reaches of Flood Canyon. Southward, these tighter folds are covered by the Flood Canyon unit, which was thrust over them. Southeast of Pass Canyon, and apparently farther away from the basement promontory, Dry Fork strata occur in more symmetrical and open folds. These folds may be followed to the east in an irregular pattern around the southeast flank of the inferred basement buttress. The irregular trace of this fold system is believed to result from offsetting shifts along tear faults that are concealed beneath the Flood Canyon unit thrust block.

Folds in the younger beds of the Flood Canyon unit, for the most part, are composed of less-competent, thin-bedded carbonate, shale, and sandstone strata. They were compressed tightly at the range front where they were shoved over the Dry Fork rocks on the steep nose of the buttress in a series of sheared-out beds and imbricate thrust- and tear-fault offsets. The beds form tight, locally asymmetric- to overturned-, in part isoclinally-folded strata that crop out on the Oquirrh Mountains ridges west of Nelson Peak, immediately east of the range front between Flood and Pass Canyons. Farther up on the slope toward Nelson Peak, where thicker clastic beds in the unit overlie a less steeply-dipping upper part of the basement ridge, the folds are crumpled but are more open and less sheared.

Along the southeast flank of the basement promontory, tight, asymmetrical to locally-overturned folds in Flood Canyon rocks overlie an unexposed imbricate thrust separating the two Pass Canyon formational units and are generally subparallel with the steeply-dipping, northeast-trending Tooele fault that forms a contact with rocks of the down-dropped Rogers Canyon nappe (fig. 8). These folds continue to the northeast as tightly-folded strata until cut off by down-dropped Rogers Canyon nappe rocks along a northwest-trending steep fault south of Harkers Canyon. The Flood Canyon folds that parallel the Tooele fault are complex, particularly at the south end where they are cut off by an imbricate thrust and are in angular unconformity with Dry Fork unit folds. To the northeast the Flood Canyon folds are less sheared-out along strike and although tightly folded, they also become more symmetrical in form along their strike.

Perhaps the best direct evidence for postulating an early arrival of the Pass Canyon nappe is from the refolding of its original folds. Sedimentary rocks of the Pass Canyon nappe were redeformed locally by the pressure and drag of the successively overriding Bingham and Rogers

Canyon thrust lobes, which approached the recesses' promontory buttress from nearly opposite directions (fig. 3). The Bingham lobe moved northeastward over the Pass Canyon plate. Its impact on the underlying folded sediments is observed in the overturned folds in the Dry Fork unit near the mouth of Bingham Canyon (Tooker and Roberts, 1988). Folds in the Flood Canyon unit southeast of the Tooele fault, between Barneys Peak and Harkers Canyon, locally are asymmetrical to overturned to the northeast. The impact of emplacement of the Rogers Canyon lobe southeastward over the Pass Canyon plate can be seen in a number of localities. Very tight isoclinally-folded strata of the Flood Canyon unit on the south side of Flood Canyon near the range front are overturned to the northeast at the base of the canyon and overturned to the southwest in the upper parts of the same fold. Folds in the more massive quartzite-rich strata of the Dry Fork unit on the north side of Flood Canyon are asymmetric and locally overturned to the southeast. An east-northeast-trending normal fault, which crosses north of the mouth of Pass Canyon, drops the Flood Canyon unit down against the Dry Fork unit (fig. 8). South of this fault, thrust fault slivers of intensely folded to overturned Flood Canyon unit rocks occur in klippen along the south side of Pass Canyon and overlie the older less-deformed Dry Fork unit, whose directions of fold axes differ from those in the Dry Fork unit.

Faults—Three main types of faults in the Pass Canyon nappe include normal faults along the western border of the Oquirrh Mountains, sole and imbricate thrusts and related tear and normal faults within the range. Faults that delimit the nappe and its constituent formational unit boundaries are generally steeply-dipping normal or tear faults and thrusts. The northern border separating the Pass Canyon and Rogers Canyon nappes on the western slope of the range is along the moderately north-dipping North Oquirrh thrust, which underlies the overriding Rogers Canyon nappe. The thrust is exposed in Bates Canyon, locally in the fault block north of Barneys Peak, and in klippen blocks on the prominent ridge south of Bates Canyon (Tooker and Roberts, 1988). The northeast contact of the Pass Canyon nappe with the Rogers Canyon nappe is along the steep, tear/normal Nelson fault, and the Tooele normal fault, whose origin is not well understood. Subsequent normal movements along both of these structures have dropped the Rogers Canyon nappe down. The southeast contact of the Pass Canyon and Bingham nappes is successively along the Pine Canyon tear fault, the steep-dipping AJ fault, which dropped the Pass Canyon nappe down on the east, the Bingham Canyon tear fault, and a northwest-trending fault parallel to the Nelson fault.

The Pass Canyon thrust fault underlies the Pass Canyon nappe, and an imbricate thrust separates its two constituent formational units; thrusts are not exposed, being concealed by down-dropped blocks of the Rogers Canyon nappe and the overriding thrusts of the Rogers Canyon and Bingham nappes. The amount of movement on these faults can not be determined; that on the sole thrust may be tens of kilometers while displacements on the imbricate thrusts are very much less. The exposed prominent imbricate thrusts within the Flood Canyon unit on the ridge west of Nelson Peak are much-limited local structures that mainly disrupt the folds by shearing out less competent beds. Their aggregate movement can not be determined without more detailed mapping.

Movement on the imbricate thrusts, particularly those on the lower slopes of the range that overlie the steep-plunging basement ridge, was facilitated by the formation of relatively close-spaced, steep-dipping tear faults that permitted jostling of the folded strata. Tear faults of this type are believed to be formed normal to the fold axes where the folds are tensed by bending into a tight arc. An irregular subparallel trend of the folds seems to be a response to the primarily east-northeast-directed movement and drag of the nappe against the basement structure. The folds are also segmented by prominent northwest-trending normal faults. The folded Flood Canyon unit in the block southeast of the Tooele fault is not in tension and is not as well segmented by tear faults as those noted above.

Numerous steep-dipping normal faults trend northeast and northwest. The northeast-trending faults are the most prominent system within the range. Some of them developed as tensional breaks in stressed, arched and folded strata formed during emplacement of the sole thrust. Later uplift along the Uinta trend and regional Basin and Range extension undoubtedly reactivated and extended earlier-formed faults by normal movement. As a general rule, the offset of stratigraphic units along the normal or steep-dipping faults is not large.

The Tooele Valley range-front boundary is a series of linked and branching north-northwest - and west-northwest-trending normal faults that were reactivated during the Basin and Range orogeny, and which, in the aggregate, may have more substantial vertical displacement than most normal faults in the range. The boundary between the Dry Fork and Flood Canyon units along Flood Canyon is a steep tear fault. A small klippen of the Rogers Canyon nappe's Erda Formation which is composed of light-gray fossiliferous limestone, occurs on the north-facing slope of Bates Canyon. It has been displaced downward a small distance along the northwest- and northeast-trending normal fault systems and is surrounded by brown-weathering quartzite and calcareous sandstone of the Dry Fork unit.

Location and types of intrusive and extrusive igneous rocks

The tightly-folded Permian sedimentary rocks in the nappe are intruded by quartz latite porphyry dikes(?) that are similar in composition to those in the Bingham area. Intrusive rocks are not well exposed in the Pass Canyon nappe, and their intermittent distribution is believed to be along faults . Only a few isolated, discontinuous, much altered patchy outcrops of porphyry dikes(?) generally are found on ridge noses in the Pass Canyon nappe (Swensen, 1975a; Tooker and Roberts, 1998). One of these in a tributary of Pass Canyon was dated at 36.5 ± 1.1 Ma (Moore, 1973b). Generally they seem to be spatially associated with the northeast -trending fault systems such as the Tooele fault (fig. 8). Andesitic dikes(?) and latitic volcanic flow rocks along the edges of the eastern side of the range were also described briefly by Swensen (1975a), but were not dated.

Associated mineral resources

The mineral resources of the Pass Canyon nappe include the recently discovered and developed disseminated gold deposits in the Barneys Canyon and Melco mine areas and abundant construction materials that occur along the margins of the nappe in Tooele and Jordan Valleys.

The Barneys Canyon and Melco mines—Sediment-hosted disseminated gold in the Barneys Canyon and Melco deposits (fig. 8, deposits 1 and 2) also contain minor silver (Gunter and others, 1990; Babcock and others, 1995). This was a known- less-mineralized area 7 km north of the Bingham center that was prospected in earlier times, but its gold potential was recognized in 1980 by Jaren Swenson. Exploration followed his collection of a small jasperoid breccia sample that assayed 0.2 oz gold per ton (Presnell, 1992). Once considered to be an extension of the ore forming event in the Bingham mining district, Presnell and Parry (1996) now believe that the gold may have been formed prior to and unrelated to the Bingham porphyry deposits. The Barneys Canyon mine is currently active and its early production of gold and silver is described by Babcock and others (1995).

Gold occurs in altered permeable beds and along imbricate shear in the Barneys Canyon mine. The deposit is localized mainly in the clastic carbonate sedimentary footwall rocks of the Flood Canyon unit (and only inadvertantly in an overlying thinned limestone fault block of the Grandeur Member of the Park City Formation, which the author believes is on a downdropped klippen of an imbricate thrust in the upper plate of the North Oquirrh thrust.)

Presnell and Parry (1996) considered that the Barneys Canyon gold deposition is not be related to the poorly exposed sparsely distributed intrusive dike(s) similar to the Bingham intrusives of presumed Tertiary age. These intrusives are sited on the northern side of the Uinta trend, which is projected across the range southwest of the mine. However, on the basis of Late Jurassic (K-Ar) ages of illite clays formed in the Mississippian limestone host rock, they proposed that the gold was leached from the host shales and migrated to sites where it encountered meteoric water in the crests of anticlines and was deposited. This hypothesis remains to be more rigorously tested in future geologic research.

Construction materials—Numerous sand and gravel pits that occur in the floor of Tooele Valley represent shoreline beach and bar deposits on successive levels of Quaternary Lake Bonneville. Thicker bench deposits of sand and gravel along the eastern and western margins of the Oquirrh Mountains also mark successive lake-level shorelines (Tooker and Roberts, 1971a). These deposits have been extensively mined locally for construction materials for highways, Great Salt Lake shoreline-containment dikes, and for construction of nearby milling, smelting, and refining facilities.

Bingham Nappe

The sedimentary rock strata comprising the Bingham nappe were folded and faulted as it moved generally eastward (fig. 3) on the sole Midas thrust fault. The nappe constitutes the largest thrust plate in the Oquirrh Mountains and is believed to extend southward to the East Tintic Mountains (Tooker, 1983, and Morris, 1983). The Paleozoic stratigraphic section in the Oquirrh Mountains includes lower Paleozoic rocks described originally by Gilluly (1932) and upper Paleozoic rocks reported by Tooker and Roberts (1970). The nappe is segmented by major tear faults and displays changes in sedimentary rock facies southward (Morris, 1983). The Oquirrh Mountains portion of the nappe extends from the vicinity of the Bingham mine to the south end of the range (fig. 9). The northern boundary of the nappe lies along steep normal or tear faults that separate it from the adjoining Pass Canyon nappe. The Bingham nappe is overlapped from the south-southwest by the structurally and stratigraphically discordant South Mountain and Fivemile Pass nappes. In the southern part in the Tintic mining district, the Bingham nappe is overlapped by the Tintic Valley thrust (Morris, 1983). This thrust also overlaps the Oquirrh Mountains' South Mountain nappe from the west.

FIGURE 9, NEAR HERE

A nearly continuous stratigraphic section exposed in the central and southern parts of the Oquirrh Mountains is approximately 8,000 m thick and contains rocks ranging in age from the Cambrian Tintic Quartzite upwards to an eroded top in the Pennsylvanian Bingham Mine Formation. The main stratigraphic features of the constituent formations are summarized in columnar sections and in tables that follow. Several revisions of Gilluly's original lower Paleozoic formation nomenclature, noted in the following summary, are the result of more recent stratigraphic studies in the Oquirrh Mountains and in neighboring areas in central Utah. The individual formations in the Bingham nappe in the Oquirrh Mountains are delineated on geologic maps by Tooker (1980, 1987, and 1992) and Tooker and Roberts (1988 and 1992). Figure 9 is generalized with minor revisions from those reports.

Erosion has removed younger Phanerozoic rocks that may have been present originally in the Oquirrh Mountains; these rocks are present elsewhere in the southern part of the nappe in the East Tintic Mountains, . Precambrian rocks, which underlie the Tintic Quartzite elsewhere in this region, are not exposed in the Oquirrh Mountains, but may be concealed in the nappe beneath the Tintic Quartzite. Precambrian-age basement rocks are inferred to underlie the Midas thrust in the Oquirrh Mountains.

Paleozoic sedimentary rocks have been folded by the sole Midas thrust and overlying imbricate thrusts into the through-going *main* Bingham syncline, Long Ridge anticline, Pole Canyon syncline, and Ophir anticline, and by numerous local *secondary* folds . Tear faults segment the folds, particularly where they are bent. Normal faults developed during Late Cretaceous Sevier thrust faulting have, in some cases, been reactivated by Basin and Range extensional tectonics. These faults are more close-spaced in the lower Paleozoic rocks on the upper-plate of the Manning (imbricate) thrust. Similarly the upper Paleozoic rocks on the thinned lead edge of the upper plate of the Midas thrust are also more intensely fractured than elsewhere in the main parts of the range.

Stratigraphic characteristics and correlation of sedimentary rocks

Sedimentary rocks of the Bingham nappe in figure 9 have been grouped into (a) those of Lower Paleozoic age (Pl), (b) the Manning Canyon Shale (IPMm), which contains the Mississippian-Pennsylvanian boundary, and (c) Upper Paleozoic strata (Po). Correlations are made with similar-aged rocks within the nappes adjoining the Bingham nappe in the Oquirrh Mountains and comparably-aged nappes in neighboring mountain ranges. Lowest Paleozoic rocks are assumed to form the base of the stratigraphic section comprising the Bingham nappe on the

Midas thrust fault in the Oquirrh Mountains. Farther south at Tintic, Utah, the upper part of the Precambrian Big Cottonwood Formation forms the base of the Bingham nappe.

Lower Paleozoic Formations—The Lower Paleozoic stratigraphic section in the Oquirrh Mountains is 2,812 m thick. The formations (shown in table 2) range from Cambrian quartzite to Mississippian limestone and crop out mainly in the cores of the Ophir anticline and eastern part of the Long Ridge anticline in the southern Oquirrh Mountains (fig 9); these formations are shown diagrammatically in a columnar section (fig. 10). The sedimentary rocks are correlated with rocks of the same ages in the Tintic mining district in figure 4 (Morris and Lovering, 1961, and Morris, 1983). Substantial facies changes occur southward in the Lower Paleozoic sedimentary rocks in the Bingham nappe. This is perhaps best illustrated in comparing the Great Blue Formation at Tintic (Morris and Lovering, 1961) with the measured section of the Great Blue Limestone in the Oquirrh Mountains (Gordon , Tooker and Dutro, 2000). In addition, the Lower Paleozoic stratigraphic section in the Oquirrh Mountains is attenuated at an unconformity caused by the uplift of the Tooele arch of Webb (1958) along the Uinta trend (Roberts, and others, 1965). As a result, in the absence of sedimentary rock deposition (or, possibly, the erosion of any sediments that may have been deposited on the plate), the Ordovician, Silurian, and most of the Devonian parts of the stratigraphic section, which are present at Tintic, do not occur either in the Oquirrh Mountains or on Mount Timpanogos in the Wasatch Mountains. I presume that the hinterland of these nappes were located in sites closer to the then uplifted Uinta trend than was the southern part of the Bingham nappe at Tintic.

FIGURE 10, and TABLE 2, NEAR HERE

The lowermost exposed Lower Paleozoic formation in the Oquirrh Mountains is the 91 m-thick Lower Cambrian Tintic Quartzite and 98 m-thick Lower and Middle Cambrian Ophir Formation, which were described originally by Gilluly (1932). The base is concealed and the total thickness of the Tintic Quartzite here is unknown. It is a thick-bedded, commonly cross-bedded white quartzite whose weathered surfaces are a rusty red-brown. The formation is shaly at the top and grades upward into the Lower and Middle Cambrian Ophir Formation, which primarily is a 98 m-thick micaceous shale that becomes sandy upward and contains several mottled shaly limestone beds. In the Tintic Mountains the Tintic Quartzite is 800 to 975 m thick and underlain by the Precambrian Big Cottonwood(?) Formation. The Tintic Quartzite may be thinned by the (sole) Midas thrust in the Oquirrh Mountains or by nondeposition due to gradual uplift and erosion along the Uinta trend. The Ophir Formation at Tintic is 116 m thick.

The Middle Cambrian Hartman and Bowman Limestones conformably overlie the Ophir Formation in the Oquirrh Mountains and are 198 m and 85 m thick, respectively (Gilluly, 1932). The Hartman Limestone is a thin-bedded, mottled-gray limestone and mudstone with shale partings and oolite layers near its top. The Bowman Limestone consists of a shaly unit at its base, but is mainly a mottled shaly limestone with intraformational conglomerate in the lower part and oolite limestone beds in the upper part. The two formations are correlated with the lower parts of the Teutonic Limestone, 128 m thick, and Herkimer Limestone, 130 m thick, at Tintic. The 20 m Middle Cambrian Dagmar Dolomite, which occurs at Tintic, has no correlative rock unit in the Oquirrh Mountains.

The Middle Cambrian formations are overlain conformably in the Oquirrh Mountains by the massive bedded Upper Cambrian Lynch Dolomite, which is 251-305 m thick (Gilluly, 1932). The massive cliff exposures of Lynch Dolomite on the south side of Ophir Canyon are thick-bedded, gray dolomite with a few interbedded limestone units in the lower half.
The lower part resembles the 62 m thick Bluebird Dolomite at Tintic and the upper part is similar to the Cole Canyon Formation, which is 259 m thick in the East Tintic Mountains. There are no formational units in the Oquirrh Mountains correlative with the Upper Cambrian Opex Formation and Ajax Dolomite, which are 75 and 152-213 m thick, respectively at Tintic.

Also missing in the Oquirrh Mountains are several formational units found at Tintic, which include the Lower Ordovician Opohonga Limestone, 259 m thick, the Middle Ordovician Fish Haven Dolomite, as much as 107 m thick, the Upper Ordovician, Silurian, and Lower Devonian

Bluebell Dolomite, up to 183 m thick, and the Lower Devonian Victoria Quartzite, 97 m thick (Morris and Lovering, 1961).

A 56-m thick Lower Mississippian and Upper Devonian Fitchville Formation and Pinyon Peak Limestone, undivided, unconformably overlies the Lynch Dolomite near Ophir. The formation is a coarsely crystalline gray dolomite that weathers dark gray. The base of the unit is composed of thin-bedded gray sandstone and limestone that weathers reddish brown. One massive gray limestone unit in the upper part, called the "eye bed," contains large oval calcite blebs. This marker bed also occurs in the Fitchville Formation at Tintic. Originally called the Jefferson(?) Dolomite by Gilluly (1932), based on his tentative correlation of it with the Jefferson Dolomite in the Northern Rocky Mountains of Utah, the rocks are now recognized as strongly resembling characteristic segments of counterparts that occur in the Tintic mining district (Morris and Lovering, 1961). The formations were attenuated in the Oquirrh Mountains along the Uinta trend, whereas in the Tintic mining district the Pinyon Peak and Fitchville Formations aggregate 121 m .

The Pinyon Peak and Fitchville strata are unconformably overlain in the Oquirrh Mountains by the 140 m-thick Lower Mississippian Gardison Limestone. This formation was originally called Madison Limestone in the Oquirrh Mountains by Gilluly (1932), a correlation made with its type locality in Montana. The Gardison Limestone is now correlated with a revised type locality, 152 m thick, on Gardison Ridge in the Tintic mining district (Morris and Lovering, 1961). The Gardison Limestone at Ophir is a highly fossiliferous blue-gray limestone, thin-bedded at the base, and more massive and cherty in its upper parts.

Above the Gardison Limestone at Ophir are conformable limestone beds of Upper Mississippian age that include the Deseret Limestone, 198 m thick, and the more clastic Humbug Formation, about 198 m thick. The Deseret Limestone is medium-bedded, blue-gray, cherty limestone containing a phosphatic shale unit at the base (Gilluly, 1932). The Humbug Formation is composed of interbedded limestone and some prominent lenticular sandstone and quartzite layers. The Humbug locally seems to interfinger with or grade into the Great Blue Limestone. At Tintic, correlative rock strata are 355 m thick.

The upper Mississippian Great Blue Limestone conformably overlies the Humbug Formation. The Great Blue Limestone is 765 m thick and subdivided into three informal members by Gilluly (1932). Gordon, Tooker and Dutro (2000) propose more formal recognition of these members. The Silveropolis limestone member (the lower limestone member of Gilluly) at the base is 260 m thick and includes beds comparable with the thicker Toplif and Paymaster members of the Great Blue Formation at Tintic (Morris and Lovering, 1961), which there are 141 and 190 m thick, respectively. The Silveropolis limestone member consists of a lower basal dark-gray, thick-bedded limestone, and interbedded locally fossiliferous and argillaceous limestone. An upper part includes thin- to medium-bedded, somewhat fossiliferous, gray argillaceous, sandy, and cherty limestones, which grade into similar beds that weather brownish gray. This member is succeeded conformably by the 33 m Long Trail Shale Member, a very fossiliferous black carbonaceous limestone and shale. The Member forms a prominent topographic break in the Oquirrh Mountains that is not observed at Tintic. The conformable overlying Mercur limestone member of the Great Blue Limestone (the upper limestone of Gilluly, 1932) is 470 m thick and consists of banded outcrops of interbedded limestone, fossiliferous and argillaceous limestone, and shale. Calcareous sandstones occur in the upper part. The member contains fewer and thinner shale beds than those that characterize the Chiulos and Polker Knoll Members of Morris and Lovering (1961) , which aggregate as much as 487 m at Tintic.

Manning Canyon Shale—The 347 m-thick Upper Mississippian and Lower Pennsylvanian Manning Canyon Shale is composed of interbedded shale, argillaceous limestone, sandstone and a medial brown-weathering quartzite. The formation seems to overlie the Great Blue Limestone conformably and in turn is overlain conformably by the Oquirrh Group (Tooker and Roberts, 1970). However, in Manning Canyon, east of the Mercur mining district, the Great Blue Limestone is locally thrust over the Manning Canyon Shale, and locally in West Canyon the contact locally seems to be along the West Canyon imbricate thrust. At Tintic the formation is of nearly comparable thickness at 320 m . It is shown as a separate formation on figure 16 to mark the boundary between the lower and upper Paleozoic rocks in the Oquirrh Mountains.

Upper Paleozoic Formations—Upper Paleozoic sedimentary rocks in the Bingham nappe consist of three Oquirrh Group formations. They crop out as broad north- to north-northwest-trending folds (fig. 9) in the higher northern and eastern parts of the Oquirrh Mountains. The type localities of the constituent formations described by Tooker and Roberts (1970) are in the north-central Oquirrh Mountains, near the Bingham mining district. The stratigraphic section is 5,177 m thick and, except as noted above, conformably overlies the Manning Canyon Shale. This sedimentary sequence originally was named the Oquirrh Formation by Gilluly (1932). It was raised to the Oquirrh Group by Welsh and James (1961). Three formations, the West Canyon Limestone, the Butterfield Peaks and Bingham Mine Formations, are described briefly in table 3 (after Tooker and Roberts, 1970), and paleontologic ages and regional correlations were discussed by Gordon, and Duncan (1970).

TABLE 3, NEAR HERE

The basal formation of the Oquirrh Group is the 442 m -thick Lower Pennsylvanian West Canyon Limestone, an interbedded, cyclic repetition of primarily clastic, thin- to medium-bedded, very fossiliferous series of arenaceous, bioclastic, cherty, dense crystalline, and argillaceous limestones and thin calcareous quartzite beds in the upper part (Nygreen 1958). These are well exposed in outcrops in Soldier Canyon. Gordon and Duncan (1970) reported a Morrowan (lower Pennsylvanian) age for these rocks.

The 2,765 m-thick Middle Pennsylvanian Butterfield Peaks Formation, which conformably overlies the West Canyon Limestone, is also an interbedded, thick, cyclic, thin- to medium-bedded, locally cross-bedded calcareous quartzite, orthoquartzite, and calcareous sandstone and prominent dense limestone, abundantly fossiliferous limestone, and arenaceous, cherty, and argillaceous limestones. The formation is of Des Moinesian (middle Pennsylvanian) age (Gordon and Duncan, 1970).

The Butterfield Peaks Formation is, in turn, conformably overlain by the Upper Pennsylvanian Bingham Mine Formation, which includes the 910 m and 1,319 m thick Clipper Ridge and overlying Markham Peak Members. The Clipper Ridge Member is composed predominantly of interbedded medium- to thick-bedded calcareous quartzite and orthoquartzite, with lesser amounts of cherty limestone and locally very thick, thin-bedded argillaceous, cherty, sandy, and fossiliferous limestone marker beds. Thick fossiliferous limestone units such as the Jordan and Commercial marker beds at the base of the Member (Tooker and Roberts, 1970) are as much as 82 m thick, in contrast with those in the overlying Markham Peak Member (figs 14 and 15 in Hansen, 1961), which are 3-21 m thick. The Clipper Ridge Member limestones are interbedded with quartzite units 46-91 m thick. The Markham Peak Member is composed mainly of thick-bedded to massive orthoquartzite and calcareous quartzite, sandstone, and silt. A few interbedded thin, 0.3-1 m-thick, fusulinid-bearing arenaceous limestone marker beds are present. These marker limestones at the base and several thinner (0.3-1 m thick) limestones higher in the stratigraphic section are the primary beds replaced by base-metal sulfide ores in the Bingham district. (Rubright and Hart, 1968; and Atkinson and Einaudi, 1978) The sediments in the Oquirrh Group formations are well-sorted and their clean-appearing, weathered surfaces are not iron- or manganese-stained, in contrast with those of similar age and composition in the Pass Canyon nappe.

No lower Permian fossils were reported in these Bingham nappe rocks by Gordon and Duncan (1970). Permian ages reported for the upper parts of the stratigraphic section by Welsh and James (1961) were based on rocks that Tooker and Roberts (1988) now include in the Pass Canyon nappe on the basis of mapped structural and stratigraphic considerations. The absence of Permian sedimentary rocks in the Bingham nappe may be due to nondeposition or erosion along the trace of the Uinta trend.

