LIMESTONE, DOLOMITE, AND BUILDING STONE OF SANPETE COUNTY, UTAH

by Andrew Rupke, Bryce Tripp, and Taylor Boden

UTAH DNR GEOLOGICAL SURVEY

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Cover photo: *Haas building stone quarry near Fayette, Sanpete County, Utah, May 2007. White limestone is quarried from the Tertiary Green River Formation dip slopes.*

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LIMESTONE, DOLOMITE, AND BUILDING STONE OF SANPETE COUNTY, UTAH

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ABSTRACT

The Utah School and Institutional Trust Lands Administration commissioned the Utah Geological Survey to evaluate and summarize high-calcium limestone, high-magnesium dolomite, and building stone potential in Sanpete County, Utah. This report summarizes existing data, but also includes analyses of carbonate samples collected by the Utah Geological Survey. The primary stratigraphic units containing carbonates in Sanpete County are the Green River Formation, the Flagstaff Limestone, and the North Horn Formation, all of which are widespread throughout the county.

Sampling and drilling show that the Paleocene-Eocene Flagstaff Limestone has the highest potential for high-calcium limestone. Drilling data from U.S. Steel and chip sampling by the Utah Geological Survey indicate the presence of stratigraphic horizons over 40 feet thick of high-calcium limestone within the Flagstaff Limestone. Samples from the Eocene Green River Formation are highly impure, and show low potential for high-calcium limestone. One sample from the Cretaceous-Paleocene North Horn Formation also shows high levels of impurities, and field observations revealed no carbonates of interest within the formation.

Both the Green River Formation and the Flagstaff Limestone contain dolomitic beds, but only a few samples indicate high-magnesium dolomite with low impurities. However, the Utah Geological Survey sampled a section nearly 100 feet thick that had relatively high magnesium content and low impurities. These results may indicate potential for dolomite, but more definitive conclusions about this possibility require additional investigation.

Building stone production in Sanpete County is significant, both currently and historically. Numerous building stone quarries exist in Sanpete County and the Utah Division of Oil, Gas, and Mining currently reports six active quarry permits. The building stone quarries are primarily in the Green River Formation extracting readily-mineable and dimensionally-favorable oolitic limestone. Considering the established building stone production and extensive exposures of Green River in Sanpete County, the potential for further stone extraction is high.

INTRODUCTION

Purpose and Scope

The Utah School and Institutional Trust Lands Administration (SITLA) requested an investigation of limestone, dolomite, and building stone potential of Sanpete County as part of an ongoing Memorandum of Understanding with the Utah Geological Survey (UGS) to evaluate the mineral resources of Trust Lands. This report summarizes the data presented to SITLA in order to make the information more broadly available.

The primary stratigraphic units containing carbonates in Sanpete County are the Green River Formation, the Flagstaff Limestone, and the North Horn Formation, all of which are widespread throughout the county. Due to the size of Sanpete County and the extent of the resources present, this study is primarily a summary of published information with limited original field examination and sampling. Much of the area of Sanpete County with potential resources does not have good outcrop, so we focused fieldwork on areas of good surface exposure, especially those included in recent detailed, published geologic maps. Adequate evaluation of Sanpete County's limestone and dolomite resources for chemistry and mineability would require detailed mapping and sampling of stratigraphic horizons with potential, followed by systematic drilling of those horizons. Figure 1 shows the location and land ownership of Sanpete County.

Previous Work

The geology and mineral resources of Sanpete County have been the subject of both academic and industry investigations. Some of the earliest detailed investigations were university geologic mapping theses, most of them by students at Ohio State University in the 1940s and 1950s, and by Brigham Young University in the 1970s and 1980s (see appendix A and selected bibliography for relevant references). Former UGS geologists mapped some areas of Sanpete County and the UGS published some student mapping. The U.S. Geological Survey compiled two 1:100,000 scale maps that together cover almost the whole county (Witkind and others, 1987; Witkind and Weiss, 1991). An index map showing available geologic map coverage for Sanpete County is in appendix A. UGS geologists Pratt and Callaghan (1970) published a comprehensive mineral resource investigation of Sanpete County, which is very useful but somewhat dated and short on detailed resource information. The one unpublished industry report for Sanpete

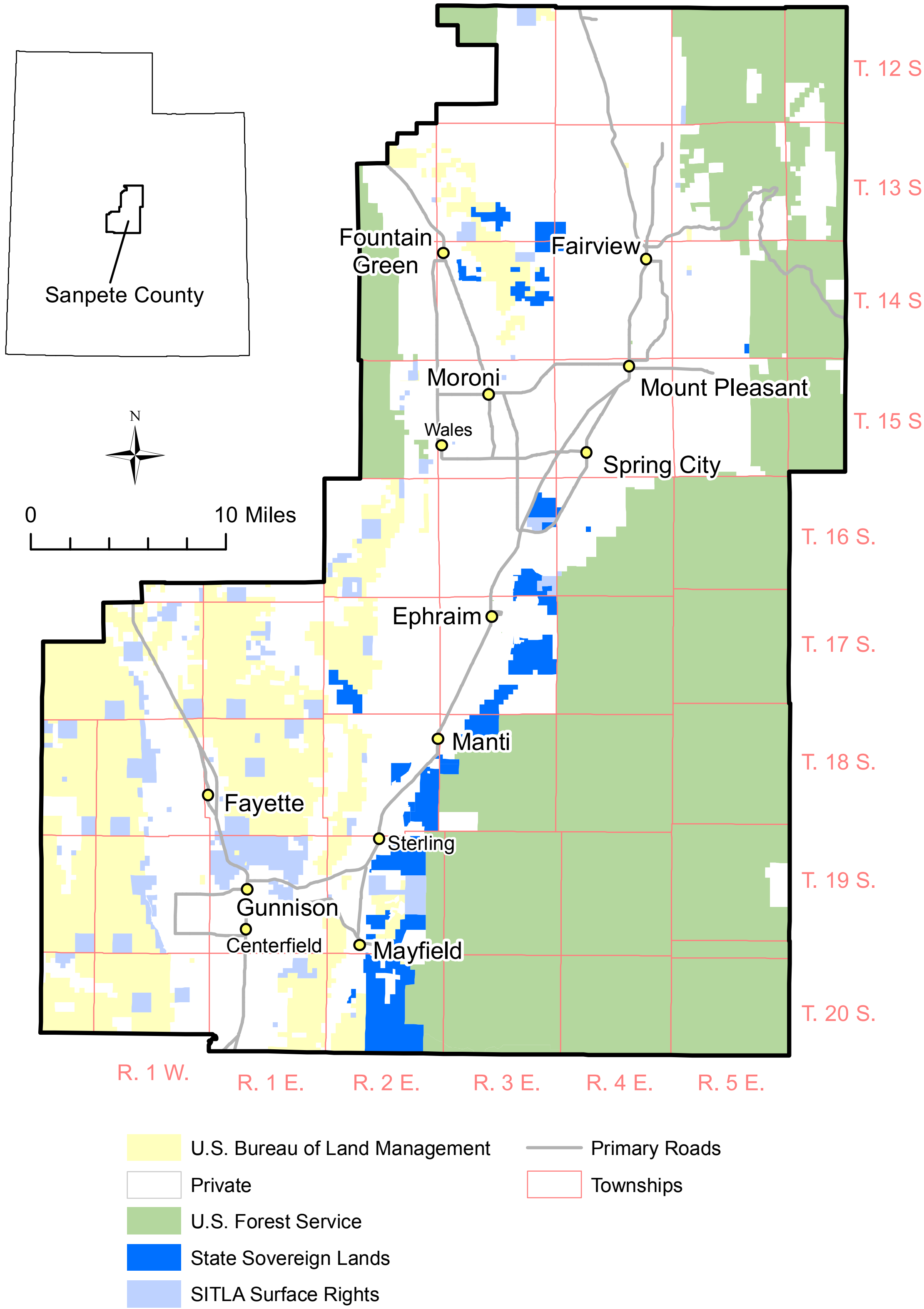

Figure 1. *Land ownership map of Sanpete County (ownership information provided by Utah Automated Geographic Reference Center).*

County was compiled by John K. Hayes and his geological staff at U.S. Steel (U.S. Steel, 1957) as part of a regional search for limestone and dolomite for use in the open hearth furnaces at the now defunct Geneva steel mill in Utah County.

Methods

General

We examined lithologic descriptions of the geologic formations of Sanpete County in Hintze and Kowallis (2009), Witkind and others (1987), and Witkind and Weiss (1991). Dennis (1930), Dixon (1938), Christensen (1967), Boleneus (2008), and other references were reviewed for information on historic and current limestone and building stone production. Tripp (2005) and the RASS database (the U.S. Geological Survey's rock analysis database) were checked for any chemical analyses of the carbonate rocks of Sanpete County, and we reviewed Pratt and Callaghan (1970) for information about the limestone, dolomite, and building stone resources of Sanpete County.

We created a geographic information system (GIS) base map for the project, which included mapped Flagstaff, Green River, and North Horn outcrops for Sanpete County. We also added permitted limestone and building stone mines from the Utah Division of Oil, Gas, and Mining's (DOGM) Minerals Data database (DOGM, 2011) and Boleneus' (2008) building stone quarry data to the GIS project.

Following library research, we drove many of the roads in Sanpete County investigating access to important stratigraphic units and exposures for good sample locations. Twenty-seven chip samples were collected for chemical analysis and keyed to measured stratigraphic sections.

UGS Analytical Methods

We processed the chip samples into pressed pellets for X-ray fluorescence (XRF) analysis. A jaw crusher was used to reduce sample fragment size to less than 0.25 inch. The samples were then split in a riffle splitter until an approximately 100-gram split was obtained to be processed in a Bleuler puck and ring pulverizer. Each sample was pulverized until it was less than about 0.0029 inch. A 4.5-gram split of each pulverized sample was combined with 0.5 grams of paraffin, and mixed in a mechanic tumbler for about 30 minutes. The sample/paraffin mixture was then placed in a 35 millimeter aluminum sample cup, loaded in a pellet die, and pressed in a hydraulic press at about 6000 pounds per square inch of pressure for about 2 minutes. Pressure was gradually reduced to zero, the pellet was removed from the pellet die and the pellet was examined and, if flawed, another pellet was prepared.

We analyzed the pressed pellets using the UGS' Rigaku ZSXmini, wavelength-dispersive XRF spectrometer. We calculated sample composition using empirical applications (comparison of the fluoresced X-ray elemental intensities to elemental regression curves generated by analysis of pressed pellet reference standards). Sample pellets were run in batches of up to nine samples preceded by a pulse height adjustment (a calibration procedure for the XRF machine) and followed by analysis of one or two check standards to detect analytical problems. We used two empirical applications to generate the results in this report: application UGS-HICAL-LSv7 for limestones, and application UGS-DOLO-DOLv2 for dolomites. All samples were initially run using the LSv7 application, and samples showing about 10% or greater MgO were then run on the DOLv2 application. We converted results reported as CaO to $CaCO_3$ by multiplying by 1.7848 and MgO to $MgCO_3$ by multiplying by 2.092.

Sources of analytical errors exist that can affect the accuracy of the reported results. Errors inherent to the XRF method include (1) low intensities of fluoresced X-rays from light elements resulting in lower accuracy for light elements, (2) matrix effects, and (3) inter-element effects. Variations in particle sizes of pulverized samples and standards, and variations in how samples and standards were pressed into pellets can also affect accuracy. Selection of standards and creation of quantitative applications have a large effect on accuracy because the analytical results rely on comparing unknown samples to regression curves for each element, constructed by analyzing certified standards using well-designed quantitative applications.

As a simple check on accuracy and precision, we analyzed a check standard with each batch of unknowns. Comparison of the certified analysis with our analyses gives an idea of the accuracy of our analyses. Comparing our analyses of the check standards over time gives an idea of the precision (reproducibility) of our results.

GENERAL STRATIGRAPHY

North Horn Formation

The Upper Cretaceous and Paleocene North Horn Formation consists of diverse rock types with only minor carbonate. The unit ranges from 500 to 3000 feet thick in the county (Witkind and others, 1987). Witkind and others (1987) described the North Horn as "Mudstone, claystone, sandstone, conglomeratic sandstone, conglomerate, and sparse limestone; units alternate irregularly. Mudstones are thick bedded to massive; sandstones range from thin to thick bedded; commonly crossbedded; fine to medium grained. Limestone beds are thin and dense, locally arenaceous. Contains minor coal beds along the east flank of Gunnison Plateau near Wales. Fluvial and some fresh-water lacustrine deposits."

Flagstaff Limestone

The Paleocene to Eocene Flagstaff Limestone is a lacustrine limestone that thickens from nothing on the central Gunnison Plateau (northwest of Sanpete County) to about 1000 feet thick in the Wasatch Plateau portion of the county (Witkind and others, 1987). Witkind and others (1987) described the Flagstaff as "Limestone, light gray to yellowish gray to light brown; locally dolomitic; red to pink near subjacent Jurassic red beds. Thin to thick bedded, locally massive, fine grained, dense, some algal nodules. Contains subordinate interbedded dark-gray, gray, and greenish-gray shale. Oncolite-rich limestone beds locally abundant (Weiss, 1965). Fresh-water lacustrine deposits. Forms resistant ledges and prominent hogbacks." Figure 2 shows a well-exposed partial section of Flagstaff Limestone along Twelvemile Creek just east of Mayfield in Sanpete County.

Green River Formation

The Eocene Green River Formation consists of lacustrine limestone overlying lacustrine shale that together range in thickness in the Sanpete County area from about 500 to 1200 feet (Witkind and others, 1987). Witkind and others (1987) described the limestone unit as "Pale-yellowish-gray to yellow-brown to light-brown limestone; thin to thick bedded; even bedded. Contains thin sandstone and tuff layers. Limestones are dense, thinly laminated, and commonly oolitic. Includes thin stromatolitic limestone beds rich in ostracodes." Witkind and others (1987) described the Green River shale unit as "Light-green to grayish-green shale; thin bedded; fissile, somewhat calcareous. A few interbedded micritic limestones. Forms gentle slopes."

Figure 3 illustrates variations in thickness of the Green River, Flagstaff, and North Horn Formations in and around Sanpete County. Figure 4 shows three stratigraphic sections of the Upper Cretaceous through Quaternary from in and near Sanpete County as compiled by Hintze and Kowallis (2009).

Figure 2. *Flagstaff Limestone cliff exposure. Photograph looks to the west and was taken a few miles east of Mayfield along Twelvemile Creek. Slope at the base of the cliff is composed of the North Horn Formation. Cliff exposure shows the lower carbonates of the Flagstaff Limestone.*

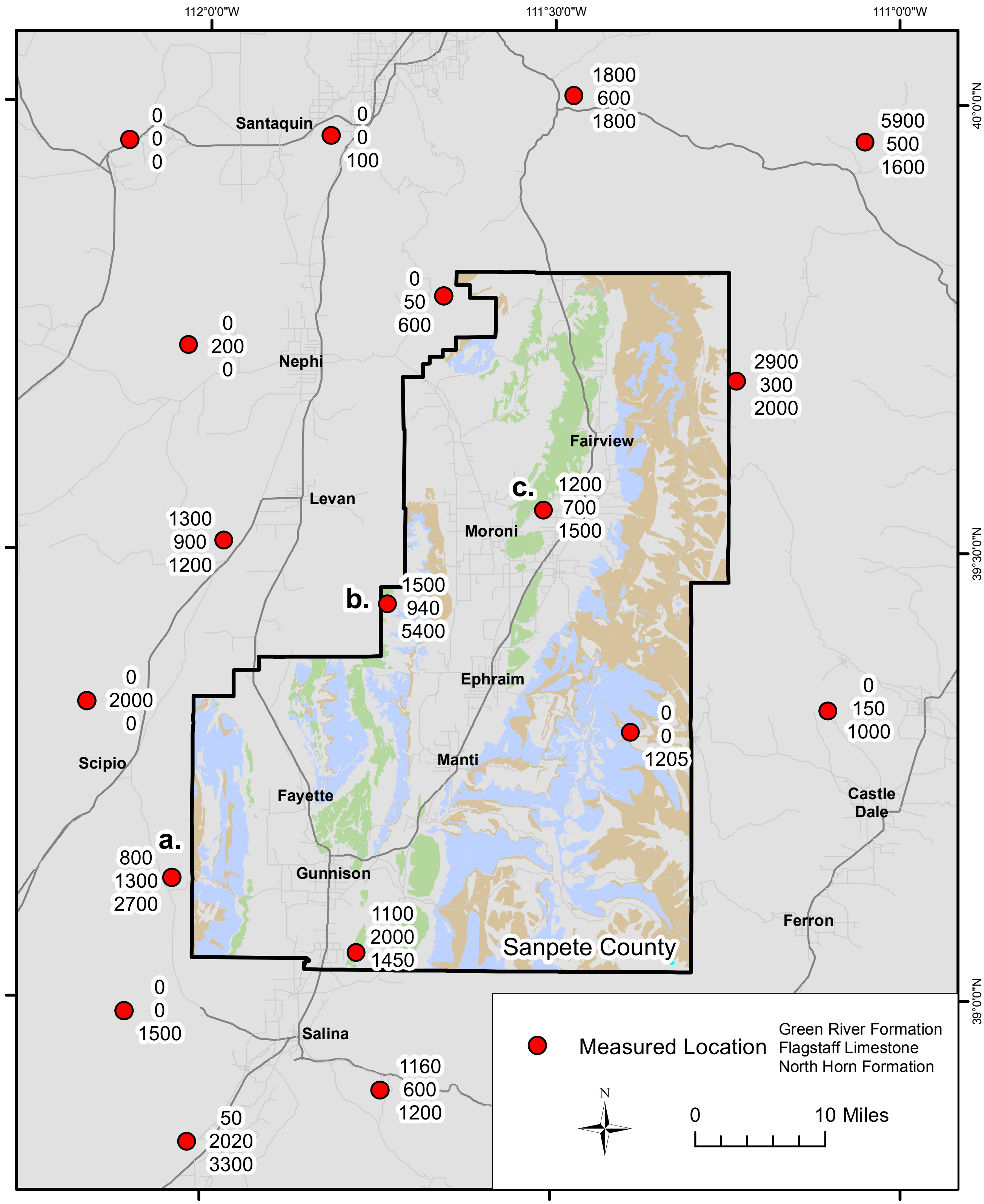

Figure 3. *Thicknesses (in feet; in stratigraphic order) of Green River Formation (green on map), Flagstaff Limestone (blue on map), and North Horn Formation (brown on map) in Sanpete County and surrounding area. Letters (a, b, c) correspond to stratigraphic sections shown on figure 4. Section locations are approximate. Thicknesses represent maximum thicknesses from Hintze and Kowallis (2009). Geology is from Hintze and Davis (2005), Witkind and others (2006), and Witkind and Weiss (2002).*

