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GEOLOGIC MAP OF THE NEPHI 30′ × 60′ QUADRANGLE, CARBON, EMERY, JUAB, SANPETE, UTAH, AND WASATCH COUNTIES, UTAH

By

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INTRODUCTION

The U.S. Geological Survey is engaged in a broad program of field studies designed to present the geologic framework of the United States on easily read topographic maps. The maps selected as a base for these geologic data are part of the Army Map Service (AMS) series of 1° × 2° quadrangles at a scale of 1:250,000. The Price, Utah, AMS 1:250,000-scale quadrangle is one of these maps (fig. 1). For certain areas, however, chiefly those sectors of the country involved in the U.S. Geological Survey's coal exploration program, the geologic data are being compiled on newly developed base maps at a scale of 1:100,000. On these new maps the configuration of the land is shown by contours having a 50-m contour interval. One of these new maps is the Nephi, Utah, 30' × 60' quadrangle (the northwestern quarter of the Price quadrangle), which has been used as a base for this geologic map.

PRICE 1° × 2° (1:250,000-SCALE) QUADRANGLE, UTAH

The geologic data compiled on the Nephi quadrangle are but part of a much larger geologic pattern best displayed on the Price, Utah, 1° × 2° quadrangle. The Price quadrangle contains parts of three major physiographic provinces: the Colorado Plateaus, the Basin and Range, and the Middle Rocky Mountains. Most of the quadrangle, including the central and eastern parts, underlies the western margin of the Colorado Plateaus. Within this part of the Colorado Plateaus are the southern edge of the Uinta Basin (expressed as the southward-facing, sinuous escarpments formed by the Book and Roan Cliffs), the northern part of the Canyon Lands section (expressed by the northeast-trending San Rafael Swell), and the northernmost of the High Plateaus of Utah (the Wasatch Plateau). The western part of the quadrangle includes the eastern edge of the Basin and Range province (the Great Basin). A small wedge of the Middle Rocky Mountains province—the southern Wasatch Range—dominates the northwest corner of the quadrangle.

NEPHI 30′ × 60′ (1:100,000-SCALE) QUADRANGLE, UTAH

All three previously described physiographic provinces are represented in the Nephi quadrangle, although the boundaries between them are somewhat indistinct; uncertainty exists as to where one province ends and another begins. The sector between the western edge of the Colorado Plateaus (the western flank of the Wasatch Plateau; see fig. 2) and the eastern edge of the Basin and Range province (the Wasatch fault zone) is a zone transitional between the two provinces. Two facts support this concept of a transition zone: the strata that form the Wasatch Plateau continue westward and underlie the San Pitch Mountains (also known as the Gunnison Plateau) and the Cedar Hills. And, in both the San Pitch Mountains and the Cedar Hills, these same rocks, almost undisturbed on the Wasatch Plateau, are intensely deformed locally into structures that are common in the Basin and Range province. We therefore include the San Pitch Mountains and the Cedar Hills within the Colorado Plateaus.

The Middle Rocky Mountains province is represented by the wedge-like mass of the southern Wasatch Range that towers above the rest of the western half of the quadrangle.

The area west of the Wasatch fault zone is within the Basin and Range province and includes a long, narrow, north-trending ridge formed by Long Ridge and the West Hills.

COLORADO PLATEAUS PROVINCE

Wasatch Plateau

The Wasatch Plateau, the northernmost of the High Plateaus of Utah, is a flat-topped mass about 130 km (80 mi) long that extends from Salina Creek canyon on the south to the valleys of Soldier Creek and Price River on the north (fig. 3). The plateau trends about N. 20° E., maintains a nearly constant width of about 40 km (25 mi), and its top is at an altitude of about 3,050 m (10,000 ft). It separates Sanpete Valley, on the west, from Castle Valley on the east.

The plateau is underlain by flat-lying Cretaceous and Tertiary beds, most of which are well exposed in the dissected cliffs that delineate its eastern flank. These strata flex down sharply along the western flank of the plateau to form the Wasatch monocline. Westward-flowing consequent streams on the monocline have locally cut through the tilted beds exposing them along the walls of deep, serpentine canyons that extend far back toward the crest of the plateau.

Wasatch monocline

The Wasatch monocline (fig. 3) faces westward and is well exposed along U.S. Highway 89, which follows the base of the monocline northward from near Sterling to Thistle. Limestone beds, mostly of the Flagstaff Limestone, form the impressive sloping surface of the monocline. Older units, chiefly the North Horn Formation, are exposed locally in the canyons cut into the monocline, whereas younger units, including the Colton, Green River, and Crazy Hollow Formations, form low, westward-dipping cuestas west and in front of the monoclinal slope. In places, south of the Nephi quadrangle, as near Ephraim and Manti, the lower slopes of the monocline are overlain by a chaotic jumble of beds, chiefly Colton strata, that slid westward off the tilted Flagstaff Limestone. In these same areas, huge earthflows also extend westward from the monocline onto the alluviated floor of Sanpete Valley. Comparable earthflows and landslides, but neither as large nor as extensive, are in the east fork of Sanpete Valley near Milburn and Fairview.

The top of the Wasatch Plateau and the Wasatch monocline are broken by north and northeast-trending high-angle normal faults, many of which are paired to form narrow, elongate grabens. Of these grabens, the most spectacular is Joes Valley graben, which extends into the Nephi quadrangle near Bald Mountain and Miller Flat Reservoir.

San Pitch Mountains (Gunnison Plateau)

The San Pitch Mountains form a high tableland that separates Sanpete Valley from Juab Valley. Many of the local inhabitants generally refer to these mountains as either the Gunnison Plateau or West Mountain. In the geologic literature describing this sector of central Utah these mountains are commonly referred to as the Gunnison Plateau. The name Gunnison Plateau has not been accepted as a formal name by the U.S. Geological Survey's Board on Geographic Names, and we, thus, use the accepted name San Pitch Mountains for this important tableland.

In gross aspect, the San Pitch Mountains can be viewed as two interrelated plateau segments: a northern third that is tilted southeastward at least as far south as Freedom, and the remainder of the plateau, southward, beyond Freedom, that is a south-plunging syncline. Locally, the plateau is marked by unusual structural complexities. For example, the strata, in a very narrow zone along the east flank of the plateau, commonly dip steeply westward and locally are vertical or overturned to the west. If one excludes the narrow zone of steeply tilted to overturned beds that delineates the east flank of the plateau, however, most of the other beds along the east flank dip gently westward.

Sanpete Valley

The San Pitch River flows southwestward and, near the town of Gunnison, joins the Sevier River, which flows northwestward. The valley of the San Pitch River is known as Sanpete Valley, the name probably resulting from a garbled version of "San Pitch Valley." Sanpete Valley trends about N. 10° E. from its junction with Sevier Valley, and it separates the high mass of the San Pitch Mountains on the west from the Wasatch Plateau on the east. Near Moroni, the valley bifurcates and forms two arms, both known as Sanpete Valley. For this discussion we refer to the east arm, which contains the San Pitch River, as the east fork of Sanpete Valley, and the west arm, which is essentially a dry valley, as the west fork of Sanpete Valley.

South of Moroni, Sanpete Valley is about 13 km (8 mi) wide; each fork is about 5 km (3 mi) wide.

Deposits of economic value in the valley include sand and gravel, building stone chiefly from the Green River Formation, and gypsum and salt deposits in the Arapien Shale.

MIDDLE ROCKY MOUNTAINS PROVINCE

Southern Wasatch Range

The Wasatch Range, the backbone of Utah, extends for about 240 km (150 mi) from near the Idaho border to Nephi in central Utah. In general, the range can be divided into two segments: a northern part that extends from the Idaho border southward to Spanish Fork Canyon, and a southern part that extends from Spanish Fork Canyon southwestward to Nephi (inset map A, fig. 3). It is this southern part that extends into the Nephi quadrangle and forms the southern Wasatch Range.