Correlation with nappes in adjoining ranges containing Oquirrh Group-age sedimentary rocks—Correlative Oquirrh Group sedimentary rocks in the surrounding Wasatch, Tintic, and

Stansbury Mountains also occur in Sevier-age nappes whose formations generally are of similar ages and composition but differ in stratigraphic and structural detail from those in the Oquirrh Mountains. In the Wasatch Mountains, east of the Oquirrh Mountains, two contrasting stratigraphic systems were recognized by Baker and others (1949) and Crittenden and others (1952). The thick Oquirrh basin-derived miogeoclinal deposits of the Timpanogos nappe on the sole Nebo-Charleston thrust lie on the southern side of the Uinta trend buttress. A thin Mount Raymond nappe deposited on or near the cratonal platform in the Sublette basin lies on the north side of the Uinta trend. South of the Oquirrh Mountains in the Tintic Mountains, the southernmost part of the Bingham nappe clearly overrides the Timpanogos nappe. The Stansbury (Mountains) nappe lies west of the Oquirrh Mountain and moved eastward on the sole Tintic Valley thrust, overriding the Bingham nappe (Tooker, 1983). The ages of the Oquirrh Group sedimentary rocks in these nappes, documented by Gordon and Duncan (1970), are based on both abundant mega- and micro-fossil assemblages and provide ample correlation of the Oquirrh fauna and host sediments in the Bingham nappe with those in adjoining Sevier-age nappes in western Utah.

Crittenden (1959, 1976) described two contrasting stratigraphic systems of Oquirrh-type sediments in the Wasatch Mountains (fig. 4) and contrasted their thin and thick sequences. Both now seem to represent Sevier-age nappes derived from different parts of the western miogeocline hinterland. The thin Mount Raymond nappe is about 241 m thick and composed of Early and Middle Pennsylvanian sedimentary rocks that rest conformably on lower platform Paleozoic strata. A correlative sedimentary rock sequence on the Rogers Canyon nappe in the northern Oquirrh Mountains is discussed later. The thick Timpanogos nappe, which was deposited in the Oquirrh basin south of the Uinta trend is, in contrast, 8,600 m thick, and composed of carbonate-rich sedimentary rocks much like those of comparable ages in the Oquirrh Mountains. Lower Paleozoic rocks, which are about 1920 m thick, conformably underlie the Oquirrh Group. These include an Early and Middle Pennsylvanian section 2,300 m thick, a Middle Pennsylvanian sequence 3,300 m thick, and an Early Permian section about 3,000 m thick (Konopka and Dott, 1982). These rocks are overlain conformably by Permian and Triassic carbonates and sandstones.

Comparable parts of the Bingham nappe's Oquirrh Group in the in the Tintic region (fig. 4) include a partial section, 293 m thick, of Morrowan-Atokan-age West Canyon Limestone, the Des Moinesian Butterfield Peaks Formation, 1,768 m thick, the Missourian age Bingham Mine Formation, 975 m thick, and the Missouri-Virgil-Wolfcamp age Furner Valley Limestone, which is 1,595 m thick. Morris and others (1977) reported that post-Oquirrh Group Paleozoic rocks in the southern East Tintic Mountains overlie these rocks disconformably and include the 209 m Leonardian (?)-age Diamond Creek Sandstone and 494 m Leonardian-Guadalupian-age Park City Formation. One may speculate that if Permian rocks overlay the Pennsylvanian rocks exposed in the northern end of the Bingham nappe in the Bingham mining district, they most probably were eroded during the Tertiary uplift along the Uinta trend. Apparently intermittent or continuous uplift along the trend continued during the formation of Tertiary igneous and intrusive rocks..

The stratigraphy and structures of 548 m of Oquirrh Group rocks in the Stansbury nappe on the upper plate of the Tintic Valley thrust were described by Rigby (1958) and Moore and Sorensen (1979). The Group conformably overlies about 651 m of distinctive Lower Paleozoic rocks that include a record of sedimentation during Ordovician, Silurian, and Devonian times, which is missing across the valley in the Oquirrh Mountains. These sedimentary rocks seem to resemble those deposited in the Oquirrh basin away from the Uinta trend. Manning Canyon Shale is 54 m thick and overlain by the Oquirrh Group. It consist of 61 m of Morrowan and Atokan carbonates, 122 m of Desmoinsian-, 26 m of Missourian-, and 139 m of Virgil-age interbedded, cyclic carbonate and quartzite sedimentary rocks. These are overlain unconformably by Tertiary rocks.

Structural features

Bingham nappe fold and fault structures in the central and southern Oquirrh Mountains, largely the result of their emplacement by the sole Midas thrust fault, vary depending on the structural competence of rock strata involved, their proximity to the leading edges of sole and imbricate thrusts and to the basement Uinta trend buttress. Through-going *main* folds are the most prominent structures in the range, but these are overprinted by *secondary* folds, which are of more local or limited extent, generally on the upper plates of imbricate thrusts. The sole Midas thrust does not crop out at the surface; it may be exposed underground in the workings of the North skarn-ore deposit in Bingham Canyon (Shrier, oral communication, 1989) and inferred from cross-sections in fig. 7 by Babcock and others (1995) showing complex folding of the Jordan and Commercial marker beds at depth north of the Bingham mine. The structure of the upper plate of the thrust along its leading edge in the nappe was inferred by Tooker and Roberts (1988) from the pattern of exposed structures such as folds, imbricate thrusts, and tear faults shown on the surface mine maps of the Bingham mining district by Lanier (1978a) and Atkinson and Einaudi (1978). The trace of the Midas thrust shown on the district map by James and others (1961a) does not seem to be the sole Midas thrust, but is a more local imbrication above the main thrust fault. This sustains their view that this thrust is not of regional scope. However, the sole Midas thrust is believed to underlie the northern part of the Bingham mine and is not exposed because it is downdropped along northwest-trending normal faults. Tear faults that offset folded strata at the lead edges of the Midas thrusts are important local structures for siting intrusive rocks and ore bearing veins in the main mining districts of the central and southern Oquirrh Mountains. Some normal faults may have been reactivated by Basin and Range extension of original Sevier-age structures.

Folds— Two principal types of folds have been mapped as *main* (named) and *secondary* folds in figure 10. Folds developed in Oquirrh Group formations that are composed of very thick, massive, and competent strata, form the main fold system on the upper plate of the Midas thrust fault. These include the through-going Long Ridge and Ophir anticlines flanked by the Pole Canyon and Bingham synclines. Except for the Ophir anticline, which is described later, these folds form the high backbone of the range and are broad, of high amplitude, generally north-northwest-trending structures that bend to the northwest at their north ends. Where the thinned stratigraphic section at the leading edge of the thrust impinges tangentially on the Uinta trend basement buttress, the folds become asymmetric and are locally overturned to the northeast, and their northern parts plunge to the northwest under Tooele Valley. Secondary, smaller-amplitude, tightly-folded, and locally overturned fold structures commonly bounded by tear faults, occur along the thinned leading edges of imbricate thrusts within the Bingham nappe. These include several small thrusts in the Bingham mining district, the more extensive Butterfield Pass, Manning, and West Canyon thrusts southwest of Bingham, and those on the upper plate of the Manning thrust along the western range-front of the Oquirrh Mountains.

Fold patterns provide some insight to the complex sedimentary rock structures located on the upper plate of the Midas thrust, which are largely obscured by the intrusive stocks, dikes, and waste dumps in the Bingham mining district (Tooker and Roberts, 1998). The main Bingham syncline on Markham Peak is overturned to the northeast . Across the northeast-trending tear faults in Bingham Canyon, the continuing offset portion of this fold is more open and its asymmetry decreases as it trends southeastward. In the zone between the Bingham Canyon and Main Hill faults, on the western side of the Bingham open-pit mine, numerous low amplitude secondary folds are close-spaced and overturned, as if they were crunched together. The similar concentration of secondary folds that occurs in the area between the Bingham and Last Chance stocks apparently are formed on the upper plate of an imbricate thrust of the Midas system. The Galena Gulch folds at the southern margin of this close-spaced system clearly intersect the Bingham syncline and its related secondary folds in angular unconformity east of the Galena Chief fault. Northwest of the Bingham Canyon fault, secondary folds are generally continuous and swing around the south edge of the Last Chance stock and are much less deformed.

The Long Ridge (main) anticline is tightly folded and overturned locally at its western end near Tooele, but broadens along Long Ridge on the eastern side of the range in West Canyon. It is accompanied by numerous secondary folds in the less competent Lower Paleozoic Manning Canyon Shale and Great Blue Limestone strata. Secondary folds were also formed on the leading edges of imbricate thrusts such as the Butterfield Peaks thrust on the south side of Middle Canyon. The secondary folds on the flanks of the main Pole Canyon syncline, on the other hand, form gentle, wide-spaced, broad open folds, in large part, probably the result of its indigenous thick competent constituent Oquirrh Group sedimentary rocks, and the absence of an imbricate thrust along this fold.

The Ophir anticline constitutes the western side of the southern Oquirrh Mountains (Tooker and Roberts, 1998). It is generally parallel or subparallel to the other main folds in the range and crops out on the low ridge west of Manning Canyon and the south fork of Ophir Canyon. In contrast with the northeastern main folds composed of Oquirrh Group sedimentary rocks, the Ophir anticline exposes lower Paleozoic sedimentary rocks. The stratigraphic section consists of interbedded thin- and medium-bedded carbonates, shaly limestone, and quartzose sedimentary rocks (sheet 3 of Tooker 1987). These more-abundant, thin-bedded argillaceous limestone and shale units are less competent than the thick siliceous beds comprising the Oquirrh Group. Characteristic lithologic compositions apparently determine different responses to compressional forces in each stack during folding attendant with thrusting.

The Ophir anticline is located in the upper plate of the Manning thrust, an upper imbrication of the Bingham nappe that moved only a moderate distance eastward to overlap the west side of the Pole Canyon syncline east of Mercur. The Ophir fold trends sinuously southeastward. At its northern end, the fold is concealed beneath local imbricate thrusts along the western range front as it plunges beneath Tooele Valley. The south end of the fold plunges to the south and is overlapped by the Fivemile Pass nappe. In between these terminal parts of the fold the symmetry of the anticline changes south of Ophir Canyon and the Lion tear fault, North of the tear, as seen on the north wall of Ophir Canyon (cross section A'-A", in Tooker, 1987), the fold is a high amplitude, nearly symmetrical structure, exposing the complete Lower Paleozoic stratigraphic section. South of the Lion tear fault, the fold is an asymmetrical, flatter, broader, much faulted arc (cross-section B'-B"" in Tooker, 1987). Locally, east of Mercur in Manning Canyon, the eastern limb of the Ophir anticline becomes steeply east-dipping to near-vertical. The Great Blue Limestone is overturned locally where thrust over the younger Manning Canyon Shale. The west side of the Ophir anticline (and the range) consists of gently-dipping slopes that contain a series of close-spaced, low- amplitude folds. Discontinuous secondary flexures formed on low-angle, west - dipping small-throw thrust faults are sub-parallel with the Ophir structure.

The flattening of the southern part of the Ophir anticline (south of the Lion Hill tear fault) may in part be the result of stretching caused by the Mercur (imbricate) thrust and later "partial collapse" of a less-competent, more highly fractured part of the Oquirrh Mountains during the Basin and Range east-west extension. This structural regime contrasts with the northward continuation of the same fold where it more nearly resembles the other main folds in the range. North of Ophir Canyon and the Lion Hill tear fault, the range also becomes much more rugged (Tooker and Roberts, 1992) where it overlies the uplifted Uinta trend basement structure. In the Dry Canyon area on the west side of the fold, steep, gently-folded steeply-dipping imbricate thrusts place older lower Mississippian carbonates such as the Humbug Formation, Deseret Limestone, and Gardison Limestone as well as the Silveropolis member of the Great Blue Limestone over over younger strata and conceal the northward exposure of the anticline, and develop small subparallel secondary folds are developed in the upper plate (Tooker, 1998).

Faults—Thrust, tear, and normal faults, shown in figure 9, define the boundaries as well as the internal configuration in the Bingham nappe. The fault pattern is controlled in part by the characteristic sedimentary rock strata that comprise discrete areas in the nappe, and in part by the location of the nappe on the Uinta trend buttress. The northern border of the nappe is defined by the sole Midas thrust, which is down-dropped and concealed by normal and tear faults in the Bingham mining district (Tooker and Roberts, 1998). The west edge of the nappe is bounded by intersecting northeast- and northwest-trending range-front normal faults. The range-front faults are overlain locally by Harkers Fanglomerate and by alluvial debris shed off that part of the range overlying the Uinta trend, whose uplift continued. The south end of the nappe in the Oquirrh Mountains is overlapped by the Fivemile Pass thrust and extensive alluvial deposits in Cedar Valley. The eastern side of the nappe is overlapped by Tertiary volcanic rocks and Quaternary gravels along the range front and in the Western Traverse Mountains, which adjoin the Oquirrh Mountains.

The Bingham nappe moved east, east-northeast to northeastward on the Midas thrust fault, depending on whether it approached the Uinta-Basin low or moved onto the Uinta-trend basement buttress and the previously docked Pass Canyon nappe. Movement was modified by tear faults that permitted segments of the folded nappe to push ahead semi-independently. The Bingham nappe is stratigraphically and structurally thinned northeastward by the Midas thrust Tightly-folded and sheared upper Oquirrh Group strata occur along the lead edge of the nappe in the Bingham mining district, whereas a few kilometers to the southwest at Ophir, the complete stratigraphic section includes Cambrian Tintic Quartzite at its base (Tooker, 1992). Although the basal strand of the sole Midas thrust is not exposed in the Oquirrh Mountains, an upper imbricate strand was identified as the Midas by James and others (1961a), and other structurally higher imbricate thrusts noted by Einaudi (1975) also occur in tight asymmetrical to overturned folded sedimentary rocks at the lead edge of the nappe in the Bingham mining district (Tooker, 1998). James and others (1961a) correctly indicated that their Midas thrust was not of regional consequence. Thus a lower (or sole Midas) thrust is inferred here.

The Bingham nappe contains a number of additional imbricate thrust faults, some of which are traceable for long distances across the range, but themselves generally show relatively minor stratigraphic displacement. In general, movement on these minor thrusts is small in comparison with that which must have occurred on the basal Midas thrust, and they occur mainly on the asymmetrical to overturned flanks of the main anticlines formed in the Paleozoic strata. Older sedimentary units apparently moved ahead to overlap younger units, usually being offset by tear and normal faults. Imbricate thrusts in the range, such as the Butterfield Pass and West Canyon thrusts, are en-echelon along the locally asymmetrical Long Ridge anticline. They ramped older parts of the Oquirrh Group over younger parts. The Manning thrust underlies Lower Paleozoic formations that constitute the broad, flattened Ophir anticline; the thrust locally places older Great Blue Limestone strata over the Manning Canyon Shale east of Mercur. The West Canyon thrust, which is developed on the north side of the increasingly asymmetric Long Ridge anticline, ramps Manning Canyon Shale over the younger West Canyon Limestone.

Imbricate thrusts on the southwest limb of the Ophir anticline east of Mercur consist mainly of a series of small displacements of the Silveropolis limestone, probably along the Long Trail Shale beds, over the upper Mercur limestone members of the Great Blue Limestone. Outcrops of the shallowly-west-dipping Silveropolis member are also repeated on the west slopes of the range. At the mouth of Ophir Canyon, the Manning Canyon Shale is in thrust contact with the Great Blue Limestone. Immediately north of Ophir Canyon and along the projection of the Uinta trend uplift, the imbricate steep-dipping thrusts in the Dry Canyon area and northwestward locally involve moving stratigraphic units as low as the Gardner Limestone over the Mercur limestone member of the Great Blue Limestone (Tooker and Roberts, 1998).

Tension produced in arched folds caused by oblique ramping of the nappe against the Uinta bulge, as at Bingham, promoted the formation of prominent, close-spaced, steep-dipping, northeast-trending tear faults normal to the fold axes. These tear faults segmented the secondary folds, locally causing the irregular displacement of fold axes forward for short distances, as seen in the Bingham mine area (Tooker and Roberts, 1988). Tear faults in the Oquirrh Group strata commonly seem to be thorough-going. A tear fault in the Ophir Canyon east of Ophir that bounds an imbricate thrust in the nappe overlaps a tear fault in the lower plate. This results in what at first may seem to be a through-going tear. However, they seem to have moved short distances in opposing directions (Tooker, 1992). Movement along the Lion tear fault, which terminates the southern part of the Manning thrust, and movement on a tear, which at first seemed to be a continuation of the Lion thrust farther up Ophir Canyon, are in opposite directions—the south side of the tear in upper Ophir Canyon moved south while the south side of the Lion tear moved north. These structural relations indicate that they are separate faults in chance alignment by the later emplaced imbricate Manning thrust fault.

Normal faults in the range are steep-dipping, generally northeast- and northwest-trending structures that seem to have only modest movement within the range in terms of offset formations, but have much greater vertical displacement along the range borders and in the valleys beyond. The intersection of these faults produce the saw-tooth western range front of the Oquirrh Mountains. The northeast-trending steep-dipping faults predominate in the northern part of the nappe in which the folded strata are bent to the northwest. The northwest-trending faults are more apparent in the southern part of the range where the Ophir fold begins to bend southward, Steeply-dipping, west-northwest-trending normal faults, which are nearly conjugate to the tear faults exhibit only moderate displacement of formational contacts. One of these, the northwest-trending Bear Trap Flat fault, extends southeastward from the mouth of Middle Canyon into the range to the headwaters of Soldier Creek. It is an important aquifer and several springs located along it are major sources of water for the cities of Tooele and Stockton, Utah (Stolp, 1994).

Normal faults seem to be more abundant in the thin- to medium-bedded Mississippian limestones and shales exposed on the upper plate of the Manning thrust (fig. 9). Here northwest-trending faults are observed as modest offsets along formational contacts (Tooker, 1992). At Ophir Canyon, the faults trend northwestward, but their trend shifts southward to the west-northwest in the Mercur Canyon area. This bending of the fault trend, which is coincident with the bending in the Ophir fold, is considered to be the result of thrust tectonics in thin, less competent strata on the upper plate of the Manning thrust. However, normal faults observed in Rush Valley, to the west of Mercur and the range front, trend to the northwest and probably are the result of Basin and Range extensional deformation. The western margin of the Oquirrh Mountains is defined by progressive down drop to the west along the systems of normal faults forming extensive thin-covered pediments, such as occurs between Ophir and Mercur Canyons. In contrast, normal faults are not as abundant in the Pole Canyon syncline, possibly because the sedimentary rocks are more massive and competent and the trend of the fold is straight, not bent. This results in constituent formational units that are not greatly offset. The through-going conjugate, northeast-trending normal faults in the Ophir mining district, which may have originated as tear faults, later became sites for the deposit of fissure-type ores.

Location and types of intrusive and extrusive rocks

The Bingham nappe is not only the largest thrust terrane in the Oquirrh Mountains, but it also contains the greatest amount and variety of intrusive and extrusive rocks in the range (Table 1); these rocks are somewhat endemic to specific regions therein (Butler, 1915). The Bingham mine area is the major center of intrusive and extrusive activity, followed by progressively lesser intrusive activity in the Middle Canyon-Soldier Creek area, the Lion Hill-Porphyry Knob and the Mercur-Ophir mining areas (Figs. 11 and 12). FIGURES 11 AND 12, NEAR HERE.

Bingham mining district area—Oquirrh Mountains' igneous activity began here with the formation of intrusive stocks, sills, and dikes and ended with extrusive volcanic flows (Bray, 1969; Moore and others (1968); and Babcock and others (1995). Details about the distribution, age, and chemical and physical properties of these rocks on which this summary is based are by Moore and Lanphere (1971); Moore (1973b, 1973c), Bray and others (1975), Moore (1978); Lanier and others (1978a, 1978b), Swensen (1975a), Warnaars and others (1978), Bowman and others (1987); and Babcock and others (1995). There remains some uncertainty about the accuracy of some of the age dates because of the hydrothermal overprint on the rocks in the mining district.

The Last Chance and Bingham stocks, which are now known to be interconnected at depth (Lanier, and others, 1978a), are composed of an early equigranular monzonite phase, beginning at about 39.8 ± 0.4 Ma that has been intruded along the northwestern border of the Bingham stock by quartz monzonite porphyry, beginning at about 38 Ma(?). These rocks, which are intrusive into the Clipper Ridge and Markham Peak Members of the Bingham Mine Formation and underlying Butterfield Peaks Formation, are, in turn, cut by latite and quartz latite dikes and plugs (about 37.7 ± 0.5 Ma) in age), and subsequently by quartz latite porphyry dikes and plugs. An intrusive porphyritic latite sill (about 36.9 ± 1.0 Ma) occurs southeast of Lark, Utah. Northeast-trending latite dikes along the range front between the mouth of Barneys Canyon and Lark may be about the same age. Several pebble dikes and breccia pipes up to 180 m diameter and as much as 910 m in vertical extent seem to be closely associated with latite intrusives south and east of the Bingham stock (Rubright and Hart, 1968; Moore, 1973a and 1973b). These bodies suggest that latitic melts became fluid-saturated and overpressured, and were released by explosive forces.

Extrusive, mostly latitic volcanic rocks overlie sediments of the Butterfield Peaks Formation mainly south and southeast of the Bingham district. Armstrong (1970) reported an age of 38.8 ± 0.9 Ma for andesite porphyry flows along the eastern range front north of the mouth of Bingham Canyon, but Warnaars and others (1978) questioned this age determination. Laharic deposits (or breccias) as much as 450 m to 610 m thick, composed of varieties of latite, make up a basal unit south of Bingham Canyon. These are interbedded with water-laid tuff, volcanic conglomerate, and crossbedded sandstone. The breccias are overlain by lenticular latitic flows, which may be as much as 250 m. thick. Rhyolite vitrophyre flows and flow breccias form sizable bodies in the Tickville Springs quadrangle. Moore (1973b) dated these rocks at 31.2 ± 0.9 Ma.. The volcanic rocks are intruded by the Shaggy Peak rhyolite stock that was dated at 33.0 Ma. Patches of monolithologic latite tuff-breccias, the youngest volcanic rocks (30.7 ± 0.9 Ma), caps this series of flows (Moore, 1973b).

Middle Canyon-Soldier Creek areas—The northwestern part of the Bingham nappe between Middle Canyon and Soldier Creek contains several dikes and plugs that cut sedimentary rocks of the Oquirrh Group (fig. 12). These were described mainly by Gilluly (1932), and by Tooker and Roberts, (1988 and 1992), with age dates by Moore (1973c), Warnaars and others (1978), and Moore and McKee (1983). A 3-4 m-thick latite porphyry dike, which intrudes the Butterfield Peaks Formation, crosses Middle Canyon southwest of the Bingham mining district, and is a continuation of the southwest-trending swarm of dikes in the southwestern part of that district. It was dated at 37.8 ± 1.1 Ma. A 3 m-thick quartz monzonite porphyry sill crops out in the Markham Peak Member of the Bingham Mine Formation at the range front south of Tooele, Utah; and a thinner sill of comparable composition intrudes the Butterfield Peaks Formation on the north slope of Settlement Canyon opposite the mouth of Dry Fork. The age of the Tooele sill was determined to be 38.6 ± 1.1 Ma., the age of the Settlement Canyon body is as yet unknown. The quartz monzonite stock and associated quartz monzonite porphyry, diorite, and diorite porphyry sills on the north side of Soldier Creek occur in the lower part of the Butterfield Peaks Formation and have not been dated. Diorite and diorite porphyry stocks, dikes, and plugs, which occur at the heads of the East Fork of Settlement Canyon and White Pine Canyon, also intrude the Butterfield Peaks Formation; no age has been determined for them.

Lion Hill and Porphyry Knob areas—Faulted altered biotite granodiorite porphyry plugs and associated sill and dikes occur in and along the Long Trail Shale Member of the Great Blue Limestone on the eastern flank of the Ophir anticline (see fig. 12, and Gilluly, 1932). The rocks were dated by Moore and McKee (1983) at 36.7 ± 0.5 Ma .

Ophir and Mercur mining district areas—The *Eagle Hill rhyolite porphyry*, named from outcrops on Eagle Hill in the Mercur mining district (fig. 12), consists mainly of intermittently-exposed, irregular, sill-like intrusive bodies that occur mostly in the Great Blue Limestone and Humbug Formation. These intrusives have been mapped from the head of Sunshine Canyon, across Eagle Hill, astride the Ophir anticline at Mercur, Utah, to the mouth of Mercur Canyon, thence northward, generally parallel to the range front, as far as Silverado Canyon (Tooker 1992). A north-trending dike of rhyolite porphyry reappears in Ophir Canyon at Ophir, Utah cutting across the Bowman Limestone and Lynch Dolomite (Cambrian), the Fitchville Formation and Pinyon Peak Limestone, undifferentiated (Mississippian and Devonian), the Gardison Limestone (Mississippian)

(Tooker 1987). It then trends northward to Dry Canyon, where several discontinuous sills occur in Deseret Limestone (Mississippian) on the hangingwall of the Dry Canyon thrust. The intrusive is terminated in a stock or large plug on the north facing slopes of Bald Mountain in the upper member of the Great Blue Limestone. Eagle Hill rhyolite has been dated at Mercur by Moore (1973c) at 31.6 ± 0.9 Ma; the unit has not been dated at Ophir.

Thin lamprophyre dikes crop out for short distances on both the north and south sides of Ophir Canyon Gilluly, (1932), but they have not been dated. The complete story of intrusive and extrusive activity and related ore deposition in the nappe has yet to be revealed through additional, coordinated, more detailed geochemical, petrologic, and age-dating studies of rocks such as these within the Oquirrh Mountains.

Associated mineral resources

The geology and metallogeny of Bingham nappe ore districts are reported in detail elsewhere, and are only briefly summarized here. The Bingham nappe is host to the main disseminated, vein, and replacement base- and precious-metal ore deposits in the Oquirrh Mountains in the Bingham, Mercur, and Ophir mining districts. These deposits seem to be localized mainly in structurally disturbed porphyritic igneous and/or carbonate-rich sedimentary rocks near the lead edges and on the upper plates of thrust faults Tooker (1998). In most cases the ore deposits are at least spatially related to intrusive igneous rocks. References to more detailed descriptions of the deposits are given in the following statements.

The Bingham mining district—The central zoned porphyry copper-molybdenum-gold ores are dispersed mostly along closely-spaced fractures in the Bingham monzonite porphyry stock and in associated dikes and sills (Peters and others, 1966; John, 1978; and Babcock and others, 1995). Surrounding these deposits are extensive vein, replacement, skarn, and disseminated lead, zinc, copper, silver, and gold deposits hosted by Oquirrh Group carbonate-rich sedimentary rocks that include the Butterfield Peaks, and Bingham Mine Formations of Upper Pennsylvanian age (Hunt, 1957; Tooker and Roberts, 1970; Swensen, 1975a and 1975b; and Tooker, 1990). The ores occur as veins in faults and as replacements of the folded and faulted limestone horizons described by Rubright and Hart (1968), and Stacey and others (1984,1988). Close to the intrusives, the carbonate rocks have been metasomatized and copper-gold-rich skarns developed (Atkinson and Einaudi, 1978; Einaudi, 1983; and Cameron and Garmoe, 1983).