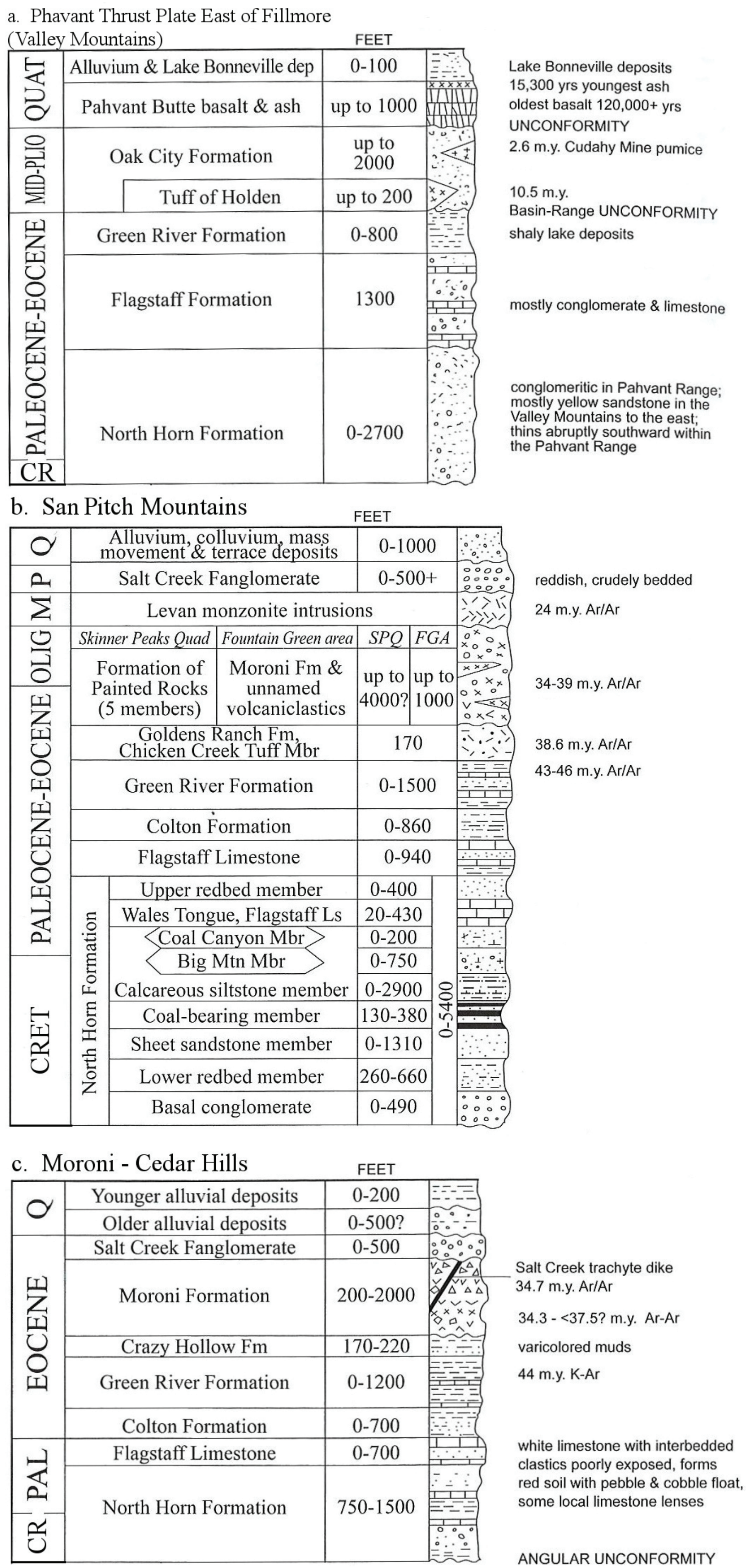

Figure 4. *Stratigraphic sections of Upper Cretaceous and younger strata from Sanpete County area (modified from Hintze and Kowallis, 2009). Locations of sections are shown on Figure 3.*

PALEOGEOGRAPHY

The Green River, Flagstaff, and North Horn Formations were deposited in latest Cretaceous to mid-Eocene time. The North Horn Formation is Late Cretaceous to mid-Paleocene, the Flagstaff Limestone is Paleocene and Eocene, and the Green River Formation is early to mid Eocene. The North Horn was deposited in a fluvial system with some associated lakes that occupied an area south of the Uinta Mountains and east of the Sevier orogenic belt of western Utah. The North Horn was deposited during and after the latest movements of the Sevier orogeny, and North Horn sediments form an angular unconformity with sediments deposited during the orogeny (Schelling and others, 2007; Hintze and Kowallis, 2009). Blakey (undated) interpreted the geography during the deposition of the North Horn as depicted on figure 5. Two extensive lakes later occupied much of the same area where the North Horn was deposited. Paleocene Lake Flagstaff deposited lacustrine sediments in a northeast-southwest belt crossing much of present-day Utah. The Eocene lake that followed and deposited the Green River Formation was centered farther to the northeast. Figure 6 shows roughly what Utah might have looked like during deposition of the Green River (Blakey, undated).

Gensmer (1977) provided a good summary of the depositional history of the Flagstaff Limestone that is useful in understanding the distribution of limestone and dolomite. Gensmer, based in part on the work of Larocque (1960), described three depositional phases. Initially Lake Flagstaff was restricted and shallow and contained abundant Paleocene plant and animal life. Substantial amounts of dark, organic, finely crystalline, often fossiliferous limestone were deposited. In the middle phase, the lake expanded rapidly in area and became very saline probably due to erosion of Jurassic salt beds exposed in the paleodrainage. The saline conditions were toxic to plants and animals, so little organic material accumulated in sediments and the deposited carbonates are light colored. Evaporation caused gypsum to precipitate in parts of the basin; the remaining brine became enriched in magnesium which dolomitized the carbonate being deposited. In the third phase, the lake freshened, plants and animals returned, and though shallow, it expanded to the southwest and reached its maximum extent. Due to increased organic carbon and decreased magnesium content, newly deposited carbonate was dark-colored limestone. The lake may have freshened due to salt beds no longer being exposed in the paleodrainage, or tectonic shifts that redirected dissolved salt away from Lake Flagstaff.

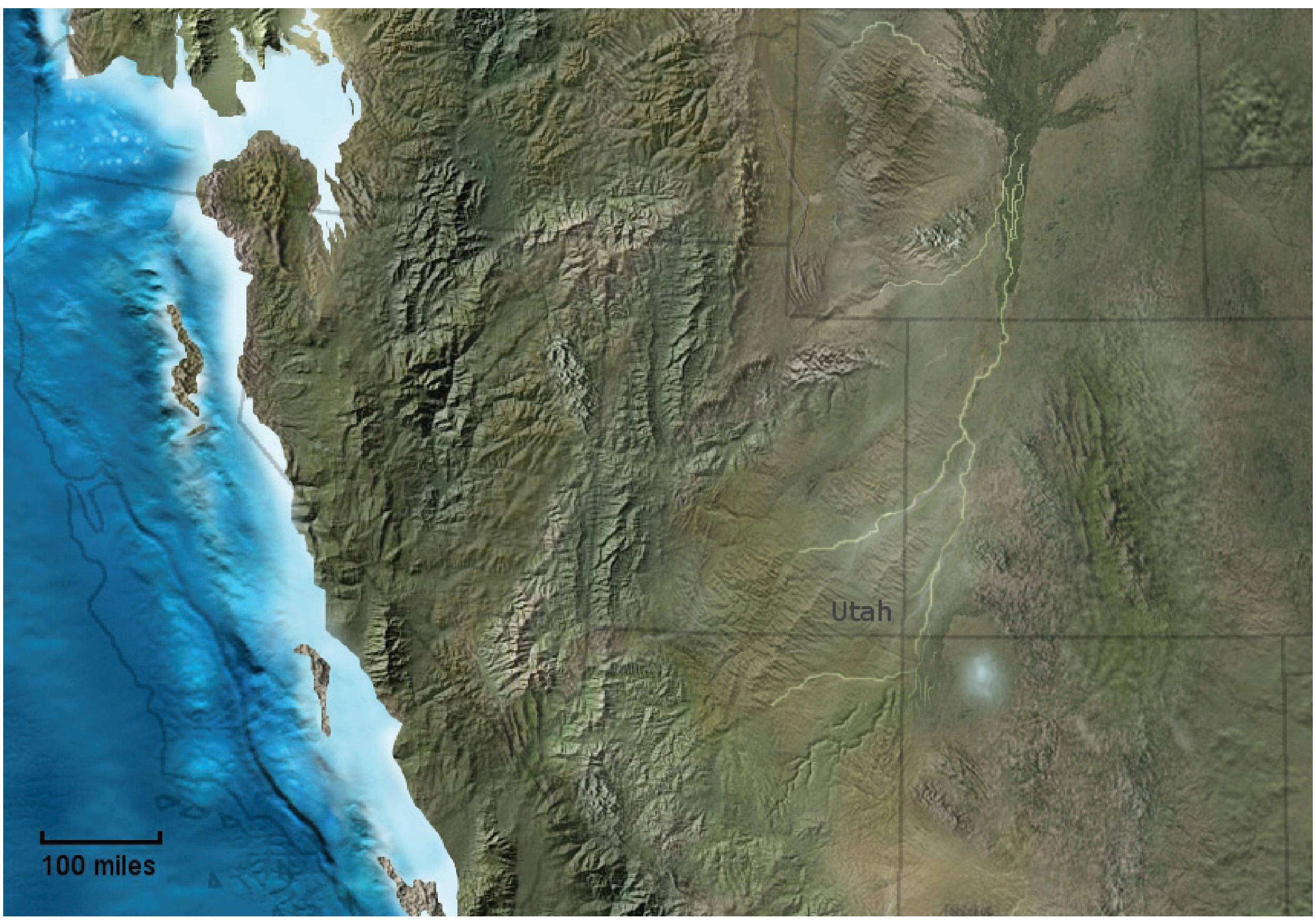

Figure 5. *Conceptual paleogeography of the western U.S. during the Late Cretaceous and early Tertiary (from Blakey, undated).*

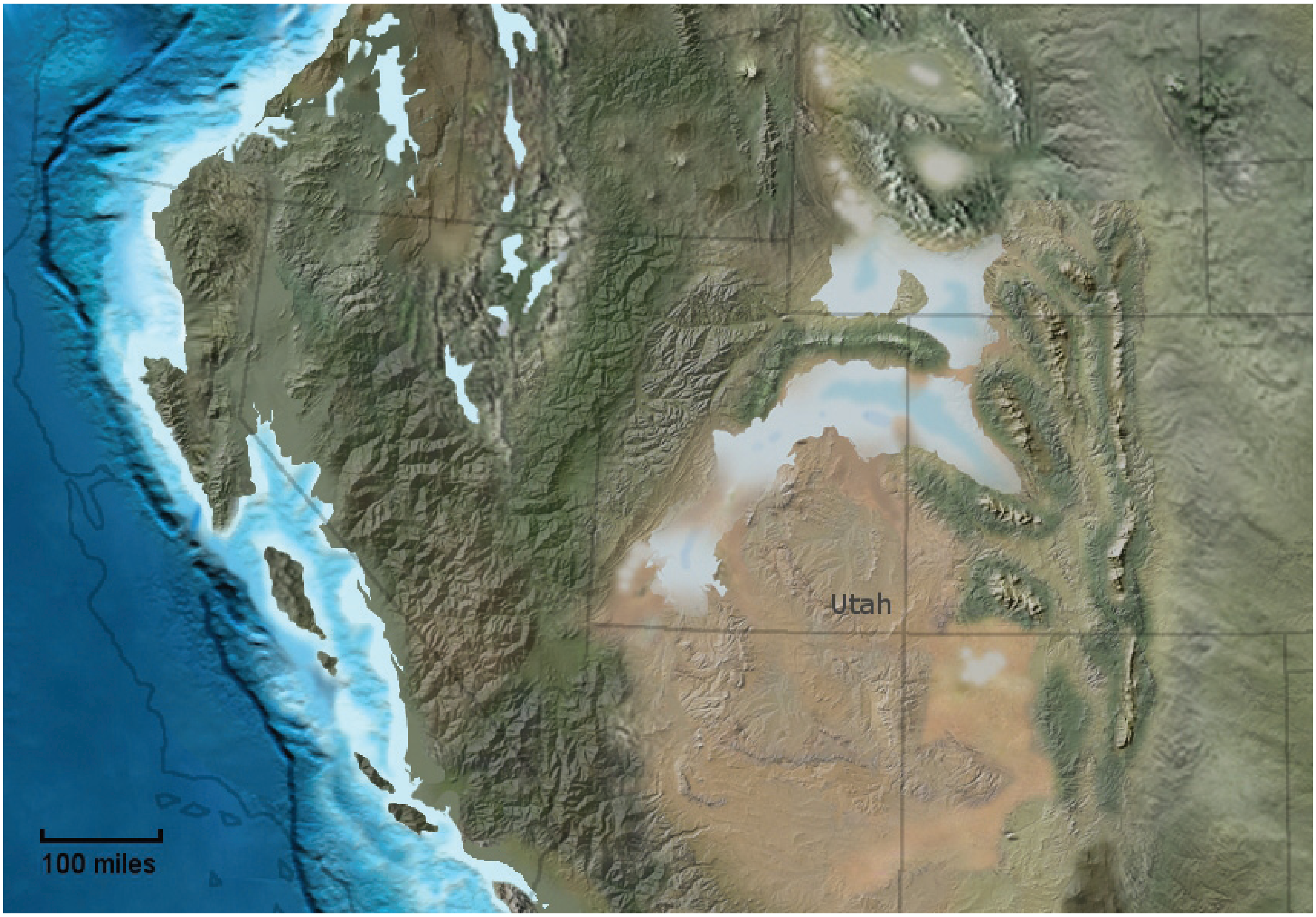

Figure 6. *Conceptual paleogeography of the western U.S. during the middle Eocene (from Blakey, undated).*

STRUCTURE

The eastern extent of Sevier-related fold-and-thrust deformation is in Sanpete County along the western edge of the Wasatch Plateau (Schelling and others, 2007). Sevier thrusting occurred from Early Cretaceous through Late Cretaceous time, and deformed older rocks present in Sanpete County's subsurface that are exposed west of the county (DeCelles and Coogan, 2006; Schelling and others, 2007). As mentioned above, the North Horn Formation was deposited during and after the latest Sevier deformation and lies unconformably above the deformed beds (Schelling and others, 2007; Hintze and Kowallis, 2009). Sanpete County also straddles the transition zone between the Colorado Plateau in the east part of the county and the Basin and Range extensional province in the west part of the county. The Neogene extensional faulting in the county overprints and, in some cases, reactivated Sevier structures (Schelling and others, 2007). Most of the following structural descriptions of the ranges are from Witkind and others (1987).

The Wasatch Plateau in Sanpete County is a large, westward-dipping monocline dissected by deep, sinuous drainages. The monocline is cut by a network of north- to north-northeast-trending normal faults that form grabens. The Gooseberry and Snow Lake grabens are located in Sanpete County, but the most extensive graben is the 40-mile-long Joes Valley graben located immediately east of the county.

The Gunnison Plateau (also called the San Pitch Mountains or West Mountain) is a north-south-trending, gently folded, south-plunging syncline cut by a complex series of normal faults. The eastern edge of the Gunnison Plateau is delineated by a long, narrow normal-fault zone that includes the Gunnison and Wales faults (Fong, 1995; Schelling and others, 2007). Researchers have suggested that these faults are reactivated Sevier-related back-thrusts (Weiss and Sprinkel, 2002; Schelling and others, 2007). Some of the faults cut Holocene-aged alluvial fans, indicating recent movement (Fong, 1995). The west side of the Gunnison Plateau is bounded by the Levan and Fayette segments of the Wasatch Fault (Hylland and Machette, 2008).

The Cedar Hills, in northern Sanpete County, consist of a relatively flat-lying section of Upper Cretaceous to Eocene rocks with local folds and few faults exposed at the surface. A substantial portion of the Cedar Hills is overlain by Oligocene to upper Eocene Moroni Formation volcaniclastics, conglomerate, and sandstone.

The Valley Mountains, in southwest Sanpete County, are a north-south-trending, eastward-tilted, fault-block range. North-south-trending normal faults with a subsidiary set of east-west-trending normal faults are common in the range. The most prominent structural surface feature of the Valley Mountains is the Japanese Valley graben, a north-south trending feature near the crest of the range.

CARBONATE RESOURCES

High-Calcium Limestone

Historical High-Calcium Limestone Production

The Flagstaff Limestone is the main source of high-calcium limestone (>95% $CaCO_3$ or 53.2% CaO) in central Utah. In the past, Western Clay Company mined the Flagstaff at the Redmond quarry in Sevier County and the Three Knolls pit in eastern Millard County. The Cherry Hill Park and Chimney Rock pits of southeast Utah County are also developed in the Flagstaff Limestone (Tripp, 2005). Limestone production in the area was originally used for sugar beet processing, then for coal-mine rock dusting and crushed stone.

High-Calcium Limestone Potential

The Flagstaff Limestone has high potential for future production of high-calcium limestone in Sanpete County, and the Green River and North Horn Formations have low potential.

Gensmer (1977) gave detailed information about the distribution of potentially high-calcium limestone from the Flagstaff Limestone in Sanpete County. Limestone comprises only 38% of the carbonate rock in the Flagstaff and it is concentrated at the base and top of the formation, while dolomite predominates in the center of the formation. Little interbedding exists between the two types of carbonate due to differing depositional settings. The limestones are medium to dark colored, commonly fossiliferous, variable in texture, and contain only small amounts of acid-insoluble, terrigenous impurities. Ninety-five percent of the limestone samples analyzed by Gensmer contained less than 9% acid-insoluble clay and silt. Appendix B presents some of Gensmer's results. Our observations and sampling are consistent with Gensmer's in that most of the high-calcium limestone potential appears to be near the base of the Flagstaff Limestone.