The southern Wasatch Range trends slightly east of north and is about 48 km (30 mi) long. The Wasatch normal fault zone truncates its west flank, which consequently appears as an imposing, straight, steep, north-trending mountain front. The eastern edge of the range is less impressive chiefly because it has been deeply eroded. Younger Cretaceous and Tertiary rocks overlie this eastern edge and appear in a dissected range of low hills—the Cedar Hills—that lie along the east flank of the range.

The southern Wasatch Range is part of the huge eastward-directed Charleston-Nebo thrust plate that extends from near Salt Lake City southward to Nephi (inset map A, fig. 3). The plate is floored by the Charleston-Nebo thrust fault, one of a series of thrust faults that reach from Montana southward to Nevada and that have brought thick basin facies over thinner shelf rocks to the east (Crittenden, 1961).

The southern Wasatch Range appears as one limb of an intensely dissected, large, overturned, almost recumbent anticline—the southern part of the Charleston-Nebo thrust plate. At the northern end of the southern Wasatch Range, near Santaquin, the Paleozoic beds are right side up and dip moderately southeastward, but southward the dips increase and near Mona the beds are vertical. Still farther south, at the southern end of the range near Nephi, the beds are overturned and dip moderately northwestward; these overturned strata are exposed in the towering mass of Mt. Nebo, northeast of Nephi. Here and there, patches of Cretaceous and Tertiary beds unconformably overlie parts of the overturned anticline.

Cedar Hills

The Cedar Hills, along the southeastern flank of the southern Wasatch Range (fig. 2), are a much dissected, thickly forested upland. Bounded on the east by the east fork of Sanpete Valley and the valley of Thistle Creek and on the southwest by the west fork of Sanpete Valley, the Cedar Hills appear as a southeast-pointing wedge that gradually diminishes in height southeastward. Consequent streams flow both to the northeast and southwest from their crest.

The Cedar Hills consist of gently folded Cretaceous and Tertiary sedimentary rocks that locally are concealed beneath a cover of Tertiary volcanic rocks. Where the sedimentary and volcanic mantle has been removed, steeply dipping and locally overturned older rocks (chiefly of Jurassic and Cretaceous age) unconformably underlie the Cretaceous-Tertiary mantle.

BASIN AND RANGE PROVINCE

Long Ridge and West Hills

A sinuous, north-trending, narrow range marked by a shallow saddle midway along its length forms the west side of Juab Valley. State Highway 132 uses the saddle as it passes from Juab Valley through Dog Valley toward Leamington. The upland north of the saddle is known as Long Ridge, and south of the saddle is known as the West Hills. In the past, both segments have been arbitrarily grouped and called Long Ridge (Muessig, 1951, p. 3).

Long Ridge, bounded on the west by both Goshen and Dog Valleys and on the east by Juab Valley, is about 32 km (20 mi) long and averages 3 km (2 mi) in width. Its crest rises gradually from about 1,750 m (5,740 ft) near its southern end to about 1,900 m (6,235 ft) near its northern end. Almost all streams are intermittent; Currant Creek, which drains Mona Reservoir, is the only perennial stream.

West of Mona Reservoir, Long Ridge is divisible into two different parts. The northern part, an irregular belt of tilted and rotated fault blocks, is cut by high-angle normal faults. The rocks are mostly of early and middle Paleozoic age with a few sparse Proterozoic and Archean rocks exposed here and there. The Paleozoic rocks are similar to units exposed along the flanks of the southern Wasatch Range. Coarse clastic sedimentary rocks of the North Horn Formation, very much like those that lap onto the dissected east flank of Mt. Nebo, unconformably overlie these Paleozoic units.

The southern part of Long Ridge consists chiefly of Oligocene volcanic rocks that unconformably overlie the Paleozoic rocks. These volcanic rocks extend to the west, where extensive deposits have been mapped by Morris (1977). The Paleozoic rocks crop out locally in this southern part of the range and reappear in the West Hills to the south; from these outcrops we infer that the sheet of broken Paleozoic rocks underlies all of Long Ridge.

The West Hills are about 24 km (15 mi) long, about 5 km (3 mi) wide, and their crest maintains a relatively even altitude of about 1,850 m (6,070 ft). Most streams are small and intermittent; only Chicken Creek, which flows westward and drains Chicken Creek Reservoir, is perennial.

The Long Ridge-West Hills topographic high decreases in altitude southward and the volcanic cover thins as well; as a result, older rocks are conspicuously exposed in the West Hills. Upper Paleozoic rocks crop out particularly in the northern West Hills. Farther south, in an east-dipping monocline, a sequence of Paleocene and Eocene beds—chiefly the Flagstaff, Colton, and Green River Formations—forms the higher parts of the range. These Tertiary beds are much like the same units exposed along the west flank of the San Pitch Mountains. Although patches of volcanic rocks and unconsolidated valley-fill sediments obscure the relations between these Tertiary strata and the underlying Paleozoic rocks, the Tertiary rocks lie unconformably on the older rocks of the Charleston-Nebo thrust plate.

In the West Hills, the Flagstaff and Green River Formations, both of lacustrine origin, contain abundant terrigenous clastic material, the same as they do on the west side of the San Pitch Mountains. From this evidence and from the absence of these beds farther to the west, we infer that the ancestral shorelines of lakes in which these strata were deposited were near the present West Hills.

STRUCTURAL GEOLOGY

THRUST FAULTS

The overturned anticline that forms the mass of the southern Wasatch Range is part of the Charleston-Nebo thrust plate, a mass of Paleozoic and Mesozoic rocks that has been moved laterally both eastward and southeastward along the well-known Charleston-Nebo thrust fault. An arc-shaped segment of the thrust fault, concave to the west, that extends from near Salt Lake City to Nephi may mark the distal edge of the thrust fault. Although the sole of the Charleston-Nebo thrust fault may crop out near Nephi, coauthor Witkind believes that, if so, it has been intensively modified by the intrusive movement of the Arapien Shale.

In our view, the exact position of the distal edge of the thrust plate—in essence, the easternmost extent of the Charleston-Nebo thrust fault—is unknown. On the east, the topographically high escarpment that marks the eastern edge of the southern Wasatch Range may be an erosional feature formed on part of the plate, or it may be the distal margin of the plate concealed beneath a cover of sedimentary and volcanic rocks that forms the Cedar Hills. On the west, overturned Paleozoic and Mesozoic strata at the northern end of the West Hills probably are a remnant of the thrust plate. On the south, the plate may extend at least as far south as Pigeon Creek, near Levan. Witkind (1983, p. 49) has interpreted a fold in Pigeon Creek, presumed to be overturned (Ritzma, 1972, p. 78), to be an erosional outlier of the thrust plate. Morris (1983, p. 77) has suggested, however, that the underlying Charleston-Nebo thrust fault may merge, near Nephi, with the Leamington transcurrent fault. Although Morris has recognized the Leamington fault to the west, we have not been able to identify it in the Nephi area.

We are uncertain about the time of emplacement of the Charleston-Nebo thrust plate. The youngest beds involved in the overturned anticline are part of the Watton Canyon Member of the Twin Creek Limestone of Middle Jurassic (Bathonian) age. Locally, these Watton Canyon beds are overlain by sandstone and conglomerate beds of the North Horn Formation of Late Cretaceous (Maestrichtian) and Paleocene age. The time of emplacement of the thrust block, then, must have been after Middle Jurassic (Bathonian) time and before Late Cretaceous (Maestrichtian) time.

Standlee (1982, p. 376, 378–379), chiefly on the basis of proprietary seismic-reflection data, has proposed that the area is underlain by both eastward- and westward-dipping faults with both thrust and normal displacements.

STRIP THRUSTS

Spieker (1949) and several of his graduate students have attributed various unusual stratigraphic relations and local structural complexities in the Sanpete-Sevier Valley area to strip thrusts. The term, coined by Billings (1933), refers to structural relations in which younger rocks seemingly have been shoved eastward over older rocks along a thrust fault that followed a pre-existing unconformity. Coauthor Witkind (1982a, p. 22–23) believes that many of these stratigraphic and structural relations are more reasonably explained as a result of salt diapirism.