The Mercur mining district—Disseminated gold, silver, and mercury ores occur as bedded and irregular replacements in limestone and as fissure veins in the "Mercur beds" of Kornze (1984a, b), Kornze and others (1985), Faddies and Kornze (1985), Guenther (1973), Klatt and Tafuri (1976), Tafuri (1987), Wicks (1987), and Kerr (1997). Near-surface oxidized ores grade into sulfide ores at depth (Jewell, 1984, and Jewell and Parry, 1984, 1988). These beds are mostly in the faulted upper part of the Upper Mississippian Silveropolis Limestone Member of the Great Blue Limestone (Gordon, Tooker and Dutro, 2000) in the "Mercur beds" as identified by Shrier (verbal commun., 1993) on the folded upper plate of the Manning thrust (Tooker, 1987 and 1998). Reserves of disseminated gold ore were exhausted in 1997 and mining ceased (Kerr, 1997).

An unresolved controversy about the origin of Mercur gold is based on the determination by Wilson and Parry (1995) of a Late Jurassic K/Ar age from illite-rich clays in limestones associated with the deposit. As in other Oquirrh Mountain mining districts, there seems to be a close spatial and structural association of ore minerals and Tertiary intrusives at Mercur, hence the previous assumption of a genetic connection (Morris and Tooker, 1996). However, the new older age implies that gold mineral formation here may have occurred in the hinterland before the Sevier thrust event, which produced the fault structures in which ore minerals commonly occur. Kerr (1997) affirms that the ores were formed after the intrusion of the associated rhyolite bodies. The final resolution of this problem must be left to future research that will be able to develop more critical data.

The Ophir mining district—Ore minerals at Ophir were deposited as bedded replacements irregular replacements, pipelike and vein and fissure as lead, silver, copper, and zinc sulfides and oxides. Small amounts of tungsten, bismuth, and cadmium occur in the lower parts of the Ophir Hill mine (Rubright, 1978), which was one of the largest and most recent producers. Mining in the district ceased in 1972, but the ore zone was not bottomed according to Rubright (verbal commun., 1988); the main part of the district (Ophir Hill} was recently purchased by Silver Eagle Resources Ltd (Vancouver, B.C., Canada). The folded host sedimentary rocks are Lower Paleozoic carbonates on the upper plates of several branch thrusts at the apex of the Ophir anticline, where it crosses the Uinta trend and is bent northwestward (Tooker, 1998).

Production from the Bingham, Mercur, and Ophir districts—A summary of the production is shown in Table 4. The production from the separate areas within the Ophir district are not specified and the pre-1902 data at Ophir are combined with those from the Stockton mining district.(from USGS and USBM data)

TABLE 4, NEAR HERE.

Industrial minerals and construction materials---These have also been mined within and bordering the Bingham nappe (Tripp, 1992). Limestone, used for flux in smelting of metallic ores, was produced from the Deseret Limestone in Mercur Canyon. Production data are unavailable. Production from extensive sand and gravel deposits that occur along the margins of the range and on the extensive pediments also is not known. The well-known Stockton bar and spit deposits of sand and gravel immediately west of Stockton were accumulated by the Lake Bonneville currents along the west side of the range, which modified the extensive older unconsolidated Harkers Fanglomerate deposits along the margin of the range.

Rogers Canyon Nappe

The folded and faulted Rogers Canyon nappe, which moved south-southeastward on the North Oquirrh thrust fault to its foreland site over the Uinta-trend buttress, crops out in the northern one-third of the Oquirrh Mountains (fig.13). Its nearly 4,000 m-thick stratigraphic section was divided into five formations (Tooker and Roberts, 1970). The general lithologic characteristics, fossils, and age correlations and map distributions of these formational units were based on the measured sections in type localities at the north end of the Oquirrh Mountains by Gordon and Duncan (1970), and Tooker and Roberts (1970, 1971a, 1971b, and 1971c). Table 5 provides a summary of these data . The north end of the Oquirrh Mountains is bordered by the Great Salt Lake, and by reverse or thrust faults in the Black Rock fault zone. The western margin of the range lies along intersecting northwest- and northeast-trending normal faults. A pediment beyond the western range front is terminated by strong, deep-reaching normal faults that defined the easternmost margin of the Tooele graben of Cook and others (1966). The southern border of the nappe is along the North Oquirrh thrust, which is best exposed in Bates Canyon. East of the crest of the range, the thrust is concealed by downdrop of the nappe along the steep-dipping Nelson Peak and Tooele northwest- and northeast-trending faults. The eastern margin of the nappe, which has been tilted to the east, is concealed by Quaternary alluvial deposits, the thick fan of the Harkers Fanglomerate, and Tertiary volcanic units.

FIGURE 13 AND TABLE 5, NEAR HERE.

Stratigraphic characteristics and correlation of sedimentary rocks

The succession of Paleozoic sedimentary rocks in the Rogers Canyon nappe are distinctive in themselves, but they also share some correlative lithologic and age characteristics with those in the Bingham nappe in the Oquirrh Mountains as well as those comprising nappes in some of the adjoining ranges. The general lithologic similarities of sedimentary rocks in the Bingham and Rogers Canyon nappes hindered earlier recognition of them as separate rock sequences in the Oquirrh Mountains. Detailed descriptions of the formational units in the Rogers Canyon nappe are based on measured sections by Tooker and Roberts (1970). The Upper Mississippian Green Ravine Formation at the base is overlain conformably by the Oquirrh Group, composed of the Lake Point Limestone, and Erda and Kessler Canyon Formations, ranging in age from Upper

Mississippian and Lower Pennsylvanian to Upper Pennsylvanian. The section is capped by the basal Grandeur Member of the Lower Permian Park City Formation.

Lower Paleozoic Green Ravine Formation—The Green Ravine Formation, 432+ m thick, is composed of abundantly fossiliferous interbedded thin-bedded limestone and calcareous shale overlain by more massive bedded cherty and fossiliferous limestone. The base of the Green Ravine Formation is concealed by alluvium and range-front faults (Tooker and Roberts, 1970).

The Upper Mississippian-Lower Pennsylvanian stratigraphic transition in the Rogers Canyon nappe differs from that in the Bingham nappe. A formational unit resembling Manning Canyon Shale, which overlies the Great Blue Limestone and encloses the Pennsylvanian-Mississippian boundary prominently throughout the Bingham nappe, is not present in the northern Oquirrh Mountains (fig. 4). That part of the Rogers Canyon stratigraphic section is a limestone facies and is included in the base of the Lake Point Limestone. The Green Ravine Formation was correlated faunally with the upper part of the Mercur limestone member of the Great Blue Limestone in the Bingham nappe in the Oquirrh Mountains and with faunal and stratigraphic characteristics of the Doughnut Formation in the Mount Raymond nappe sequence in the Wasatch Mountains (Crittenden, 1959; Tooker and Roberts, 1962; and Gordon, Tooker and Dutro, 2000). Although the lower part of the Green Ravine Formation is correlated lithologically with one or more of the interbedded shale and limestone strata of the upper part of the Mercur Member of the Great Blue Limestone, the upper part of the Green Ravine Formation does not contain prominent interbedded shales and is not transitional into a thick shale unit, such as the Manning Canyon Shale in the Bingham nappe (Gordon and Duncan, 1970; and Gordon, Tooker, and Dutro, 2000). As noted earlier, the Green Ravine is conformable with a crossbedded sandy limestone and limestone facies that resembles the similar smaller-scale transition from Great Blue Limestone to Doughnut Formation in the Mount Raymond nappe. Because the lithologies of the Mississippian-age rocks in the Rogers Canyon nappe are not generally similar to those in the Great Blue Limestone and its overlying Manning Canyon Shale in their type sections in the Bingham nappe, the name Green Ravine Formation was retained for these age-correlative rocks in the northern Oquirrh Mountains.

Oquirrh Group (Upper Paleozoic) formations—The lithology and fossil collections of Oquirrh Group sedimentary rocks, which include the Lake Point Limestone, the Erda, and Kessler Canyon Formations, summarized below, were described in more detail by Tooker and Roberts (1970, fig.3) and Gordon and Duncan (1970). The summary map (fig. 1), does not show the individual Oquirrh Group formations; their distribution and structures in the Rogers Canyon nappe in the Mills Junction, Farnsworth Peak, Magna, and Bingham Canyon quadrangles werer detailed in the maps by Tooker and Roberts (1971a, 1971b, 1971c, and 1988) Figure 13 shows the distribution of the underlying conformable Greene Ravine Formation and the overlying disconformable Grandeur Member of the Park City Formation.

The *Lake Point Limestone* is 529 m thick and is a prominent thick light-gray unit at its type locality between Big Canyon and Rogers Canyon . The formation consists chiefly of interbedded thin- to medium-bedded limestone and massive cherty, fossiliferous, bioclastic, arenaceous, and thin argillaceous limestone and thin carbonaceous shale beds . In addition to the abundant brachiopod, foraminifera, coral and bryozoan fauna , the conodonts reported by Davis and Webster (1987) and Davis and others (1994) demonstrate the presence of diverse platform elements and permits recognition of the Mississippian-Pennsylvanian (Chester-Morrow) and Morrowan/Atokan boundary.

The *Erda Formation* is characterized by a 1,255 m-thick banded sequence of cyclically repeated thick-bedded limestone, fossiliferous and argillaceous limestone, thin quartzite, and cross-bedded calcareous sandstone and carbonaceous shale partings . Although less abundant than in the Lake Point Limestone, the mega-fossil assemblages demonstrate a Middle Pennsylvanian (Des Moines) age. These rocks are the approximate age equivalents of the lower and middle parts of the Oquirrh Group in the thick Timpanogos nappe in the Wasatch Mountains and in the Bingham nappes in the Oquirrh and East Tintic Mountains (Tooker and Roberts, 1962).

The *Kessler Canyon Formation* , about 1,362 m thick, consists predominantly of interbedded massive orthoquartzite, calcareous quartzite, and cherty limestone, which becomes interbedded ferruginous dolomite, dolomitic sandstone, dolomite, and thin fusulinid chert layers in the upper part. The formation is sparsely fossiliferous throughout and contains highly-altered iron-stained zones in its upper parts—perhaps evidence of a weathered surfaces. There may be Missouri-age fusulinids in the basal part of the formation, but the upper part is of Virgil age (Gordon and Duncan, 1970).

These observations lead to other comparisons in considerations of lithologic characteristics in the Rogers Canyon and Wasatch Mountains' Mount Raymond and Bingham nappes. The Kessler Canyon Formation is, in part, age-correlative with the Markham Peak Member of the Bingham Mine Formation. Gordon and Duncan (1970) suggestedthat the absence of Missouri-age rocks in the Kessler Canyon Formation, which is in sharp contrast with their abundance in the Bingham Mine Formation, may indicate a period of non-deposition or uplift and erosion in the Sublette basin hinterland of the Rogers Canyon nappe, which Steele (1960) called the regional Middle Pennsylvanian unconformity in west-central and northwest Utah and eastern Nevada. Wolfcamp-age sediments are also missing in the Rogers Canyon nappe in the Oquirrh Mountains, and the Early Permian (Leonardian) Park City strata rest without angular unconformity on Virgil(?)-age beds. Comparable rocks are also missing in the Mount Raymond section (Baker and others, 1949; Crittenden, 1959; and as diagrammed in figure 4). These stratigraphic relations lend further support for the inference in this report that Pennsylvanian-Permian sedimentation along the miogeocline shelf varied from north to south across the Uinta trend in the Sublette and Oquirrh basins.

Grandeur Member of the Park City Formation (Permian)—The Grandeur Member of the Permian Park City Formation is 232+ m thick and is composed of thin- to medium-bedded arenaceous limestone, dolomite, dolomitic limestone, and interbedded thin partings of shale, argillaceous and fossiliferous limestone, phosphorite, chert, orthoquartzite and calcareous sandstone. The Tooker and Roberts (1970) measured section divides the member into a lower limestone, 66-m thick, a medial quartzite, dolomite, sandstone, shale, chert and phosphorite, 86-m thick, and an upper dolomite and quartzite 79-m thick. The member rests disconformably on the Kessler Canyon Formation , which Gordon and Duncan (1970) believed accounted for the absence of Wolfcamp- and part of the Leonard-age rocks. Mega fossils are abundant in the prominent white lower limestone and are of late Leonard (Early Permian) age. The top of the member is an erosion surface.

Structural features

The fold and fault structural regime in the Rogers Canyon nappe is primarily the result of its emplacement from the northwest on the North Oquirrh thrust (fig. 3), and subsequent adjustments along Basin and Range extensional normal faults (Roberts and Tooker, 1961). The prominent *main* folds are restricted to the western half of the nappe and trend predominantly east-northeast- to northeast. Their flanks contain numerous *secondary* folds. A major fault, the Garfield, effectively drops the eastern half of the nappe. Closer-spaced more symmetrical folds in the eastern part of the nappe, which are composed of younger beds of the Kessler Canyon Formation, trend northeast and are nearly equal to each other in amplitude. A regional map (Tooker and Roberts, 1998) showed a prominent northwest trend for steep-dipping normal (in part tear?) faults in this eastern structural block. This suggests the possibility that the eastern half of the nappe lies on an imbricate thrust above the North Oquirrh sole thrust that responded differently to stress than the thicker western half of the nappe on the North Oquirrh thrust. Imbricate thrusts also occur both at the north end of the range (perhaps, in part, as reverse faults) as well as in the southern part of the nappe, which over-rode the Uinta-trend basement and Bingham-nappe structures.

Folds—Fold patterns in the nappe, which are different in the western and eastern halves of the range, are separated by the north-trending, steeply east-dipping extended Garfield fault . The

Mills Junction syncline, Kessler anticline, and Farnsworth (formerly Coon) syncline, and the Bates Canyon anticline, considered to be main folds, are well exposed on the western flank of the range as broad, high-amplitude, and southeast-leaning asymmetrical structures that trend to the northeast (Tooker and Roberts, 1971c). These rocks are composed of Upper Mississippian and Lower and Middle Pennsylvanian sedimentary strata (Tooker and Roberts, 1971b). The less steeply-dipping north flanks of the main folds contain numerous secondary folds. A small folded imbrication in the upper plate of the North Oquirrh thrust at the mouth of Rogers Canyon, the Lake Point thrust, consists of tight, isoclinal, low-amplitude, northeast-trending folds of the Middle Pennsylvanian Erda Formation, which are overturned to the southeast. The Lake Point thrust is overlain by the older Green Ravine Formation and Lake Point Limestone. The upper plate of the Black Rock thrust (or reverse fault(?) along the northern border of the nappe contains tightly-folded secondary close-spaced, low-amplitude, asymmetrical, and locally overturned folds composed of Lower and Middle Pennsylvanian strata (Tooker and Roberts, 1971b). The Lake Point Limestone was thrust over Erda Formation, and in turn, is overlapped by flat-lying Quaternary (Lake Bonneville and alluvium) deposits along the northern and western sides of the range.

The pattern of folds in the eastern half of the nappe is different—there are no prominent main folds. Instead, the folds are more closely spaced, symmetrical and open, northeast-trending, and generally low-amplitude structures whose axes plunge gently to the northeast. The rocks include Upper Pennsylvanian and Lower Permian strata noted above (Tooker and Roberts, 1971b). These strata are overlapped by generally flat-lying Tertiary conglomerate that is overlain, in turn, by Tertiary volcanic rocks. Quaternary sedimentary rock units that include the Harkers Fanglomerate and Quaternary alluvial deposits overlap the consolidated formational units along the eastern border of the range.

Faults—The distribution of faults in sedimentary rocks in the Rogers Canyon nappe (fig. 21) is the result of deformation by the emplacement of the North Oquirrh thrust fault and its upper plate imbricate thrusts, and the associated steep-dipping and tensional-tear faults, and later normal Basin and Range extensional faults. The sole North Oquirrh thrust crops out in Bates Canyon, on the west side of the range, and also in a structural block that includes Barneys Peak. The thrust is a shallow north-dipping fault at the mouth of Bates Canyon, and apparently also along the western front of the range where it is inferred to underlie the Adobe Rock pediment between Lake Point and the mouth of Bates Canyon. However, the northern dip of the thrust appears to steepen upward as it is traced southeastward up Bates Canyon toward Nelson Peak. The North Oquirrh thrust is not exposed east of the Nelson Peak fault. Where exposed northwest of Barneys Peak in the down-dropped block west of the Nelson Peak fault, the dip of the thrust is not clear, but seems to have a low dip to the south. Here one may assume that the thrust has ramped across the earlier accumulated Pass Canyon and Bingham nappes overlying the Uinta-trend structure. The same assumption may be made for the origin of several imbricate thrusts that crop out east of the Nelson Peak fault and have relatively small displacement within the Erda Formation. These imbrications seem to break out and form where the thrust crosses the Uinta trend.

The North Oquirrh thrust thus seems to ramp up across the stratigraphic section in its southward movement. In Bates Canyon the Lake Point Limestone (Lower Pennsylvanian) lies on the thrust surface with little or no deformation or alteration. On the crest of the range west of Nelson Peak, the fault rides on the Erda Formation. The Lake Point Limestone also occurs above the thrust in the klippen on the ridge on the south side of Bates Canyon. Where exposed northwest of Barneys Peak, the Erda Formation (Middle Pennsylvanian) overlies the thrust. The Nelson Peak and Tooele faults drop the nappe and conceal the North Oquirrh thrust between these exposures and also form the boundary between the adjoining Pass Canyon and Rogers Canyon nappes. On the eastern border of the range, immediately north of the mouth of Barneys Canyon, a small exposure of a south-dipping easternmost outcrop of the Rogers Canyon nappe, possibly on the upper plate of the North Oquirrh thrust or on an imbricate thrust in the nappe, underlies a sliver of the Grandeur Member, which is preserved in a klippen bloc.

The steep, north-dipping Black Rock and Pony Express thrusts, which may have developed somewhat later than the North Oquirrh thrust, are imbricate fault structures that form over-steepened to overturned folds in the upper plate at the north end of the Oquirrh Mountains. The Lake Point thrust, along the range front at the mouth of Rogers Canyon (Tooker and Roberts, 1971c), is also believed to be a folded lower imbrication above the North Oquirrh thrust.

Normal faults are predominantly northwest-trending, steep-dipping structures with less prominent conjugate northeast-trending steep faults. None of these faults markedly offset the sedimentary rocks, and are thought to have developed, in part, as tensional and later tear breaks during the folding of the nappe. Some may have been reactivated as Basin and Range normal faults. The eastern part of the range seems to have been downdropped along the Garfield fault, which now is interpreted to be a combination of intersecting tear- and northeast-trending normal faults that drop the eastern younger sedimentary section down on the east.

The western range front is shaped by intersecting northeast-and northwest-trending normal faults. The Adobe Rock pediment at Lake Point resulted from fault blocks that are still visible above the unconsolidated sediments of Tooele Valley. The blocks to the west in the valley have been dropped variable distances that were estimated as much as 1.5 km below the surface, forming the Tooele graben (Cook, and others, 1966; and Tooker and Roberts, 1971a). The nappe fault boundaries on the eastern side of the range are not as well revealed owing to the eastward tilt of the range and consequent overlap of Quaternary sediments.

Proposed formation of Rogers Canyon nappe structures—Stratigraphic and structural features exposed in the eastern and western parts of the Rogers Canyon nappe support the following explanation for the formation of the contrasting stratigraphic and structural elements. First, there is a striking difference in the stratigraphic character between the Lower and Middle Pennsylvanian rocks exposures on the western side of the range and the Upper Pennsylvanian-Lower Permian rocks on the east side. The sedimentary rock succession on the west side of the range includes a high proportion of competent interbedded thick orthoquartzite, calcareous quartzite, and limestone beds of the Lake Point Limestone, the Erda Formation, and the lower part of the Kessler Canyon Formation. Their competent thick sedimentary rock lithology resulted in formation of main-type folds with subsidiary small overprinted secondary folds. The stratigraphic sequence of the upper part of the Kessler Canyon Formation and Grandeur Member strata on the east side are composed of a high proportion of thin- to medium-bedded ferruginous sandstone, dolomite, and shaly limestone units. These rocks are generally compositionally less competent, forming more evenly distributed close-spaced, low-amplitude folds. These seem to have been formed on the upper plate of an unexposed imbricate thrust.

The map distribution of formational units suggests that the folding in the western and eastern was accomplished in separately detached structural blocks. The west-side main folds were formed as the west side moved on the North Oquirrh thrust onto the Uinta trend. The thrust began to cut upwards across beds in the Lake Point Limestone and Erda Formation. Imbricate thrusts in the Erda were formed as the nappe crossed the Uinta trend buttress. The Lake Point thrust is a folded lower imbrication that crops out on the western side of the Rogers Canyon nappe at the range front.

East-side folds developed in an upper imbricate plate separated from the west-side plate. The southern lead edge of the imbricate thrust is inferred to be on the ridge south of Harkers Canyon, where the thrust plane is marked by a thick silicated quartzite breccia formed against the Uinta trend. The composite Garfield fault became the break during Basin and Range extension along which the east side was dropped down to its present position. Erosion completed the present topography.

The Black Rock imbricate thrust zone, possibly the last gasp in the North Oquirrh thrust system, ramped the Lower Pennsylvanian Lake Point and Erda Formations along the northern range front to overlap both the west- and east-sides of the nappe.

Location and types of igneous rocks

The only igneous rocks present in the nappe occur closer to the southern fault border with the Pass Canyon nappe. These are believed to be extensions similar to intrusions originating in the underlying Pass Canyon nappe. A thin (up to 1.2 m thick) flow composed of andesite breccia, apparently conformably overlies Tertiary conglomerate capping the low ridge west of Mahogany Hill in the southeastern corner of the Farnsworth Peak (Garfield) quadrangle (Tooker and Roberts, 1971b). This rock has not been dated. Tertiary flows of latite and latite breccia crop out along the southeastern range front (Swensen, 1975a and 1975b), where they unconformably overlap the sedimentary rocks of the nappe.

Associated mineral resources

The Rogers Canyon nappe is not mineralized, however, the Barneys Canyon disseminated gold mine (Skillings, 1988) is located mainly in the Pass Canyon nappe (Babcock and others, 1995) near its contact with the Rogers Canyon nappe. Hydrothermal solutions penetrated and altered a sliver of Grandeur Member limestone in the North Oquirrh thrust fault that overlies the Flood Canyon unit near the mouth of Barneys Canyon. The Grandeur Member crops out elsewhere in the Farnsworth Peak and Magna quadrangles (Tooker and Roberts, 1971b, 1971c) and has been prospected with little apparent success.

Industrial mineral and construction materials (Tripp and others, 1989; and Tripp, 1992) were produced from or peripheral to the Rogers Canyon nappe. While some of these materials are not directly derived from the nappe, they are indirectly the result of its erosion and concentration by evaporation of Great Salt Lake. Gravel deposits formed about the margins of the Oquirrh Mountains by Pleistocene Lake Bonneville have been mined extensively in the area for road metal and for construction of mine facilities and evaporators A byproduct of smelting activity at the north end of the range is crushed smelter slag used in construction of highways, as railroad ballast, and the Great Salt Lake containment dikes . Oolitic carbonate sands that occur along the southern shores of Great Salt Lake have been mined for use as a flux in the adjoining Kennecott refinery. Halite has been recovered from the evaporation of Great Salt Lake brines. Data on the production of most of these materials are unavailable.

South Mountain Nappe

The South Mountain nappe is located on South Mountain and in the adjoining area east of Stockton, Utah, in the west-central part of the Oquirrh Mountains and includes the Stockton mining district (Tooker and Roberts, 1992; and fig. 14). The nappe is the upper plate of the sole Stockton thrust fault, recognized initially because of its overall stratigraphic and structural discordance with those geologic features in the adjoining Bingham nappe. North of South Mountain, the northern boundary of the nappe is along the TAD thrust fault concealed beneath Quaternary alluvial deposits. The South Mountain nappe is overlapped on the west by the Tintic Valley thrust fault whose upper plate contains the Stansbury Mountains (Tooker, 1983). The eastern boundary of the nappe is the Soldier tear fault at the mouth of Soldier Creek. Quaternary alluvial deposits overlap the nappe on the south.

FIGURE 14, NEAR HERE

The sedimentary rocks in the nappe include three informally-named formational units of the Oquirrh Group: the South Peak, Salvation, and Rush Lake units of Tooker and Roberts (1988). Table 6. Although there is a general gross similarity in the types of rocks comprising the Oquirrh Group in the South Mountain and Bingham nappes, the lithologic character of South Mountain sedimentary rocks is sufficiently different to recognize that it is a separate structural unit from the Bingham nappe.

TABLE 6, NEAR HERE.

The patterns of folded and faulted sedimentary rocks in the South Mountain nappe contrast markedly with those in the Bingham nappe. The discordance in fold directions and their styles and magnitudes is most apparent. Gilluly (1932) correlated the major fold on South Mountain with the westward extension of the Ophir anticline. More detailed mapping there and in the Stockton mining district indicated that they were not related stratigraphically and structurally (Tooker and Roberts, 1992). Figure 14 also shows that the sole Stockton thrust of the South Mountain nappe in the Oquirrh Mountains and the TAD[3] thrust north of South Mountain are most probably separate faults separated by an inferred Rush Valley fault of at least moderate offset. The inference is that the TAD thrust is an imbrication above the Stockton thrust. The Rush Valley fault zone is the locale of warm springs at the Morgan Ranch, on the southwest, and along the margins of Rush Lake southwest of Stockton, Utah.

Stratigraphic characteristics and correlation of sedimentary rocks

While there is structural discontinuity across the Rush Valley fault, the sedimentary rocks on both sides are readily correlated in age, and to an extent they also share characteristic formational stratigraphic features in their Upper Paleozoic Oquirrh Group formational units and overlapping unconsolidated sediments of Quaternary age. The type localities and measured sections of the Oquirrh Group formational units in the South Mountain nappe are on South Mountain (Tooker and Roberts, 1992), and details of their lithology are shown in app. 2. The Rush Lake and Salvation units also crop out in the Stockton mining district. Unit designations are retained for rocks in the South Mountain nappe pending more detailed mapping and stratigraphic and faunal information. The units are not areally extensive, and possibly do not warrant more than unit designation accorded here. They were included previously with rocks of the Bingham nappe (Welsh and James, 1961), but such designation does not recognize their separate distinctive stratigraphic and structural characteristics.