Nine of the 27 samples taken from the Flagstaff Limestone by Pratt and Callaghan (1970) were high-calcium limestone. They averaged 96.7% $CaCO_3$. Appendix C presents Pratt and Callaghan's (1970) analytical data and sample location information. U.S. Steel (1957) also collected high-calcium samples from the Flagstaff at sites near Fayette and Manti. U.S. Steel chip samples in the Fayette deposit revealed two beds of high-calcium limestone totaling 25 feet thick (appendix D). Nine grab samples or drill hole samples from the Manti deposit were high-calcium limestone (appendix E). The best sample (drill hole 3) contained 45 feet of 97.6% $CaCO_3$. Figure 7 shows the Manti deposit area, which is just west of the Gunnison Reservoir. Seven recent samples collected by the UGS were high-calcium limestone. Samples SP-3 and SP-4 averaged 96.1% $CaCO_3$ and represent a continuous section that is 33 feet thick; samples SP-14 and SP-15 also averaged 96.1% $CaCO_3$ and represent a continuous stratigraphic interval 44 feet thick. Samples SP-3 and SP-4 were collected near the Manti deposit, and samples SP-14 and SP-15 were collected in section 16, T. 18 S., R. 1 E., Salt Lake Base Line and Meridian (SLBLM) near the Fayette deposit (figure 8). Appendices F and G provide detailed analytical, location, and geologic information on 27 UGS samples.

None of the samples from the Green River Formation collected by Pratt and Callaghan (1970) or this study (UGS) were high-calcium limestone, and they typically had high magnesium and silica content. During our fieldwork, we did not observe any units in the North Horn Formation that showed high-calcium limestone potential, and the only sample collected from the North Horn contained significant magnesium and silica.

Plate 1 shows distribution of high-calcium limestone samples from Pratt and Callaghan (1970), U.S. Steel (1957), and the UGS, and table 1 summarizes the analyses. Sampling shows that high-calcium limestone is widely distributed in the southwestern part of the county, but it could likely be delineated in other parts of the county with additional sampling and exploration. The southeastern part of the county is a likely target due to its extensive Flagstaff outcrop. However, the southwestern part of Sanpete County has higher development potential due to much of the land being administered by SITLA and BLM rather than the U.S. Forest Service (figure 1).

High-Magnesium Dolomite

Historical High-Magnesium Dolomite Production

No known production of dolomite has come from North Horn, Flagstaff, or Green River Formations in Utah. All of the dolomite produced in Utah is from marine, lower Paleozoic strata in the Basin and Range Province to the west of Sanpete County, especially from the Ordovician Fish Haven Dolomite of north-central Utah and Cambrian limestone of the Cricket Mountains.

High-Magnesium Dolomite Potential

County-wide sampling by Pratt and Callaghan (1970) showed that both the Green River and Flagstaff contain many dolomitic beds. Gensmer (1977) gave detailed information about the distribution of potentially high-magnesium dolomite in the Flagstaff Limestone in Sanpete County. Dolomite forms 62% of the carbonate rock in

Figure 7. *Manti limestone deposit, looking towards the northeast. The deposit is on the west side of the Gunnison Reservoir. The hills are composed of Flagstaff Limestone, and sampling indicates that much of the limestone in the area is high-calcium.*

the Flagstaff Limestone of the Sanpete County area and primarily occurs in the middle of the formation. The dolomite is typically pale pinkish gray, very pale orange, and pale yellow-gray. It is often microcrystalline, unfossiliferous, and contains large amounts of terrigenous impurities. Dolomites analyzed by Gensmer typically contained 10–24% clay, silt, or sand.

The 12 Green River samples from Pratt and Callaghan (1970) assayed from 13.0 to 39.3% $MgCO_3$ and averaged 23.3% $MgCO_3$. The 27 Flagstaff samples assayed from 1.7 to 49.2% $MgCO_3$ and averaged 21.0% $MgCO_3$. Pure dolomite consists of 54.3% $CaCO_3$ (30.4% CaO) and 45.7% $MgCO_3$ (21.9% MgO). Two of the Flagstaff samples from Pratt and Callaghan (1970) actually exceed the 45.7% $MgCO_3$ of pure dolomite; while this likely indicates problems with the assay technique, the results may also indicate some potential for dolomite production from the Flagstaff. Three UGS samples (SP-7 through SP-9) averaged relatively high $MgCO_3$ content (39.6%) and low SiO_2 content (1.1%), and represent a continuous stratigraphic section 97 feet thick. The UGS did not observe high-potential dolomite elsewhere in Sanpete County during field investigations. Plate 1 shows distribution of dolomite analyses over 39% $MgCO_3$.

Building Stone

Historical Building Stone Production

Sanpete County has a long history of building stone quarrying, not only for local buildings, but also for export around the western United States. The best-known stone in the area is the “Sanpete oolite” or “Sanpete white” stone of the Eocene Green River Formation. Less important is the “Birdseye marble” of the Eocene and Paleocene Flagstaff Limestone. Sandstone of the Eocene Crazy Hollow Formation and welded tuff of the Eocene-Oligocene

Moroni Formation were quarried in small amounts for local use (Witkind and Weiss, 1991).

Sanpete oolite stone is a cream to buff-colored, relatively soft, porous, locally oolitic lacustrine limestone. The light color, ease of cutting and carving, uniformity, lateral extent, low degree of fracturing, and occurrence predominantly in thin- to thick-bedded strata that are easy to quarry and use, made this stone popular for local and regional use. Famous examples of buildings built in Utah with this stone include the Church of Jesus Christ of Latter-day Saints (LDS) Temple in Manti (figure 9), the LDS Tabernacle at Moroni, the Park Building at the University of Utah in Salt Lake City, the Kerns Building and Clark residence in Salt Lake City, the Maeser Building at Brigham Young University in Provo, and the Hearst Castle in San Simeon, California (Dennis, 1930; Dixon, 1938; Christensen, 1967). This stone was submitted for use in the Utah State Capitol, but apparently was not selected (Pack, 1912). However, the stone has been used out-of-state including in San Francisco (Dennis, 1930). A negative characteristic of the stone is its susceptibility to damage by acidic air pollution (SO_2 in the air alters the $CaCO_3$ in the stone to gypsum – $CaSO_4 \cdot 2H_2O$) and by freeze/thaw. Freeze/thaw damage and exposure to sulfur dioxide in the atmosphere has caused spalling for decades on the Sanpete white stone of the Park Building. Christensen (1967) discussed the limitations of Sanpete white stone as a building stone for use on exterior walls and the lack of effective treatments to preserve this stone. One interesting fact he mentioned is that masons had to chisel off the weathered surface of the Manti Temple in the 1940s to restore its appearance. Numerous historic quarries exist around Manti and Sterling, and this stone is still mined by the Parry Estate quarry at Manti and by the Haas Brothers just east of Fayette.

The Birdseye marble is a light gray to medium brown, lacustrine limestone that takes a fine polish and is ornamental due to an abundance of algal oncolites. The Cache Valley Bank Building in Logan, Utah, the Western State Bank in Los Angeles, California

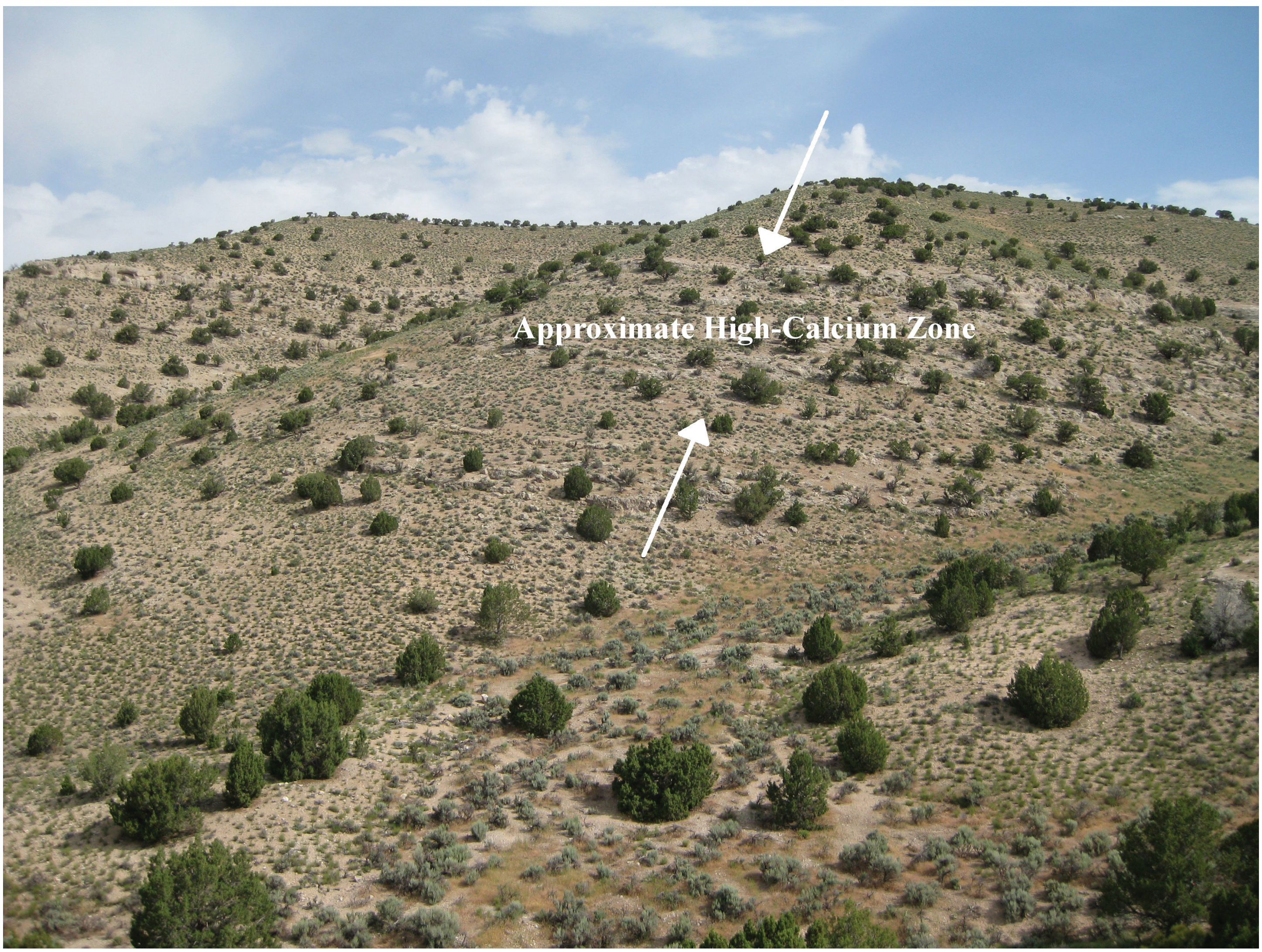

Figure 8. *Flagstaff Limestone outcrop. Approximate high-calcium zone is labeled. Photo is looking to the north and was taken in section 16, T. 18 S., R. 1 E. (SLBLM). Samples SP-14 and SP-15 were collected in this area.*

Table 1. *Partial chemical analyses for Sanpete County carbonate samples.*

			Weight Percent						Weight Percent		
Sample	**Sampler[1]**	**Fm.[2]**	**$CaCO_3$**	**$MgCO_3$**	**SiO_2**	**Sample**	**Sampler[1]**	**Fm.[2]**	**$CaCO_3$**	**$MgCO_3$**	**SiO_2**
SP-1	UGS	F	60.0	29.5	9.8	27-1	PC	F	58.7	30.1	10.5
SP-2	UGS	F	97.6	1.4	0.4	27-2	PC	F	66.2	34.5	2.0
SP-3	UGS	F	96.5	2.2	0.3	31-1	PC	F	55.3	34.5	10.0
SP-4	UGS	F	95.7	3.6	0.2	31-2	PC	F	51.4	33.1	13.0
SP-5	UGS	F	88.6	2.3	3.5	34	PC	F	56.4	46.4	
SP-6	UGS	F	46.6	28.3	21.5	36	PC	GR	48.2	32.4	14.0
SP-7	UGS	F	55.9	40.2	1.1	37	PC	F	55.7	36.4	6.0
SP-8	UGS	F	56.1	39.7	1.1	38	PC	F	96.7	1.7	1.0
SP-9	UGS	F	54.9	39.3	1.2	39	PC	F	96.4	1.7	1.0
SP-10	UGS	GR	84.6	12.9	1.4	40	PC	F	86.9	7.3	3.0
SP-11	UGS	F	94.8	1.1	1.9	42	PC	GR	58.0	30.1	10.0
SP-12	UGS	NH	87.0	3.5	4.8	45	PC	GR	37.8	20.5	40.0
SP-13	UGS	F	86.4	4.2	4.5	46	PC	GR	58.4	39.3	2.4
SP-14	UGS	F	95.6	1.4	0.8	48	PC	F	91.2	6.5	1.0
SP-15	UGS	F	96.5	1.4	0.7	49	PC	F	97.3	1.7	1.0
SP-16	UGS	F	54.8	35.1	9.2	51-1	PC	F	52.7	41.4	---
SP-17	UGS	F	95.1	0.9	1.8	51-2	PC	F	52.7	49.2	---
SP-18	UGS	F	96.6	1.1	0.5	52-1	PC	F	95.1	4.6	---
SP-19	UGS	F	90.2	0.8	4.4	52-2	PC	F	94.6	4.4	---
SP-20	UGS	F	94.2	4.3	0.7	5686	USX	F	67.6	31.2	0.6
GR-Milburn[3]	UGS	GR	72.7	24.1	9.0	5687	USX	F	98.0	0.6	0.3
1	PC	F	94.4	37.4	---	5688	USX	F	87.1	7.9	2.8
2	PC	F	55.3	3.8	---	5689	USX	F	80.3	16.5	0.8
3	PC	F	58.5	38.9	---	5690	USX	F	69.6	24.5	4.4
5	PC	GR	66.9	23.4	10.0	5691	USX	F	78.9	15.1	5.0
6	PC	GR	78.5	17.2	4.2	5692	USX	F	95.3	3.3	0.2
7	PC	GR	69.6	20.9	6.0	1	USX	F	95.8	2.7	0.4
8	PC	GR	67.8	17.4	12.0	6	USX	F	95.3	3.6	0.3
9	PC	GR	78.5	16.5	4.0	9	USX	F	95.3	3.6	0.3
10	PC	GR	56.8	30.8	9.3	8	USX	F	95.3	3.6	0.3
13	PC	GR	71.0	18.0	8.4	7	USX	F	95.3	3.6	0.3
14	PC	F	60.0	35.1	3.7	5-2	USX	F	95.3	3.6	0.3
15	PC	F	56.2	42.3	3.0	5-1	USX	F	98.9	1.7	0.3
17	PC	F	53.4	33.1	11.0	4	USX	F	95.3	3.6	0.3
19	PC	F	62.1	38.9	2.0	2	USX	F	92.5	5.9	0.6
20	PC	F	97.3	1.7	1.0	3	USX	F	96.7	2.1	0.2
21	PC	F	97.1	1.7	1.0	DH4	USX	F	94.2	4.2	0.7
22	PC	F	97.3	1.7	1.0	DH3	USX	F	97.6	1.0	0.9
23	PC	F	97.3	1.7	1.0	DH2	USX	F	96.2	2.1	1.0
24	PC	F	96.4	2.5	1.0	DH1	USX	F	95.1	2.9	1.3
25	PC	GR	77.6	13.0	6.0						

Complete chemical analyses are available in appendices C, D E, and F. Locations are shown on plate 1, and more detailed location information is available in appendices C, D, E, and G.

[1]Sampler - UGS = Utah Geological Survey; PC = Pratt and Callaghan (1970); USX = U.S. Steel (1957)

[2]Formation - NH = North Horn Formation; F = Flagstaff Limestone; GR - Green River Formation

[3]Average of GR-Milburn-01 through -07

Figure 9. *Church of Jesus Christ of Latter-day Saints Temple in Manti. The temple is constructed of oolitic limestone from the Green River Formation.*

(Dennis, 1930), the LDS Chapel in Washington, D.C., the Utah State Capitol Building, and the United States Post Offices in Salt Lake City and Provo (Dixon, 1938) used the marble as interior building stone. The only quarry is south of Thistle in Utah County in Section 30, T. 10 S., R. 4 E. (SLBLM), but it has been inactive for many years.

Dixon (1938) mentioned local production of a gray sandstone near Fairview and a trachyte near Moroni, but did not give quarry locations or other details.

Building Stone Potential

Historically speaking, Sanpete County is an important producer of building stone, and it will likely continue to be. DOGM (2011) reports six active building stone quarry permits in Sanpete County; however, a few of these permits are under review by the DOGM board. Boleneus (2008) reported nine active quarries in Sanpete County in his building stone report. Figure 10 shows known active and historic building stone quarries in Sanpete County. Appendix H and I contain additional information from DOGM (2011) and Boleneus (2008) on quarries in Sanpete County. Boleneus (2008) reported that B and H Stone Supply recorded over 29,000 personnel hours in 2004 and over 23,000 hours in 2003. In both of those years, B and H recorded the second highest number of hours among building stone quarries in Utah. The report did not include hourly information beyond 2004.

Figure 10 shows that most of the current and historic building stone quarries are in the Green River Formation. Due to the extensive amount of Green River Formation outcrop in Sanpete County, building stone can likely be extracted under favorable mining circumstances for the foreseeable future.