NORMAL FAULTS

The Wasatch fault, the major high-angle normal fault in the area, has been described repeatedly (Marsell, 1964; Cluff and others, 1973; Swan and others, 1980), and no attempt is made to duplicate those descriptions here. In general, the fault is a range-front fault that trends north and truncates the west flanks of both the southern Wasatch Range and the San Pitch Mountains. The fault is active and is marked by evidence of repeated movement. Modern scarps offset surficial deposits, and these scarps are locally expressed as triangular facets that delineate the mountain front, indicating that the Wasatch fault has been reactivated time and time again. Swan and his colleagues (1980) estimate that the recurrence interval of moderate- to large-magnitude earthquakes along the entire Wasatch fault zone may be on the order of 50 to 430 years. By contrast, Schwartz and Coppersmith (1984, p. 5690) "consider 400–666 years to be a reasonable range for the average recurrence interval of a surface faulting earthquake along the entire Wasatch fault zone."

A system of high-angle normal faults that range in trend from N. 10° W. to about N. 30° E. breaks the crest and west flank of the entire Wasatch Plateau. Locally, these faults are paired to form grabens that are as much as 65 km (40 mi) long; most of the grabens maintain a relatively constant width of about 3 km (2 mi). This fault system extends the full length and width of the plateau, reaching from Salina Creek canyon on the south to Spanish Fork Canyon (Soldier Creek) on the north, and from Castle Valley (east of this quadrangle) on the east to Sanpete Valley on the west. Both faults and grabens are remarkably straight; commonly the faults persist as single breaks, or very narrow fault zones, traceable for very long distances. The faults that bound the grabens invariably dip inward. Structural relief differs from graben to graben. In some grabens it is as little as 100 m (several hundred feet); elsewhere it is hundreds of meters. Spieker (1949, p. 43) suggested that the structural relief on some grabens may be as great as 915 m (3,000 ft).

In many grabens the downthrown blocks are unbroken, but locally they are cut by a series of small internal faults that parallel the larger faults that bound the graben.

The origin of the faults and, thus, the grabens is uncertain. The faults may reflect widespread crustal spreading stemming from an episode of extensional tectonism that has dominated the western interior of the United States since Miocene time. If so, they are tectonic in origin. By contrast, the faults may be related to the salt that underlies much of the Sanpete-Sevier Valley area. If so, the grabens may be collapse features related to withdrawal of salt (Stokes, 1952; Stokes and Holmes, 1954, p. 40). Moulton (1975, fig. 19) implies that many of the faults that break the crest of the Wasatch Plateau do not extend below the base of the salt-bearing beds of Jurassic age. L. A. Standlee (oral commun., 1984) of Chevron, U.S.A., also has suggested, on the basis of proprietary seismic-reflection data, that those faults that bound large grabens, such as the Joes Valley graben (south of this quadrangle), do not extend below the underlying Jurassic beds. This suggests that at least some of the faults and grabens may be genetically related to withdrawal of salt.

Faults and grabens that may stem from salt dissolution are not confined to the Wasatch Plateau. The Gunnison fault, which extends along the east flank of the San Pitch Mountains, dips easterly, is downthrown to the east, and locally has cut and offset Quaternary surficial deposits. Most young normal faults in the area, however, such as those that mark the Wasatch fault zone, dip westerly and are downthrown to the west. The eastward-dipping Gunnison fault, essentially following the projected trace of the Sanpete-Sevier Valley salt diapir, would seem to be related to dissolution of part of that diapir. The Dairy Fork graben begins where the Little Clear Creek diapiric fold ends; this suggests to us that salt dissolution may be a significant factor in the development of that graben.

If some grabens are indeed salt-induced structures, possibly they formed in response to an outward (valley-ward) flowage of the salt, much as postulated by Baker (1933, p. 74) to explain the development of the grabens that are so common in the Paradox Basin of southeastern Utah and southwestern Colorado.

COMPLEXLY DEFORMED ROCKS

Except for the overturned anticline that forms the bulk of the Charleston-Nebo thrust plate, most rocks in the Nephi quadrangle are but moderately deformed. Here and there, however, are linear to sinuous belts of intensely deformed strata. In places, these strata are vertical or overturned; elsewhere, they are steeply inclined. Locally, one or more angular unconformities break the sedimentary sequence. In several places, two profound angular unconformities are exposed in a single outcrop, but surprisingly these unconformities are not extensive laterally. Strata that are separated by an angular unconformity, when traced laterally, become conformable in distances as short as three-fourths of a kilometer (half a mile). Furthermore, overturned beds become near-horizontal in unusually short distances. The intense deformation is extremely localized.

These belts of intensely deformed rocks are not confined to the Nephi quadrangle; they extend southward and are well exposed at various localities along the margins of the Sanpete and Sevier Valleys (Witkind and others, 1985). Expectably, these belts of deformed rocks have been and still are the subject of considerable controversy.

Alternative interpretations

Three interpretations have been offered to explain these complex structures: (1) multiple episodes of crustal disturbance (Spieker, 1946, 1949; Stanley and Collinson, 1979; Standlee, 1982), (2) mobilization of plastic mudstone in the Arapien Shale as a result of orogenic pulses (Gilliland, 1963), and (3) multiple episodes of salt (halite) diapirism (Stokes, 1952, 1956; Witkind, 1982a). For ease of discussion we here group Gilliland's views with Spieker's and other workers' interpretations, for it is clear from Gilliland's article that he believes, much as Spieker and the other workers do, that the deformation ultimately stems from eastward-directed orogenic pulses. Thus, two contrasting interpretations are available to explain the deformation: multiple episodes of orogeny and multiple episodes of salt diapirism. Definitive evidence in support of either hypothesis is not available, and both concepts are considered viable.

Multiple episodes of orogeny

Coauthor Weiss favors the interpretation involving multiple episodes of orogeny. He believes that salt diapirism played some role in the structural deformation of central Utah, but he is uncertain how large that role was. Weiss believes the question is moot on the basis of evidence from surface geology, and that multiple episodes of tectonism cannot be fully discredited until diapirism can be demonstrated by subsurface data. He attributes the intense deformation that marks the east flank of the San Pitch Mountains to an antiformal welt that lay just east of the San Pitch Mountains in latest Cretaceous and Paleocene time and that subsequently bent the end of the mountain block toward the west (Weiss, 1982). This welt may have been caused by compression from the east, diapirism, or both.

Multiple episodes of salt diapirism

By contrast, coauthor Witkind strongly favors an interpretation involving multiple episodes of salt diapirism, which he believes shaped this sector of central Utah. In his view, almost every complex structure is related, in whole or in part, to one or more salt-generated features.

In light of this scientific conflict between us, we have agreed to disagree. Consequently, the interpretations in the following section entitled "Diapiric concept" are those of Witkind. Coauthor Weiss agrees with some of the interpretations offered but not necessarily all.

DIAPIRIC CONCEPT

by

Irving J. Witkind

Stokes (1952, 1956) first advanced the possibility that salt-generated structures might be responsible for most of the intense deformation in the Sanpete-Sevier Valley area of central Utah. Although subsequent workers also considered salt diapirism as one possible explanation for the deformation, they rejected it chiefly because they believed that insufficient salt underlay the area for it to have played an important role (Gilliland, 1963, p. 122–123; Standlee, 1982, p. 380). Indeed, only a small amount of salt is exposed, chiefly near Redmond, where the salt is mined from intensely deformed, near-vertical beds (Picard, 1980, p. 145). The mine exploits salt-bearing beds about 60 m (200 ft) thick, and the total thickness of all salt beds in the Redmond area ranges from 180 to 300 m (600–1,000 ft) (Pratt and others, 1966, p. 54). Seismic surveys conducted during the past two decades suggest that much mudstone and interbedded salt does underlie the Sanpete-Sevier Valley area. More significantly, the Phillips Price-N well (SE¼ SE¼, sec. 29, T. 15 S., R. 3 E.), in Sanpete Valley southwest of Moroni, penetrated a bed of salt and subordinate intermixed calcareous mudstone 610 m (2,000 ft) thick. In the West Hills, west of Juab Valley, Placid Oil Company's Howard 1-A well (NE¼ NW¼, sec. 5, T. 14 S., R. 1 W.) cut about 170 m (550 ft) of salt. And Chevron's Chriss Canyon No. 1 well (NE¼ SW¼, sec. 33, T. 16 N., R. 1 E.), near the center of the San Pitch Mountains, drilled through about 245 m (800 ft) of salt (Standlee, 1982, p 362). Little or no salt has been found in several other wells drilled in the region although almost all the wells penetrated mudstones of the Arapien Shale. I believe the absence of salt from those wells does not necessarily mean nondeposition, but rather migration toward diapirs. I concur with Sannemann's views (1968) that once salt diapirs begin to form, the bedded salt migrates laterally toward the rising diapirs.