Rush Lake unit of Tooker and Roberts (1988)—The type locality of the unit on South Mountain consists of nearly 1,352 m of interbedded limestones, quartzites, and local shale intervals of Middle Pennsylvanian age The lowest part of the stratigraphic section, where

[3] TAD is the acronym for Tooele Army Depot, which includes most of the area in Tooele Valley north of South Mountain.

measured, is covered by Quaternary sand and gravel deposits on the shore of Rush Lake. Only the upper part of the unit is exposed in the Stockton mining district (app. 2-C; and Tooker and Roberts, 1992), thus its total thickness there is unknown. Limestone predominates and is generally medium-bedded, medium-gray, with local light-gray, thin-bedded, and fissile shale partings; some beds are also sandy, silty, or bio-clastic and crossbedded, locally argillaceous, and some contain black chert nodules and layers. Buff- or tan-colored quartzite beds contain thin limestone partings, are locally crossbedded, and weather with pitted surface rinds. Local interbedded punky ferruginous layers contain worm trails The measured section by Tooker and Roberts (1992) identified the location of beds containing a sparse coral, bryozoan, and fusulinid fauna. The unit is age-correlative with the upper part of the Butterfield Peaks Formation (R.C. Douglass, written commun., 1962; and Mackenzie Gordon, Jr., written commun. 1966); however, the thick sequence of cyclic repetitions of limestones quartzite, sandstone, and shale, which are characteristic of the neighboring Butterfield Peaks Formation, are absent. The clean, rounded sand grains in well-sorted clastic rock materials are inferred to be derived mainly from a craton source.

Salvation unit of Tooker and Roberts (1988)—Named for exposures generally north of Ben Harrison Gulch near the Salvation mine in the Stockton mining district, the type (measured) locality is on adjoining South Mountain (Tooker and Roberts, 1988). The unit consists of 823 m of interbedded calcareous quartzite, orthoquartzite, and sandy, argillaceous, fossiliferous, and dense crystalline limestone (app. 2-B; and Tooker and Roberts, 1992). Medium-bedded quartzite predominates over thin-bedded limestone and shale partings. The rocks are age-correlative with the Late Pennsylvanian Oquirrh Group Clipper Ridge Member of the Bingham Mine Formation (Mackenzie Gordon, Jr., and R.C. Douglass, written commun., 1962). The main distinction between the Bingham and South Mountain nappes is the absence of thick limestone marker beds in the Salvation unit comparable with those in the Jordan and Commercial marker beds at the base of the Clipper Ridge Member and the overlying massive orthoquartzite beds (Tooker and Roberts, 1970).

South Peak Unit of Tooker and Roberts (1988)—The South Peak unit is 1,903 m thick where exposed along the crest of the western part of South Mountain and is named for the peak labelled *South* in the high southwestern part of the range. The lower 678 m thick section (beds 1-9, appendix 4-A, Tooker and Roberts, 1992) contains interbedded light gray-tan, medium-bedded-to-massive calcareous quartzite that contain fusulinid molds, light-gray, silica-cemented orthoquartzite, reddish-brown-weathering ferruginous sandstone with worm trails, and thin (0.6-6 m thick) dark gray, fine-grained to sandy limestone with sandstone partings. No well-preserved fossils were collected, although fragments and molds were relatively abundant. The upper 1,225 m. (beds 10-22, app. 2-A; and Tooker and Roberts, 1992) of the South Peak unit consists of interbedded tan to buff and light gray, weathering light brown, commonly finely-banded calcareous quartzite, and interbedded light-gray orthoquartzite, reddish-brown weathering ferruginous sandstone containing worm trails, thin-bedded chert with fusulinid molds, and, less commonly, thin-bedded dark-gray sandy limestone. Although most fossils are poorly preserved, fusulinid fossil collections contain detrital fragments of bryozoa and fusulinids. The age suggested is Early Permian, late Wolfcamp equivalent. (R.C. Douglass, written commun., 1963).

Quaternary deposits.—Unconsolidated sediments in the vicinity of the South Mountain nappe comprise the Harkers Fanglomerate and Quaternary alluvium, which also includes Pleistocene clastic sand and gravel deposits formed along the shores of Lake Bonneville. The Harkers Fanglomerate deposits occur on both sides of the Oquirrh Mountains, and are thickest where they overlie the trace of the Uinta trend. Apparently it was being uplifted during the Quaternary, producing extensive deposits of coarse gravels. These were redistributed by currents along the shores of Lake Bonneville. The classic bar and spit deposit at Stockton, described by

Gilbert (1886), and numerous smaller sand and gravel deposits in Tooele Valley formed in successively lower lake levels in the adjoining Tooele Quadrangle are described by Tooker (1980).

Regional correlations of formational units_The ages of sedimentary rocks on the north flank of the Ophir anticline in the Bingham nappe, which immediately adjoin those in the South Mountains nappe, are dissimilar. The adjoining Bingham nappe rocks are also structurally discordant. These include Mississippian Great Blue Limestone, Mississippian-Pennsylvanian Manning Canyon Shale, and Lower and Middle Pennsylvanian West Canyon Limestone and lower Butterfield Peaks Formation in the Oquirrh Group. The adjacent rocks in the South Mountain nappe include only the upper part of the Middle Pennsylvanian Rush Lake and the lower part of the Upper-Pennsylvanian Salvation units.

Rocks of the Salvation and Rush Lake units are roughly equivalent in age and of generally comparable but thinner lithologies with those in the upper part of the Butterfield Peaks Formation, and the Clipper Ridge and the lower part of the Markham Peak Members of the Bingham Mine Formation in the Bingham nappe (Tooker, 1992). The lower part of South Peak strata are probably correlative with the upper Markham Peak Member of the Bingham Mine Formation (Missouri-Virgil age) in the Oquirrh Mountains. Sedimentary rocks of Wolfcamp age in the upper part of the South Peak unit are not found in the Oquirrh Mountain's Bingham nappe. The South Peak unit is also probably lithologically correlative with unnamed sedimentary rock units of that age in the Timpanogos nappe in the Wasatch Mountains (Baker and Crittenden, 1961; Tooker and Roberts, 1962; and fig. 4, this report). The lithology of rocks in the South Mountain nappe and Missouri-, Virgil-, and Wolfcamp-age sedimentary rocks in the southernmost part of the Bingham nappe at Tintic also differ. The Furner Valley Limestone at Tintic is correlated with the Pennsylvanian-age arenaceous Bingham Mine Formation in the Bingham nappe and parts of the Upper Pennsylvanian and Lower Permian South Peak and Salvation units in the South Mountain nappe. The Furner Valley consists of 1595 m, mainly limestone section that is readily distinguishable from its underlying more arenaceous Butterfield Peaks Formation (Morris and others, 1977). At Tintic, the Furner Valley Limestone is overlain by the Diamond Creek Sandstone, which probably is correlative with the upper part of the South Peak unit of Tooker and Roberts (1988).

Comparison of age-correlative parts of the stratigraphic columns for the Bingham and South Mountain nappes (fig. 15; Tooker and Roberts, 1992) also demonstrate significant differences in the character and thickness of the sedimentary rock lithologies in the Bingham and Stockton nappes. The Jordan and Commercial marker beds in the base of the Clipper Ridge Member of the Bingham Mine Formation, which is the main host horizon of replacement base metal ore bodies at Bingham, cross the Oquirrh Mountains from the Bingham mining district to the range front south of the mouth of Middle Canyon, east of Tooele, with almost no thinning of these units. They are cut off by Basin and Range normal range-front faults (Tooker, 1980; and Tooker and Roberts, 1988). In the Southport Gulch area of the Stockton mining district, just across the Stockton thrust, and only a few miles to the southwest of the mouth of Middle Canyon at Tooele, correlative rocks are considerably thinned and their lithology is similar but not truly comparable with those in the Bingham nappe (Tooker and Roberts, 1992).

FIGURE 15, NEAR HERE.

There remains a possibility that the strata of the South Mountain nappe are more closely related to the sedimentary rock facies found in the west-central part of the Bingham nappe than suggested here; and, in fact, this plate may be a large overlapping imbrication that includes clastic Upper Pennsylvanian (Wolfcampian) strata that were eroded from the Bingham nappe in the Oquirrh Mountains, assuming that they were deposited there originally. Differences in the thickness and composition of age-correlative units may represent local facies changes in miogeoclinal sediments observed southwestward in the Bingham nappe away from the uplifted area along the Uinta trend. This relationship was suggested for other reasons by Welsh and James, (1961).

Structural features

The South Mountain nappe comprises two areas of distinctive fold and fault structures on the upper plates of the Stockton and TAD thrusts that are separated from one another by the Rush Valley tear fault (fig. 14). The eastern border of the nappe with the Bingham nappe is along the Soldier tear fault, and although concealed by unconsolidated Quaternary deposits, the western part of the South Mountain nappe is terminated by the east-directed, north-south trending, later Tintic Valley thrust.

Folds—Fold patterns in the eastern and western parts of the nappe, as shown in figure 14 differ from each other and from those in the adjoining Bingham and Stansbury nappes. The eastern part of the nappe, lying between the Soldier and Rush Valley tear faults, is the thinned, low amplitude folded, south-southwest dipping, north- northeast driven leading edge of the nappe that ramped onto the Uinta trend and earlier docked Bingham nappe. Close-spaced, bent, secondary folds produced in the Stockton thrust in the Stockton mining district area are of small amplitude, asymmetrical to overturned locally, and aligned in an east-northeast-to west-northwest -trending arc. The folds are segmented by tensional steep-dipping north-northeast trending normal faults, which in some areas are filled by porphyry dikes. The sedimentary rocks comprising the folds include Oquirrh Group strata in the upper part of the Rush Valley and the lower part of the Salvation units of Tooker and Roberts (1992).

In contrast, the major fold structure exposed in the western part of the nappe on South Mountain defines a single high-amplitude *main* fold, the South Mountain anticline (fig. 14) that also moved generally north-northeast. Here the upper plate of the nappe overlies the TAD thrust, believed to be an imbrication in the South Mountain nappe that is composed of a competent, thick stratigraphic body of medium-to-thick-bedded sedimentary rocks of the Rush Lake, Salvation, and South Peak units (Tooker and Roberts,1992). The fold is asymmetrical, locally overturned to the north, and lies in a northwest- to west-northwest-trending more-open arc than those that occur in the Stockton district. The fold plunges westward beneath the Tintic Valley thrust. Before the

Sevier thrust belt was recognized, Gilluly (1932) considered that this fold was a continuation of the Ophir anticline, which it seemed to extend. However, the Ophir anticline plunges beneath overlying imbricate thrusts in the Bingham nappe along its western border (Tooker and Roberts, 1992), and is cut off by the Soldier tear fault. The folds across the tear fault in the South Mountain nappe are of distinctly different types and are directionally discordant. The folds in the Stansbury nappe on the upper plate of the Tintic Valley thrust, which overlaps the South Mountain nappe from the west, are nearly north-south trending.

Why the geometry of folds in the nappe differ on opposite sides of the Rush Valley fault can only be inferred. One reason for applying individual names for the Stockton and TAD thrusts is to indicate that although there seems to be only a moderate amount of stratigraphic displacement along the Rush Valley tear fault, there is a more fundamental difference in the formation of their folds. Folds on the upper plate of the Stockton thrust are characteristic of those developed in a thinned-plate wedge that laps onto a barrier, in this case the uplifted(?) Bingham nappe that itself overlies the Uinta trend basement structure. The main South Mountain anticline on South Mountain may best be explained as having formed farther southwest as a thicker, and therefore more competent upper plate of an imbricate (TAD) thrust within the South Mountain nappe. It overran the thinner lead wedge of the Stockton thrust, as it also crunched against the Uinta trend foreland barrier.

Faults—The principal faults in the nappe are sole and imbricate thrusts, tear, and normal faults. The sole fault of the South Mountain nappe, the Stockton thrust, exposed north of the Stockton mining district, apparently is a moderate- to shallow, south-dipping structure. The amount of northeastward transport on the Stockton thrust is not known, but does not seem to be of the same magnitude as that on the Midas thrust. Several branch or imbricate thrust faults having much less throw occur in the upper plate in the Stockton mining district. The TAD thrust north of South Mountain is inferred to be an imbrication above the sole thrust in the western half of the South Mountain nappe. It probably was dropped down along what had been the Rush Lake tear fault during the later Basin and Range extensional structural deformation. The arcuate trend of the anticline may be due, in part, to drag along the Rush Valley tear fault, and the overturn at the west end ascribed to drag along the TAD thrust fault against the Uinta trend. The western part of the nappe is less broken by steep-dipping tensional faults normal to the folds direction, but few if any tear faults offset the folded formations.. The structural and stratigraphic discontinuity between South Mountain and the Stansbury Mountains is best explained by the concealed Tintic Valley thrust (Tooker, 1983; and Morris, 1983). Contrasting Paleozoic stratigraphic sequences (Rigby, 1958; and Taylor 1991) are juxtaposed by the Tintic Valley fault, which has comparable regional significance in the Tintic region.

The nearly-vertical Rush Valley tear fault, whose western side apparently moved an unknown distance farther north-northeast than the eastern side, separates the South Mountain nappe into two parts. The Rush Valley tear fault does not crop out and can only be inferred from several lines of evidence. Most obvious is the striking difference in the structure of folded rocks on both sides of the fault (fig. 14). The presence of several warm springs along its trend from Morgan Ranch to the shores of Rush Lake is also permissive evidence of the existence of this unexposed fault. The source of heat sustaining these hotsprings is believed to be related to young basaltic or bi-modal volcanic systems, similar to those elsewhere in central Utah (H.T. Morris, verbal communication, 1997), that remain at depth along the Uinta-trend and related to earlier intrusives and hydrothermal ores in the Stockton mining district.

The eastern side of the South Mountain nappe adjoins the Bingham nappe along the Soldier tear fault. Outcrops of the Soldier tear fault on the eastern boundary of the nappe juxtapose contrasting stratigraphic and structural terranes. The southwestward extension of the fault is concealed beneath thick deposits of the Harkers Fanglomerate and younger Quaternary alluvium.

Normal faults, which were largely developed originally as tensional structures formed during the folding of the nappe, may have generated additional normal but small displacements during Basin and Range extension. These are steep-dipping, north-trending and commonly contain porphyritic dike rocks in the Stockton mining district. These faults also were conduits for the movement of hydrothermal sulfide solutions that formed veins and altered and replaced adjoining favorable carbonate sedimentary host rocks (Tooker, 1998). The amount of displacement on these normal faults is generally small. Some of the northeast-trending normal faults developed as extensions into the Bingham nappe and represent later Basin and Range movement along those structures. The structure of the Oquirrh Mountains range front is defined by numerous normal extensional faults, which locally also displace the Quaternary gravels. Older Harker Fanglomerate deposits at the mouths of the main drainages are also truncated by these faults.

Location and types of igneous rocks

The main types of igneous rocks in the South Mountain nappe originally described by Gilluly (1932) and later by Moore and McKee (1983) are intrusive facies of monzonitic porphyry that occur as small plugs, irregular dike-like bodies, and sills in the Stockton mining district and basalt dikes on South Mountain. Their ages are in the range of 38-39 My (Moore and McKee, 1983). Extrusive volcanic rocks occur locally along the trace of the TAD thrust.

Numerous dikes, sills, and small stocks of quartz monzonite porphyry, and related monzonite porphyry, diorite porphyry, and quartz-diorite porphyry phases occur in and adjacent to the Stockton mining district (Gilluly, 1932). The dikes fill north-trending, nearly-vertical tension fractures. The composition of the largest stock, locally known as the "Raddatz" porphyry, resembles that of a nearby thick sill near Tooele in the Bingham nappe (Gilluly, 1932; and Tooker, 1980). A smaller fine-grained monzonite porphyry stock near the Calumet mine is dated at 38.0 ± 1.1 Ma by Moore (1973a). A number of porphyry sills occur in the southeastern part of the nappe and in adjoining parts of the Bingham nappe on the north side of Soldier Creek. The nepheline basalt sill described by Gilluly (1932), one of four smaller sills exposed nearby on the crest of South Mountain, is dated at 40.1 Ma (Moore and McKee, 1983).

Hornblende latite tuff-breccia, which also includes water-laid tuffs and flows, is shown on Gilluly's map (1932) on the northeast foot of South Mountain. It is dated at 30.7 ± 0.9 Ma by Moore (1973a).

Associated mineral resources

Sulfide ore deposits in the Stockton mining district are located on the structurally broken lead edge of the folded upper plate of the Stockton thrust (Lufkin, 1965; Moore and others (1966); and Tooker, 1998). Early production in the Stockton mining district between 1864 and 1901 was combined with that at Ophir; more recent production at Stockton is shown in Table 4. The district has been inactive since 1972. The typical sulfide ores occur in fissure- and bedded-replacement deposits of lead, zinc, copper, gold, and silver. Near-surface ores are oxidized, but grade into sulfides at depth (Gilluly, 1932). The Stockton district ores occur mainly in the Pennsylvanian Rush Lake and Salvation units of Tooker and Roberts (1992), which are correlated with the ore-bearing horizon of the Clipper Ridge Member of the Bingham Mine Formation at Bingham. The ores are in close spatial association with quartz monzonite dikes and plugs and occur mainly along steep-dipping, north-northwest-trending faults and in adjacent locally replaced carbonate beds. The ores seem to diminish at moderate depth, leading to the supposition that mineralization is restricted to the much-broken upper plate of the Stockton thrust. Although prospected thoroughly, the same rocks along the less-broken South Mountain anticline are not mineralized sufficiently to produce ores.

Mining activity in the Stockton mining district apparently was restricted to the upper plate of the Stockton thrust. No deep exploration seems to have been undertaken to determine if mineralization occurs in the lower plate (Bingham nappe) Butterfield Peaks Formation, which hosts ores in the Bingham mining district , and through which magma and hydrothermal solutions passed.

Abundant resources of sand and gravel construction materials occur along the edges of the nappe. These locally thick deposits are mainly the result of wave action in Quaternary Lake

Bonneville (Gilbert, 1886) that distributed debris shed from the accelerated erosion of the uplifted nappes overlying the Uinta trend. The very substantial Bonneville bar and spit near Stockton, Utah, has been extensively quarried for highway, railroad, and other construction in the area, but no production data are available. Numerous borrow pits also occur in the nearby beach deposits.

Fivemile Pass Nappe

Located in the southernmost part of the Oquirrh Mountains, immediately north of Fivemile Pass and mainly in the drainages of Wells and Clay Canyons (fig. 16), the allochthonous Fivemile Pass nappe [originally called Wells-Clay Canyon nappe by Tooker (1987)] is distinguished from the adjoining Bingham nappe by its limited yet distinctive stratigraphy, and by its complex, discordant fold structures. The geology of the nappe is generalized from maps by Tooker (1987) and Tooker and Roberts (1998). The nappe is bounded on the north and northeast by the Clay thrust, on the west by the Sunshine tear fault, and on the east and south by the Cedar tear fault, which is concealed by Quaternary alluvium. However, the entire range and nappe are terminated by the inferred northeast-trending Fivemile tear fault in Cedar Valley that separates them from the Thorpe Hills' stratigraphic and structural regime. A measured section of the sedimentary rocks in the Fivemile Pass nappe was not made because only fault-bounded, fragmented parts of the Mercur limestone member of the Great Blue Limestone and normally overlying Manning Canyon Shale are present. Thick clay-shale beds in the Mercur limestone member in Wells and Clay Canyons have been mined for structural clay mineral products (Hyatt, 1956). The gem mineral variscite (Sinkankas, 1976) occurs locally in the Mercur limestone member of the Great Blue Limestone in the southern Oquirrh Mountains only in the Fivemile Pass nappe. The mineral occurs elsewhere in adjoining ranges to the southwest, apparently in fragments of this same nappe.

FIGURE 16, NEAR HERE.

Stratigraphic characteristics and correlation of sedimentary rocks

The sedimentary rocks within the Fivemile Pass nappe include portions of the Mercur limestone member of Gordon,Tooker and Dutro (1999) of the Great Blue Limestone and mostly covered portions of the middle part of the Manning Canyon Shale, both of Late Mississippian (Chester) age (Gordon, written communication, 1985). Unconsolidated Quaternary alluvial deposits overlap the sedimentary rocks.

Mercur limestone member of the Great Blue Limestone—While similar in age to strata in the type and reference localities in the southern Oquirrh Mountains, the Mercur limestone member of the Great Blue Limestone in the Fivemile Pass nappe differs in having relatively larger proportions of shale to banded silty limestone and interbedded arenaceous, argillaceous, and sparsely fossiliferous limestones. The member's top and bottom beds are not exposed; the section probably is a part of the lower-middle part above the Caninia zone of Gordon, (written commun.1985). Thick green-black shale beds with thin interbedded chert and quartzite bands have displaced limestone and thin shaly intervals that characterize the type section near Ophir (Gordon, Tooker, and Dutro, 1999). This shift of sedimentational facies in the Fivemile Pass nappe, which is believed to have formed an unknown distance south-southwest of its present location, is believed to resemble a transitional depositional system in the Bingham nappe intermediate between that observed in the Mercur member of the Great Blue Limestone at Ophir and that of the type section of the Chiulos Shale member of the Great Blue Formation in the East Tintic Mountains (Morris and Lovering, 1961). Several thick altered shale units in Wells Canyon, which locally have been mined for brick clay, originally were thought to be part of the Manning Canyon Shale. They are now correlated with the much-faulted middle part of the Mercur limestone member of the Great Blue Limestone (Tooker, 1987).

The thickness of the upper part of the Mercur limestone is not known. The absence of sufficient fossils to date these rocks precisely makes their correlation with the Poker Knoll or Chulios Members of the Great Blue Formation at Tintic (Morris and Lovering, 1961) only tentative. However, the upper part of the member at Ophir is composed of interbedded fossiliferous, sandy, and cherty limestone intervals up to 20 ft thick, and thin (1 to 10 ft thick) shale and argillaceous limestone. These characteristics also suggest that the sedimentary rocks in the nappe represent a transitional facies between those at Ophir and Tintic.

Manning Canyon Shale—The rocks correlated stratigraphically with the middle part of the Manning Canyon Shale by Tooker (1987) occur in the upper plate of the Wells thrust, which is an imbricate thrust in the Fivemile Pass nappe. About 46 m are exposed and consist of a thick-bedded, fossiliferous, brown-weathering quartzite and thin-bedded dark-gray limestone and interbedded argillaceous limestone and shale partings. Fossils include plant debris, and a brachiopod and gastropod fauna of Late Mississippian age (M.Gordon, Jr., written commun. 1990). The unit is overlain by Lake Bonneville sediments.

Structural features

The folded and complexly faulted sedimentary rocks of the Fivemile Pass nappe are recognized by fold structures on the upper plate of the sole Clay thrust, which are discordant with and overlap rocks of the Bingham nappe. They were emplaced into their present position from the south-southwest. The main fold in the Bingham nappe, the Ophir anticline, trends due south and plunges to the south beneath the Fivemile Pass nappe, whereas, for the most part, folds in the Mercur limestone member and Manning Canyon Shale on the Fivemile Pass nappe trend southeastward. Three main northeast-trending, steep-dipping tear faults segment the nappe into two main blocks. Imbricate thrusts emplace Manning Canyon Shale over the younger parts of the Mercur limestone member of the Great Blue near the south end of the nappe. Several steep-dipping normal faults do not greatly offset the sedimentary rocks.

Folds—The folds above the Clay thrust, which underlies the Fivemile Pass nappe, are evenly spaced, broad, with low amplitude, and are open in cross section. These probably were formed in a thinned, less competent leading edge of this thrust plate. However, locally, in the upper plate of an imbricate thrust lying between the Sunshine and Wells tear faults, east-northeast-trending folds in the Mercur limestone are tight and asymmetrical, most probably the result of more intense friction between the tear faults in a more shallowly-dipping part of the sole thrust plane or and imbrication above it. The east-southeast-trending, low amplitude, open folds in Manning Canyon Shale and Mercur limestone member of the Great Blue Limestone are on the upper plate of the imbricate Wells thrust fault, east of the Fivemile Pass tear fault.

Faults—The sole Clay thrust, thrust fault imbrications in the upper plate, and tear and normal faults define the Fivemile Pass nappe. The Clay thrust is a relatively steep-dipping fault, judging by its trend across the topography and lack of asymmetrical or overturned folds. Its upper-plate folds are offset progressively by the northeast-trending Sunshine, Fivemile, and Cedar tear faults. These tear faults are steep-dipping, north-northeast trending, mostly with only relatively small apparent displacement within the nappe. An overlying imbricate Wells thrust in the nappe places younger Manning Canyon Shale over the Mercur limestone member east of the Fivemile fault. Mercur limestone reappears at the south end of the range by sedimentary succession and normal faulting. The impact of Basin and Range extensional faulting is presumed, but apparently is not as marked here as in the adjoining Bingham nappe.

Location and types of igneous rocks

No igneous rocks have been observed in the nappe. Several small breccia pipes, presumed to be of igneous origin, intrude the Great Blue Limestone in the Sunshine mining area, near the boundary of the Bingham and Fivemile Pass nappes (Tooker, 1987). They contain angular fragments of altered limestone and rhyolite porphyry(?). The largest breccia pipe (61 x 183 m), which occurs in Clay Canyon northeast of Sunshine, in the Fivemile Pass nappe (Tooker, 1987), has been extensively altered in part to clay minerals How this body is related to Tertiary igneous activity, if at all, remains to be determined.

Associated mineral resources

Economic brick-clay deposits and the semiprecious mineral variscite have been mined in the Wells and Clay Canyon areas and along the south end of the Oquirrh Mountains in the Fivemile Pass area (Ornelas 1953; and Hyatt, 1956). There is no evidence of the occurrence of base and precious metal deposits in the nappe. The clay deposits occur in the relatively thick, altered shale horizons of the Mercur limestone member of the Great Blue Limestone in Wells Canyon. The clay layers in the interbedded shale units range in thickness from 8 to 15 m, from light gray to dark gray in color, and with thin interbedded red and yellow iron-stained oxide bands and layers. The plastic non-calcareous, greenish-gray to black, and iron-stained clay-rich zone is overlain by medium-bedded to massive, medium-gray limestone. Production data of mined clay materials are unavailable.