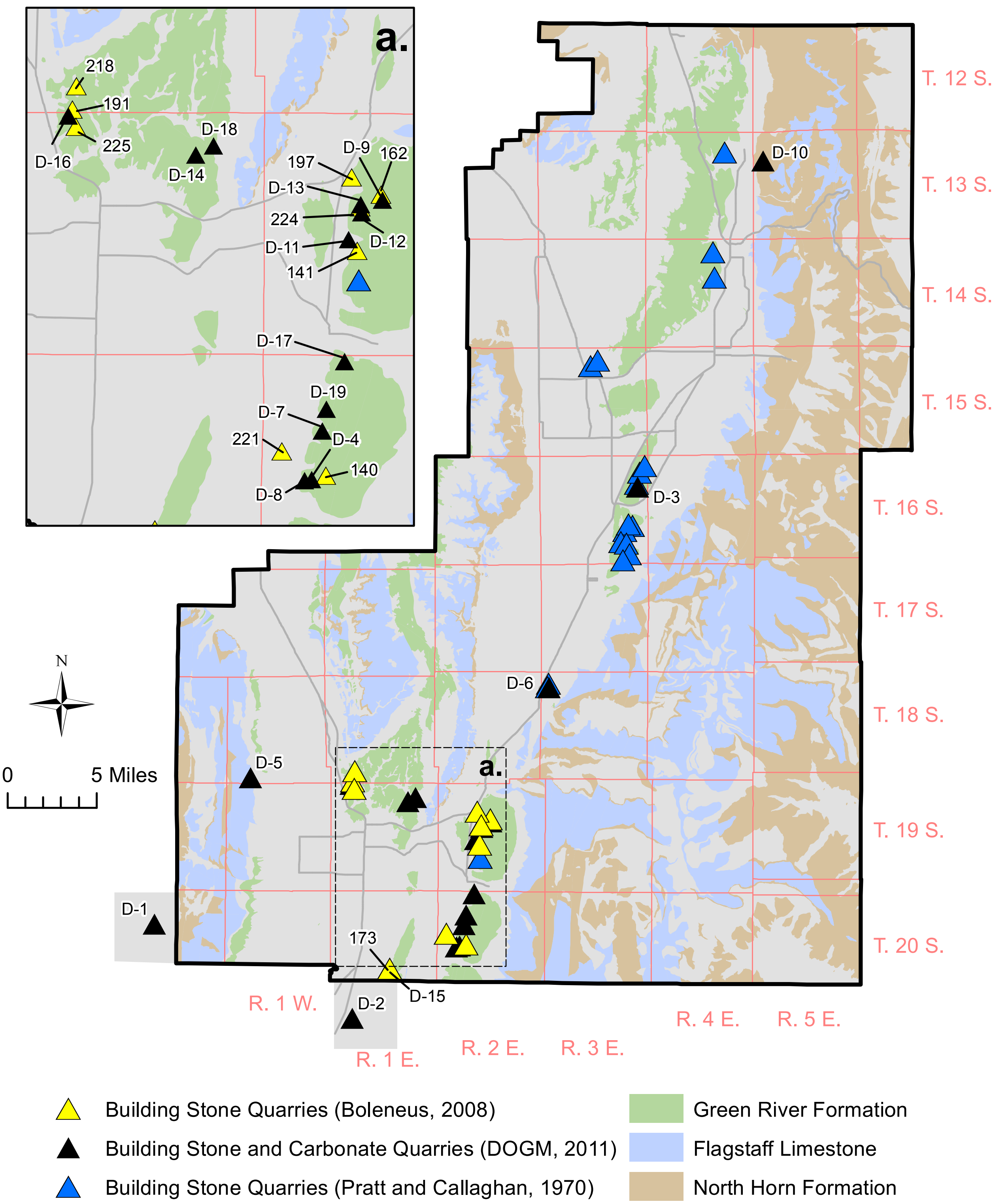

Figure 10. *Historical and active carbonate and building stone quarries in Sanpete County. Additional information for labeled quarry sites is located in Appendices H and I. Pratt and Callaghan's (1970), DOGM's (2011), and Boleneus' (2008) locations are redundant in some cases. Geology is from Hintze and Davis (2005), Witkind and others (2006), and Witkind and Weiss (2002).*

CONCLUSIONS

Previous geologic work suggests that three formations in Sanpete County contain carbonate lithology: the Green River Formation, the Flagstaff Limestone, and the North Horn Formation. The primary source for high-calcium limestone in central Utah is the Flagstaff Limestone, and sampling data indicate that the Flagstaff Limestone has the highest potential for high-calcium limestone in Sanpete County. Numerous samples collected by Pratt and Callaghan (1970), U.S. Steel (1957), and the UGS indicate that high-calcium limestone is present, typically in the lower portions of the Flagstaff. U.S. Steel drilling data and UGS sampling both indicate high-calcium stratigraphic intervals over 40 feet thick in the Flagstaff Limestone. Detailed mapping, sampling, and drilling within the Flagstaff Limestone could likely delineate zones of high-calcium limestone with favorable stripping ratios given the extensive outcrop in Sanpete County. Available analyses indicate little or no potential for high-calcium limestone in the Green River and North Horn Formations.

Available data indicate that Sanpete County may have limited high-purity dolomite potential. Both Pratt and Callaghan (1970) and the UGS collected samples with over 39% $MgCO_3$. The most promising samples, collected by the UGS, indicate nearly 100 feet of 18.9% $MgCO_3$ with slightly over 1% SiO_2 in one location on the east side of the Gunnison Plateau. However, the UGS did not observe or sample dolomite with potential elsewhere in Sanpete County. To determine the presence of high-purity dolomite elsewhere in the county would require additional field investigation.

Historically, the Green River Formation in Sanpete County is an important source of building stone and it has been used in a number of notable buildings. While the "Sanpete oolite" has some weathering problems, DOGM (2011) reports six active building stone quarry permits in Sanpete County in 2011; one of them recording the second-highest man hours for a Utah building stone quarry in 2004. The established historical production of building stone coupled with the extensive Green River Formation outcrop make it likely that the building stone industry will continue in Sanpete County as long as sufficient demand exists.

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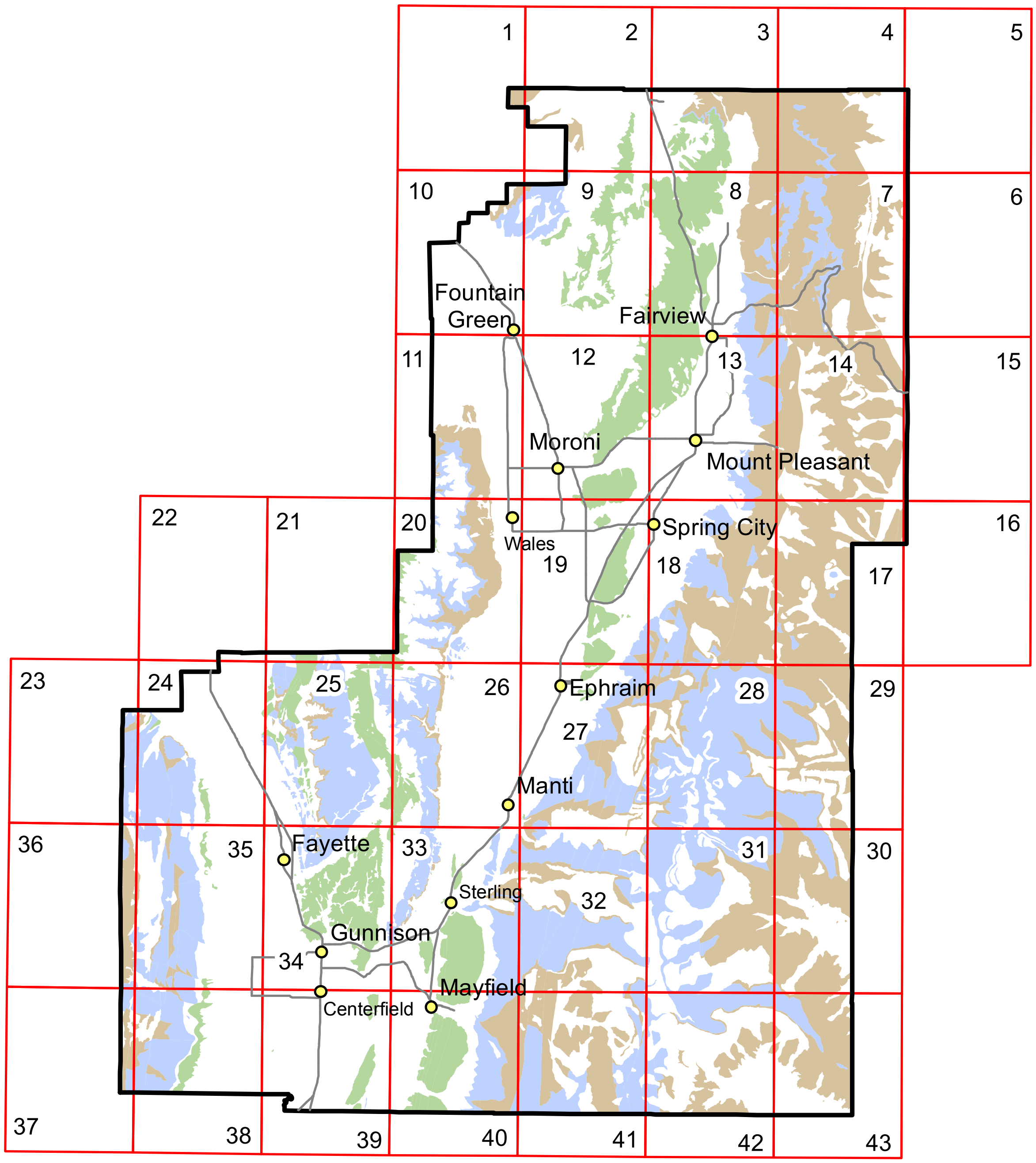
APPENDICES

Appendix A – Index to geologic maps available for Sanpete County, explanation on page 24



Appendix A. Geologic quadrangle map index for Sanpete County. Explanation is on the following page. Green River Formation is show in green, Flagstaff Limestone is shown in blue, and North Horn Formation is shown in brown. Geology is from Hintze and Davis (2005), Witkind and others (2006), and Witkind and Weiss (2002).

Appendix A – Explanation

Quad No.	Quad Name	Geologic Map Coverage
1	Nebo Basin	Witkind and Weiss, 1991, 2002 (digital)
2	Spenser Canyon	Witkind and Weiss, 1991, 2002 (digital)
3	Indianola	Runyon, 1976
4	C Canyon	Witkind and Weiss, 1991, 2002 (digital)
5	Scofield Reservoir	Witkind and Weiss, 1991, 2002 (digital)
6	Scofield	Knowles, 1996
7	Fairview Lakes	Oberhansley, 1980
8	Fairview	Jensen, 1993
9	Big Hollow	Hawks, 1979
10	Fountain Green North	Banks, 1991
11	Fountain Green South	Fong, 1995
12	Moroni	Witkind and Weiss, 1991, 2002 (digital)
13	Mount Pleasant	Fograscher, 1956
14	Huntington Reservoir	Witkind and Weiss, 1991, 2002 (digital)
15	Candland Mountain	Sanchez and Ellis, 1990
16	Rilda Canyon	Brown, Sanchez, and Ellis, 1987
17	South Tent Mtn.	Davis and Doelling 1977
18	Spring City	Witkind and others, 1987, 2006 (digital)
19	Chester	Faulk, 1948
20	Wales	Lawton and Weiss, 1999
21	Chriss Canyon	Weiss and others, 2003
22	Skinner Peaks	Vogel, 1957
23	Scipio North	Hintze, 1990a
24	Hells Kitchen Canyon SW	Witkind and others, 1987, 2006 (digital)
25	Hells Kitchen Canyon SE	Mattox, 1987
26	Manti	Weiss and Sprinkel, 2002
27	Ephraim	Bonar 1948, Faulk, 1948
28	Danish Knoll	Davis and Doelling, 1977
29	Joes Valley Reservoir	Kitzmiller, 1982
30	Ferron Canyon	Ellis, 1981
31	Ferron Reservoir	Witkind and others, 1987, 2006 (digital)
32	Black Mountain	Wilson, 1949
33	Sterling	Weiss, 1994
34	Gunnison	Mattox, 1992
35	Hayes Canyon	Peterson, 1997
36	Scipio South	Hintze, 1991
37	Scipio Lake	Hintze 1990b
38	Redmond Canyon	Willis, 1991
39	Redmond	Witkind, 1981
40	Mayfield	Johnson, 1949
41	Woods Lake	Johnson, 1949; Baughman, 1959
42	Heliotrope Mtn	Sanchez and Brown, 1983
43	Flagstaff Peak	Sanchez, 1979

Appendix B – Copy of selected Gensmer (1977) data

(table reproduced from Gensmer, 1977)

Locations of Measured Sections

Locations	Canyon	Township	Range	Section	Quadrant
A	Pigeon	T. 16 S.	R. 4 E.	19	SE 1/4
B	Ephraim	T. 17 S.	R. 3 E.	14	NE 1/4
C	Middle Manti	T. 18 S.	R. 3 E.	9	Center
D	Manti Gap	T. 18 S.	R. 3 E.	8	SW 1/4
E	Sixmile	T. 18 S.	R. 3 E.	29	Center
F	Warm Springs	T. 18 S.	R. 2 E.	24	SW 1/4
G	Snows	T. 19 S.	R. 2 E.	11	NW 1/4
H	Bent	T. 18 S.	R. 2 E.	5	NE 1/4
I	South Maple	T. 17 S.	R. 2 E.	18	SE 1/4
J	Dry	T. 16 S.	R. 2 E.	33	NW 1/4
K	Petes	T. 15 S.	R. 2 E.	34	NW 1/4
L	Wales	T. 15 S.	R. 2 E.	15	Center

(table reproduced from Gensmer, 1977)

Unit Thicknesses at Each Location*

Unit Location	A	B	C	D	E	F	G	H	I	J	K	L
One	113	211										
Two	98	104										
Three-A	41											
Three	94	75										
Four-A			29		30							
Four	46	63	21									
Five	70	82										
Six	41	35	74		121				52	30		
Seven	17	45	81		53				248	127	86	
Eight	59	31	55	85	27	89	101		94	30	73	
Nine	45	41	116	205	329**	61**	110**	595**	188	256	171	134
Ten	48	81							146	146	76	
Eleven	54	34	97**	65					113	34	29	
Ten	106	264		68					57	153	243	

*Measured in feet, rounded to the nearest foot.
**Top of this unit eroded, caps dip slope.

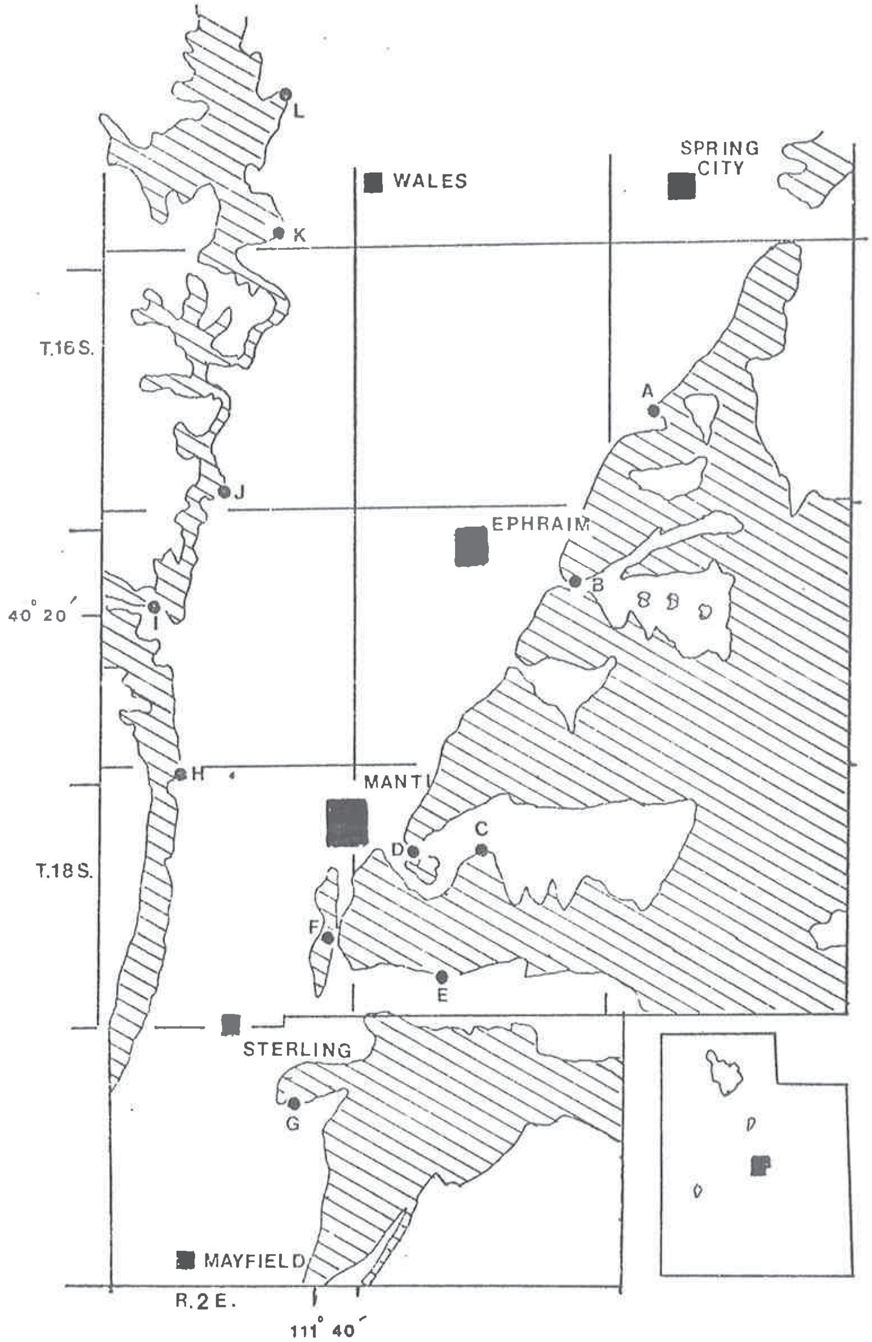


Fig. 2. Map of the study area showing the location of the measured sections and sampling sites (lettered dots) and the outcrop pattern of the Flagstaff Formation (shaded area). These measured sections are shown in Plate 1. Measured sections B, K, and G are detailed in Fig. 15, 16, and 17, respectively.