I have proposed elsewhere (Witkind, 1981, 1982a, 1982b, 1983, 1987; Witkind and Page, 1984) that the structural complexity that marks this sector of central Utah is directly attributable to the repeated growth and collapse of salt diapirs. The causative rock salt is contained within the Arapien Shale of Middle Jurassic age. Since Middle Jurassic time the salt has welled upward slowly, producing paleostructural and paleotopographic highs against which younger sedimentary units thin and locally pinch out. This slow upwelling has been interrupted sporadically and repeatedly by sudden upward surges of the salt. These surges have forced up the enveloping Arapien mudstones, and these, in turn, have pushed up, and in places cut across, the overlying younger consolidated strata to form elongate, linear, diapiric folds that are fan-shaped in cross section (fig. 4). These upward surges of salt have occurred at least three times: once during the Late Cretaceous, again during the early Paleocene, and a third time during either the late Oligocene or Miocene. Because of this repeated, sporadic movement, I view the Arapien Shale as an intrusive unit that has a Middle Jurassic depositional age but that has several emplacement ages. To show this difference between depositional and emplacement ages, I use map symbols such as T(Ja) or K(Ja). The T (Tertiary) and K (Cretaceous) refer to the different emplacement ages of the Arapien Shale (Ja). Removal of the salt by extrusion, dissolution, or lateral flowage has resulted in the partial destruction of the diapiric folds, either by collapse along faults or by general subsidence. As a result of this episodic diapirism, younger diapiric folds occupy much the same structural zones as the older diapiric folds.

The diapiric folds are expressed at the surface either by elongate belts of exposed calcareous mudstone of the Arapien Shale or by tilted (locally vertical or overturned) beds of country rock or by both. The calcareous mudstone outcrops represent the cores of the diapiric folds, and the upturned beds represent the eroded limbs.

In most localities, only one limb of a diapiric fold is exposed. The other limb seemingly has been eroded and now either is concealed beneath alluvium or has been destroyed. For example, the vertical to overturned beds along the east flank of the San Pitch Mountains represent the west limb of the north-trending Sanpete-Sevier Valley diapiric fold (fig. 3, no. 1), which in this area abuts the east flank of the mountains.

MAJOR DIAPIRIC FOLDS

I recognize twelve diapiric folds in the Sanpete-Sevier Valley area (fig. 3), and I suspect that other comparable folds are still to be found. Of these twelve folds, nine extend into the Nephi quadrangle and only these are described below.

Levan diapiric fold (fig. 3, no. 3)

Widespread exposures of the Arapien Shale extend along the western flank and around the northern end of the San Pitch Mountains. Along the western flank, the younger, consolidated sedimentary strata, adjacent to these Arapien Shale exposures, dip outward on both sides. Consequently, I interpret these Arapien exposures to be part of the core of the major Levan diapiric fold (Witkind, 1982a, p. 21). The core trends about N. 15° E. for some 40 km (25 mi) from Little Salt Creek (south of this quadrangle) on the south to Salt Creek on the north. At Salt Creek the fold divides to form three branches. The western fold—for which I retain the name "Levan fold"—extends northward beyond Salt Creek and passes below and deforms the upper plate of the Charleston-Nebo thrust (Witkind, 1983, p. 51–54).

The Arapien exposures along the west flank of the San Pitch Mountains (the diapiric core of the Levan fold) are collinear with similar exposures that form the core of the Redmond diapiric fold (fig. 3, no. 2) south of this quadrangle, and the possibility exists that the two separate folds are actually one long fold.

Pole Creek diapiric fold (fig. 3, no. 12)

The Pole Creek diapiric fold extends from Salt Creek, where the Levan fold trifurcates, to its disappearance beneath younger volcanic rocks some 11 km (7 mi) to the northeast. The fold deforms both the northern end of the San Pitch Mountains as well as rocks that lap onto the erosional eastern margin of the Charleston-Nebo thrust plate.

The attitude of the consolidated sedimentary rocks, which flank the diapiric core of the Pole Creek fold, stem from the intrusive nature of the fold. Thus, the north end of the San Pitch Mountains is tilted southeastward where it forms or is part of the southeastern flank of the fold. I believe that the northwestward tilt of most of the Charleston-Nebo thrust plate, near Nephi, reflects the northwestern flank of the Pole Creek fold.

About 8 km (5 mi) east of Nephi, where the Mt. Nebo scenic loop road joins State Highway 132, the diapiric core of the fold, trending northeast and expressed as outcrops of amorphous reddish-brown Arapien mudstone, is clearly exposed between tilted layers of volcaniclastic rocks. Those volcaniclastic rocks that overlie the northwestern flank of the core dip northwestward; those that overlie the southeastern flank dip southeastward. From this point, the Pole Creek fold trends about N. 40° E.; its core and southeast flank are well exposed in the Middle Fork of Pole Creek (cross section *A–A '*). The sedimentary strata, chiefly units of the Twist Gulch Formation (Jtg), are vertical adjacent to the diapiric core, but lessen in dip away from the core.

The fold has determined the structural pattern of the Cedar Hills. West of the Middle Fork Pole Creek, all strata, volcanic as well as sedimentary, dip northwestward toward the Charleston-Nebo thrust plate. East of the creek, all strata dip steeply southeastward; in a few places, these beds are overturned to the southeast and dip steeply to the northwest. These steeply dipping to vertical strata, all part of the Indianola Group, are well exposed along Hop Creek Ridge and in Hop Creek.

Seemingly, the Pole Creek fold continues northeastward, concealed beneath the volcanic mantle, and eventually reappears east of Thistle, in Dry Hollow, to form the Dry Hollow diapiric fold (fig. 3, no. 10).

Dry Hollow diapiric fold (fig. 3, no. 10)

East of Thistle, vertical to overturned beds of the Indianola Group, which strike about N. 40° E., are exposed in a deep canyon known as Dry Hollow (cross section *B–B '*). The canyon, tributary to northwest-flowing Lake Fork, trends northeastward, its course probably determined by the strike of the steeply dipping Indianola beds. These vertical to near-vertical strata are overlain with striking angular unconformity by gently dipping beds of reddish-brown conglomerate, sandstone, and mudstone of the North Horn Formation. These North Horn strata have been arched, apparently as a result of the upward movement of the underlying fold. Thus, North Horn beds that overlie the northwest flank of the fold dip about 25° northwestward; those North Horn beds that overlie the southeast flank dip about 10° southeastward.

Only part of the diapiric fold is exposed in Dry Hollow. On the basis of limited exposures, the fold trends about N. 40° E. for some 6 km (4 mi), from the head of Dry Hollow across Lake Fork and Soldier Creek to the north wall of Spanish Fork Canyon where the fold passes below North Horn beds. The fold probably continues southwestward, concealed beneath the volcanic mantle, and connects with the Pole Creek fold (fig. 3, no. 12).