Hamilton (1959) and Sinkankas (1976) described the occurrence of variscite, originally discovered in 1890, in more massive overlying beds of the Great Blue Limestone in Clay Canyon. The shale-rich horizon is overlain by massive, medium-bedded, dark-gray to black limestones, which, where brecciated locally in Clay Canyon, contain small deposits of the nodular semi-precious gem mineral variscite, ($Al(PO_4) \cdot 2H_2O$). The mineral is believed to form by seepage of phosphate-impregnated waters through aluminous rocks to form seams and crevices along shear and fracture zones. Cryptocrystalline quartz accompanies the variscite as chalcedony veinlets or chert, and the nodules are generally oval, flattened, and embedded in a matrix of quartz and calcite. The color of variscite varies from "light to dark shades of rich yellowish green, but very pale to almost white shades are known as well as those of purest deep green (Sinkankas, 1976, p. 230)". The source, time, and place of impregnation of phosphate waters is not known. Production of variscite peaked in 1909-1911, resulting in thousands of pounds. Since that time production has been sporadic, the last known production was in 1942.

Quaternary sand and gravel deposits are also abundant and mined in the Fivemile Pass area. Their production has been intermittent and the amount taken is not known.

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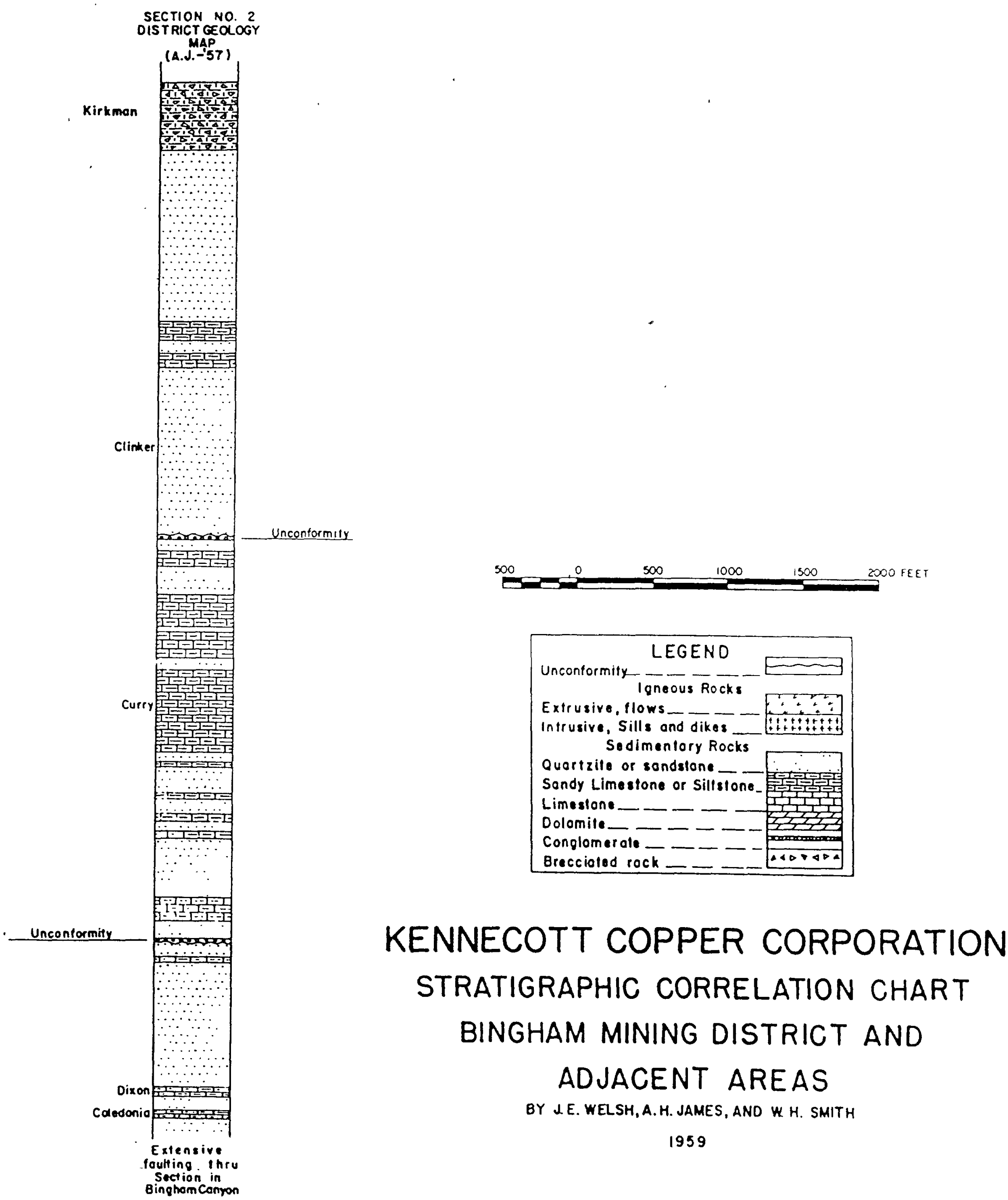
APPENDIX

1. Columnar section of the Permian-age Curry, Clinker, and Kirkman formational units of Welsh and James (1961, plate 5), from section no. 2, [Bingham] district geology map.



2. Measured sections of the A, South Peak, B, Salvation, and C, Rush Lake formational units of Tooker and Roberts, that constitute the Oquirrh Group sedimentary rocks in the South Mountain nappe. --

A--Stratigraphic section of the South Peak unit of Tooker and Roberts (1992) composed of the upper part of the Oquirrh Group (Early Permian) measured on South Mountain along the ridge across SE-1/4 sec. 13, R. 6 W., T.4 S. and S-1/2 sec. 18, SW-1/4 sec. 17, R. 5 W., T. 4 S., South Mountain 7 1/2-min. quadrangle, Utah.

[Measured by R.J. Roberts and E.W. Tooker, October 1961]

	Thickness (meters)	Distance above base (meters)
Covered by alluvium and overlapped by the concealed north-trending Tintic Valley thrust fault		1904
Unconformity		
South Peak unit of Tooker and Roberts (1992) Oquirrh Group		
22. Calcareous quartzite, light buff-tan, fine sand, medium-bedded to massive, well-jointed and fractured, interbedded orthoquartzite, bioclastic limestone and sand partings with fusulinids; weathers red-brown to tan, thin surface rind, in part platy float; mostly covered slope USGS colln. f22621 near top. "Bioclastic limestone with well rounded sand grains, bryozoa, *Triticites* sp. and *Schwagerina* sp. some incipient euniculi. The age suggested is early Permian, late Wolfcamp to earliest Leonard equivalent" (R.C. Douglass, written commun. 1962)	243	1661
21. Calcareous quartzite, orthoquartzite and		

	limestone interbedded, medium light-gray, coarse-grained to sandy, calcareous cement, medium-bedded orthoquartzite and sand partings, banded; weathers light-gray, grains in relief; finer dark gray limy clastic sands include fossil fragments (brachiopods), calcareous mudstone at 11 m, and fusulinids in sandy limestone with phosphate coating; mostly covered slope USGS colln. f22620 at 16 m "Well-rounded sandstone with detrital fragments of bryozoa, *Triticites* sp. and *Schwagerina* sp. The age suggested is Early Permian, late Wolfcamp equivalent" (R.C Douglass, written commun, 1962)	47	1614
20.	Calcareous quartzite, tan-to-olive gray, sandy, mostly calcareous cement, medium-bedded to massive, thin-bedded sandstone layers with worm trails; weathers red-brown to buff with thick surface rind; mostly covered slope	265	1349
19.	Sandstone and calcareous quartzite, interbedded; buff, sandy; weathers deep yellow-brown; contains worm trails and fusulinid molds; mostly covered slope	119	1230
18.	Calcareous quartzite and orthoquartzite, interbedded, tan-buff, to olive-gray and light-gray, sandy, medium bedded; interbedded ferruginous sandstone 0.9-1.8 m thick contains worm trails; weathers light brown-tan; covered slope	52	1178
17.	Orthoquartzite, and calcareous quartzite, interbedded, tan-buff and light brown bands, sandy; interbedded ferruginous sandstone; weathers yellow-tan and reddish brown, ferruginous surface rind on calcareous quartzite, worm trails; covered slope	8	1170
	Porphyry dike	11	
16.	Calcareous quartzite and orthoquartzite interbedded, tan-buff to light-gray, medium grained to sandy, medium-bedded, local banding; interbedded limy sandstone layers; weathers light brown-tan, very thin		

surface rind; covered slope	5	1165
15. Calcareous quartzite, orthoquartzite, interbedded; quartzite contains molds of fusulinids, near top; bedded chert with preserved fusulinids; chert pebbles of earlier rocks; phosphatic replacement of fusulinids; mostly covered slope USGS colln. f22619 at 12.9 m, "Coarse sand with Schwagerina sp. as detrital fragments, abraded and chemically altered. The age suggested is Early Permian, Wolfcamp equivalent" (R.C. Douglass, written commun, 1962)	13	1152
14. Calcareous quartzite, tan-buff to olive-gray, fine to coarse grained in upper part, medium-bedded, often thin interbedded orthoquartzite and limy sandstone beds; weathers reddish-brown to light-buff-gray, with soft surface rind 8 cm thick; poorly preserved fusulinid molds at top; mostly covered slope	158	994
13. Ferruginous sandstone, yellow-brown, sandy, medium to thin bedded with thin interbedded calcareous quartzite and bedded chert; weathers medium brown, rounded float; covered slope	53	941
12. Calcareous quartzite, medium-gray, sandy, thin to medium bedded, interbedded sandy limestone and platy limy sandstone, largely ferruginous beds up to 1 m in upper part, local banded thin phosphatic chert beds; weather reddish-brown and yellow-brown, rounded fragments with medium soft surface rind; worm trails common in ferruginous sandstone; mostly covered slope	114	827
Porphyry dike	51	
11. Calcareous quartzite, medium-gray, medium-grained, thin- to medium-bedded, locally banded, interbedded thin, sandy limestone containing worm trails and limy sandstone partings; weathers reddish-brown and light-tan, sandy surface, thin surface rind, platy fragments in part; mostly covered slope	18	809
10. Calcareous quartzite and sandstone,		

interbedded; orthoquartzite and platy limy sandstone with worm trails, and bedded chert; covered slope	132	677
9. Limestone, dark gray, sandy, thin-bedded sandstone parting; weathers medium dark gray, sand partings weather brown-tan; covered slope	0.6	676
8. Orthoquartzite, light gray-tan to olive gray, medium grained to sandy, mostly medium-bedded with interbedded calcareous quartzite, ferruginous sandstone, bedded chert, and platy limy sandstone; weathers brown-tan; fusulinid molds locally, worm trails in sandstone; covered slope	114	562
7. Limestone, medium dark-gray, dense, fine-grained to silty, sandstone partings; weathers medium light-gray; covered slope	0.7	561
6. Calcareous quartzite and ferruginous sandstone, interbedded, light gray-tan, medium grained to sandy; worm trails and fusulinid molds in sandstone and quartzite, weathers brown-tan; covered slope	41	521
5. Limestone, medium dark-gray, fine grained to sandy, with sand partings and lenses; weathers medium-gray; covered slope	0.6	520
4. Calcareous quartzite and orthoquartzite, interbedded; light gray-tan, medium grained to sandy, occasional yellow-brown, thin-bedded partings and thin to medium beds of ferruginous sandstone that weather reddish-brown-tan, thick surface rinds on rounded float from calcareous quartzite, orthoquartzite has more angular float; fusulinid molds found in sandstone at 104 m, worm trails occur in some of the ferruginous sandstone; mostly covered slope	357	163
3. Ferruginous sandstone and calcareous quartzite, interbedded; sandstone brown, medium		

grained to sandy, ferruginous cement; weathers dark reddish-brown; worm trails, and fusulinid molds occur locally; quartzite thin-bedded, banded; covered slope	38	125
2. Orthoquartzite, tan, sandy, silica cement, medium bedded, banded and crossbedded locally, weathers reddish-brown; covered slope	4	121
1. Limestone and calcareous quartzite, interbedded; sandy limestone with interbedded ferruginous sandstone locally; covered slope	121	
Total South Peak unit measured	1903	

Conformable contact

Salvation unit, Oquirrh Group (upper beds only)

17. Limestone, medium-gray, fossiliferous

B. Stratigraphic section of the Salvation unit of Tooker and Roberts (19892 in the Oquirrh Group on the South Mountain nappe, measured on South Mountain along the ridge across S-1/2 sec. 22 and N-1/2 sec. 21, T. 4 S., R. 5 W., Stockton 15-min. or South Mountain 7-1/2 min. quadrangles

[Measured by R.J. Roberts and E.W. Tooker, October, 1961]

	Thickness (meters)	Distanc above ba (meters
South unit, Oquirrh Group (lowest beds only):		
Limestone and quartzite, interbedded; sandy limestone and calcareous quartzite with local interlaminated ferruginous sandstone; covered slope		832

Contact conformable.

Salvation unit, Oquirrh Group:

17. Limestone, medium-gray, fine-grained to sandy, medium-bedded; weathers medium light gray; productid brachiopods, fusulinids in sandy limestone.

USGS colln. f22623 at 14 m, "Fine sand with *Triticites* sp. The age suggested is Late Pennsylvanian, probably late Missouri or earliest Virgil equivalent." (R.C. Douglass, written commun. 7/20/62). A brachiopod was identified as "*Linoproductus* sp. indet." (Mackenzie Gordon, Jr., written commun. 10/14/66).
USGS colln. f22624 at 24 m, "Fine sand with *Triticites* sp. It probably is referable to latest Missouri equivalent but an early Virgil age is a possibility." (R.C Douglass, written commun. 7/20/62). Productid brachiopods and bryozoans common in other layers 29 803

16. Quartzite and limestone, interbedded; light tan-gray, sandy, calcareous cement, medium-bedded quartzite, and medium-gray, fine grained to sandy, medium-bedded limestone with shale partings; weathers buff (quartzite) and light blue gray (limestone); fossils locally in limestone include bryozoans and fusulinids

USGS colln. f22622 at 10 m, "Fine sand with some bryozoa and *Kansanella* sp. The age suggested is Late Pennsylvanian, probably Missouri equivalent." (R.C. Douglass, written commun. 7/20/62). 12 791

15. Quartzite, light-gray, sandy, mostly calcareous cement in lower part, silica cement more common in upper part, medium-bedded, local banding, interbedded silica-cemented quartzite in lower part and sandy limestone throughout, sparse ripple marked surfaces noted locally; weathers red brown to tan; covered slope 69 722

14. Quartzite, light tan-gray, sandy, mostly calcareous cement, interbedded with locally crossbedded, and often fossiliferous, medium dark-gray sandy limestone up to 1 m thick; quartzite weathers buff, limestone medium blue-gray; fossils (identified by R.C. Douglass, written commun., 7/20/62) in sandy limestone layers include fusulinids, brachiopods, crinoids, bryozoans, *Syringopora* and cup corals

USGS colln. 22615 at 5 m, "Fine sand with crinoidal debris, bryozoan fragments and fragments of *Kansanella* sp. The age suggested is Late Pennsylvanian, probably Missouri equivalent."

USGS colln f22616 at 46 m, " Fine sand with *Triticites* sp., scattered, and bioclastic limestone with *Tetrataxis* sp., texturalid, *Bradyina* sp., *Millerella* sp., and *Fusulinella* sp. or *Pseudofusulinella* sp. This second piece really looks like a piece from the middle Pennsylvanian."

USGS colln f22617 at 147 m, "Silty fragmented limestone with *Bradyina* sp. and *Kansanella* sp. The age suggested is Late Pennsylvanian, probably Missouri equivalent."

USGS colln. f22618 at 126-132 m, "Fine sand with abundant small fusulinids something like the kind Thompson calls *Oketaella* but more globular." and brachiopods and corals in the uppermost part; mostly covered slope | 203 | 519

13. Limestone, medium-gray, fine-grained to sandy, thick bedded; weathers olive brown to light gray; corals, *Derbyia* brachiopods, bryozoans, and fusulinids

USGS colln f22614 at 155 m, " Fine sand with textularids and *Triticites* sp. The age suggests Late Pennsylvanian, probably Missouri equivalent." R.C. Douglass, written commun. 7/20/62 | 4 | 515

12. Quartzite, light tan-gray, sandy, mostly calcareous cemented, medium-bedded with interbedded limy sandstone, crossbedded in part, thin platy to shaly limestone partings; weathers reddish brown to buff, medium-soft surface rind; covered slope | 116 | 399

11. Quartzite, light tan-gray, sandy, mostly silica-cemented, massive to medium-bedded with interbedded sandy limestone up to .3 m thick and thin interlayers of calcareous-cemented quartzite, crossbedded locally; weathers tan buff, platy float; partly covered slope | 41 | 358

10. Limestone, medium-gray, fine-grained, thin-bedded; weathers light gray; mostly covered slope | 1 | 357

9. Quartzite, medium tan-gray, medium- to coarse-sandy, mostly calcareous cement, medium-bedded to massive, interbedded thin laminae of limestone, limy sandstone, and shale partings, well-jointed, banded locally; weathers tan buff, pitted thin surface rind, alternate hard and softer layers locally weather in relief; fossils in interbedded sandy limestone, cup and *Syringopora* corals, brachiopods, gastropods, crinoid stems, bryozoans

USGS colln. 61F76 at 247 m, "Syringoporoid coral, *Straparollus* (*Euomphalus*) sp. ident." (Mackenzie Gordon, Jr., written commun. 10/4/66) | 271 | 86

8.	Limestone, medium dark gray, fine grained to sandy, medium-bedded; weathers light gray with brown sand partings; platy float	3	83
7.	Quartzite, medium dark-gray, sandy, calcareous cement, medium-bedded, banded locally; weathers medium light gray with light-brown bands; mostly covered slope	8	75
6.	Limestone, medium-gray, fine grained to sandy--size increases upward--medium-bedded, sand partings more abundant in upper part; weathers tan to medium light gray, sandy surface, platy float; well-preserved fusulinids, cup corals abundant at base	4	67
5.	Quartzite and limestone, interbedded; (quartzite) calcareous cement (limestone) sandy; covered slope	6	61
4.	Limestone, medium-gray, fine-grained to sandy, medium-bedded; weathers light blue gray, sandy surface; abundant fusulinid, brachiopod, bryozoan, crinoid assemblage USGS colln. f22611 at base, "Coarse bioclastic limestone with fragments of foraminifera including *Bradyina* sp., and *Pseudofusulinella* sp." USGS colln. f22612 at 1 m, "Fine sand with fragments of *Triticites* sp. The age suggested is Late Pennsylvanian, Missouri equivalent." (R.C. Douglass, written commun. 7/20/62)	2	59
3.	Quartzite and limestone, interbedded; light gray-tan to olive brown, sandy, calcareous cemented, medium-bedded, locally banded and crossbedded quartzite, and medium-gray platy limestone; weathers yellow brown to reddish brown, thick surface rind (quartzite) and light gray (limestone); mostly covered slope	55	4
2.	Limestone, medium-gray, sandy, medium-bedded; weathers light tan gray; abundant crinoids, cup and *Syringopora* corals and fusulinid fauna USGS colln. f22610 at 2 m, "Fine sand with scattered fragments of *Triticites* sp. The age suggested is Late Pennsylvanian, Missouri equivalent." (R.C. Douglass, written commun. 7/20/62).	3	1
1.	Limestone, medium dark-gray, fine-grained thin-bedded, locally laminated; weathers blue gray, sandy surface; top .3 m brecciated and cemented with white calcite	1	
	Total Salvation unit measured		832

Conformable contact.

Rush Lake unit, Oquirrh Group (upper beds only)

37 Quartzite, calcareous cement, interbedding limy sandstone

C. Stratigraphic section of the Rush Lake unit of Tooker and Roberts (1992) in the Oquirrh Group, South Mountain nappe measured on South Mountain along the main ridge across S-1/2 sec. 22 and N-1/2 sec. 21, T. 4 S., R. 5 W., Stockton 7-1/2-minute quadrangle, Utah.

[Measured by R.J. Roberts and E.W. Tooker, October, 1961]

Salvation unit, Oquirrh Group (lowest beds only):

Limestone, medium dark-gray, thin bedded, locally laminated
Contact conformable

Rush Lake unit, Oquirrh Group:

	Thickness (meters)	Distanc above ba (meters
37.Quartzite, light gray-tan, sandy, mostly calcareous cement, thin interbedded limy sandstone and sandy limestone partings and layers in upper part; worm trails in thin ferruginous layers and brachiopods, crinoids, and fusulinids, in limestones; weathers light brown-tan to yellow-gray, slight local pitting; brachiopod shells and spines, crinoid fragments in limestone, and fusulinids in sandy limestones near top; mostly covered slope	182	1,170
36. Limestone, medium dark-gray, fine-grained, medium-bedded, black chert nodules and lenses; weathers medium gray, chert weathers brown and stands in relief; partly covered slope	1	1,169
35. Quartzite, light gray-tan, sandy, calcareous-cemented, interbedded sandy limestone and limy sandstone layers and partings, in part banded near top; weathers brown with thick surface rind; covered slope	150	1,019
34. Limestone and quartzite, interbedded; sandy limestone and silica and calcareous-cemented fine-grained to sandy quartzite, local ferruginous sandstone and fine-grained sandstone layers; mostly covered slope	133	8861
33. Limestone, medium dark-gray, fine-grained, medium- to thick-bedded; weathers dark blue-gray, rough pitted		

	surface; abundant well-preserved *Syringopora* and cup corals, brachiopods, and fusulinids USGS colln. f22609, "Silty bioclastic limestone with *Tetretaris* sp., *Millerella* sp., textularids, *Bradyina* sp., and *Wedekindellina* sp. The age suggested a Middle Pennsylvanian, late Des Moines equivalent." (R.C. Douglass, written commun., 7/20/62)	2	884
32.	Quartzite, medium-gray, sandy, mostly calcareous cement, medium-bedded with interbedded thin silica-cemented quartzite, interbedded thin sandy limestone layers in middle part, banded in upper part, crossbedded locally; weathers reddish-tan, platy to blocky float, in part pitted; sandy limestone contains sparse well-preserved fusulinids and *Syringopora* and cup corals at 52+ m; mostly covered slope	111	773
31.	Quartzite, tan-gray, sandy, cemented by silica; covered slope	10	763
30.	Limestone, medium light-gray, fine-grained and silty to sandy, thin-bedded with interbedded thin (up to .3 m) calcareous quartzite layers, black chert nodules locally abundant; weathers yellow-gray to tan, platy; covered slope	12	751
29.	Limestone, medium dark-gray, fine-grained, thin- to medium-bedded, very thinly laminated in part, sand partings locally, black chert nodules and lenses moderately abundant; weathers medium blue-gray, platy; well-preserved brachiopods are sparse, worm trails in yellow-weathered limy sandstone at 53 m; covered slope	57	694
28.	Quartzite, buff-tan, coarse-sandy, mostly calcareous cement, medium-bedded, banded with minor crossbedding, shaly limestone partings, thin interbedded limestone layers in basal part; weathers reddish-tan, thick 5-cm partly ferruginous, porous weathered rind, pitted surface in more silicified beds; sparse silicified *Syringopora* coral in limestone at base; mostly covered slope	91	603
27.	Limestone, medium dark-gray, fine-grained to silty, shaly and thin-bedded; sandy limestone partings; weathers medium light gray; common well-preserved crinoid, bryozoan, and brachiopod assemblage; mostly covered slope	7	596
26.	Limestone, medium-gray, fine-grained, dense, medium-bedded to massive, local laminar bands; weathers blue-gray, pitted surface; sparse, well-preserved silicified brachiopods, corals, and crinoid fossils; prominent outcrop	12	584

25.	Quartzite, light gray-tan, sandy, silica-cemented, banded in part, interbedded ferruginous sandstone layer at 8 m weathers brown to light tan-brown; covered slope	25	559
24.	Shale, light-gray, silty, thin-bedded, interbedded thin banded quartzite and sandy limestone beds; weathers buff to light reddish-brown-gray; platy covered slope	70	489
23.	Quartzite, light tan-gray, sandy, calcareous cement, medium-bedded; weathers tan to light brown; partly covered slope	16	473
22.	Limestone, medium gray, sandy, thin-bedded at base, medium-bedded toward top, sand partings and laminae in lower part, medial 1-meter quartzite layer; weathers light gray; platy float	3	470
21.	Quartzite, light gray-brown, sandy, calcareous cement, medium-bedded; weathers tan	7	463
20.	Limestone, dark gray, fine grained, medium bedded, dense; weathers light blue-gray; pitted surface	1	462
19.	Quartzite and sandstone, medium brown-grey, sandy, calcareous and ferruginous cement, medium-bedded; weathers tan and dark brown	9	453
18.	Limestone, medium gray, fine-grained to sandy, medium-bedded, crossbedded locally; weathers light gray, platy float; sparse, well-preserved small cup corals	5	448
17.	Quartzite, light gray-tan, sandy, silica-cemented, medium bedded, a .6 m interbedded sandy limestone with crossbedded sandy partings at top; weathers tan, very thin surface rind, slope and ledge outcrops	14	434
16.	Quartzite, light gray-tan, coarse grained sandy, calcareous-cemented, medium-bedded to massive; weathers light brown, thick porous surface rind, blocky float	9	425
15.	Limestone, medium gray, silty, medium bedded; weathers yellow-gray to buff, platy; well-preserved, abundant, crinoid, bryozoan, productid, and spiriferid brachiopod fauna; mostly covered slope		

USGS colln. 224387-PC at 23 m, "*Derbyia* aff. *D. crassa* (Meek and Hander), *Neochoneltes* sp., *Grandaurispina* sp., *J urasania* cf. *J. nebrascensis* (Owen), *Cancrinella* cf. *C. broonensis* (Swallow), *Crurithuris* cf. *C. planoconvexa* (Shumard), *Condtathyris perplexa* (McChessney), *Hustedia mormoni* (Marcou), *Composita* ? sp. indet. (fragment), *Beecheria* cf. *B. bovidens* (Morton), *Paralleolodon* ? sp indet., and *Ammonoid* indet. (juvenile). The age of this

	collection of small silicified fossils is Middle Pennsylvanian (Des Moines), although it can also be somewhat younger Pennsylvanian." (Mackenzie Gordon, Jr., written common. 10/14/66).	27	368
14.	Quartzite, light gray, sandy, silica-cemented, thin- to medium-bedded, banded in part; weathers reddish light gray, hard conchoidal fracture; partly covered slope	30	368
13.	Limestone, medium dark-gray, fine-grained to silty, thin-bedded; weathers light gray-tan; common well preserved fenestrate bryozoans and productid and spiriferid brachiopods; mostly covered slope	1	367
12.	Quartzite and limestone, interbedded; thin laminated platy sandy limestone and blocky quartzite, medium bedded; covered slope	9	358
11.	Limestone, dark gray, fine grained, medium bedded; weathers blue gray, smooth surface	1	357
10.	Quartzite, tan-gray, calcareous-cemented quartz grains, medium-bedded; weathers tan to light brown with thin softer weathered surface rind; platy to blocky float, covered slope	3	354
9.	Sandy limestone and quartzite, interbedded; medium gray (limestone) and tan-gray (quartzite), sandy, thin- to medium-bedded, black chert nodules with sandy margins locally; mostly covered slope	36	318
8.	Quartzite and shaly limestone, interbedded; well-preserved bryozoans and crinoid stems in limestone; covered slope	13	305
7.	Shaly limestone, medium dark-gray, silty, thin-bedded to platy at top; weathers purple gray and medium gray; brachiopods, bryozoans at base; mostly covered	36	269
6.	Limestone, medium gray, medium to fine grained, medium bedded; weathers medium light gray, rough pitted surface, fossils rare	3	266
5.	Sandstone, reddish-brown and tan, sandy, calcareous cement to part, medium-bedded; weathers light brown-tan; mostly covered slope	7	259
4.	Quartzite, brown-tan, sandy mostly silica cemented quartz grains, but is slightly calcareous, medium-bedded with thin interbeds of calcareous sandstone; weathers light brown tan with smooth surface; upper part covered slope	31	228
3.	Limestone, medium gray and tan, silty and sandy, thin platy and medium bedded, in part with black chert nodules, in part bioclastic, interbedded with thin (5 cm) quartzite and		

shale partings; weathers medium light gray-brown and yellow-brown; fenestrate and stem bryozoans, and brachiopods locally abundant 27 201

2. Limestone, medium-gray, silty to sandy, thin and platy to medium-bedded,, interbedded shaly and sandy units, crossbedded in part, locally thin interbedded cherty limestone units; weathers medium light gray and yellow brown; bryozoans

USGS colln. 61F70A at 169 feet, "Fistuliporoid (?) bryozoan, indet., *Fenestella* sp., *Polypora* sp., *Archimedes* sp. (fragments of fronds), *Penniretepra* sp., rhomboproid bryozoans, crinoid colummals, *Juresania* sp. indet." Fauna is compatible with Des Moines age of section." (Mackenzie Gordon, Jr., written commun. 10/14/66) 30 171

1. Limestone, medium gray, fine grained to sandy, thin bedded, and distinctly laminated and locally convoluted, to medium bedded, black chert nodules moderately abundant in medium-bedded rock, shale partings common and sandy bioclastic rock locally abundant; weathers medium light gray, chert nodules to light sandy-brown; locally brecciated medium sandy layers; fossiliferous with coral bryozoan, and crinoid stems, and small brachiopods

USGS colln f22608 at 3 m, "Bioclastic limestone with *Bradyina*, textularids, and *Fusulina* sp. The age suggested is Middle Pennsylvanian, late Des Moines equivalent." (R.C. Douglass, written commun. 7/20/62) 171

Total Rush Lake unit measured 1,352

Conformable contact (?), lower part of the Rush Lake unit is covered by alluvium.