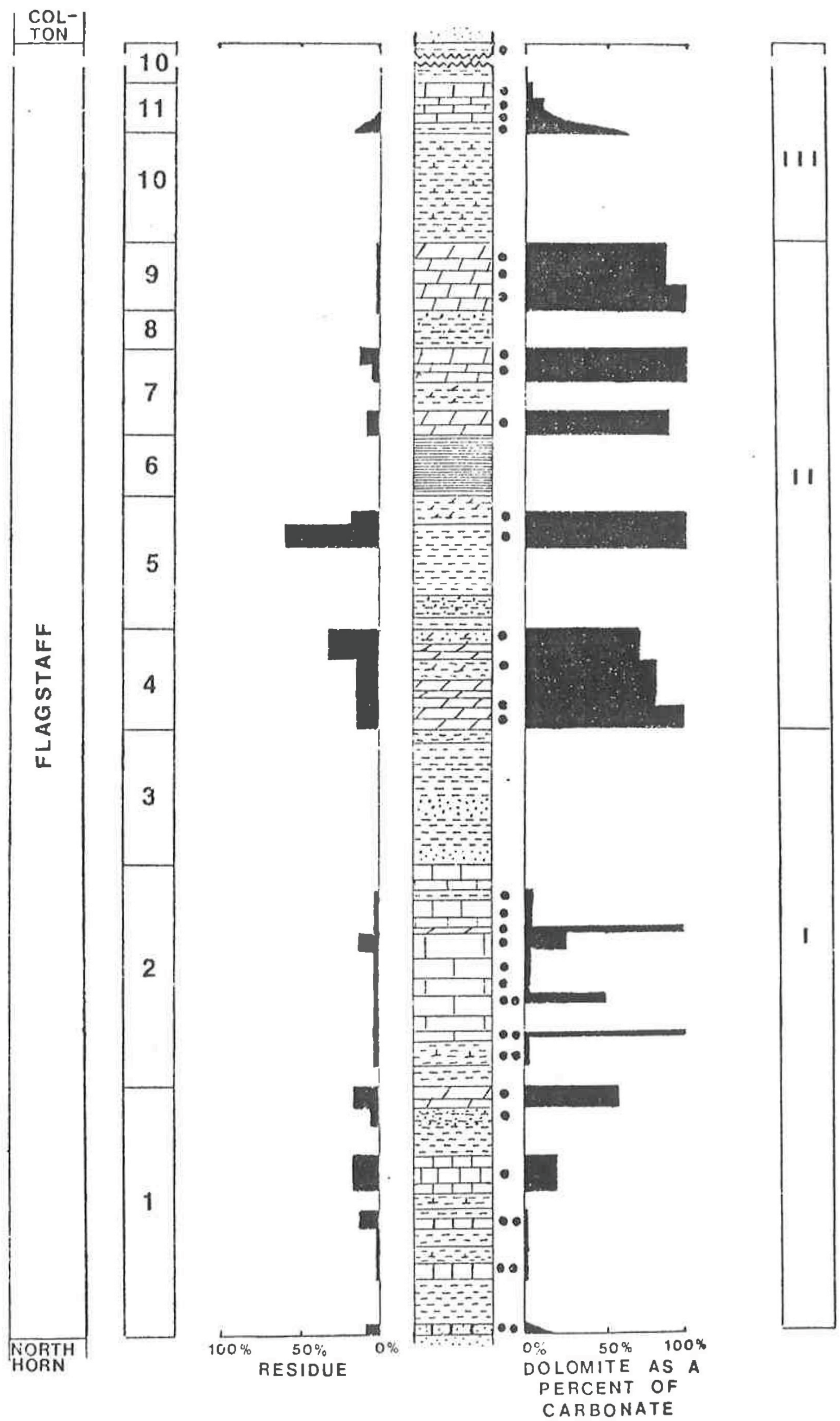


Fig. 15. Ephraim Canyon, measured section B (see Fig. 17 for explanation of symbols). Break in unit 10 represents 225 feet of homogeneous strata. The unit has been telescoped due to space limitations. Vertical scale 1' = 100'.

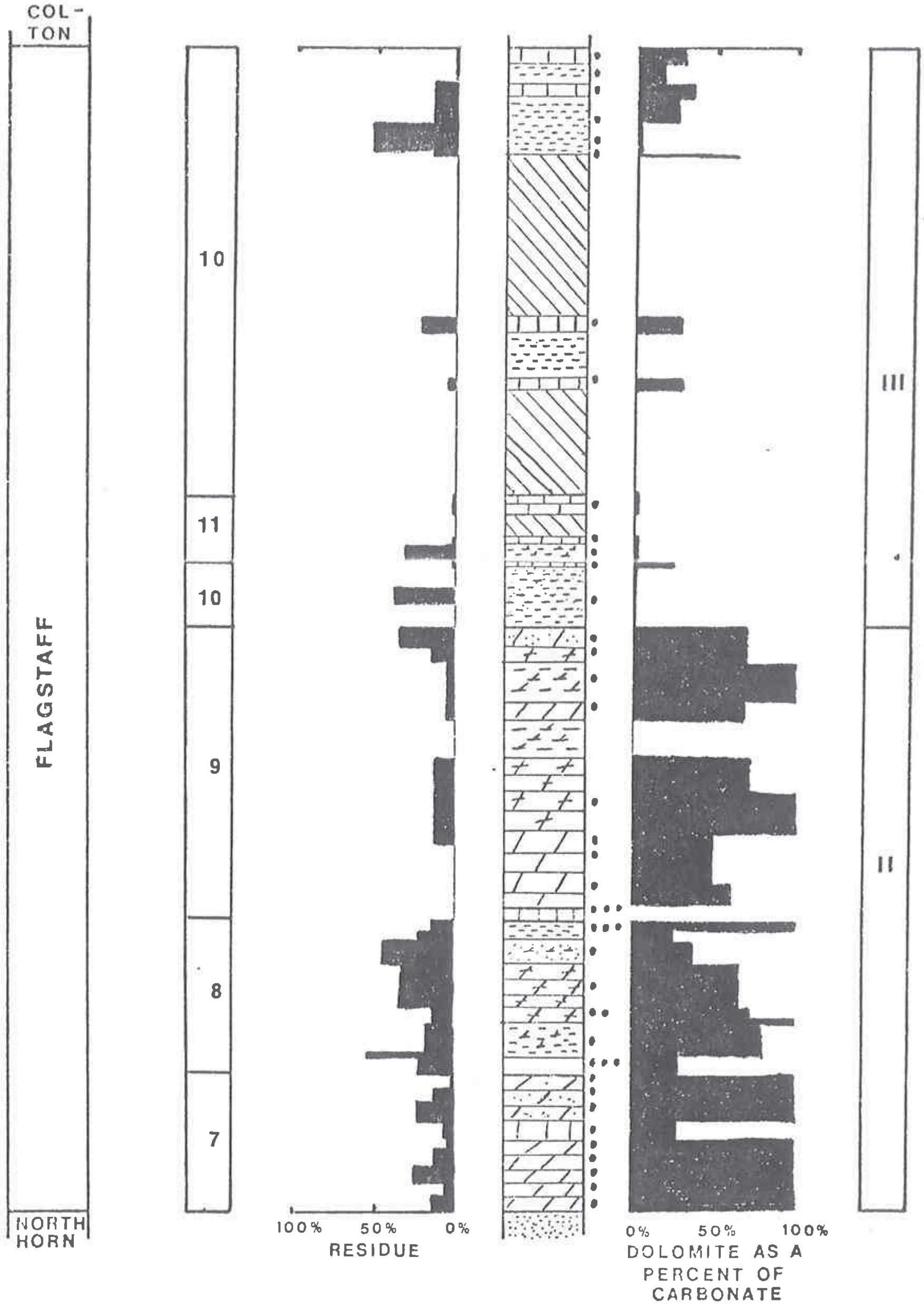


Fig. 16. Petes Canyon, measured section K (see Fig. 17 for explanation of symbols). Vertical scale: 1" = 100'.

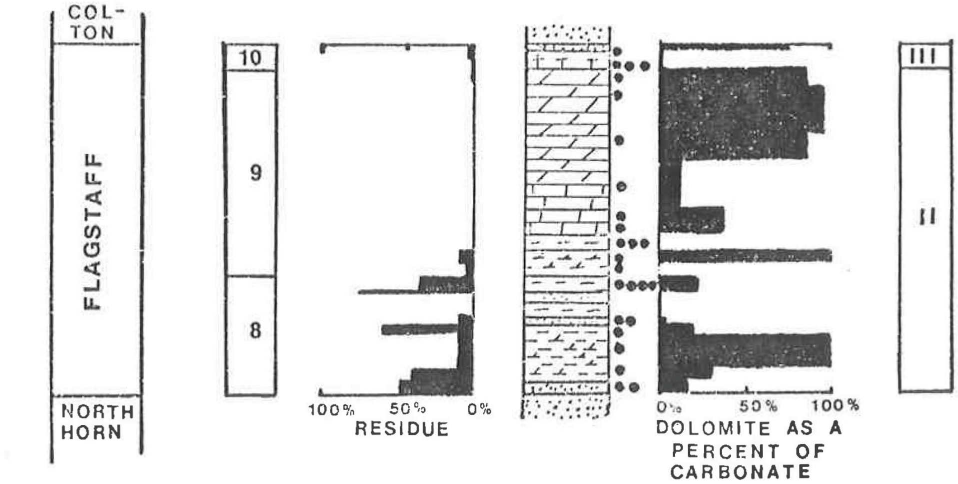
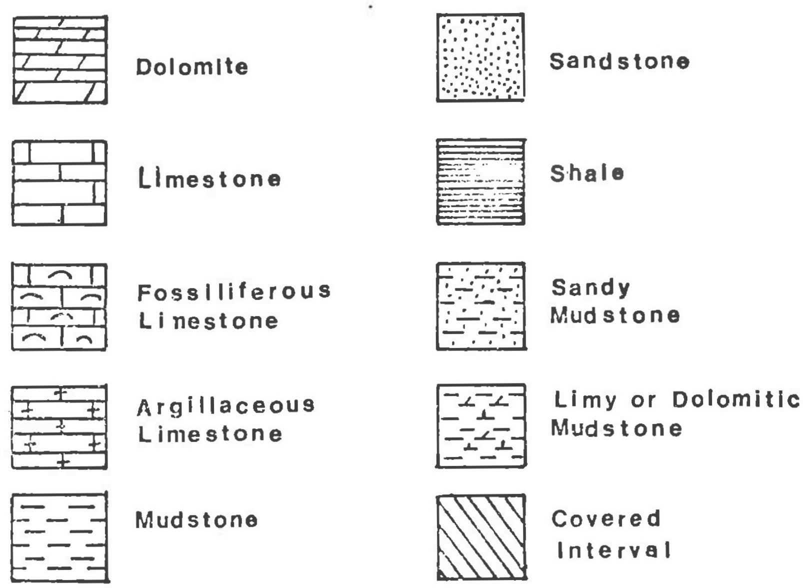


Fig. 17. Snows Canyon, measured section G. Vertical scale: 1" = 100'.

EXPLANATION OF SYMBOLS FOR FIGURES 15, 16, and 17.

1 Informal units defined in this paper.

I Lake phases defined by La Rocque (1960).



Appendix C – Copy of Pratt and Callaghan (1970) analytical results and sample location data

Table 16. Analyses of carbonate rocks from the Green River Formation and the Flagstaff Limestone.

Locality No.[a]	percent CaO	MgO	Insoluble	SiO_2	Fe_2O_3 and Al_2O_3	Ignition loss	A = selected analyses[b]
Green River Formation							
5	37.5	11.2	11.2	10.0	1.2	40.0	A
6	44.0	8.2	5.2	4.2	1.0	42.6	A
7	39.0	10.0	7.6	6.0	1.6	42.5	A
8	38.0	8.3	13.5	12.0	1.5	39.0	
9	44.0	7.9	5.2	4.0	1.2	42.0	
10	31.8	14.7	13.5	9.3	4.2	40.0	
13	39.8	8.6	9.5	8.4	1.1	41.0	A
25	43.5	6.2	7.0	6.0	1.0	42.0	A
36	27.0	15.5	16.3	14.0	2.3	39.8	A
42	32.5	14.4	11.0	10.0	1.0	40.5	A
45	21.2	9.8	41.8	40.0	1.8	27.0	
46	32.7	18.8	5.2	2.4	2.8	43.3	A
Flagstaff Limestone							
1	52.9	17.9	3.4			41.8	A
2	31.0	1.8	9.6			41.4	A
3	32.8	18.6	5.6			42.9	A
14	33.6	16.8	7.4	3.7	3.7	42.2	A
15	31.5	20.2	4.0	3.0	1.0	44.3	A
17	29.9	15.8	14.5	11.0	3.5	39.8	
19	34.8	18.6	2.0	2.0	.0	44.6	A
20	54.5	0.8	1.0	1.0	.0	43.7	
21	54.4	0.8	1.0	1.0	.0	43.8	A
22	54.5	0.8	1.0	1.0	.0	43.7	
23	54.5	0.8	1.0	1.0	.0	43.7	
24	54.0	1.2	1.0	1.0	.0	43.8	
27	32.9	14.4	13.4	10.5	2.9	39.3	A
27	37.1	16.5	2.0	2.0	.0	44.4	A
31	31.0	16.5	12.0	10.0	2.0	40.5	A
31	28.8	15.8	18.0	13.0	5.0	37.4	A
34	31.6	22.2	1.6			44.4	A
37	31.2	17.4	9.8	6.0	3.8	41.6	A
38	54.2	0.8	1.0	1.0	.0	44.4	A
39	54.0	0.8	2.0	1.0	1.0	43.2	A
40	48.7	3.5	6.3	3.0	3.3	41.5	A
48	51.1	3.1	2.0	1.0	1.0	43.8	
49	54.5	0.8	1.0	1.0	.0	43.7	A
51	29.5	19.8	8.5			42.0	A
51	29.5	23.5	1.6			45.2	A
52	53.3	2.2	1.6			42.6	A
52	53.0	2.1	2.2			42.5	
Theoretical limestone							
	56.0					44.0	
Theoretical dolomite							
	30.4	21.7				47.9	

[a] Used to obtain an average Sanpete County Green River and Flagstaff limestone analyses.

Pratt and Callaghan, 1970

Utah Geological and Mineralogical Survey, Bulletin 85, 1970

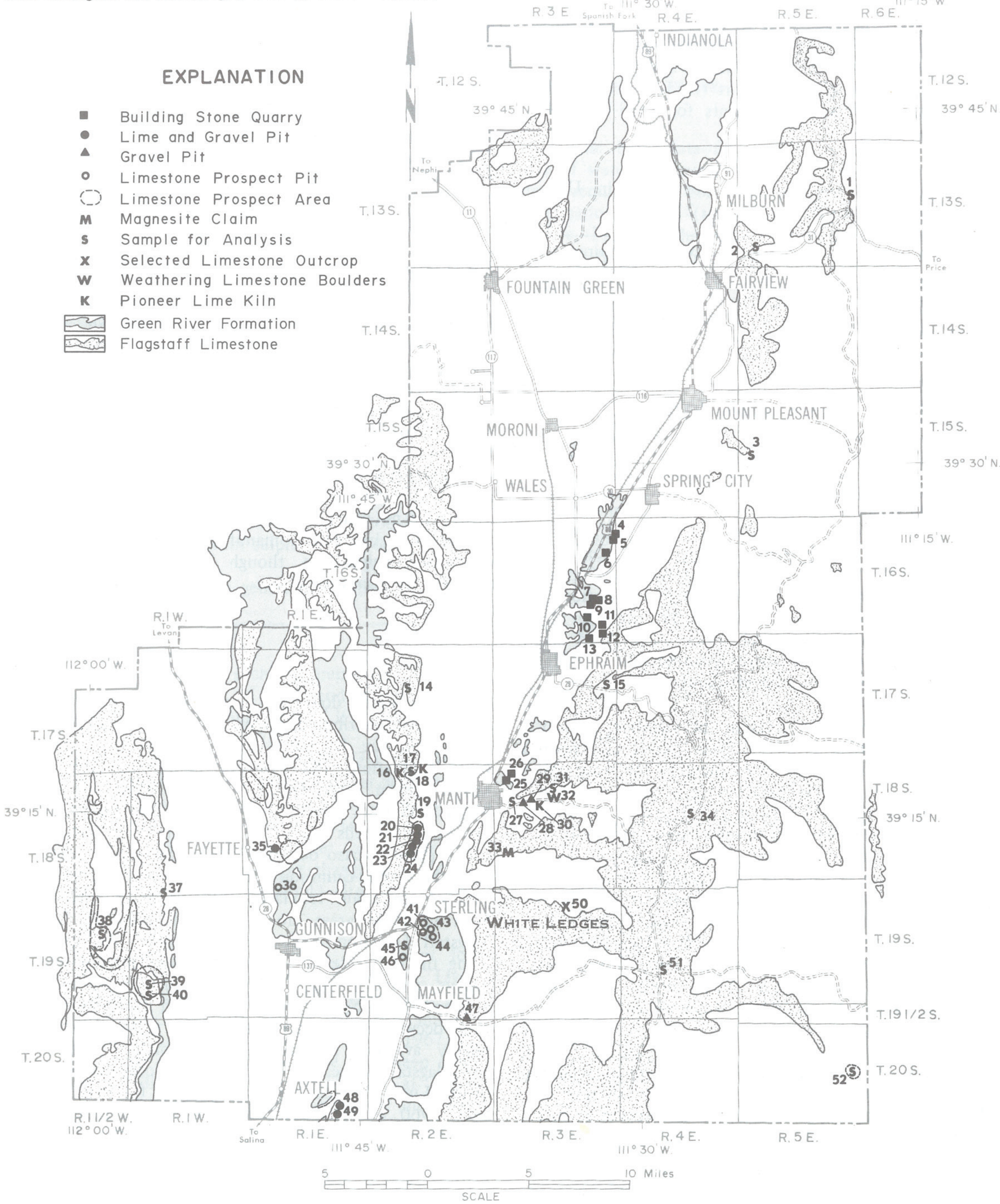


Figure 9. Carbonate rock localities, Sanpete County.

Pratt and Callaghan, 1970

Table 17. Sample localities for carbonate rocks in Sanpete County.

Locality No.	Location				Formation	Commercial Commodity	A=samples analyzed
	1/4	Sec.	Township	Range			
1	CN½	13	13S	5E	Flagstaff		A
2	NE	31	13S	5E	Flagstaff		A
3	CS½	18	15S	5E	Flagstaff		A
4	SW	1	16S	3E	Green River	Building stone	
5	SW	1	16S	3E	Green River	Building stone	A
6	SW	12	16S	3E	Green River	Building stone	A
7	SE (2 quarries)	23	16S	3E	Green River	Building stone	A
8	SW	24	16S	3E	Green River	Building stone	A
9	NE	26	16S	3E	Green River	Building stone	A
10	CS½	26	16S	3E	Green River	Building stone	A
11	SE	26	16S	3E	Green River	Building stone	
12	NE	35	16S	3E	Green River	Building stone	
13	SE	35	16S	3E	Green River	Building stone	A
14	SE	17	17S	2E	Flagstaff		A
15	CN½	13	17S	3E	Flagstaff		A
16	NE	5	18S	2E		(lime kiln)	
17	NE	5	18S	2E	Flagstaff		A
18	NW	4	18S	2E		(lime kiln)	
19	NW	16	18S	2E	Flagstaff		A
20	NW	21	18S	2E	Flagstaff	Lime and gravel	A
21	CW½	21	18S	2E	Flagstaff	Lime and gravel	A
22	SW	21	18S	2E	Flagstaff	Lime and gravel	A
23	NE	29	18S	2E	Flagstaff	Lime and gravel	A
24	CE½	29	18S	2E	Flagstaff	Lime and gravel	A
25	SW (2 quarries)	6	18S	3E	Green River	Building stone	A
26	SW (5 quarries)	6	18S	3E	Green River	Building stone	
27	SE	7	18S	3E	Flagstaff		A
28	SW	8	18S	3E	Flagstaff	Talus gravel	
29	SE	8	18S	3E	Flagstaff	Talus gravel	
30	SE	8	18S	3E		(lime kiln)	
31	NE	9	18S	3E	Flagstaff		A
32			18S	3E	Flagstaff	(weathered boulders)	
33	NE	30	18S	3E	North Horn (?)	Magnesite claim	
34	NE	15	18S	4E	Flagstaff		A
35	SW	20	18S	1E	Flagstaff	Lime and gravel	
36	SW	32	18S	1E	Green River		
37	CS½	32	18S	1W	Flagstaff		A
38	CS½	11	19S	1½W	Flagstaff		A
39	SE	30	19S	1W	Flagstaff		A
40	NE	31	19S	1W	Flagstaff		A
41	SW	9	19S	2E	Green River		
42	SW	9	19S	2E	Green River		A
43	CS½	9	19S	2E	Green River		
44	NE	16	19S	2E	Green River		
45	SE	17	19S	2E	Green River		A
46	SE	17	19S	2E	Green River		A
47	NW	2	20S	2E	Flagstaff	Talus gravel	
48	NW	26	20S	1E	Flagstaff	Lime and gravel	A
49	SW	26	20S	1E	Flagstaff	Lime and gravel	A
50	SW	3	19S	3E	Flagstaff	White Ledges	
51	CW½	21	19S	4E	Flagstaff		A
52	CW½	13	20S	5E	Flagstaff		A

Pratt and Callaghan, 1970

Appendix D – Copy of U.S. Steel (1957) exploration results for the Fayette deposit

(The Utah Geological Survey and U.S. Steel do not make any representations or warranties, expressed or implied, of any kind or nature, whatsoever, with respect to the accuracy, reliability, or completeness of this information or matter. Any use of or reliance upon this information or matter by any person, firm, or corporation shall be at his or its sole risk, liability, and responsibility.)