Thistle Creek diapiric(?) fold (fig. 3, no. 11)

In the Thistle area, a diapiric fold is suggested only by arched Cretaceous and Tertiary strata that unconformably overlie rocks of the Charleston-Nebo thrust plate (cross section *B–B '*). Here, Cretaceous and Tertiary strata have been eroded to expose the underlying thrust plate, which appears as an imposing ridge of steeply tilted beds of Navajo Sandstone overlain chiefly by gray, thin beds of the Twin Creek Limestone. All beds are right side up and dip about 60° to the east; they are particularly well exposed where the newly constructed U.S. Highway 6 cuts through the ridge. The younger Cretaceous and Tertiary units partly mantle this outcrop of the thrust plate; along both its east and west flanks the thrust plate is overlain by beds of the North Horn Formation, which in turn are overlain by beds of the Flagstaff Limestone. East of the ridge, the North Horn-Flagstaff sequence dips gently eastward; west of the ridge, this sequence, in addition to the younger units, dips gently westward.

I suggest that the thrust plate was buried beneath nearly horizontal North Horn and younger strata. As a diapiric fold developed beneath the thrust plate it raised the plate and arched the overlying younger rocks. Erosion has since removed the crestal part of the arched sheet of North Horn and younger rocks and exposed the Navajo and Twin Creek beds of the underlying thrust plate.

The Arapien Shale, the intrusive unit believed responsible for the upwarp of the thrust plate, crops out in this area along Thistle Creek and near Thistle along Soldier Creek, where it both deforms Tertiary strata and intrudes Twin Creek units.

Hjorth Canyon diapiric fold (fig. 3, no. 9)

Part of a northeast-trending diapiric fold is exposed in Hjorth Canyon about 5 km (3 mi) north of Indianola. This fold was first recognized and called the Hjork Creek dome by Runyon (1977, p. 76). Exposures along the north wall of Hjorth Canyon consist of a diapiric core of Arapien Shale that trends about N. 40° E., bounded on each flank by beds of the Twist Gulch Formation (Jtg). Exposures are poor but I suspect that beds of the Cedar Mountain Formation are stratigraphically above the Twist Gulch beds; these Cedar Mountain(?) beds are mapped with Twist Gulch strata. All units are unusually thin. Twist Gulch beds that form the northwest flank of the fold strike about N. 40° E., are overturned to the northwest, and dip about 85° southeast. Twist Gulch beds that form the southeast flank of the fold are right side up and dip southeasterly between 35° and 85°. The outermost flanks of the fold are formed by units of the Indianola Group that dip about 20° northwesterly along the northwest flank and about 85° southeasterly along the southeast flank. All beds that form the fold are locally unconformably overlain either by moderately dipping strata of the North Horn Formation or by volcanic units of the Moroni Formation. As in the Dry Hollow fold, these younger beds appear to have been arched by an upward movement of the underlying fold. Thus, those North Horn beds that overlie the northwest flank of the fold dip westerly at about 10°; those North Horn beds that overlie the southeast flank dip southeasterly 30° to 50°. These southeast dips persist southeastward for about 1.6 km (1 mi) at which point the North Horn beds pass beneath volcanic beds of the Moroni Formation. Attitudes of Moroni beds are difficult to determine; southeast of the exposures described above, however, near Little Clear Creek, Moroni beds dip northwest. This northwest dip of the Moroni strata reflects the northwestern flank of the Little Clear Creek diapiric fold (fig. 3, no. 8), which also trends northeast and is parallel to and about 3 km (2 mi) southeast of the Hjorth Canyon fold.

Little Clear Creek diapiric fold (fig. 3, no. 8)

Little Clear Creek has cut a deep, narrow canyon into the crest of a major diapiric fold that trends about N. 40° E. Twist Gulch strata (Jtg) form the crest of the fold, and these beds dip steeply away from the crest for much of the exposed length of the fold (cross section *B–B'*). Thus, Twist Gulch beds on the northwestern flank dip about 85° northwest; comparable dips to the southeast mark the southeastern flank of the fold. Only a narrow part of the fold's northwestern flank is exposed along Little Clear Creek; much of that flank unconformably underlies beds of either the North Horn or Moroni Formations that dip northwesterly at moderate dips. By contrast, the southeastern flank of the fold is well exposed and includes units of the Cedar Mountain Formation and the Indianola Group. All these strata dip at high angles, commonly to the southeast, but locally some beds are vertical or are overturned to the southeast and so dip northwesterly. These steeply inclined units are unconformably overlain by a sequence of Price River-North Horn beds that dips southeast at about 35°.

The arched strata that either overlie or flank the axial part of this fold duplicate arched strata near the Thistle Creek, Dry Hollow, and Hjorth Canyon diapiric folds. I interpret these arched strata near all these folds to mean that formerly near horizontal strata were bowed up as a result of the upward movement of the underlying diapirs. Because volcanic rocks of the Moroni Formation, dated as young as Oligocene (Witkind and Marvin, 1989), are involved in the arching, the implication is strong that the diapiric folds were raised at some time during or after Oligocene time. If so, it seems unreasonable to attribute the uplift of the folds to eastward-directed thrusting stemming from the Sevier orogeny (Standlee, 1982), which apparently ended in Paleocene time.

Near Smiths Reservoir (where Side Canyon joins Lake Fork), the fold passes northeastward into a northeast-trending graben, the Dairy Fork graben of Merrill (1972, p. 79), that is collinear with the fold. The graben probably represents collapse of the axial part of the Little Clear Creek fold as a result of salt dissolution (cross section *B–C'*).

Fairview diapiric(?) fold (fig. 3, no. 7)

I propose that a major diapiric fold underlies the northern end of the east fork of Sanpete Valley, in essence, that part of the valley that extends from near Ephraim northeastward past Mount Pleasant and Fairview to near Milburn. I call this fold the Fairview diapiric(?) fold; the northern part of the fold has been referred to as the "North San Pitch River Valley diapir" by Runyon (1977, p. 76).

Whereas I recognize most diapiric folds in central Utah either by linear belts of Arapien Shale (the cores of the diapiric folds) or by steeply dipping to overturned consolidated sedimentary strata (the flanks of the diapiric folds), neither of these features mark the Fairview diapiric(?) fold. Instead its presence is suggested by downwarped strata that form the Wasatch monocline.

Elsewhere in this sector of the Colorado Plateaus, late Tertiary and Quaternary block faulting has played a dominant role in determining the structural framework of the plateaus and ranges. It seems reasonable to conclude that the Wasatch Plateau was also shaped and influenced to some extent by block faulting. Although many of the ranges and plateaus in central and southern Utah are bordered on one or more flanks by high-angle normal faults, the Wasatch Plateau, by contrast, is bounded on its west flank by the Wasatch monocline rather than by a distinctive fault zone, suggesting that rocks in the west flank of the Wasatch Plateau, at least at present levels of exposure, failed by flexure rather than by faulting. Seemingly, the linearity and northeast trend of the monocline reflect movement along a causative fault. Although some of the 1,100 m (3,600 ft) of relief between the plateau crest and the floor of Sanpete Valley must be the result of warping as a result of movement on this fault, I believe that some offset was due to subsidence as a result of gradual salt withdrawal.

Presumably, movement along this fault opened a conduit for the confined and compressed salt, which in its upward rise forced up the overlying calcareous mudstone and effectively obliterated the fault plane. The end result was a diapir whose length and trend reflected, to some extent, the length and trend of the fault. Elsewhere, my colleague W. R. Page and I have proposed (Witkind and Page, 1984) that some of the warpage that marks the Wasatch monocline is the result of subsidence stemming from the progressive dissolution of salt from that diapir. Removal of the salt caused the overlying strata to subside slowly into the developing void and thus steepen the monocline.

The Wasatch monocline extends northeastward from Salina Creek canyon to its end near Indianola. Near Indianola, however, the downwarped strata are flexed up and become part of the east flank of the Little Clear Creek diapiric fold. Between the north end of the Fairview diapiric(?) fold and the south end of the Little Clear Creek fold, the intervening strata are warped to form a south-plunging syncline best exposed along the south flank of Black Hawk, some 3 km (2 mi) east of Indianola.