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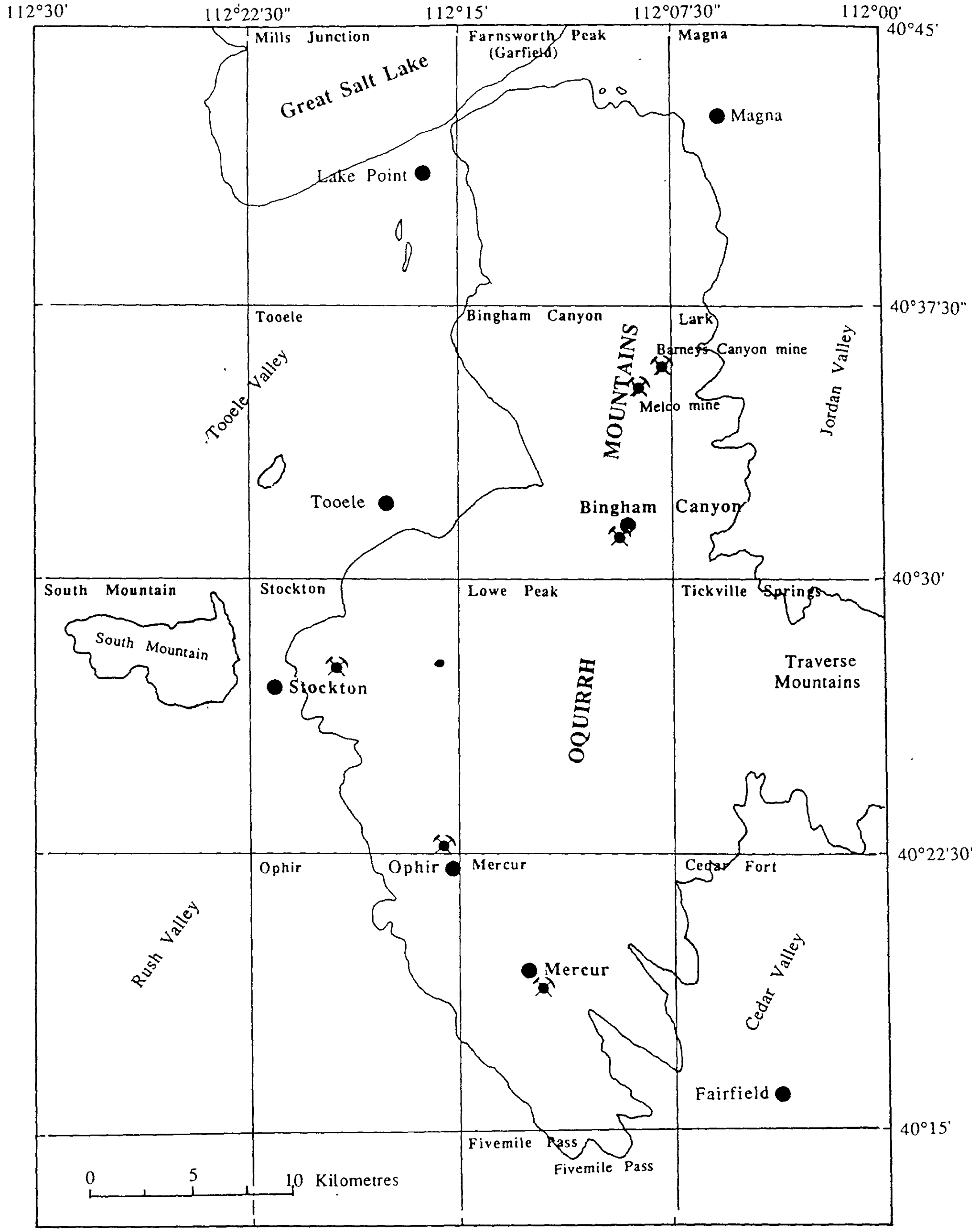


Figure 1.—The Oquirrh Mountains, Utah, its constituent 7 1/2-minute topographic quadrangles, and the main mining areas in the range.

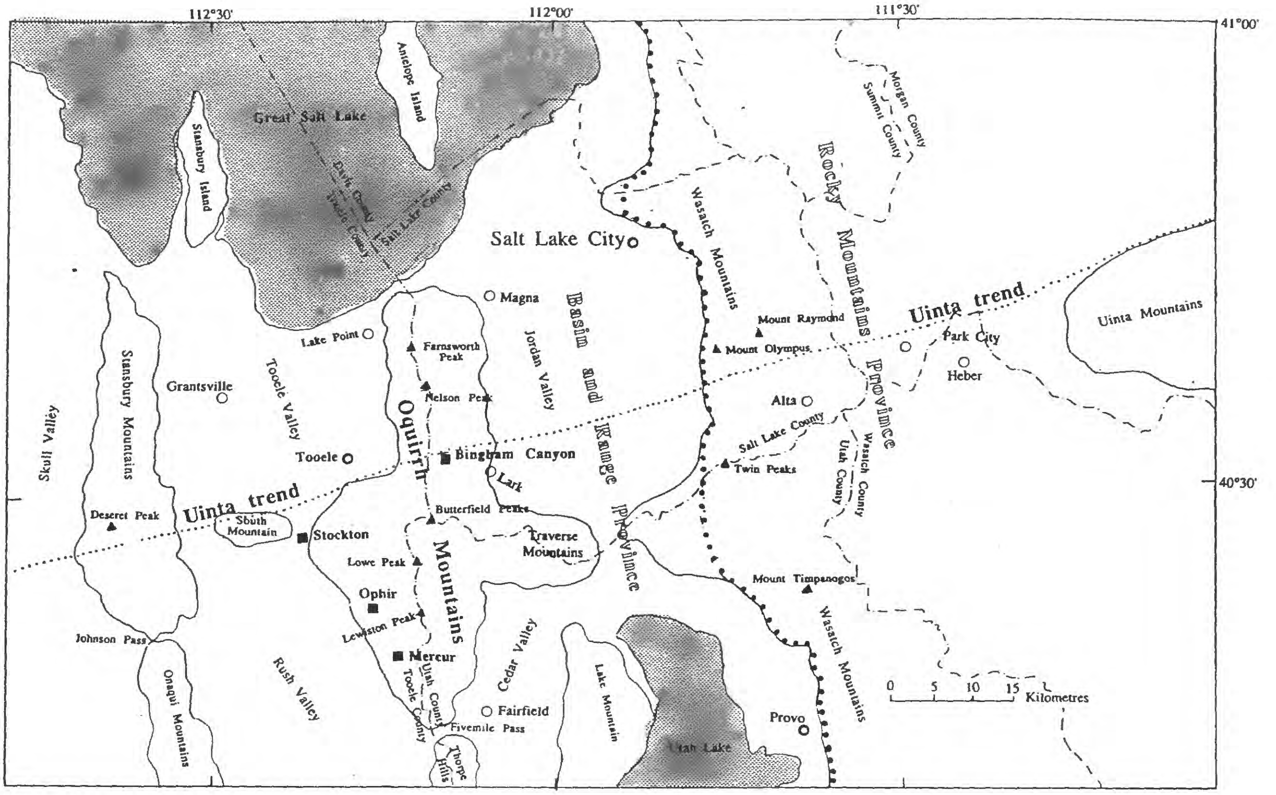


Figure 2.—North-central Utah locations of the Oquirrh Mountains and neighboring ranges, the Basin and Range and Rocky Mountains physiographic provinces, and the inferred generalized axial trace of the basement Uinta trend zone.

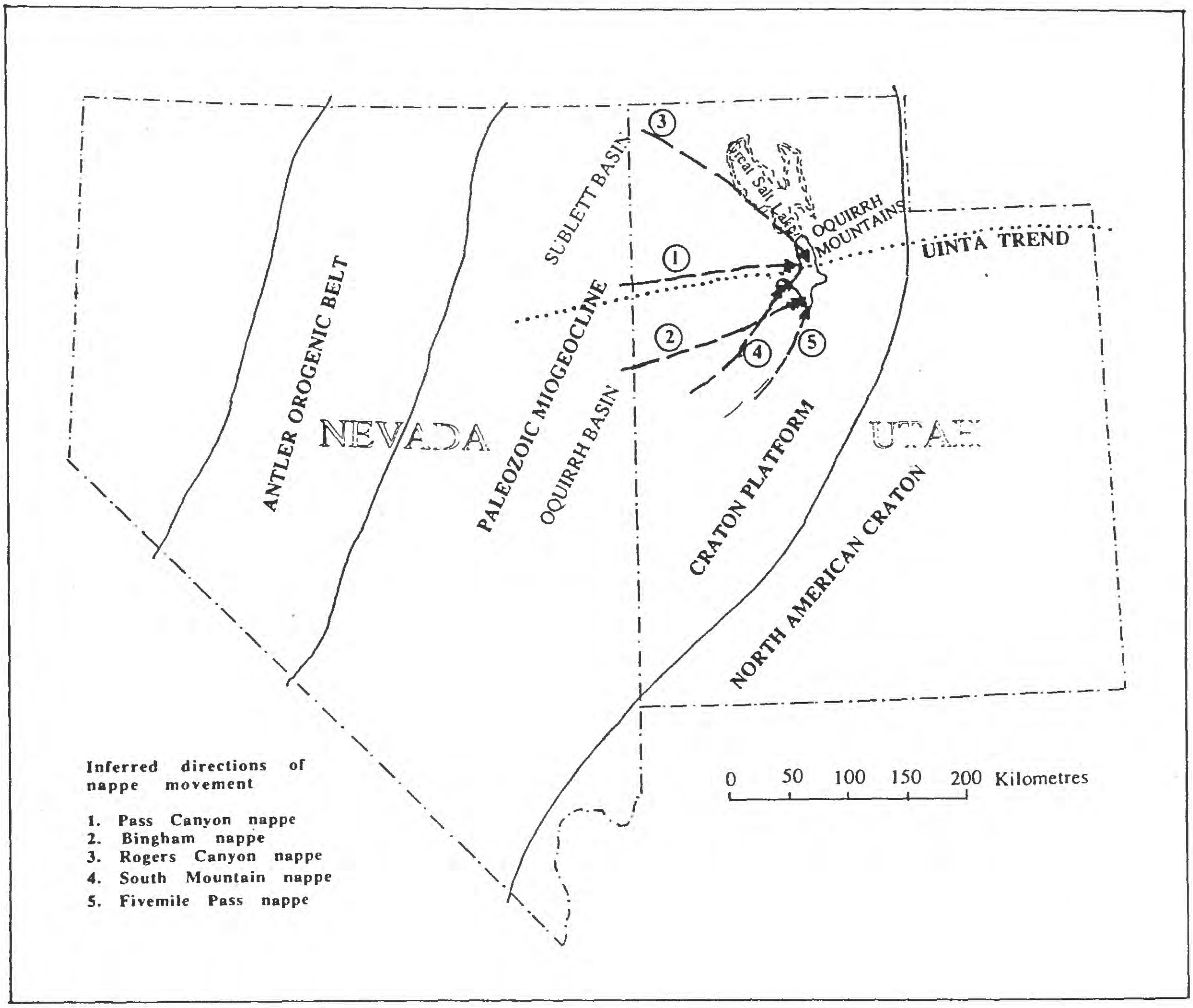


Figure 3.—Inferred locations of the Paleozoic miogeoclinal Oquirrh and Sublette basin deposition areas on the craton platform, the North American craton and Antler orogenic belt sediment source areas, directions of individual nappe movements to their foreland placement areas, and the trace of the Uinta-trend axis.

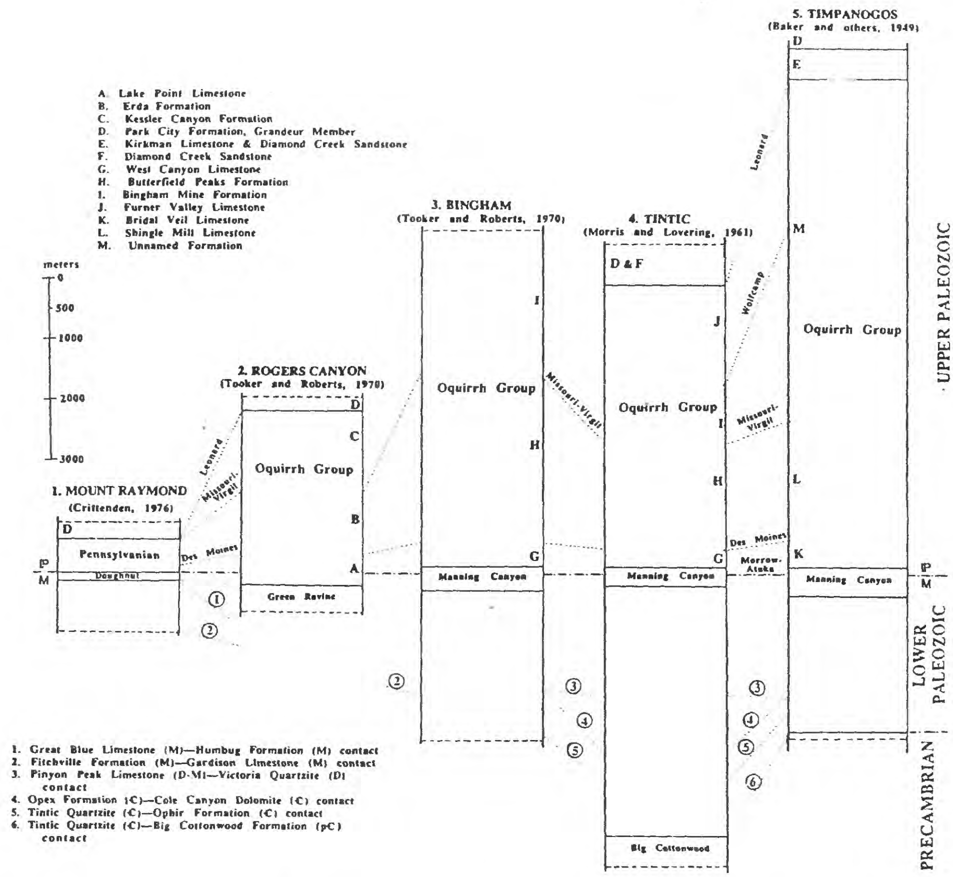


Figure 4.—Generalized columnar sections showing the correlation of Paleozoic formations in the Sevier belt foreland nappes in the Oquirrh and Wasatch Mountains.

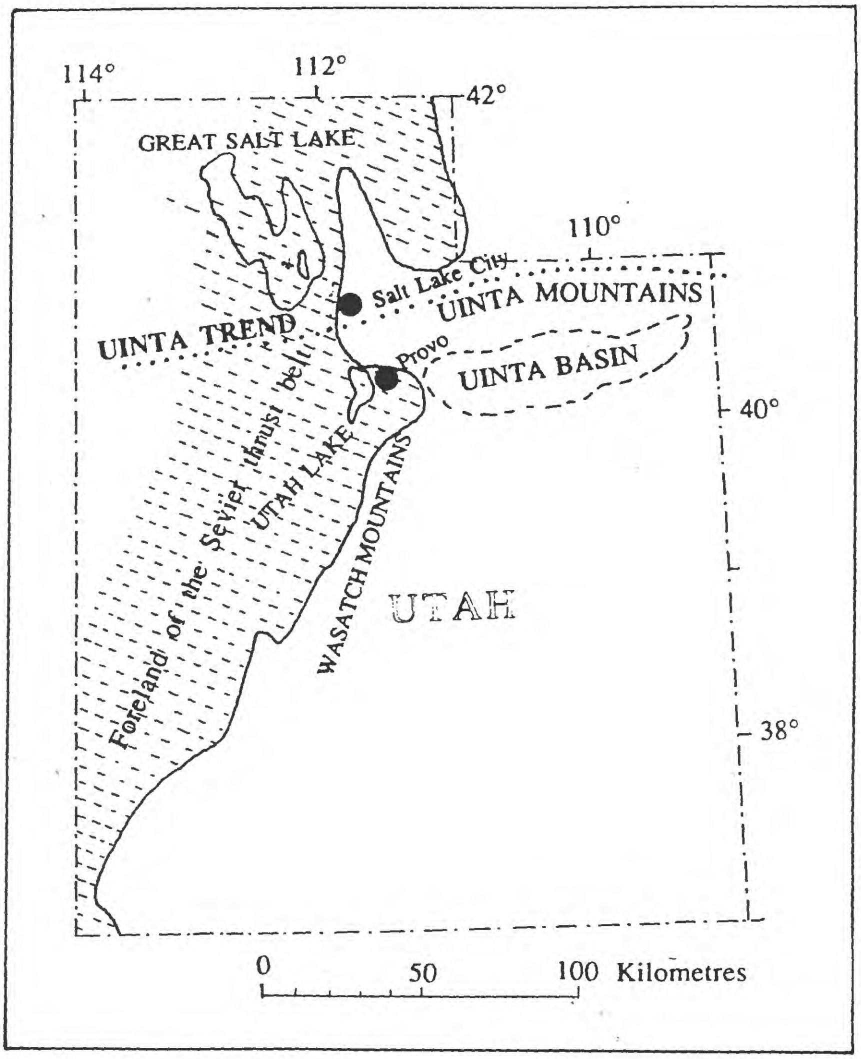


Figure 5.—Locations of the Sevier foreland thrust belt, the approximate axis of the Uinta trend and its uplifted basement buttress area.

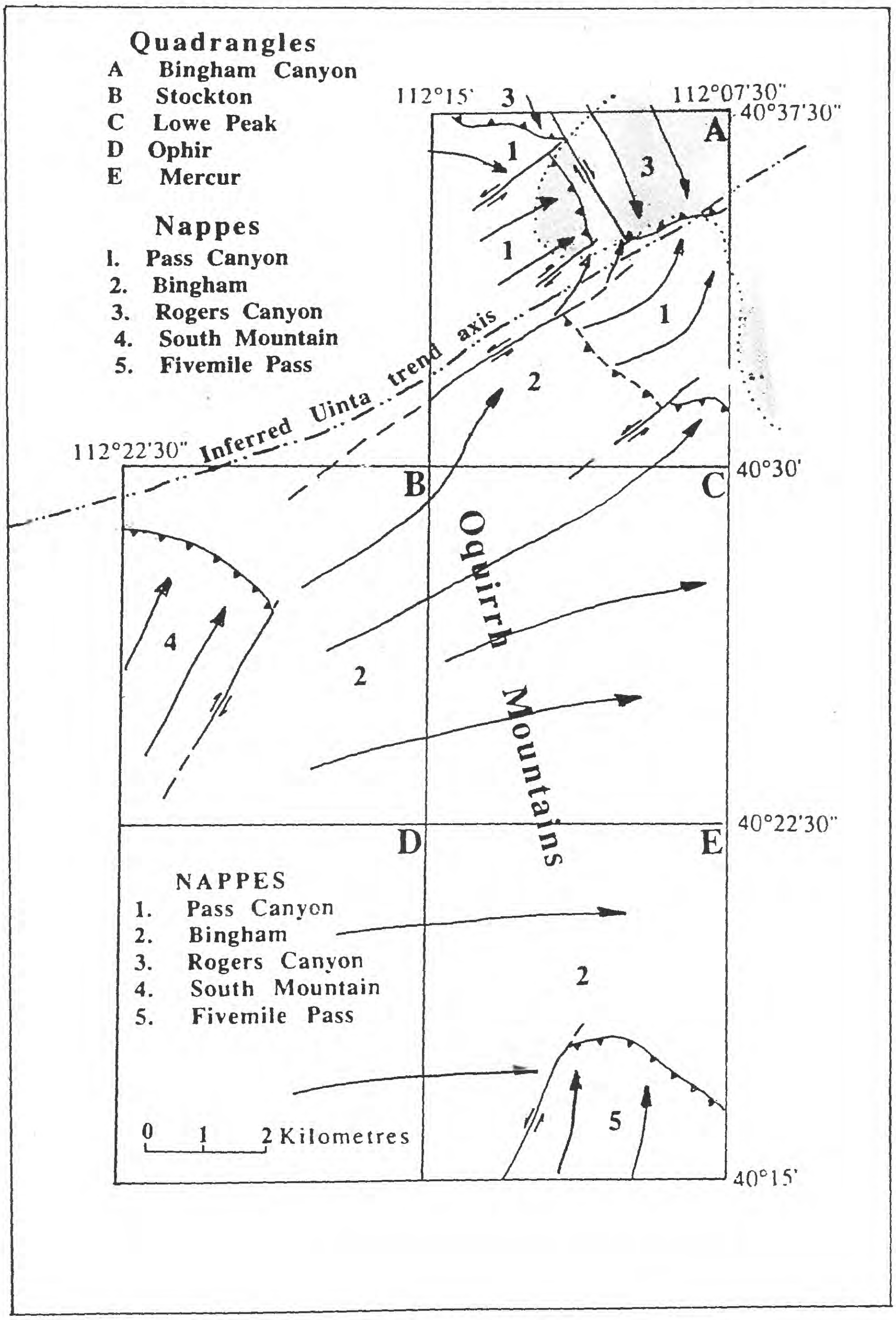


Figure 6.—Diagram showing the inferred directions and sequence (1—5) of Sevier-age nappe movements approaching their foreland placement areas on and about the Uinta trend basement buttress in the present Oquirrh Mountains.

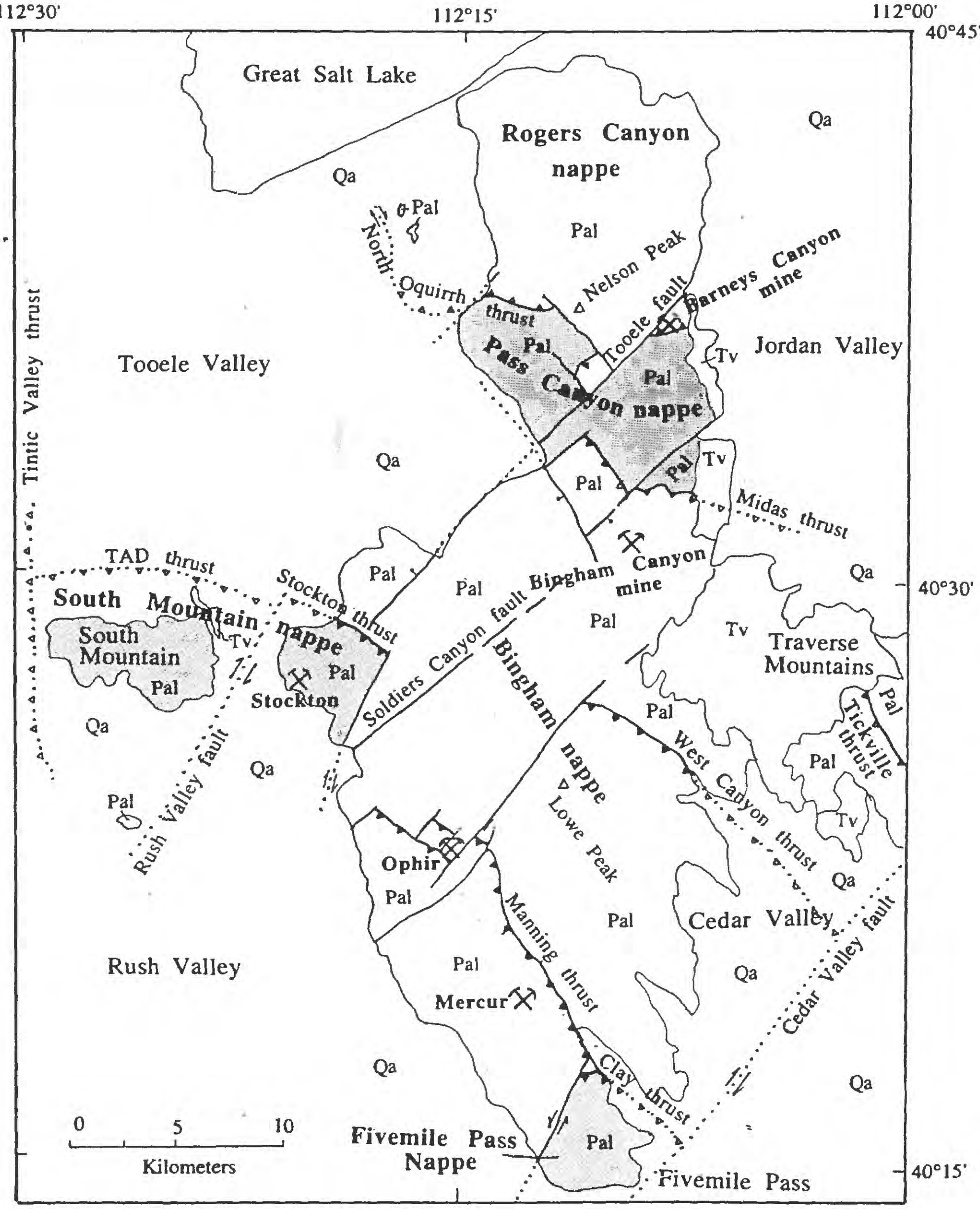


Figure 7.—The Rogers Canyon, Pass Canyon, Bingham, South Mountain, and Fivemile Pass nappes, and the main mining areas in the Oquirrh Mountains. Shading is to help differentiate the nappes.