FAYETTE LIMESTONE DEPOSIT
Sanpete County, Utah

Summary

Location and Accessibility

The Fayette limestone deposit is located in Sections 15-22, and 27-30, T 18 S-R 1 E, S.L.B.M., Sanpete County, Utah. It lies 1.8 miles east of Fayette, Utah. A graded dirt road crosses the property and connects with state highway No. 28 at Fayette. It is six miles from Fayette to the Gunnison siding of the Denver and Rio Grande Railroad via existing roads, and 99 miles from Gunnison siding to Geneva by rail.

Ownership

The 45 unpatented claims covering the deposit are held by M. J. Hill (Rt. 2, Box 375, Provo, Utah) and J. R. Driggs (279 Hubbard Avenue, Salt Lake City, Utah).

Geologic Setting

The limestone beds strike about N 70 E and dip 5 to 10 degrees to the southeast. Total thickness of the formation is on the order of one hundred feet.

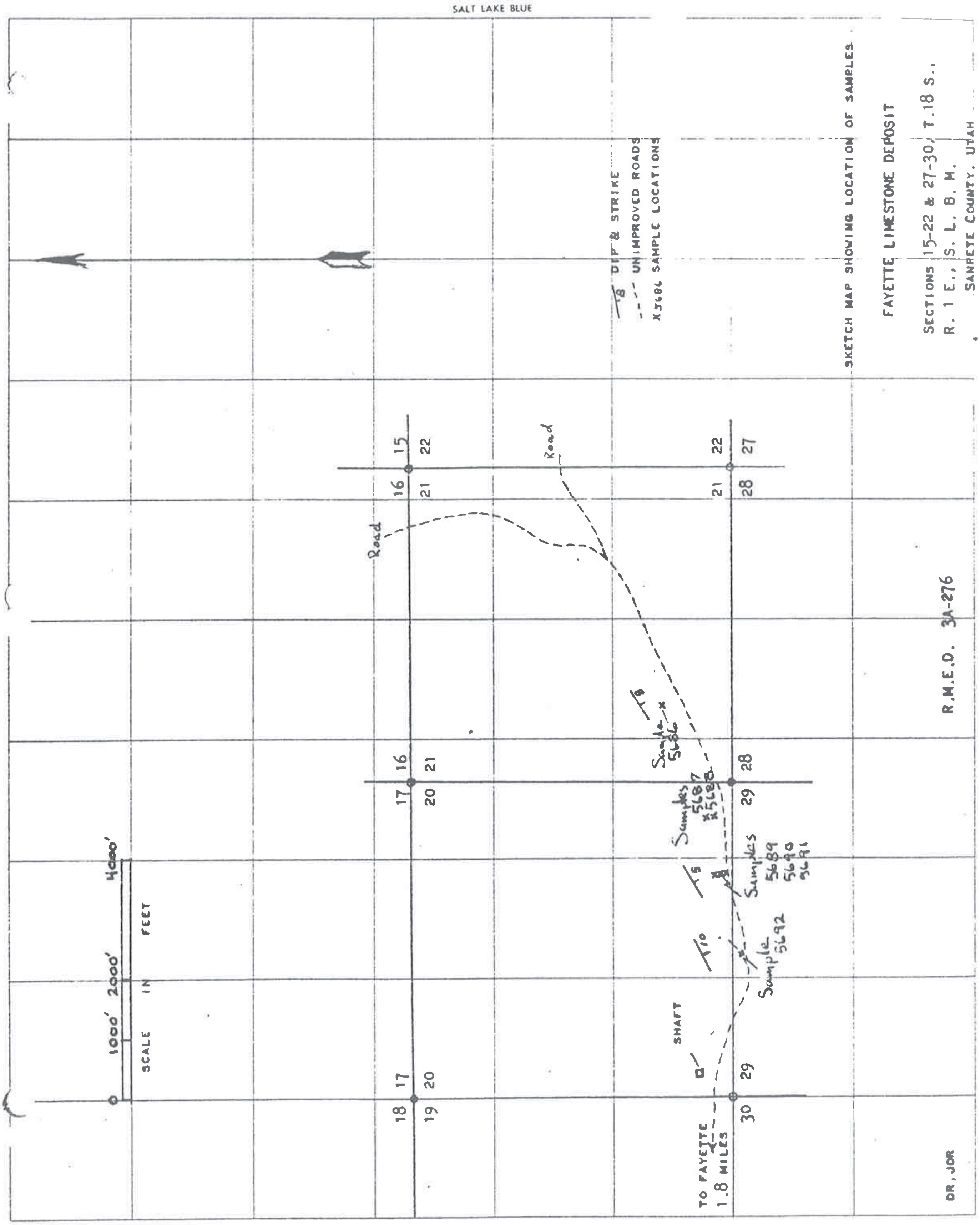
Analyses

Results of analysis of seven chip samples are listed in the table below.

Fayette Limestone Deposit
Sanpete County, Utah

Sample No.	Thickness (Feet)	Analyses %				
		SiO_2	CaO	MgO	Al_2O_3	S
5686	4	0.60	37.90	14.90	-	0.39
5687	15	0.30	54.94	0.29	-	0.022
5688	20	2.75	48.75	3.82	-	0.024
5689	25	0.80	45.00	7.92	-	0.009
5690	20	4.40	39.00	11.74	-	0.026
5691	18	5.00	44.20	7.21	-	0.037
5692	10	0.20	53.40	1.55	-	0.025

Sample 5687 is the only one that falls within the one per cent maximum limit for silica and for magnesia specified for open hearth limestone use. The stratigraphic interval represented by sample 5687 is also covered by the submarginal sample 5688. This suggests that the chemical composition of the limestone is variable. See sketch Map 3A-276 for the location of samples.


SALT LAKE BLUE
SKETCH MAP SHOWING LOCATION OF SAMPLES
FAYETTE LIMESTONE DEPOSIT
SECTIONS 15-22 & 27-30, T. 18 S.,
R. 1 E., S. L. B. M.
SANPETE COUNTY, UTAH
DIP & STRIKE
UNIMPROVED ROADS
X5686 SAMPLE LOCATIONS
R.M.E.D. 3A-276
SCALE IN FEET
1000' 2000' 4000'
Road
Road
Sample 5686
Samples 5687 5688
Samples 5689 5690 5691
Sample 5692
SHAFT
TO FAYETTE 1.8 MILES
DR, JOR

Much of the potential open hearth limestone is intensely shattered, which indicates that difficulty might be experienced in maintaining the 9 by 2½ inch size requirement for open hearth use.

Tonnage Estimates and Mining Considerations

No estimates of tonnage available were made, considering that the sample analyses obtained were unfavorable for the occurrence of acceptable open hearth limestone in quantity. However, the potential open hearth quality bed is exposed or lies at shallow depth throughout most of the area covered by 45 claims (dimensions 600 by 1500 feet each), indicating a very large tonnage.

The deposit is amenable to open pit mining methods. Maximum stripping depth is seldom greater than 10 feet.

Conclusions and Recommendations

The property contains a large tonnage of limestone that could be mined at relatively low cost. Chemical analyses suggest that the limestone is variable in composition and that it is over allowable limits in silica and magnesia content. The limestone is highly shattered and much of it probably does not meet physical size requirements.

No further work on the deposit is recommended at this time.

Appendix E – Copy of U.S. Steel (1957) exploration results for the Manti deposit

(The Utah Geological Survey and U.S. Steel do not make any representations or warranties, expressed or implied, of any kind or nature, whatsoever, with respect to the accuracy, reliability, or completeness of this information or matter. Any use of or reliance upon this information or matter by any person, firm, or corporation shall be at his or its sole risk, liability, and responsibility.)

MANTI LIMESTONE DEPOSIT
Sanpete County, Utah

Summary

Location

The Manti deposit is located in Sections 20, 21, and 29, T 18 S-R 2 E, S.L.B.M., Sanpete County, Utah. It lies near the southwest end of Gunnison Reservoir, near Manti, Utah.

Accessibility

Truck haulage distance to a siding near Sterling, Utah, is approximately a mile from the southern end of the deposit via unimproved dirt roads and a jeep trail. No loading facilities are available at the Sterling siding. Rail distance from the siding to Geneva is 93 miles.

Weather conditions are considered conducive to year-round operations.

Ownership

The Utah Lime and Stone Company has placer claims covering the area. Field examination of location and assessment work notices indicates no assessment work has been done for several years.

Geologic Setting

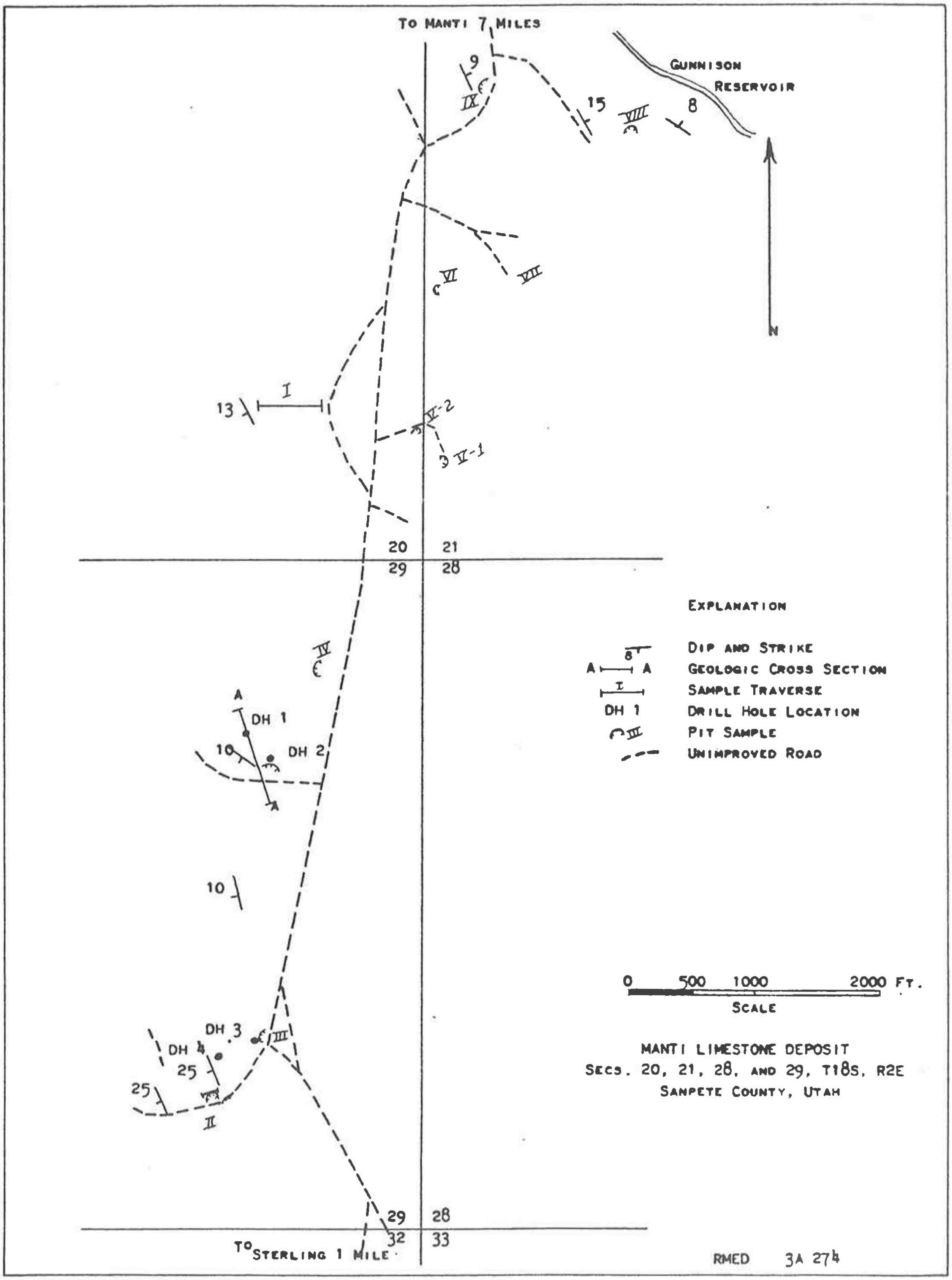
The deposit consists of alternating limestones and dolomites of undetermined age. Areal dip is generally westward at a low angle, with local flexures and faults present. Toward the north end of the deposit, dip is locally eastward.

The potential open hearth stone horizon is very poorly exposed and considerably displaced by faulting. Continuous tracing of the bed is difficult. The greatest known thickness of the potential horizon is 45 feet, and this may approach the maximum for the bed.

The reconnaissance map (3A-274) shows sample locations and a few physical features. Further detail on this deposit was not considered warranted in view of the chemical analyses of the stone.

Analyses

Sample line I represents chemical analyses of the stratigraphy above the potential stone horizon. Sample line II includes most of the potential stone horizon. Samples III through IX represent grab samples taken in pits at scattered locations throughout the deposit.



MANTI LIMESTONE DEPOSIT
Secs. 20, 21, 28, and 29, T18S, R2E
Sanpete County, Utah

Manti Limestone
Sanpete County, Utah

Sample Traverse or Location	Thickness (Ft.) Where Applicable	Analyses %				
		SiO_2	CaO	MgO	Al_2O_3	S
I	8.5	0.40	53.70	1.34	0.12	-
I	118.3	Predominantly shale				
I	130.4	1.89	36.28	15.23	0.25	-
II	38.4	0.64	51.83	2.79	0.18	-
III	Grab	0.20	54.19	1.00	0.18	-
Composite IV, V-2, VI, VII, VIII and IX	Grab	0.27	53.38	1.74	0.16	-
V-1	Grab	0.32	55.40	0.79	0.41	-
11 R.R. cars from Quarry	-	0.50	53.86	1.23	0.14	-
Drill Hole 1*	27.7	1.26	53.35	1.43	-	-
Drill Hole 2*	35.0	1.00	53.90	1.05	-	-
Drill Hole 3*	45.0	0.89	54.70	0.46	-	-
Drill Hole 4*	21.0	0.71	52.80	1.96	-	-
Wtd. Avg. above drill holes	32.2	0.97	53.88	1.07	-	-

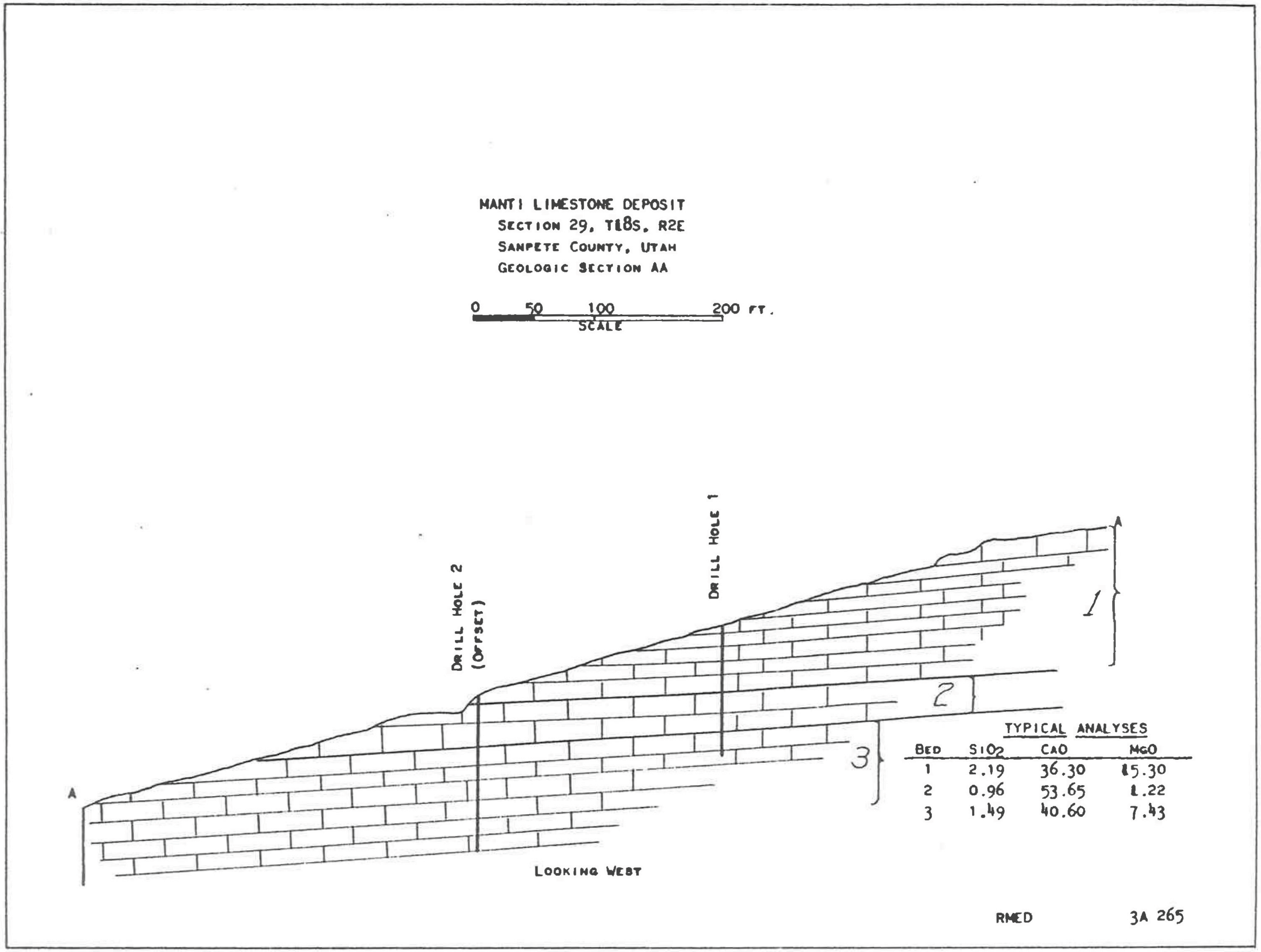
*Information from Utah Lime and Stone Company.