Sanpete-Sevier Valley diapiric fold (fig. 3, no. 1)

Only the northern end of the Sanpete-Sevier Valley diapiric fold, one of the dominant folds in central Utah, extends into the Nephi quadrangle. The fold extends about 125 km (75 mi) from near Richfield on the south to Freedom on the north. The core of the fold, expressed as a continuous belt of Arapien mudstone, extends from near Richfield to near Manti where it disappears beneath the alluvial floor of Sanpete Valley. Oil test wells in Sanpete Valley indicate that Arapien mudstone underlies the surficial valley fill. The vertical to overturned beds in the east flank of the San Pitch Mountains are remnants of the Sanpete-Sevier Valley diapiric fold's eroded west flank and indicate that in this sector, at least, the fold abuts the east edge of the San Pitch Mountains.

Just as the structural pattern of the Cedar Hills has been determined by the Pole Creek diapiric fold, so also has the configuration of the San Pitch Mountains been determined by three other diapiric folds. The rocks that underlie the north end of the San Pitch Mountains dip southeasterly, reflecting the southeastern flank of the Pole Creek fold. This southeasterly dip ends near Freedom; from that point southward the San Pitch Mountains appears as a south-plunging syncline. The synclinal aspects of the mountains stem from the intrusive action of two flanking diapiric folds: upward movement of the Levan diapiric fold (west of the mountains) warped up the west flank of the plateau; upward movement of the Sanpete-Sevier Valley diapiric fold (east of the mountains) warped up the east flank. The plunging aspect of the syncline is due to the upward movement of the Pole Creek diapiric fold (north of the mountains), which warped up the north end of the mountains.

West Hills diapiric(?) fold (fig. 3, no. 5)

West Hills, along the west side of Juab Valley, is an elongate upwarp, about 24 km (15 mi) long, that trends about N. 10° E. On the south, the fold extends from the gap formed by Chicken Creek as it cuts through the West Hills (south of this quadrangle) to State Highway 132 on the north. At that point the fold passes beneath part of a thrust plate that likely is an erosional remnant of the Charleston-Nebo thrust plate. Although the Arapien Shale is nowhere exposed in the West Hills, recent drilling by Placid Oil Company (Howard Well No. 1, NW¼ NW¼, sec. 5, T. 14 S., R. 1 W.) penetrated salt at depth (about 1,120 m (5,646 ft); D.A. Sprinkel, Placid Oil Co., oral commun., 1980). Thus, I suspect that the anticlinal configuration of the West Hills is the surface expression of still another large diapiric fold.

SURFACE-WATER RESOURCES

Details about the surface-water resources of the Nephi quadrangle are contained in a companion publication, U.S. Geological Survey Miscellaneous Investigations Series Map I–1512 (Price, 1984).

ECONOMIC DEPOSITS

Materials of economic interest in and near the Nephi quadrangle include gypsum and salt (in the Arapien Shale), sand and gravel (chiefly in alluvial-fan deposits), and building stone (chiefly from the Green River and Flagstaff Formations). In the past, small mines along the west flank of the southern Wasatch Range produced lead, zinc, and silver. At no time were the amounts of ore minerals mined large enough to recoup costs of exploration. Large deposits of bituminous coal underlie the Wasatch Plateau; some of it is being mined through underground workings near Scofield and Clear Creek. Most of the coal, however, is deeply buried. A few thin coal beds crop out locally throughout the Sanpete-Sevier Valley, but these are thin and discontinuous and of no significant economic interest. In general, the search for oil and gas has been unsuccessful, although a few hydrocarbon and carbon dioxide gas pools are within the confines of the Wasatch Plateau. Some small deposits of asphalt-impregnated strata, oil shale, and ozocerite are also in the area.

NONMETALLIC MINERAL DEPOSITS

Gypsum

Extensive gypsum deposits are in the Arapien Shale. Most known commercial deposits, however, are concentrated some 65 km (40 mi) south of the Nephi quadrangle between Salina and Sigurd (fig. 3). In the Nephi quadrangle, small deposits of commercial gypsum are in Salt Creek (east of Nephi) and in both Pigeon and Chicken Creeks (east of Levan). Most mined gypsum is transported by truck to cement plants either near Leamington (west of the Nephi quadrangle) or near Salt Lake City. Some gypsum, however, is trucked to several gypsum plants at Sigurd where it is fabricated into plaster board.

The Arapien Shale crops out in five places within the Nephi quadrangle: (1) the west flank of the San Pitch Mountains, (2) Salt Creek (the north end of the San Pitch Mountains), (3) Pole Creek, (4) Hjorth Canyon, and (5) the Thistle Creek-Spanish Fork Canyon area. Despite this paucity of Arapien exposures, we believe that much of the western half of the Nephi quadrangle is underlain by the Arapien.

The extensive exposures of the Arapien along the west and north flanks of the San Pitch Mountains, part of the diapiric cores of the Levan and Pole Creek folds, are the only exposures within this quadrangle that contain commercial deposits of gypsum. Most of these deposits appear as disconnected pods and sheets. In both Pigeon and Chicken Creeks, the gypsum pods and lenses appear to have been intruded into the thinly bedded Twin Creek Limestone. Only a few of these intrusive knots of gypsum are in Pigeon Creek; by contrast, many are in Chicken Creek, and these have been mined extensively in the past.

Most outcrops of the Arapien Shale contain minor amounts of gypsum, chiefly as small knots and lenses. The gypsum is light gray to white, and commonly weathers as grayish, granular knots that stand out above the surface of the surrounding mudstones of the Arapien Shale. These small, scattered occurrences may be misleading, because extreme irregularity of thickness, width, and length are characteristic of many gypsum deposits. What may appear as a thin pod of gypsum on the outcrop may thicken and widen rapidly in the subsurface to become a significant deposit. In general, we estimate that the range in thickness of gypsum lenses is from about 15 m to as much as 105 m (50 to 350 ft). The width and length are also highly irregular; we estimate that some lenses are as much as 305 m (1,000 ft) wide, and about 210 m (700 ft) long.

Salt

Only a small amount of rock salt (halite) is exposed at the surface, although drill data indicate that much salt probably underlies the Sanpete-Sevier Valley area. It seems likely that much salt has been removed from the area. The names applied by early settlers to many of the geographic features bespeak the presence of salt, for example Salt Creek, Little Salt Creek, Salt Spring Creek, and Salina.

The salt contained within the Arapien Shale is mined from near-surface deposits near Redmond (about 80 km (50 mi) south of Nephi), where the salt appears as near-vertical, much-contorted beds interleaved with reddish-brown calcareous mudstone. The salt, commonly reddish brown as a result of a thin film of red clay, is used chiefly for livestock and on highways during winter months.

In the Nephi quadrangle, salt was once mined through underground workings from a salt bed in the Arapien Shale exposed in Salt Spring Creek, a tributary to Salt Creek. The mined salt was then transported some 5 km (3 mi) southward to a small processing plant near the junction of the Mt. Nebo scenic loop road with State Highway 132. The underground mine is now, abandoned, the adits closed, and only remnants of the former plant remain at the KOA campground, some 8 km (5 mi) east of Nephi.

The salt is extremely mobile and plastic. Chevron Oil Company was forced to abandon their Chriss Canyon well before reaching potential reservoir rocks because the mobile salt repeatedly crushed the casing of the well (L.A. Standlee, Chevron Oil Co., oral commun., 1982).

Sand and gravel

Vast amounts of sand and gravel are exposed in the Nephi quadrangle, chiefly along the base of the southern Wasatch Range and the Wasatch Plateau and San Pitch Mountains. Most of the material was deposited as broad, low alluvial fans that coalesced to form extensive aprons.

These large alluvial fans partly fill broad valleys. Gravel pits have been opened in the various deposits; most of the sand and gravel that is produced is used extensively for both highway and building construction.

The deposits are crudely sorted and commonly contain cobbles, boulders, and many impurities, chiefly shale or mudstone fragments; consequently much of the material must be crushed, sized, and purified before it is suitable for use. In places, discontinuous lenses of silt interleaved in the sand and gravel deposits detract somewhat from the quality of the deposit. Details on the sand and gravel deposits throughout much of the Nephi quadrangle are available from the Materials and Research Division of the Utah Transportation Department.