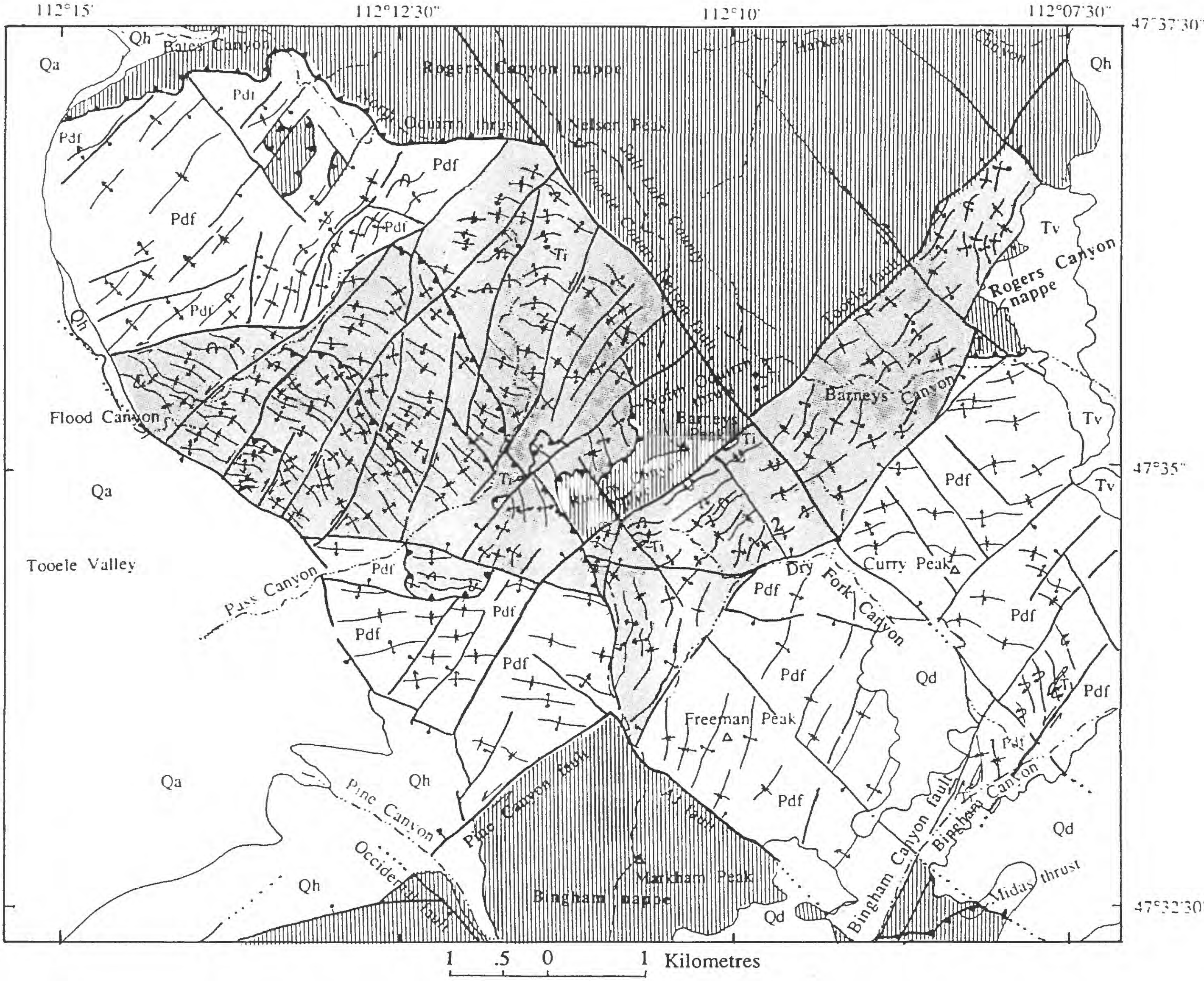


Figure 8.—Generalized geologic map of the Pass Canyon nappe showing the main structures and the Dry Fork (Pdf) and Flood Canyon (light shaded) formational units of Tooker and Roberts (1988). The adjoining Rogers Canyon and Bingham nappes are dark patterned.

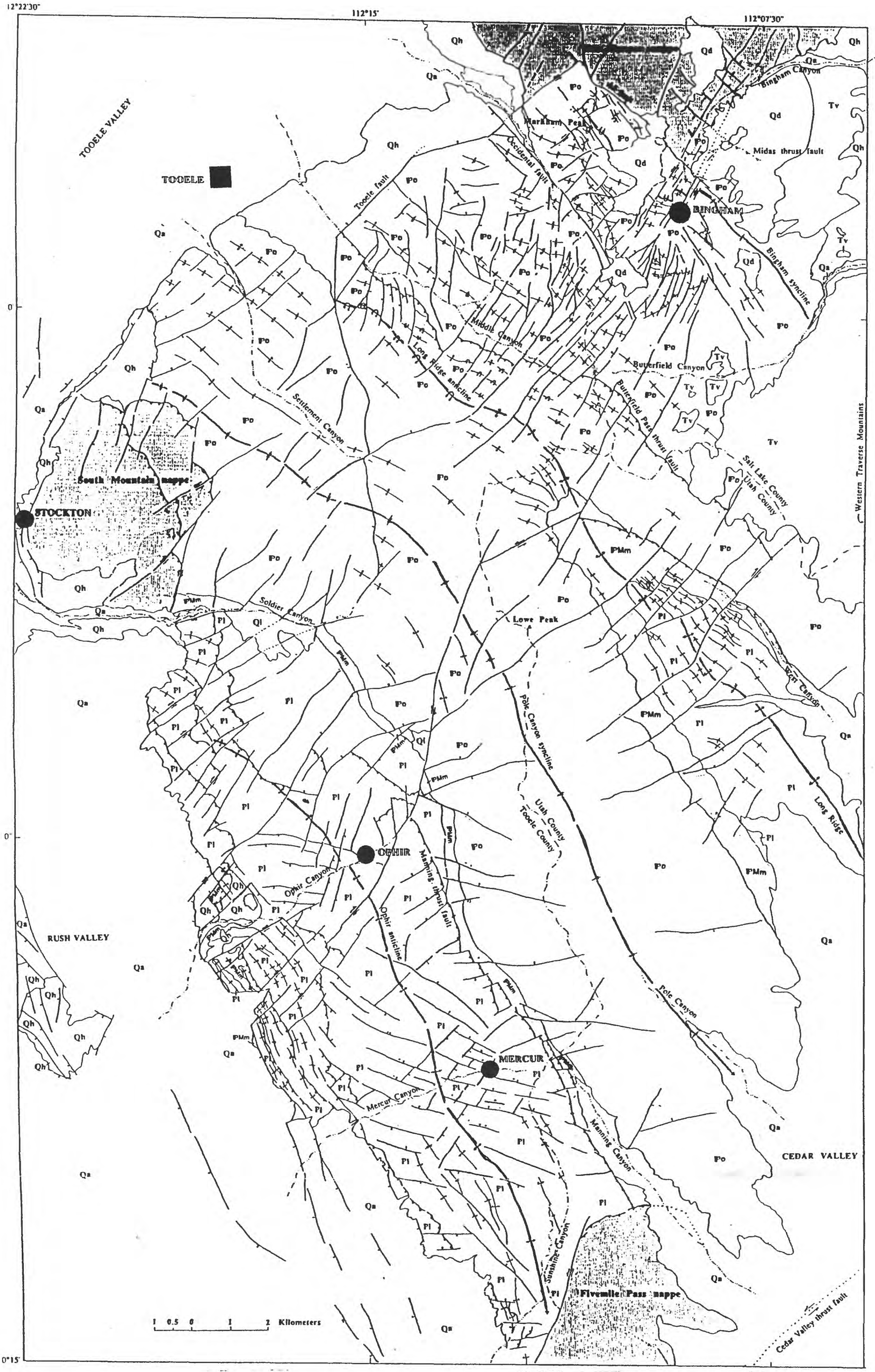


Figure 9.—Generalized geologic map of the Bingham nappe showing the distribution of Paleozoic rocks and their major structural features. Main folds are shown by heavy lines. Adjoining nappes are shown by light shading. Pl, Lower Paleozoic sedimentary rocks, ℙMm, Manning Canyon Shale, Po, Upper Paleozoic Oquirrh Group.

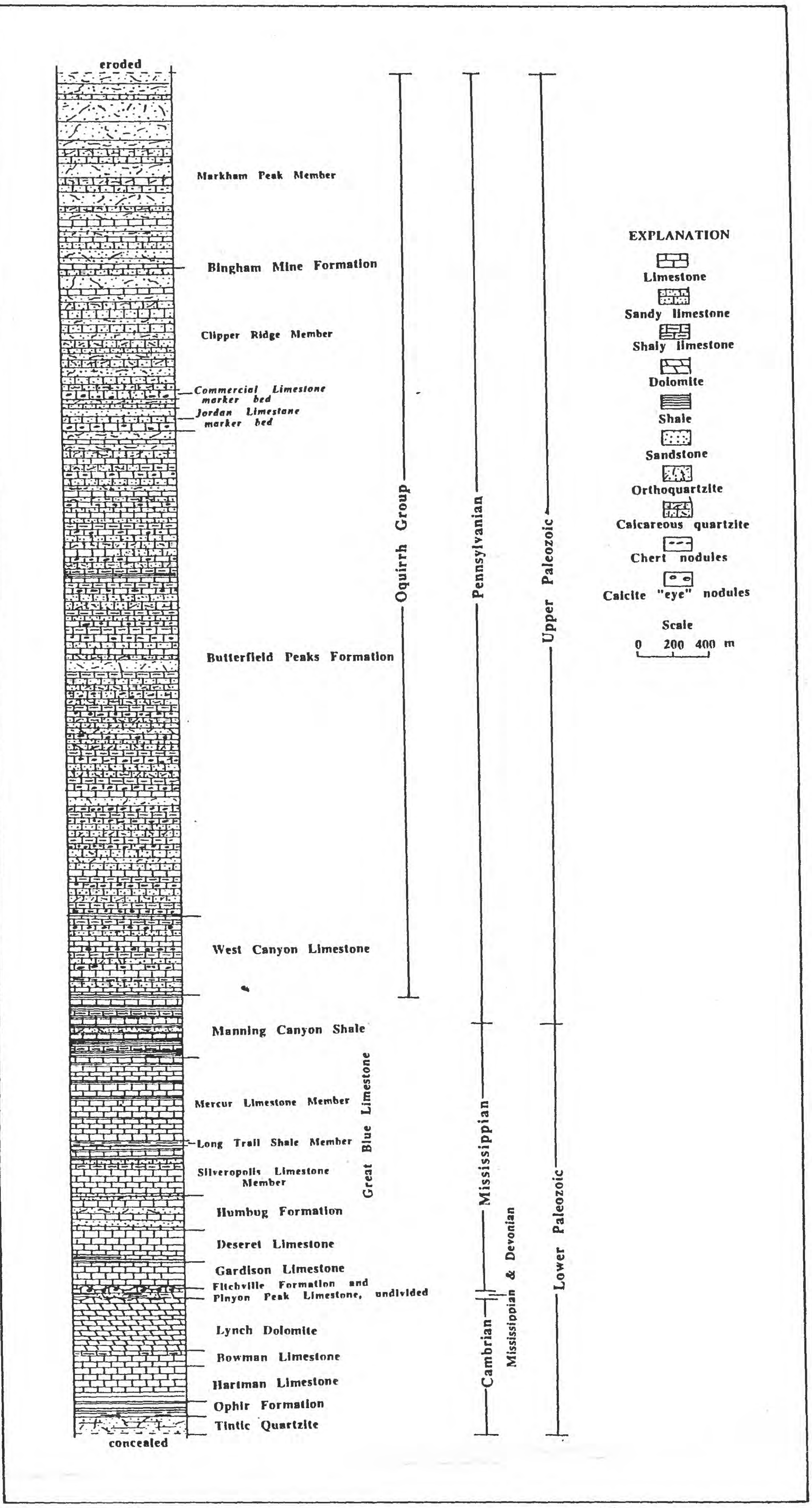


Figure 10.—Generalized columnar section of lower and upper Paleozoic formations in the Bingham nappe.

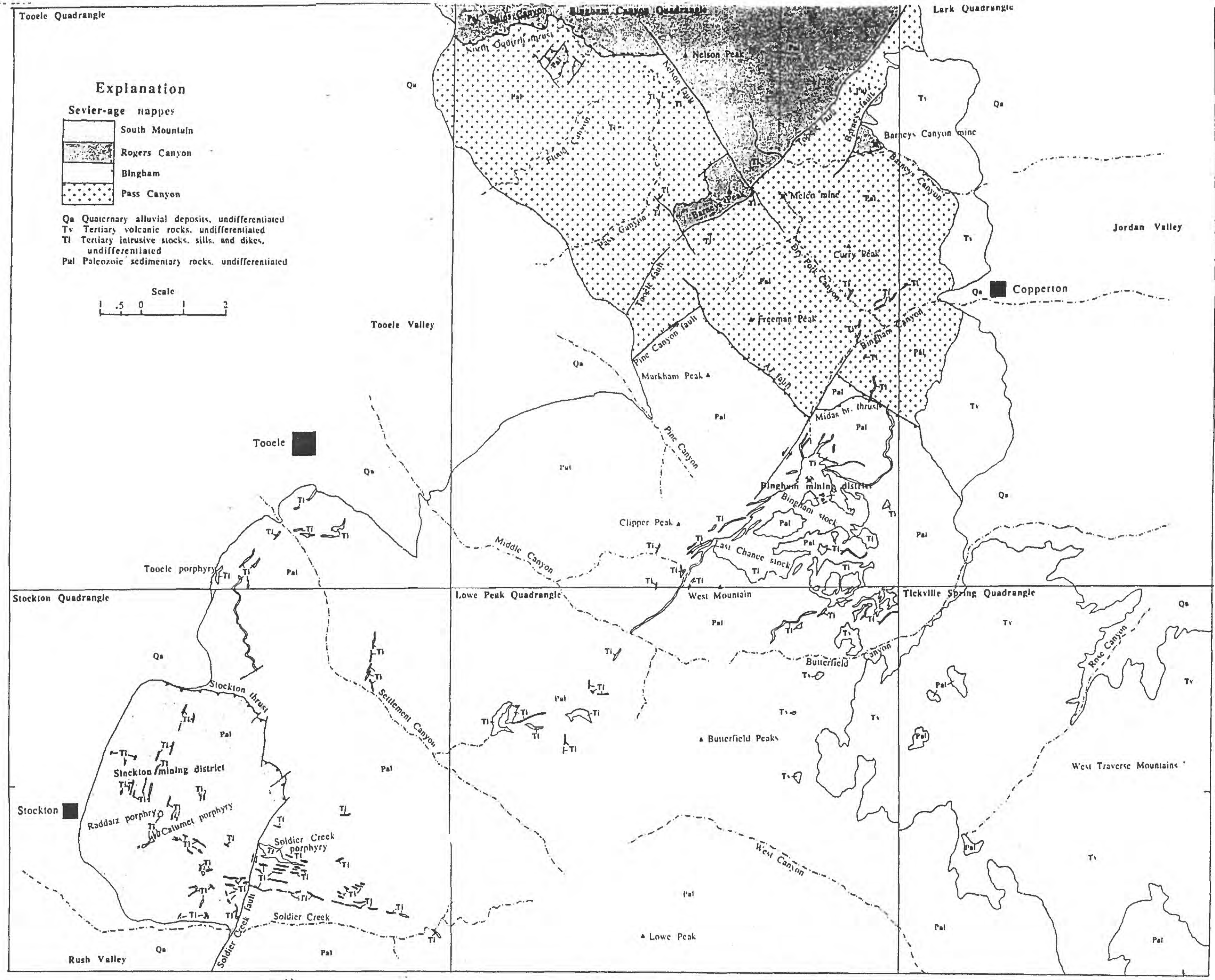


Figure 11.—Generalized map showing the distribution of the main bodies of igneous intrusive and extrusive rocks in the Pass Canyon, Bingham, and South Mountain nappes in the Oquirrh Mountains, Utah.

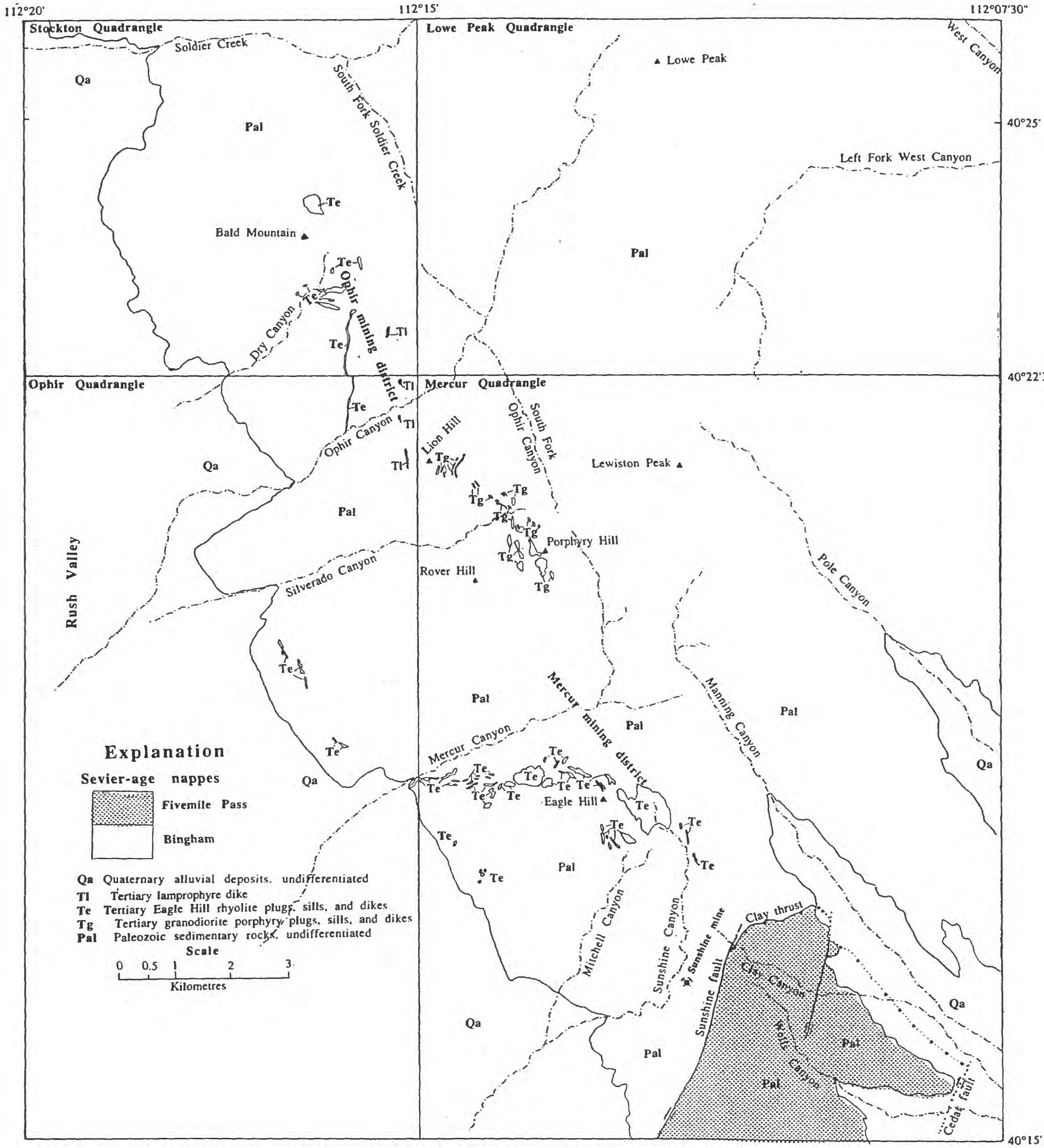


Figure 12.—Generalized map showing the distribution of intrusive igneous rocks in the Bingham nappe in the southern part of the Oquirrh Mountains.

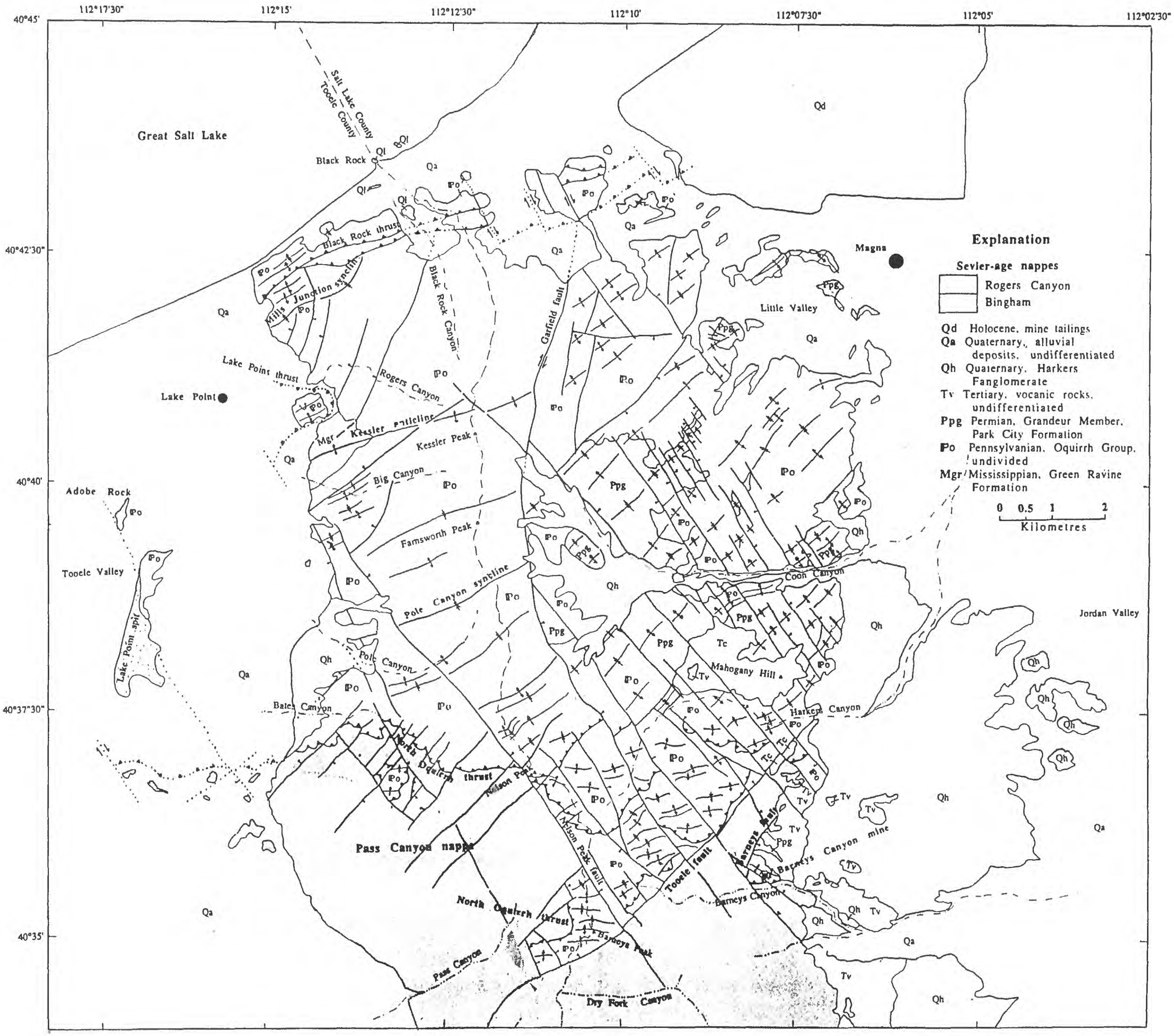


Figure 13.—Generalized geologic map of the Rogers Canyon nappe in the northern Oquirrh Mountains.