Tonnage Estimates

Because of off-grade characteristics and difficulty in correlation of the beds, no tonnage estimates have been made for the deposit.

Mining Considerations

Were the deposit to be mined, a more detailed study and perhaps drilling would be required to formulate a reasonable mining method. Near the quarry, a considerable amount of cover is present (Section 3A-265). Moderate cover exists near Sample III and elsewhere. In general, the area would involve open-pit type mining.



TYPICAL ANALYSES

BED	SiO_2	CaO	MgO
1	2.19	36.30	15.30
2	0.96	53.65	1.22
3	1.49	40.60	7.43

Conclusions and Recommendations

The magnesia content at the Manti deposit is generally in excess of one per cent. Silica and lime contents would probably meet desired open hearth specifications. The potential stone horizon is relatively thin, averaging probably less than 35 feet, and finally, stripping would be required to recover the stone. These factors indicate the deposit is not a desirable source of open hearth stone at the present time.

Appendix F – UGS analytical data

Appendix F. UGS Analytical Data

Sample No.	Application	CaO	CaCO3	MgO	MgCO3	SiO2	Na2O	Al2O3	P2O5	S/SO3*	Cl	K2O	TiO2	MnO	Fe2O3	Total
		(results are reported in weight percent)														
SP-1	UGS-DOLO-DOLv2	33.61	59.99	14.08	29.46	9.75	0.034	1.02	0.073	0.055		0.238		0.014	0.392	101.03
SP-2	UGS-HICAL-LSv7	54.68	97.60	0.67	1.40	0.35	0.037	0.096	0.049	0.002	0.005	0.007	0.010	0.001	0.086	99.64
SP-3	UGS-HICAL-LSv7	54.05	96.46	1.06	2.22	0.32	---	0.084	0.060	0.000	0.005	0.013	0.009	---	0.095	99.27
SP-4	UGS-HICAL-LSv7	53.59	95.65	1.72	3.59	0.20	---	0.041	0.038	0.001	0.006	0.011	0.010	---	0.078	99.63
SP-5	UGS-HICAL-LSv7	49.65	88.62	1.10	2.29	3.54	0.094	0.580	0.083	0.068	0.007	0.150	0.041	0.047	1.558	97.08
SP-6	UGS-DOLO-DOLv2	26.14	46.65	13.53	28.31	21.51	0.027	3.156	0.019	0.038		0.61		0.041	1.222	101.58
SP-7	UGS-DOLO-DOLv2	31.33	55.92	19.20	40.16	1.09	0.087	0.328	0.006	0.024		0.017		0.021	0.218	97.88
SP-8	UGS-DOLO-DOLv2	31.41	56.06	18.99	39.72	1.08	0.089	0.332	0.01	0.013		0.011		0.033	0.306	97.66
SP-9	UGS-DOLO-DOLv2	30.75	54.88	18.80	39.33	1.23	0.107	0.285	0.032	0.021		0.016		0.039	0.348	96.29
SP-10	UGS-HICAL-LSv7	47.42	84.63	6.15	12.86	1.38	0.080	0.018	0.115	0.009	0.023	0.022	0.007	---	0.072	99.22
SP-11	UGS-HICAL-LSv7	53.10	94.76	0.53	1.12	1.94	---	0.346	0.051	0.001	0.005	0.031	0.023	0.007	0.125	98.41
SP-12	UGS-HICAL-LSv7	48.77	87.04	1.67	3.50	4.76	0.022	0.720	0.061	0.001	0.008	0.193	0.042	0.043	0.333	96.72
SP-13	UGS-HICAL-LSv7	48.42	86.42	2.01	4.20	4.50	0.074	0.634	0.098	0.025	0.012	0.177	0.042	0.028	0.525	96.73
SP-14	UGS-HICAL-LSv7	53.56	95.60	0.65	1.37	0.81	0.012	0.204	0.046	0.003	0.005	0.015	0.018	0.009	0.135	98.22
SP-15	UGS-HICAL-LSv7	54.08	96.52	0.66	1.39	0.68	0.066	0.166	0.031	0.002	0.004	0.024	0.016	0.009	0.100	99.00
SP-16	UGS-DOLO-DOLv2	30.71	54.81	16.76	35.06	9.16	0.082	1.222	0.04	0.045		0.352		0.012	0.392	101.18
SP-17	UGS-HICAL-LSv7	53.26	95.06	0.43	0.91	1.80	0.070	0.371	0.052	0.004	0.002	0.034	0.019	0.011	0.133	98.47
SP-18	UGS-HICAL-LSv7	54.14	96.63	0.54	1.12	0.50	---	0.109	0.029	0.001	0.003	0.019	0.017	0.011	0.153	98.59
SP-19	UGS-HICAL-LSv7	50.53	90.18	0.39	0.81	4.44	---	0.743	0.050	0.001	0.003	0.125	0.045	0.013	0.300	96.71
SP-20	UGS-HICAL-LSv7	52.79	94.22	2.05	4.28	0.74	0.009	0.074	0.023	0.002	0.005	0.022	0.010	0.005	0.103	99.49
GR-Milburn-01	UGS-HICAL-LSv7	47.75	85.22	6.53	13.65	4.06	0.093	0.301	0.012	0.035	0.161	0.092	0.019	0.030	0.173	103.85
GR-Milburn-02	UGS-DOLO-DOLv2	34.79	62.09	8.53	17.85	15.73	0.164	0.689	0.029	0.095		0.12		0.019	0.276	97.06
GR-Milburn-03	UGS-DOLO-DOLv2	37.39	66.73	13.93	29.13	6.06	0.138	0.256	0.036	0.071		0.077		0.016	0.067	102.58
GR-Milburn-04	UGS-DOLO-DOLv2	33.95	60.59	9.87	20.65	8.63	0.156	0.152	0.002	0.045		0.09		0.016	0.097	90.42
GR-Milburn-05	UGS-HICAL-LSv7	47.97	85.61	3.68	7.70	5.16	0.020	---	0.000	0.003	0.009	0.005	0.005	0.113	---	98.63
GR-Milburn-06	UGS-DOLO-DOLv2	29.37	52.42	14.74	30.84	10.94	0.081	0.462	0.001	0.082		0.137		0.014	0.186	95.17
GR-Milburn-07	UGS-DOLO-DOLv2	37.00	66.04	14.03	29.34	5.64	0.067	0.137	0.03	0.032		0.074		0.023	0.097	101.49

*The UGS-HICAL-LSv7 application reports sulfur as an element; the UGS-DOLO-DOLv2 application reports sulfur as an oxide (SO3).
--- indicates below detection limit

Appendix F (continued). UGS Analytical Data

Analytical test standard results (reported in weight percent)

	CaO	MgO	SiO2	Na2O	Al2O3	P2O5	S	Cl	K2O	TiO2	MnO	Fe2O3
UGS-HICAL-LSv7 Test Standard NCS DC 60107												
Actual Value	53.27	1.4	1.98	0.026	0.29	0.0088	0.007	0.0034	0.059	0.016	0.0045	0.14
Analytical run Aug 16, 2010	53.32	1.31	1.71	0.058	0.286	0.029	0.015	0.005	0.063	0.016	0.002	0.155
Analytical run Aug 17, 2010 (1)	53.74	1.40	1.72	0.083	0.286	-0.003	0.018	0.006	0.065	0.013	0.003	0.153
Analytical run Aug 17, 2010 (2)	53.52	1.35	1.72	0.053	0.292	0.021	0.016	0.006	0.061	0.016	0.002	0.152
Analytical run Aug 17, 2010 (3)	53.41	1.34	1.72	0.012	0.279	0.011	0.01	0.006	0.061	0.017	0.002	0.151
UGS-HICAL-LSv7 Test Standard NCS DC 60108												
Actual Value	50.38	2.28	4.38	0.07	0.64	0.013	0.006	0.0039	0.14	0.034	0.0071	0.29
Analytical run Aug 16, 2010	50.28	2.20	3.78	0.047	0.663	0.033	0.013	0.004	0.136	0.035	0.007	0.328
Analytical run Aug 17, 2010 (2)	50.41	2.31	3.78	0.052	0.655	0.016	0.014	0.004	0.137	0.039	0.006	0.329

	CaO	MgO	SiO2	Na2O	Al2O3	P2O5	SO3		K2O		MnO	Fe2O3
UGS-DOLO-DOLv2 Test Standard NCS DC 14021A												
Actual Value	35.02	17.88	0.049	0.013	0.024	0.0027	0.023		0.001		0.02	0.495
Analytical run Aug 19, 2010	34.85	17.68	0.05	0.09	0.01	0.006	0.037		-0.004		0.021	0.494
Analytical run Aug 23, 2010	34.40	17.48	0.06	0.016	0.008	0.011	0.037		-0.003		0.02	0.485
UGS-DOLO-DOLv2 Test Standard NCS DC 18007												
Actual Value	28.57	19.84	5.01	0.031	1.05		0.05		0.68			0.56
Analytical run Aug 19, 2010	29.03	19.68	3.73	0.038	1.019	-0.017	0.038		0.675		0.013	0.576
Analytical run Aug 23, 2010	28.73	19.61	4.13	0.081	1.028	-0.01	0.034		0.68		0.012	0.575

Appendix G – Location and geologic information for UGS samples

Appendix G. Location and geologic information for UGS Samples

Coordinates are UTM Z12 NAD83

Sample Number	UTM N (m)	UTM E (m)	Formation	Sample Thickness (ft)	Sampler	Brief Geologic Description
SP-1	4329859	418659	Flagstaff Limestone	40	A. Rupke	dolomitic mudstone
SP-2	4329871	418275	Flagstaff Limestone	15	A. Rupke	micrite/lime mudstone
SP-3	4340930	438272	Flagstaff Limestone	17	A. Rupke	micrite/lime mudstone
SP-4	4340932	438255	Flagstaff Limestone	16	A. Rupke	micrite/lime mudstone
SP-5	4364736	438860	Flagstaff Limestone	2	A. Rupke	lime mudstone to packstone
SP-6	4364650	438742	Flagstaff Limestone	16	A. Rupke	sandy dolomite
SP-7	4358068	440121	Flagstaff Limestone	17	A. Rupke	dolomitic mudstone
SP-8	4358074	440123	Flagstaff Limestone	40	A. Rupke	dolomitic mudstone
SP-9	4358076	440139	Flagstaff Limestone	40	A. Rupke	dolomitic mudstone
SP-10	4397002	459524	Green River Formation	5	A. Rupke	lime mudstone
SP-11	4338915	418919	Flagstaff Limestone	19	A. Rupke	micrite/lime mudstone
SP-12	4350420	416958	North Horn Formation	4	A. Rupke	lime mudstone
SP-13	4340627	416154	Flagstaff Limestone	7	A. Rupke	argillaceous lime mudstone
SP-14	4343873	429223	Flagstaff Limestone	18	A. Rupke	micrite/lime mudstone
SP-15	4343861	429224	Flagstaff Limestone	26	A. Rupke	micrite/lime mudstone
SP-16	4347256	432659	Flagstaff Limestone	6	A. Rupke	dolomitic mudstone (sandy?)
SP-17	4340675	416839	Flagstaff Limestone	20	A. Rupke	micrite/lime mudstone
SP-18	4348744	414429	Flagstaff Limestone	15	A. Rupke	micrite/lime mudstone
SP-19	4348737	414420	Flagstaff Limestone	18	A. Rupke	micrite/lime mudstone
SP-20	4328380	442737	Flagstaff Limestone	21	A. Rupke	micrite/lime mudstone

Notes: Thicknesses are approximate. Samples 3 and 4, 7 through 9, 14 and 15, and 18 and 19 are continuous sections. Coordinate is from the base of sample interval.

Samples below are a continuous section:

Sample Number	UTM N (m)	UTM E (m)	Formation	Sample Thickness (ft)	Sampler	Brief Geologic Description
GR-Milburn-01	4390092	461814	Green River Formation	1.8	B. Tripp	*
GR-Milburn-02	4390092	461814	Green River Formation	0.4	B. Tripp	*
GR-Milburn-03	4390092	461814	Green River Formation	1.4	B. Tripp	*
GR-Milburn-04	4390092	461814	Green River Formation	0.5	B. Tripp	*
GR-Milburn-05	4390092	461814	Green River Formation	1.7	B. Tripp	*
GR-Milburn-06	4390092	461814	Green River Formation	0.2	B. Tripp	*
GR-Milburn-07	4390092	461814	Green River Formation	2.3	B. Tripp	*

*Zone is oolitic, dolomitic limestone interbedded with argillaceous limestone

Appendix G (continued). Location and geologic information for UGS samples

Geologic notes:

SP-1

Light buff to cream-colored dolomitic mudstone. Sparry calcite common. Chalky white intraclasts in some areas (almost a breccia texture?). Minor, red hematitic staining in some areas. Outcrop has scaly weathing appearance with pieces spalling off. Unit is cliff-forming where sampled, but is slope-forming in other areas. Sampled section represents about 40 feet.

SP-2

Light gray to light buff micrite. Has a slightly sugary texture. Small dark specks observed (manganese?). Possible minor fenestral/bird's eye structure. Thin, orange, clay-filled stylolite observed. Unit is resistant and ledge forming where sampled. Sampled section represents about 15 feet.

Unit forms a dip slope in a small area where sampled. Was sampled near the road in section 32, T. 19 S., R. 1 W. (SLBLM).

SP-3

Light gray to light buff micrite. Minor cream-colored mottling (burrow mottling?). Secondary calcite in linear vugs is common (vugs follow burrows?). Minor hematitic staining. Unit is mostly slope-forming in the area. Possible fenestral/bird's eye structure. Sampled section represents about 17 feet.

Stratigraphically, this sample lies directly below SP-4. Limestone is abundant in this area, but is primarily slope-forming.

SP-4

Light gray to light buff micrite. Some sparry calcite present. A few covered intervals appear to be present in the unit that are only a few inches each. Covered intervals appear to be higher in dolomitic content. Slope-forming where sampled. Sampled section represents about 16 feet. Stratigraphically directly above SP-3.

SP-5

Gray to brownish gray lime mudstone to packstone. Black specks are common (possibly manganese). Slight argillaceous content. Forms a discontinous small ledge where sampled. Sampled section represents about 2 feet.

SP-6

Light gray (sandy?) dolomite. Cliff-forming where sampled, but also observed to be slope-forming. Sampled section represents about 16 feet.

SP-7

Gray dolomitic mudstone. White sparry calcite is common. Unit is ledge-forming. Sampled section represents about 17 feet.

Samples SP-7, SP-8, and SP-9 represent a continuous section. They form the crest of a small hill on the west side of Sanpete Valley that would be readily mineable with little or no stripping. Stratigraphically, SP-7 is the bottom and SP-9 is the top.

SP-8

Gray dolomitic mudstone. White sparry calcite is common. Hematitic staining and grungy/crumbly alteration present in some areas. Unit is ledge-forming. Sampled section represents about 40 feet.

See notes on SP-7.

SP-9

Gray to pinkish dolomitic mudstone. White sparry calcite common. Reddish, hematitic alteration is present. Small (1/2 inch diameter) siliceous (?) nodules were observed, but were very minor. Sampled section represents about 40 feet.

See notes on SP-7.

SP-10

Gray micrite. Some breccia texture was observed with some white, chalky (dolomitic?) clasts. Secondary calcite is present. Unit is ledge-forming. Unit appears to be isolated limestone within more argillaceous and calcareous mudstones. Sampled section represents about 5 feet.

SP-11

Gray micrite. Minor sparry calcite observed. Minor dark, circular spots observed in limestone (possibly manganese). Unit is ledge-forming. Total thickness of limestone in the area likely exceeds the area sampled. Sampled section represents about 19 feet. Sample was collected in section 32, T. 18 S., R. 1 W. (SLBLM). Unit forms a dip-slope where sampled, and some material could be extracted with little or no stripping.

SP-12

Gray to brownish argillaceous (?) lime mudstone. Vuggy with sparry calcite. Red, hematitic staining in some areas. Appears to be an isolated limestone outcrop sampled in a road cut with siliceous units above and below. Sampled section represents about 4 feet.

SP-13

Brown to tan argillaceous lime mudstone. Outcrop is very fractured. Ledge-forming unit. Sampled section represents about 7 feet.

SP-14

Buff to dark gray micrite. Minor calcite blebs. Minor pink, hematitic staining in some areas. Unit is ledge-forming. Very difficult to sample due to smooth nature of limestone outcrop. Sampled section represents about 18 feet.

Sample is stratigraphically below and continuous with SP-15. Sampled in section 16, T. 18 S., R. 1 E. (SLBLM). This unit is well exposed on the west side of Section 16, but excessive stripping ratios would likely limit the ability to mine the unit.

SP-15

Light gray micrite. Some sparry calcite present. Minor gray dots in some areas (manganese?). Ledge-forming unit. Very difficult to sample due to smooth nature of limestone outcrop. Continuous with SP-15. Sampled section represents about 26 feet.

See notes on SP-14.

SP-16

Light gray dolomitic mudstone. Siliceous? Some clear, sparry calcite is present. Ledge-forming. Sampled section represents about 6 feet.

Unit sampled in section 2, T. 18 S., R. 1 E. (SLBLM). The exposure of Flagstaff in section 2 is not very good.

SP-17

Gray to cream-colored micrite. Some brecciated areas were noticed in unit. Breccia clasts tended to be stained orange by hematite. Unit is cliff-forming where sampled. Sampled section represents about 20 feet.

Limestone continues above sample for a few feet, and has a pinkish color throughout due to hematitic staining. Limestone also continues below sampled portion.

SP-18

Light gray to cream to buff colored micrite. Minor fenestral/bird's eye calcite. Minor hematitic staining. Ledge-forming where sampled. Sampled section represents about 15 feet.

This sample is continuous to SP-19, which lies directly below. Limestone exposure in this area is not very good due to dense vegetation. Due to marginal outcrop it was difficult to determine whether additional limestone is found above or below. It appears that some amount of limestone could be extracted in this area with low stripping.