Building stone

Although several formations within the quadrangle contain sedimentary units suitable for use as building stone, the lithologic unit most favored by the local inhabitants is the light-tan to ivory, locally oolitic limestone contained within the upper limestone unit of the Green River Formation. The limestone is an excellent dimension stone because it has a pleasing color, is easily quarried and worked, and is generally free of closely spaced fractures. Many of the older homes and storage houses in the area, built by the early pioneers, are constructed of this attractive limestone. The rock has also been used for monuments, curbstones, and flagstones because it stands up well in the dry climate of central Utah.

Other lithologic units that have been used locally as building stone include sandstone from the Crazy Hollow Formation and welded tuff from the Moroni Formation. These units are either not as pleasing or not as durable as the stone from the Green River Formation.

Near Birdseye, in the Thistle area, beds of the Flagstaff Limestone that are unusually rich in oncolites (small, rounded concretions) have been quarried for building stone. The stone, known locally as the "Birdseye marble," is a light-gray to light-tan, attractive rock commonly used as facings for fireplaces and other interior trim. The abandoned Birdseye Quarry is atop a high ridge in the NE¼, sec. 30, T. 10 S., R. 4 E., about 2.5 km (1.5 mi) east of Birdseye.

MINERAL FUELS

Coal

Of the six coal fields in and near the Price 1°×2° quadrangle (the Wasatch Plateau, Book Cliffs, Salina Canyon, Mount Pleasant, Wales, and Sterling fields), all but the Book Cliffs and Salina fields can be traced into the Nephi quadrangle. Of those fields, or parts of those fields within the quadrangle, only the Wasatch Plateau field contains large deposits of coal that are economically significant at present, but many of these deposits, although large, are deeply buried (Spieker, 1931; Doelling, 1972a, 1972b).

Seams and beds of bituminous coal crop out west of the Wasatch Plateau, in the Wales, Mount Pleasant, and Sterling fields of the Sanpete Valley, but most of these beds are thin, discontinuous, and of poor quality. These beds were mined, however, until the thicker, higher quality, and more continuous beds that are exposed along the east edge of the Wasatch Plateau were discovered.

Data from test holes drilled by the U.S. Bureau of Mines indicate that at least three minable coal beds, ranging from 1 to 2 m (4 to 6 ft) in thickness, are in the subsurface in the Mount Pleasant area at depths between 290 m (955 ft) and 350 m (1150 ft) (Doelling, 1972b, p. 30).

Coal in the Nephi quadrangle is contained chiefly within four units of Tertiary and Cretaceous age: the North Horn and Blackhawk Formations, the Sixmile Canyon Formation of the Indianola Group, and the Ferron Sandstone Member of the Mancos Shale. Of these, only the Blackhawk contains thick (as much as 8 m (25 ft)) coal beds that are either exposed or are buried beneath an overburden of 305 m (1,000 ft) or less.

Within the North Horn Formation, a thin bed of dark-gray to brownish-gray lignite crops out in secs. 7 and 8, T. 13 S., R. 5 E. in Dry Creek Canyon, east of Milburn (Pratt and Callaghan, 1970, p. 59). The lignite was formerly mixed with turkey feathers and used as a soil conditioner.

Principal coal reserves in the combined Salina Canyon, Mount Pleasant, Wales, and Sterling fields are about 350 million short tons (Doelling, 1972a, p. 88). Yet the reserves in the Wasatch Plateau coal field probably are greater than this, and the presence of rich coal beds that crop out either along the east flank of the Wasatch Plateau, or underlie the plateau, has led to tentative plans for the construction of a series of coal-fired power plants in and near the Price quadrangle. Five power plants are planned for areas east of the Wasatch Plateau, and three for areas west of the plateau (Witkind, 1979). The Intermountain Power Plant, now under construction near Lynndyl (about 50 km (30 mi) west of the San Pitch Mountains), is one of these; when completed, it will be the largest coal-fired power plant in the world. Details about the coal in and near the Nephi quadrangle are given by Doelling (1972a, 1972b; Pratt and Callaghan, 1970; and Averitt, 1964).

OIL AND GAS

In the past decade, central Utah has been the scene of an intensive search for oil and gas. Seismic surveys have crisscrossed the area repeatedly; new surveys are launched even as previous ones end. Many wells have been drilled to test geologic concepts, favorable structures, and sedimentary units. As of late 1984, the search in the Sanpete-Sevier Valley area, on the whole, has been unsuccessful. Most test wells were either dry or had only small shows of oil or gas. Only those wells drilled on the crest of the Wasatch Plateau have had some success, chiefly in the discovery of sizable amounts of hydrocarbon and carbon dioxide gases. Although some petroleum companies have lost interest in the area and have shifted their attention elsewhere, other companies are undeterred and apparently believe that the area has a strong potential for oil and gas.

Source rocks

Possible source rocks for oil and gas include the Mancos Shale of Late Cretaceous age, the Manning Canyon Shale of Late Mississippian and Early Pennsylvanian age, and the Arapien Shale of Middle Jurassic age.

Three exploratory wells drilled near Moroni in Sanpete Valley penetrated the entire thickness of the Mancos Shale, which is composed chiefly of black, marine, sedimentary rocks. The easternmost test well, Hanson Oil Corporation's well No. 1 A–X Moroni (SE¼ NW¼, sec. 14, T. 15 S., R. 3 E.) cut about 2,135 m (7,000 ft) of Mancos strata. About 2.4 km (1.5 mi) to the southwest, the Tennessee Gas Transmission Company's J. W. Irons well No. 1 (center of SE¼ NE¼, sec. 16, T. 15 S., R. 3 E.) penetrated about 1,700 m (3,500 ft) of Mancos. And the westernmost well, the Phillips Petroleum Company's well No. 1 Price-N (SE¼ SE¼, sec. 29, T. 15 S., R. 3 E.) cut only about 610 m (2,000 ft) of Mancos Shale. Seemingly, the Mancos Shale thins markedly westward, implying a shoaling of the Mancos sea near the east edge of the San Pitch Mountains. How much of the Nephi quadrangle is underlain by the Mancos is uncertain; we suspect that it underlies most of the Wasatch Plateau and Sanpete Valley at the very least (cross section *A–A'*).

The Manning Canyon Shale is another black, marine sedimentary unit that may underlie the area at depth. This shale, like the Mancos, is rich in an oil-generative type of organic material, and so it is a most suitable source rock. The Manning Canyon is a conspicuous unit in the Charleston-Nebo thrust plate that forms the Mt. Nebo massif.

The Arapien Shale may be a source rock. Recently Kirkland and Evans (1981) suggested that calcareous mudstone deposited in highly saline, marine evaporitic basins may be rich source rocks. Considerable uncertainty exists, however, about the suitability of the Arapien Shale as a source rock for oil and gas because of its apparent low content of total organic carbon (R. J. Coskey, Forest Oil Company, oral commun., 1982).

Reservoir rocks

We believe that potential reservoir rocks are within the Mancos Shale, chiefly the Ferron Sandstone Member and sandstone units in the Emery Sandstone Member. Among the other beds in the stratigraphic section that have served as reservoir rocks for either hydrocarbon or carbon dioxide gas are the Dakota Sandstone, the Navajo Sandstone, the Sinbad Limestone Member of the Moenkopi Formation, and the "Coconino Sandstone" (probably the Cedar Mesa Sandstone of the Cutler Formation). Significantly, these beds have served as good reservoir rocks mainly because they are strongly fractured and apparently not because of high primary porosity. How severely a unit has been fractured may determine its suitability as a reservoir rock.

Structural traps

Much of the drilling in the Sanpete-Sevier Valley area has tested thrust-related structures in an attempt to determine whether the Wyoming overthrust belt extends into this sector of central Utah. Seemingly, geophysical products, such as seismic-reflection profiles, have guided the search for oil and gas and determined the location of most test wells. Other structures, for example the anticline east of Levan, are clearly discernible on the surface and may be related to the Charleston-Nebo thrust plate. The Phillips Price-N, Hanson, and J.W. Irons wells, south of Moroni and east of the San Pitch Mountains, appear to have been drilled because they are on the flank of a major structure. Much the same seems to be true of Exxon's Mount Baldy well that was drilled west of Indianola. Of the many smaller folds that have been tested in recent years, most, in the opinion of the petroleum geologists involved, are related in one way or another to thrust faults that are not exposed at the surface.