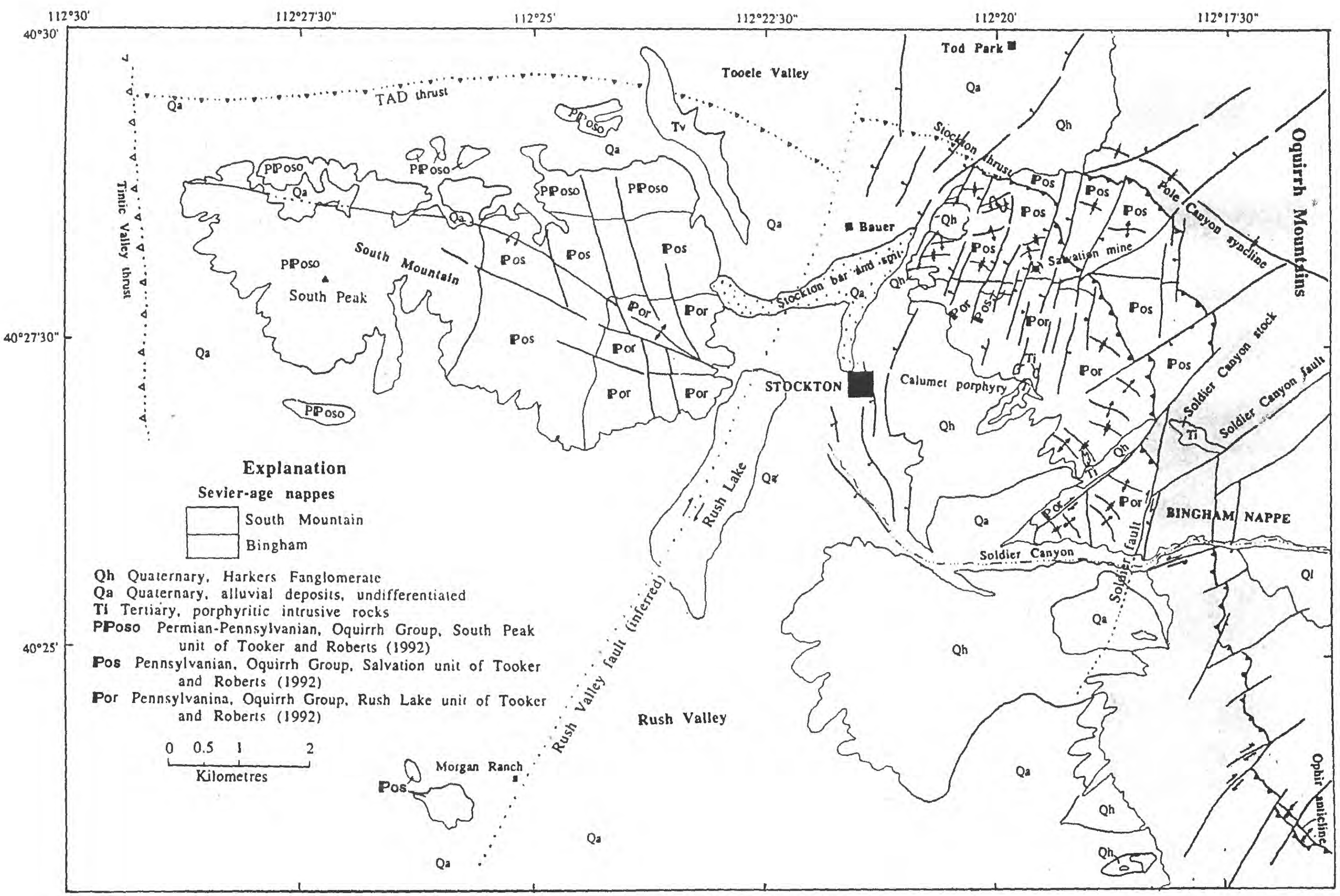


Figure 14.—Generalized geologic map of the South Mountain nappe on South Mountain and west-central Oquirrh Mountains.

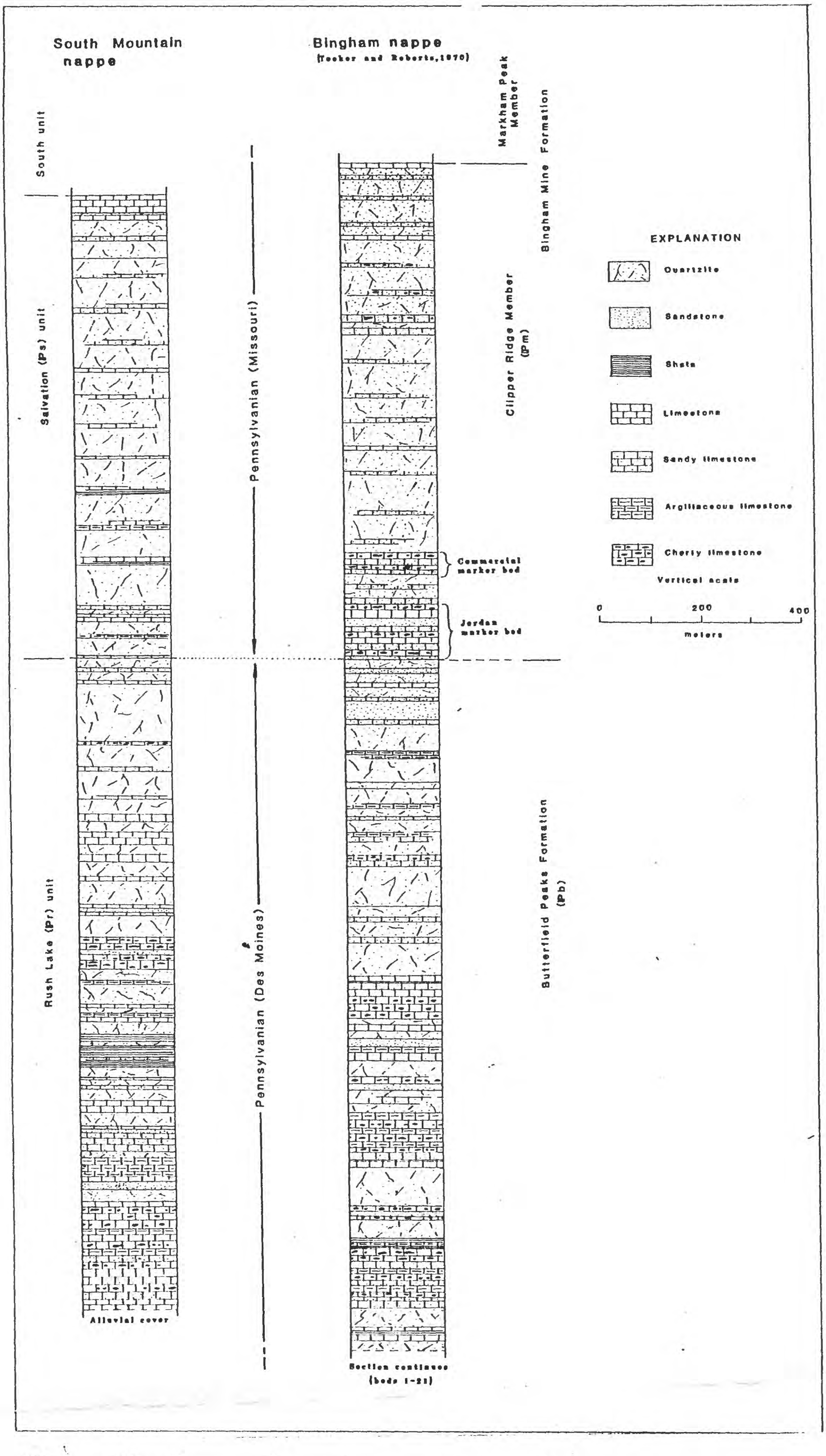
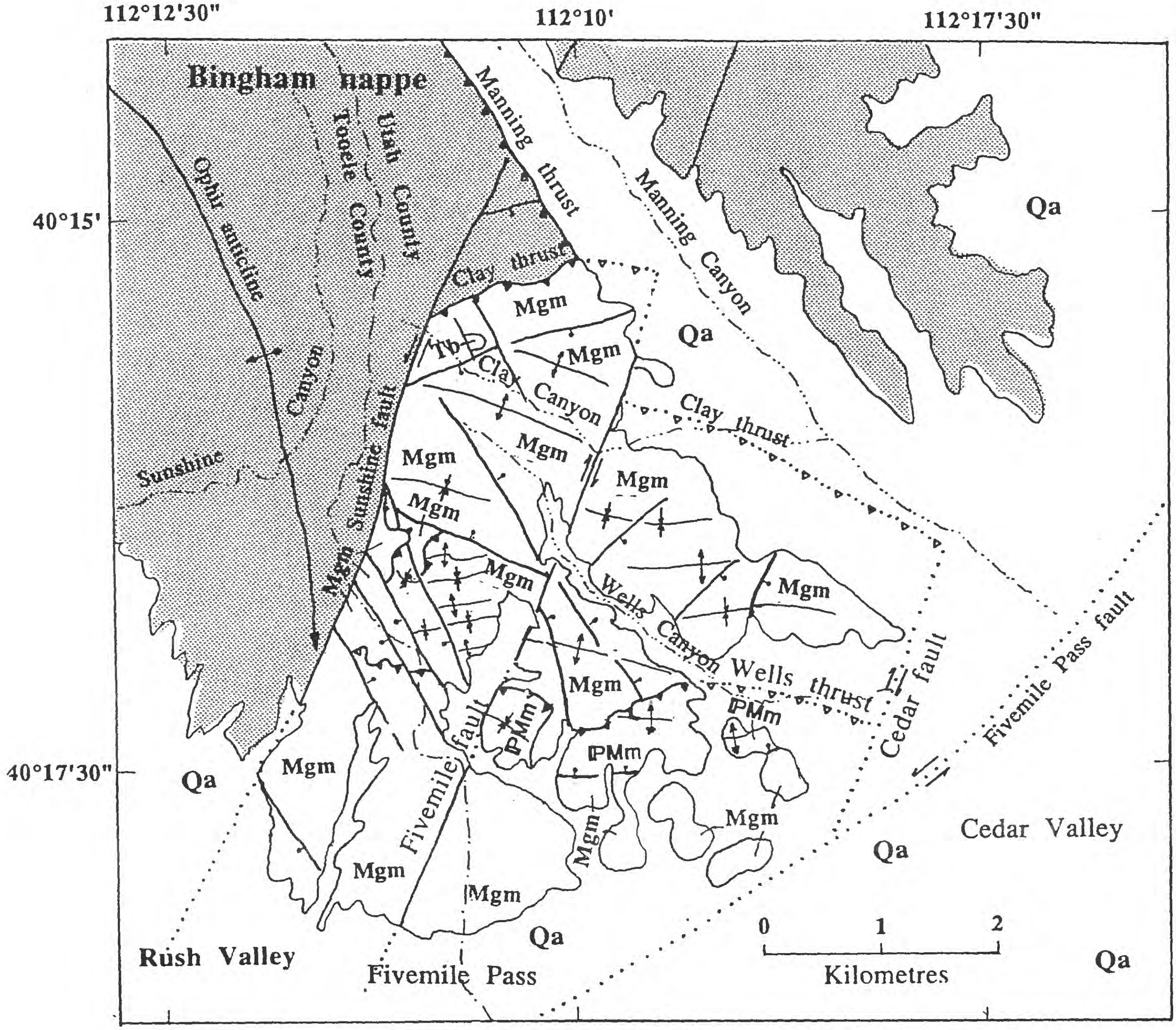


Figure 15.—Comparative columnar stratigraphic sections of common parts of the South Mountain and Bingham nappes.



Explanation

Sevier-age nappes

Fivemile Pass

Bingham

Qa Quaternary, alluvial deposits, undifferentiated

PMm Mississipian, Manning Canyon Shale

Mgm Pennsylvanian-Mississippian, Mercur Member, Great Blue Limestone

Figure 16.—Generalized geologic map of the Fivemile Pass nappe. The adjoining Bingham nappe is shaded.

Table 1. --Main types of igneous rocks in the Oquirrh Mountains nappes

Location	Type of body	Composition	Age in m.y.	Reference
BINGHAM NAPPE				
Bingham mining district area				
1	Last Chance stock	Equigranular monzonite	39	Moore and McKee, 1983
2	Bingham stock	Equigranular monzonite (border)	38	Moore and McKee, 1983
3	Bingham stock	Porphyritic monzonite (core)	37	Moore and Lanphere, 1971
4	Dike cutting Bing. stock	Quartz latite porphyry	36	Moore and others, 1968
5	Volcanic flow	Andesite porphyry	38	Moore, 1973c
6	Shaggy Peak plug	Biotite rhyolite vitrophyre	33	Moore, 1973c
Middle Canyon area				
7	Dike	Quartz latite porphyry	37	Moore, 1973c
Selkirk Canyon area				
8	Tooele dike or sill	Quartz monzonite prophyry	38	Moore, 1973c
Mercur minining district area				
9	Eagle Hill plug	Rhyolite	32	Moore and McKee, 1983
Ophir mining district area				
10	Lion Hill stock (?)	Biotite granodiorite porphyry	37	Moore and McKee, 1983
PASS CANYON NAPPE				
Pass Canyon area				
11	Sill or dike	Latite porphyry	36	Moore, 1973c
SOUTH MOUNTAIN NAPPE				
Stockton mining district area				
12	Calumet mine stock	Monzonite porphyry	38	Moore, 1973
13	South Mountain	Hornblende latite tuff breccia	30	Moore, 1973b
14	South Mountain	Nepheline basalt	40	Moore and McKee, 1983

Note: Location numbers shown on figures

TABLE 2 -- LITHOLOGY OF LOWER PALEOZOIC FORMATIONS IN THE BINGHAM NAPPE (Gilluly, 1932; Gordon, Tooker, and Dutro 199)

AGE	FORMATION	MEMBER	THICKNESS (m)	LITHOLOGY, AGE, AND CORRELATION
(continued on Table 3)				
Upper Mississippian (Chesterian)	Great Blue Limestone	Mercur limestone	437	Interbedded thin- to medium-bedded limestone, cherty and argillaceous limestones, calcareous shale intervals; sparsely fossiliferous with brachiopods, bryozoa, and corals; conformable contacts. Correlative in part with the Green Ravine Formation, Rogers Canyon nappe, and with the Chulios and Polker Knoll Members of Great Blue Formation in Bingham nappe at Tintic (Morris and Lovering, 1961)
		Long Trail Shale	29	Interbedded thin-bedded calcareous and carbonaceous shale in upper part, thin- bedded fossiliferous argillaceous and silty limestone below. Upper and lower contacts are transitional and conformable.
Upper Mississippian (Meramcian)		Silveropolis limestone	280	Interbedded thin- to meduim-bedded locally fossiliferous and argillaceous limestones, locally silicified, and calcareous sandstone or sandy limestone. Cherty limestone lenses common in the middle part. Fossils include brachiopods, corals, and bryozoa. Correlative with the Toplif and Paymaster members of the Great Blue Formation in the Bingham nappe at Tintic (Morris and Lovering, 1961)
	Humbug		197	Interbedded thin- to medium-bedded, medium-gray limestone which weathers brown-gray, and brown-weathered qua4rtzite up to 30 m thick; occasional sparse brachiopod, coral, and bryozoa fauna. Correlative with Humbug Formation in Bingham nappe at Tintic (Morris and Lovering, 1961).
	Desert Limestone		198	Very fossiliferous, thin- to medium-bedded, blue-gray cherty limestone with thin (1-2.5 m) bed of phosphatic shale at the base. Brachiopods, bryozoa and coral fauna.

Gardison
(Continued)

TABLE 2 -- LITHOLOGY OF LOWER PALEOZOIC FORMATIONS IN THE BINGHAM NAPPE (continued)

AGE	FORMATION	MEMBER	THICKNESS (m)	LITHOLOGY, AGE, AND CORRELATION
Lower Mississippian	Gardison		140	Very fossiliferous, thin-bedded toward the base, more massive sandy, and cherty limestones in upper part. Unconformable lower contact, conformable upper contact. Correlative with the Gardison Formation, Bingham nappe at Tintic.
Unconformity				
Middle Devonian (?)	Fitchville Formation and Pinyon Peak Limestone, undivided		56	Coarsely crystalline gray dolomite, weathers dark gray, one massive bed contains conspicuous white calcite fossil casts. Correlative in part with the Pinyon Peak limestone and Fitchville Formation at Tintic
Unconformity				
Upper Cambrian	Lynch Dolomite		25-305	Thick-bedded, light gray dolomite with some dark-gray dolomite containing short white rods in the lower part, and with a few limestone beds in the lower half; is a prominent cliff-forming unit in Ophir Canyon. The lower part resembles Bluebird dolomite at Tintic; the upper part is similar to the Cole Canyon Formation, also at Tintic (Morris and Lovering, 1961).
Middle Cambrian	Bowman Limestone		85	Mottled shaly limestones, infraformational conglomerate, and oolitic limestone; a shaly unit about 11 m thick is at the base. Sparse trilobite fauna. Probably correlated with Herkimer Limestone at Tintic (Morris and Lovering, 1961).
	Hartman Limestone		198	Banded gray mottled thin-bedded limestone with shale partings, some oolites toward the top. Sparse trilobite fauna. Correlated with the lower part of the Teutoinic Limestone at Tintic (Morris and Lovering, 1961).
- - - - - - - - Lower Cambrian	Ophir Formation		98	Micaceous shale, sandy shale toward the base, contains several beds of mottled shaly limestone. Brachiopod and trilobite (Olenellis) fauna. Correlated with the Ophir Formation at Tintic (Morris and Lovering, 1961).
	Tintic Quartzite Concealed		90	Thick-bedded, cross-bedded, white quartzite, which weathers reddish brown. Becomes shaly toward the top and grades into the Ophir Formation. Correlated with the Tintic Quartzite at Tintic (Morris and Lovering, 1961).

TABLE 3 -- LITHOLOGY OF MIDDLE AND UPPER PALEOZOIC FORMATIONS IN THE BINGHAM NAPPE (Tooker and Roberts, 1970)

AGE	GROUP	FORMATION	MEMBER	THICKNESS (m)	LITHOLOGY AND CORRELATION
Unconformity (erosion)					
Upper Pennsylvanian (Missourian)	Oquirrh	Bingham Mine	Marham Peak	1311	Multibedded, intergradational, medium-to-thick bedded orthoquartzite, calcareous quartzite, calcareous sandstone, and thin limestone; upper contact is erosional, lower contact is conformable; sparse fossils include colonial corals, brachiopods, and fusulinids. Roughly correlative with the Kessler Canyon Formation in the Rogers Canyon nappe.
			Clipper Ridge	910	Thick bedded orthoquartzite, calcareous quartzite, calcareous and quartzose sandstone, and medium interbeds of cherty, argillaceous, and fossiliferous limestones. Two prominent thick limestone marker beds at the base include the Jordan and Commercial limestones. Contacts are conformable. Member is correlative in part with the Kessler Canyon Formation, Rogers Canyon nappe, and the Salvation unit in the South Mountain nappe (Tooker and Roberts, 1992).
Middle Pennsylvanian (Desmoinesian)	Oquirrh	Butterfield Peaks		1177	Cyclic interlayered thin- to medium-bedded, locally crossbedded calcareous quartzite, orthoquartzite, and calcareous sandstone, cherty, fossiliferous, and argrillaceous limestones. Fossils include abundant coral, brachiopod, and fusulinid fauna. Generally correlative with the Erda Formation, Rogers Canyon nappe, and the Rush Lake unit, South Mountain nappe (Tooker and Roberts, 1992).
Lower Pennsylvanian (Morrowan)	Oquirrh	West Canyon Limestone		442	Cyclical thin-to medium-bedded, clastic, arenaceous limestones, cherty, argillaceous, and dense limestones, calcareous quartzite, silica-cemented sandstone, generally banded and crossbedded. Fossils locally abundant include brachiopods, bryozoans, corals, rare trilobite fragments, and fusulinids. Correlated with the Lake Point Limestone, Rogers Canyon nappe.
Upper Mississippian (Chesterian)		Manning Canyon Shale		347	Predominantly shale with thin interbeds of limestone and thin- to thick-bedded dark brown quartzite in the lower half. Grades into dominant limestone in the uppermost part, transitional into the Oquirrh Group, West Canyon Limestone. Fossils abundant, include brachiopods, corals, and bryozoans.

(continued on Table 2)

TABLE 4. METAL PRODUCTION FROM THE OQUIRRH MOUNTAINS MINING DISTRICTS, UTAH

	CU (000 t)	MO (000 t)	AU (000 oz)	AG (000 oz)	PB (000 t)	ZN (000 t)	HG Flasks
BINGHAM							
1863-1972[1]	11,900	360	13,253	244,413[4]	2,400[4]	1004[4]	
1973-1981[2]	1,670	?	3,639	?	?	?	
1982-1990[3]	551	27	616	811			
1991-1992[2]	579		973	7,679			
1993-1996[2]	1,217		>51	>8,600			
Total	15,917	>387	18,997	261,503	2,400	1,000	
MERCUR							
1871-1950[6]	0.2		1,100	223	1.8	0.7	3,338
1983-1990[7]			766.6				?
1991-1992[2]			248.5				?
1994-1995[2]			210.1				
1996-1997[8]			875				
Total			3,200				>3,338
OPHIR and STOCKTON							
1870-1901[2&5]	101.5		12	50	329	17	
OPHIR							
1902-1972[2&5]	4.8		10.6	14	172	46	
STOCKTON							
1902-1970[2&5]	2.9		74	11	245	86	
BARNEYS CANYON							
1989-1990[2]			157				
1991-1992[2]			238				
1993			395				
Total			790				
TOTAL PROD.	16,026.40	>387	23,017.20	253,201	3,147.80	1,149.70	>3,338

[1] James (1978)
[2] USGS (1883-1923, 1995-1996) and USBM (1924-1994)
[3] British Petroleum Co. (1986) and USBM (*1924-1993)
[4] The UV Industries closed the Lark and U.S. Mines underground workings in 1970, ending the main production of silver, lead, and zinc ores (Tooker, 1990)
[5] Stowe (1975)
[6] Kornze and others (1985)
[7] Shrier, American Barrick (1993, verbal commun.)
[8] Kerr (1997)

TABLE 5-- SUMMARY OF LITHOLOGY OF PALEOZOIC FORMATIONS IN THE ROGERS CANYON NAPPE (Tooker and Roberts, 19

AGE	GROUP	FORMATION	MEMBER	THICKNESS (m)	LITHOLOGY AND CORRELATION
Erosional unconformity					
Tertiary(?)		Unnamed conglomerate		Unknown	Poorly sorted reddish-brown, limonite-stained consolidated gravels capped by andesite breccia. M be correlative with the Apex conglomerate at Tintic (Morris and Lovering, 1961).
Unconformity, erosion interval					
Early Permian (Leonardian)		Park City	Grandeur	232	Thin- to medium-bedded, fine- to coarse-grained, arenaceous limestone, dolomite, dolomitic limestone and interbedded shale, argillaceous limestone, phosphorite, chert, orthoquartzite, and calcareous sandstone partings. Beds are very fossiliferous, and lithologically comparable with the type section in t Wasatch Mountains. Unconformably overlies the Kessler Canyon Formations. Wolfcamp-age rocks ar not -present here.
Unconformity					
Late Pennsylvanian (Missouri-Virgil)	Oquirrh	Kessler Canyon		2145	Upper part is thin- to medium-bedded, interbedded orthoquartzite calcareous, ferruginous, and dolomitic sandstone, and dolomite. Lower part is thick, silica-cemented orthoquartzite and cherty limestone. Loca sedimentary dolomite breccia. Worm trails are comm poorly preserved fusulinids in bedded chert layers. Correlative in age with the Clipper Ridge Member, Bingham Mine Formation.

(Continued)

TABLE 5-- SUMMARY OF LITHOLOGY OF PALEOZOIC FORMATIONS IN THE ROGERS CANYON NAPPE (Continued)

AGE	GROUP	FORMATION	MEMBER	THICKNESS	LITHOLOGY AND CORRELATION
Middle Pennsylvanian (Desmoines)	Oquirrh	Erda		530	Cyclically repeated layers of medium-gray limestone and dark-gray argillaceous limestone, light-brown carbonaceous shale, medium brown and tan calcareous quartzite, crossbedded light-brown sandstone. Argillaceous and cherty limestones are abundantly fossiliferous with gastropods, bryozoans, brachiopods, and fusulinids. These rocks are the approximate age equivalents of the lower and middle parts of the Oquirrh Group in the thick Oquirrh and Wasatch Mountain nappes and the thin Wasatch (Mt. Raymond sequence) (Crittenden, 1959).
Early Pennsylvanian (Morrow)	Oquirrh	Lake Point Limestone		432	Interbedded medium- to light-gray, tan-weathered, thin- to medium-bedded limestone and massive (thick bedded) gray limestone. Locally the limestone is cherty and contains bioclastic, crossbedded, and arenaceous layers and shale partings. Beds in upper part are more massive and less fossiliferious than those below. Cyclic repetitions of beds is common. Locally abundant fossils include bryozoans, brachiopods, and coral assemblages. Formation is an age equivalent of the Manning Canyon Shale at the base and the West Canyon Limestone above in the Bingham nappe, and the Bridal Veil Falls Formation in the Timpanoghos nappe in the Wasatch Mountains (Baker and Crittenden, 1961).
Late Mississippian (Chester)		Green Ravine		232	The upper part is medium-bedded to massive (09.6 to 1 m thick, medium-gray, locally fossiliferous limestone, banded nodular black cherty limestone interbedded with thin argillaceous and fossiliferous limestone beds. The lower part is 0.3 to 0.6 m thick limestone and shale beds. Limestone is dark gray to olive gray, shale is black. Formation is fossiliferous with brachiopods, corals, and bryozoans, and is correlative with the upper part of the Great Blue Limestone in the Bingham and Timpanogos nappes in the Oquirrh and Wasatch Mountains and the lower part of the Doughnut Formation in the Mount Raymond (thin) sequence in the Wasatch Mountains.
Covered					

TABLE 6-- SUMMARY OF LITHOLOGY OF PALEOZOIC FORMATIONS IN THE SOUTH MOUNTAIN NAPPE (Tooker and Roberts, 1992)

AGE	GROUP	FORMATION	THICKNESS	LITHOLOGY AND CORRELATION
Erosion surface				
Early Permian (Wolfcamp)	Oquirrh	South Peak unit of Tooker and Roberts (1992)	1966	Predominantly calcareous quartzite, medium-bedded to massive, light buff-tan to olive-gray, weathers reddish-brown, thin surface rind, well jointed, worm trails common. Thin interbedded silica-cemented quartzite, fossiliferous medium-gray, sandy and platy limestones with fusulinids (mostly fragmental), calcareous mudstone, local bedded chert, phosphatic chert, and ferruginous sandstone that weathers yellow-brown; mostly covered slope. Age correlative with the Dry Fork unit in the Pass Canyon nappe. (Tooker and Roberts, 1988)
Late Pennsylvanian (Late Missouri or early Virgil)	Oquirrh	Salvation unit of Tooker and Roberts (1992)	823	Interbedded calcareous quartzite, orthoquartzite, and sandy, argillaceous, fossiliferous, and dense crystalline limestones. Medium-bedded quartzite predominates over thn-bedded limestone and shale partings. Fusulinids sparse in the limestones. Unit is correlative in age with the Clipper Ridge Member of the Bingham Mine Formation in the Binham nappe. (Tooker and Roberts, 1970)
Middle Pennsylvanian Desmoines	Oquirrh	Rush Lake unit of Tooker and Roberts (1992)	>1,352	Interbedded limestone, quartzite, and occasional shale beds. Limestone is medium grained, medium bedded, locally with shale partings, often sandy, silty, bioclastic, and crossbedded as well as argillacous and cherty limestone. Sandstone has pitted porous weathered crust when carbonate cemented. Local interbedded ferruginous layers with worm trails; megafossils include colonial and cup corals, brachiopods, and fusulinids. Unit is correlative in age with upper Butterfield Peaks Formation in the Bingham nappe. (Tooker and Roberts, 1970)
Covered				