If the diapiric concept as proposed above (see also Witkind, 1982a) is valid, structural traps may be adjacent either to the salt diapirs or to the mudstone sheaths of Arapien Shale strata that are integral parts of the diapiric folds. As the salt surged upward it raised the enveloping mudstone of the Arapien Shale, and it, in turn, bowed up the adjacent country rocks. The traps formed between the upturned country rocks and either the intrusive salt or the mudstone would seem suitable sites for the accumulation of oil and gas.

OIL-IMPREGNATED (BITUMINOUS) STRATA

Three oil-impregnated outcrops (tar sands) near Thistle have been described by Peterson and Ritzma (1972, p. 93–95). These oil-impregnated rocks have been used, much like asphalt, as a paving compound for roads. One exposure, in the SW¼, sec. 3, T. 10 S. R. 4 E., known as the Asphaltum Quarry, is about 3 km (2 mi) southeast of Thistle. A second, along the south flank of Billies Mountain in secs. 26, 27, and 28, T. 9 S., R. 4 E., is about 3 km (2 mi) northeast of Thistle, and a third, southeast of Coal Hollow, is in the center of sec. 28, T. 10 S., R. 5 E. (unsurveyed), about 13 km (8 mi) southeast of Thistle. The first two exposures are in either the Flagstaff Limestone or in a vague zone that includes some Flagstaff limestone beds and some of the overlying Colton Formation beds. The third exposure is in the Green River Formation. All three exposures have been either mined or prospected. The Asphaltum Quarry, southeast of Thistle, although extensively worked in the past, seems most likely to contain oil-impregnated rock that may be of economic interest.

In general, the lithologic units most intensively saturated with oil are medium- to coarse-grained sandstone beds, although some limestone beds are also impregnated (Pinnell, 1972, p. 120). The oil is thick and viscous and is perhaps best described as asphalt-like. Seemingly, the intensity of the oil saturation determines the appearance of the oil-impregnated rocks. Those rocks that are strongly saturated are dark gray to black; those less so are light gray to gray. The oil-impregnated material generally forms an ill-defined zone, about 6 to 9 m (10 to 20 ft) thick, that is traceable laterally for hundreds of meters.

OZOCERITE

Ozocerite is a brown to black, paraffin-like, mineral wax that is used in insulation and polishes. After conversion to ceresine, a white wax resulting from the bleaching of ozocerite, and added as an extender to bees wax, it has been used as a waterproof sealant. One of the larger ozocerite zones in the United States is in the Soldier Summit area. The zone, about 19 km (12 mi) long and some 2 to 6 km (1 to 4 mi) wide (Robinson, 1917, p. 76–77), extends from near Colton on the east to near Tucker on the west (parts of Tps. 10 and 11 S., Rs. 7 and 8 E.). One deposit in this zone, about 1 km (0.5 mi) east of Soldier Summit, has been mined intermittently over the years. The ozocerite deposits occur as a series of small veins that fill fissures that strike about N. 10° W. and that dip steeply southwest (Cashion, 1964, p. 66; Henderson, 1964, p. 166). No veins are greater than 1 m (3 ft) wide; all are discontinuous and irregular in length. Stratigraphically, the veins are in a transition zone that includes the uppermost beds of the Colton Formation and the lowermost beds of the Green River Formation. The origin of the ozocerite is uncertain; it is probably related to emanations from petroleum.

OIL SHALE

Although oil shale is in the Soldier Summit area, it is economically unimportant and far less significant than the much richer oil shale that crops out to the east and that underlies the Uinta Basin to the north. Two oil-shale zones are recognized by Henderson (1958): an upper zone that consists of light-brown shale having paper-thin fissility, and a lower zone that contains massive beds of dark-brown shale having paper-thin fissility. Bruce Bryant (U.S. Geol. Survey, oral commun., 1985), as a result of his geologic mapping north of this quadrangle, recognizes a third zone some 120 m (400 ft) below the upper zone, and correlates this middle zone with the well-known Mahogany zone of eastern Utah and western Colorado. None of the zones exposed in this quadrangle contain oil shale that could be characterized as rich. Details about the oil shale in the Soldier Summit area are in Henderson (1958) and Prescott (1958).

Winchester (1917, p. 141), considering oil shale exposures along the west flank of the San Pitch Mountains, commented "Before petroleum was discovered in Pennsylvania, the Mormons distilled oil from shale near Juab, Utah, where the ruins of an old still can yet be seen." Subsequently, Winchester (1923, p. 114) cited a partial measured section of Green River strata that contained several thin (0.5 to 1 m (2 to 4 ft)) oil shale beds at the "mouth of old tunnel in Chris Canyon, southeast of Juab, Utah". This locality, some 8 km (5 mi) southeast of Levan, is now spelled Chriss (pronounced Chris's), and is south of this quadrangle near the north edge of the Manti 30′×60′ quadrangle. Crawford (1961) has described an old retort that had been constructed at the site noted by Winchester. Apparently much of the oil shale mined came from an old nearby shaft that has since collapsed.

URANIFEROUS DEPOSITS

Small uraniferous prospects and an abandoned uranium mine are in a complexly deformed area along the southwest flank of Mt. Nebo. The area reportedly has produced some uranium ore (Robert Steele, Nephi, Utah, oral commun., 1984), and disseminated, secondary, yellow uranium-vanadium minerals, chiefly tyuyamunite(?), mark some outcrops. Bluish-green secondary copper minerals (malachite) appear to be associated with the uranium minerals. The area known as the "Steele Uranium Property" is about 6 km (4 mi) northeast of Nephi and occupies parts of secs. 15 and 22 of T. 12 S., R. 1 E., (unsurveyed). Best exposures are high above the stream floor along the uppermost part of the south valley wall of Birch Creek, and the exposures can be readily reached by an unimproved road that extends northward from Gardner Creek. The area has been drilled repeatedly by various companies in an attempt to locate significant ore bodies; all drilling has been fruitless. As far as can be determined, the area has no measureable ore reserves. Most of the uranium minerals are confined to oolitic limestone beds of the Sliderock Member of the Twin Creek Limestone that appear to have been modified by hydrothermal solutions.

METALLIC MINERAL DEPOSITS

A series of small mines, abandoned for decades but that once produced small amounts of lead, zinc, and silver, are scattered along the west flank of the southern Wasatch Range, chiefly near the mouths of Mendenhall Creek, and Bear and North Canyons. Most mines, clustered some 6 to 11 km (4 to 7 mi) east and northeast of Mona, are grouped within the Mt. Nebo mining district. Over the years, much money has been invested in the search for ore deposits in the mountains, but the ore mined has never approximated the amount invested (Phillips, 1940, p. 6–7). The value of ore production has been less than $400,000 (Bullock, 1962, p. 88). The ore bodies that have been found are small, discontinuous, generally of low metal content, and are at or near the surface.

Phillips (1940) undertook a detailed study of the Mt. Nebo mining district and concluded that a close relation exists between a series of lamprophyre dikes and the ore minerals. Seemingly, the dikes and the mineralizing solutions used the same fissures; the dikes being emplaced first, followed shortly after by the mineralizing solutions. Major ore minerals are galena, sphalerite, and cerrusite. Minute amounts of gold and silver are contained in the galena. The richest deposits were formed either as replacements of bedded Mississippian limestone or as fissure fillings.

Small amounts of copper of no economic significance appear to be related to a Cambrian diabase lava flow (Ꞓdf) intercalated in the Tintic Quartzite. Tintic beds directly above the flow contain minute amounts of chalcopyrite, azurite, and malachite. Some chalcopyrite and pyrite are disseminated through the flow.

On the basis of the ore deposits found so far, we suspect that any new ore bodies found will be small, of low to moderate metal content, and likely confined to Mississippian limestone. Details about the mines and their metal content are included in Bullock (1962) and Phillips (1940).