SP-19

Buff to light gray dolomitic (?) lime mudstone. Highly fractured in some areas. Dark gray oval spots common (manganese?). Vuggy in some areas with sparry calcite. Pinkish hematitic staining is common. Slope- to ledge-forming in the area where sampled. Sampled section represents about 18 feet.

See notes on SP-18.

SP-20

Light gray to gray dolomitic (?) lime mudstone. Rock has chalky texture in some areas indicating some dolomitization. Very fractured outcrop. Rock breaks off easily. Near the base of the Flagstaff Limestone. Cliff-forming where sampled. Sampled section represents about 21 feet.

Additional limestone is above this unit. Unit sampled in section 2, T. 20 S., R. 2 E. (SLBLM). If limestone above this sample is of good quality, a small tonnage might be extractable from this site. However, a large operation may be unlikely as Manti National Forest is adjacent to site.

Appendix H – Historic and active carbonate and building stone quarries in and near Sanpete County (DOGM, 2011)

Appendix H. Historic and active carbonate and building stone quarries in and near Sanpete County (DOGM, 2011)

ID*	Quarry Name	Operator	Minerals	UTM N (m)	UTM E (m)
D-1	Three Knolls Mine	Western Clay Company	Limestone	4325848	410267
D-2	Redmond Limestone Quarry	Western Clay Company	Stone	4317351	428131
D-3	Sanpete White	Quality Building Stone, Inc.	Limestone	4365302	453925
D-4	Flower Patch Quarry	Bown Stone Products, Inc.	Limestone - Building Stone	4323852	437844
D-5	ML 45726	Farnsworth, Ron	Building Stone, Limestone	4339061	418968
D-6	Perry Estate	State Stone Corp. Inc.	Limestone - Oolite	4347186	445923
D-7	Cream Time Quarry	Jensen, Lanny	Building Stone	4325807	438262
D-8	Mayfield Quarry	Bown, Phyllis	Limestone	4323800	437556
D-9	Nine Mile Quarry	Bown, Danny	Limestone	4335081	440694
D-10	Clawson 1-2-3	U S Ferto Corporation	Building Stone	4394720	465256
D-11	Temple Strike	Day, William E.	Limestone	4333495	439323
D-12	Haas Limestone - Gunnison	Haas, Bryce	Limestone	4334570	439855
D-13	Cream Time Claim	Young, Jon	Building Stone	4334902	439813
D-14	Antelope Quarry	Bown Stone Products, Inc.	Limestone	4336892	433168
D-15	Glen Goff Property	KSC Rocks	Limestone/Flagstone	4321627	431595
D-16	B & C Limestone	Haas, Bryce	Mill(On) - Limestone/Building Stone	4338460	428051
D-17	Mayfield Quarry (B & H Quarry)	Haas, Bryce	Limestone	4328579	439163
D-18	Antelope Valley	Zamaroni Quarry, Inc.	Limestone	4337255	433881
D-19	J & J Quarries 1	Jensen, Zachery	Limestone	4326673	438433

*ID used to identify quarries in Figure 11.

Appendix I – Boleneus (2008) building stone data from Sanpete County

Appendix I. Building stone data table of Sanpete County sites from Boleneus (2008)

IDNo	Name	Alt_Name	Location_ State	Surface_Mgmt	Case_Type	Visited	Photos	Sampled	Date_Visit
140	Cream Time (DOGM's Mayfield)	Mayfield	UT	State of Utah lease/Private	State of Utah lease	Yes	Yes	Yes	June 1 2004
141	Day quarry (DOGM's Temple Strike)	Temple Strike	UT	State of Utah lease	State of Utah lease	Yes	Yes	Yes	June 1 2004
162	Nine Mile (Bown State lease)	Bown State of Utah Lease	UT	State of Utah lease	State of Utah lease	No	No	No	--
173	Glen Goff Property	--	UT	Private	Private	No	No	No	--
191	B & C Limestone	--	UT	State of Utah lease	State of Utah lease	No	No	No	--
197	Cream Time (Young/Bryce Haas state lease)	Young/Bryce Haas State of Utah Lease	UT	State of Utah lease	State of Utah lease	No	No	No	--
218	Haas Limestone - Gunnison	--	UT	Unknown	Unknown	No	No	No	--
221	Lanny Jensen state lease	Danny Bown, operator	UT	State of Utah lease	State of Utah lease	No	No	No	--
224	Bryce Haas state lease-1	--	UT	State of Utah lease	State of Utah lease	No	No	No	--
225	Bryce Haas state lease-2	--	UT	State of Utah lease	State of Utah lease	No	No	No	--

Appendix I (continued). Building stone data table of Sanpete County sites from Boleneus (2008)

Status	Map_Name	Type_Site	Claim_Name	BLM_Case	SubTerra_Number	UT_DOGM_ID	UT_SITLA_ID	Data_Source
Active	Manti 100k	Quarry	--	--	s390011	s390011	ML 47722 MP	Danny Bown, Phyllis Bown; SubTerra (2004); UT DOGM; John Blake Utah SITLA
Active	Manti 100k	Quarry	--	--	s390015	s390015	47844	Michael Jackson Richfield FO; SubTerra (2004); UT DOGM; John Blake Utah SITLA
Active	Manti 100k	Quarry	--	--	s390010	s390010	ML 47244	UT DOGM files, SubTerra (2004); John Blake Utah SITLA
Active	Manti 100k	Quarry	--	--	s390014	s390014	--	UT DOGM files, SubTerra (2004)
Active	Manti 100k	Quarry	--	--	m390013	m390013	48949	UT DOGM files, SubTerra (2004); John Blake Utah SITLA
Past producer	Manti 100k	Quarry	--	--	s390009; s390003	s390003	ML 43391	UT DOGM files, SubTerra (2004); John Blake Utah SITLA
Active	Manti 100k	Quarry	--	--	--	s390012	--	UT DOGM files
Active	Manti 100k	Quarry	--	--	--	s390009	ML 47868 MP	John Blake Utah SITLA
Active	Manti 100k	Quarry	--	--	s390012	--	ML 48949OBA (ML 47244a & 47272a)	John Blake Utah SITLA; SubTerra (2004)
Active	Manti 100k	Quarry	--	--	--	--	ML 48949 (ML48313MP)	John Blake Utah SITLA

Appendix I (continued). Building stone data table of Sanpete County sites from Boleneus (2008)

Operator_Name	Operator_Address	Operator_ State	Operator_ Tele	Location_ Descr	Location_ County	Tp	Rg	Sec&Sub	Lat_dd
Bown, Danny and Phyllis Bown	595 E 600 S PO Box 27 Manti, UT 84642	UT	435-835-7542	--	Sanpete	20 S	2 E	17 swsw	39.061
Day, William	521 E 1910 S Orem, UT 84058	UT	801-225-4440	--	Sanpete	19 S	2 E	21	39.1426
Bown, Danny	595 E 600 S PO Box 27 Manti, UT 84642-0027	UT	435-835-7542	--	Sanpete	19 S	2 E	16 nene	39.1629
Sorenson, Steven Lamar	KSC Rocks 235 N Main Kanosh, UT 84637	UT	435-759-2639	W. side White Hills	Sanpete	20 S	1 E	27 nwse, nw	39.041
Haas, Bryce	331 E 200 S Lindon UT 84042	UT	801-796-6214	--	Sanpete	18 S	1 E	32 swsw	39.1928
Young, Jon	2402 Broadview Ct Sandy UT 84092	UT	801-571-6558	--	Sanpete	19 S	2 E	16 nenw	39.1692
Haas, Bryce	331 E 200 S Lindon UT 84042	UT	801-796-6214	--	Sanpete	18 S	1 E	32 swsw	39.2013
Bown, Danny	595 E 600 S PO Box 27 Manti, UT 84642-0027	UT	435-835-7542	--	Sanpete	20 S	2 E	18 sese	39.0696
Haas, Bryce	331 E 200 S Lindon UT 84042	UT	435-528-5342	--	Sanpete	19 S	2 E	16 w2w2ne, senw	39.1583
Haas, Bryce	331 E 200 S Lindon UT 84042	UT	435-528-5342	--	Sanpete	19 S	1 E	5 nw & T18S-R1E-32 s2sw	39.1867

Appendix I (continued). Building stone data table of Sanpete County sites from Boleneus (2008)

Long_dd	UTM_E	UTM_N	UTM_ Zone	Coll_Method	Color	Geology	Generalized_ Rock_Unit	Lithologic_Description	Generalized_ Lithology
-111.7111	438478	4323790	12S	Copy from SubTerra	Light brown	Green River Formation (Eocene)	GreenRiver	Sandstone, limey, 2-3" thick	Sandstone
-111.6973	439737	4332832	12S	Copy from SubTerra	Light brown	Green River Formation (Eocene)	GreenRiver	Limestone, sandy, finely laminated, with concretions, breaks into 2"-6" thick blocks	Limestone
-111.6865	440694	4335081	12S	Copy from SubTerra	--	Green River Formation (Eocene)	GreenRiver	Limestone, flaggy.	Limestone
-111.7904	431595	4321627	12S	Copy from SubTerra		Green River Formation (Eocene)	GreenRiver	Limestone, flaggy, of weathered caprock	Limestone
-111.8306	428272	4338504	12S	Copy from SubTerra	--	--	--	Limestone block	Limestone
-111.7001	439521	4335787	12S	Calculated from trs	Light brown	Green River Formation (Eocene)	GreenRiver	Limestone, sandy, flaggy, light grown to buff in color	Limestone
-111.8289	428427	4339443	12S	Calculated from trs	--	--	--	Limestone	Limestone
-111.7317	436702	4324754	12S	Calculated from trs	--	Upper Green River Form.	GreenRiver	Limestone	Limestone
-111.6961	439855	4334570	12S	Copy from SubTerra	Light brown	Green River Formation (Eocene)	GreenRiver	Sandstone, flaggy, light brown to buff in color	Sandstone
-111.8289	428413	4337822	12S	Calculated from trs	Light brown	Green River Formation (Eocene)	GreenRiver	Sandstone, flaggy, light brown to buff in color	Sandstone

Appendix I (continued). Building stone data table of Sanpete County sites from Boleneus (2008)

Other_characteristics	Extraction_Fractures_Cleavability	Product_Dimension_Fractures_Cleavability	Influence_of_Texture	Uniform_Thickness
Light brown color; durable, breaks into flaggy blocks	Favorable with respect to extraction	Favorable with respect to product dimensions.	No Influence	Yes
--	Favorable with respect to extraction	Favorable with respect to product dimensions.	Likely influence	Yes
--	--	--	--	--
Moderately durable and decorative	Favorable with respect to extraction	Favorable with respect to product dimensions.	No Influence	Yes
--	Favorable with respect to extraction	Favorable with respect to product dimensions.	No Influence	Yes
--	--	--	--	--
--	--	--	--	--
--	--	--	--	--
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Appendix I (continued). Building stone data table of Sanpete County sites from Boleneus (2008)

Lithology_Hardness_ Durability	Rock_Quality_ Suitability	Size	Ease_of_Extraction	Extent_of_ Deposit	Reserve_Limits_ Overburden	Number_P roducts
Advantageous	Excellent quality	Large	Moderately easy (extraction by ripping)	Extended	Unknown reserve; 15 ft overburden	Medium (3-5 products)
Advantageous	Good to excellent	Small	Moderately easy	Extended	Unknown reserve	Medium (3-5 products)
--	--	Medium	--	--	Unknown	
Advantageous	Moderate durability for flagstone	Small	Moderately Easy (extraction by ripping)	Extended	Limited reserves due to thin cap rock horizon	Small (1 - 2 products)
Advantageous	--	Medium	Moderately difficult (blasting likely required, or extraction otherwise made difficult through extensive overburden, unfavorable structure, etc.)	Extended	Extensive > 10 year reserve	Large (>5 products)
--	Unknown	Medium	--	--	Unknown	--
--	--	Small	--	--	--	--
--	--	Medium	--	--	--	--
--	--	Large	--	--	--	--
--	--	Large	--	--	--	--

Appendix I (continued). Building stone data table of Sanpete County sites from Boleneus (2008)

Known_Products	Acres	Mining_Method	Hand_Methods	Mining_Description
Flagstone, building stone	20	Hand-mechanized combined	Hand split, sort	Rip/loosen with dozer; dig and load with track excavator
Flagstone, river cobbles		Hand-mechanized combined	Hand split, sort	Dig with hyd excavator
Flagstone, building stone	--	Hand-mechanized combined	Hand split, sort	Dig with hyd excavator
Decorative flagstone	--	--	--	--
Palleted block; 'Flagstone, building stone, ashlar	--	--	--	--
Flaggy, limey sandstone	--	Hand-mechanized combined	Hand split, sort	--
Building stone, palleted block	--	--	--	--
--	--	Hand only	Surface collection	--
Saw block, stand-up flagstone, premium flagstone, snap ledger, boulders, ground cover, dry stack, guillotined flagstone, 3/4-inch minus, tumbled flagstone, wall rock	--	Hand only	Surface collection	Quarrying operation
	--	Hand only	Surface collection	Quarrying operation

Appendix I (continued). Building stone data table of Sanpete County sites from Boleneus (2008)

Production_rate	Processing_ onsite	Work_schedule	Personnel	Buildings
3,000 t/y; 2-5 pallets/ d/person; ship 1 semi load/day of 10-11 pallets each	Split and palletize	Year-round, depending on weather; 5 d/wk	5 laborers, 1 owner-operator	--
--	--	--	--	--
--	--	--	--	--
--	--	--	--	--
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Appendix I (continued). Building stone data table of Sanpete County sites from Boleneus (2008)

Equipment	Product_inventory
1 MixRight tumbler ($30,000); 1 track excavator Volvo EC360; 1 dozer Cat D-8k; 1 Ford PU; 1 Cat wheel loader 955; 1 dump truck; 1 4-wheel flat bed tow trailer; 1 cris-cutter; 1 generator 8kva; 1 flatbed semi trailer; 2 volvo wheel loaders 90c, 120c; 1 New Holland wheel loader; 1 compressor.	8, 4-6" flagstone, sandy LS; 23, 2-3" flagstone, sandy LS; 40, 1" flagstone, vertical
1 track excavator, Kato; 2 forklifts; 1 cris-cutter; 2 trailers; 1 2 ton truck, F350	12, 1" flagstone; 31, 2-3" flagstone; 4, 8-10" cut boulders split on cris-cutter; 66, 3-6" blocky flagstone
--	--
Excavator	--
Backhoe, tumbler, generator, saw on site	--
--	--
--	--
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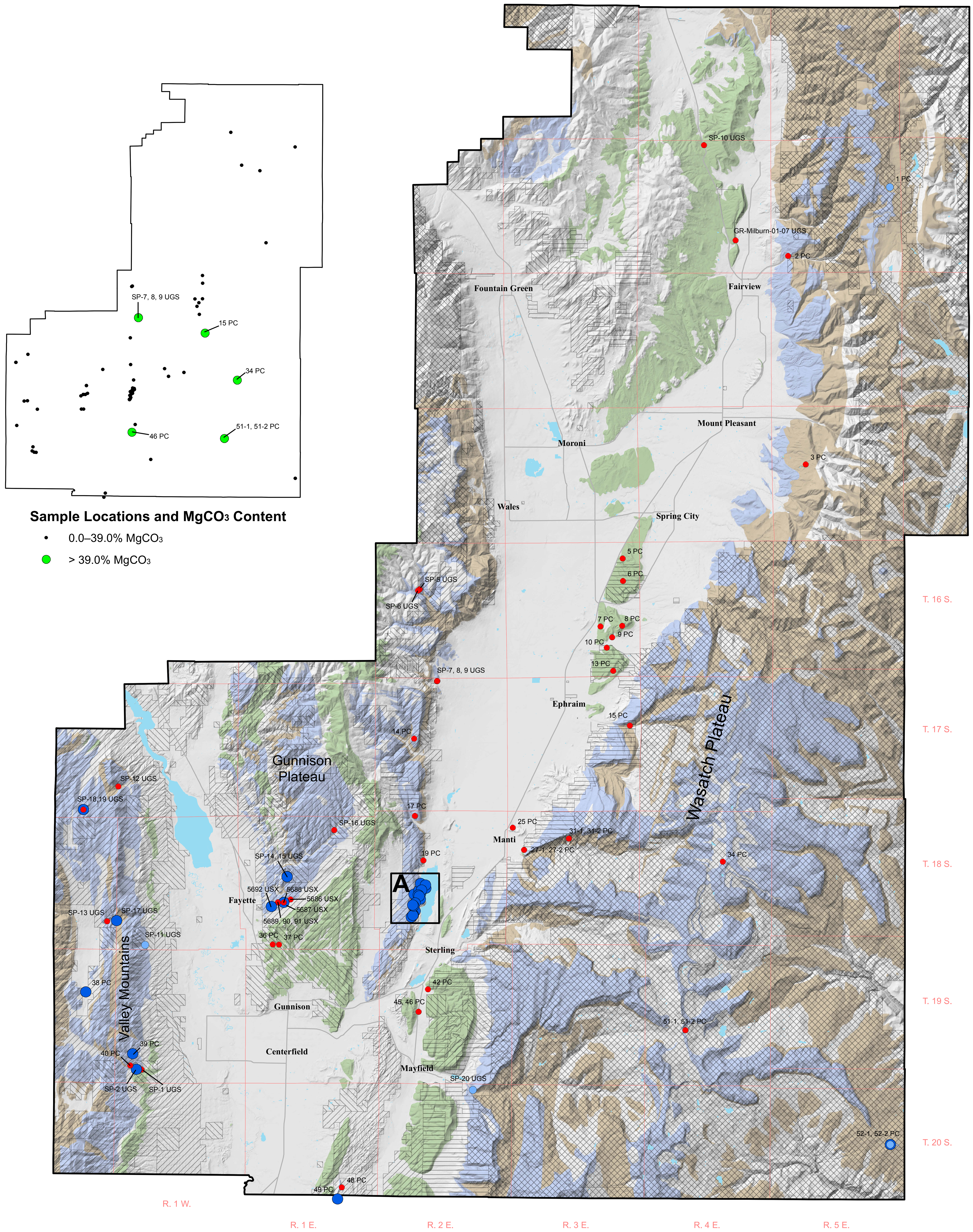
Appendix I (continued). Building stone data table of Sanpete County sites from Boleneus (2008)

Sales_price	**Market_description**	**Destination**	**Prod_1995** (tons)	**Prod_1996** (tons)	**Prod_1997** (tons)	**Prod_1998** (tons)	**Prod_1999** (tons)	**Prod_2000** (tons)
1" flagstone = $240/ton; 2" flagstone = $180/ton; 3-5" flagstone = $75/ton	Sells to broker in Calif.	California				0	0	350
--	--	--						
--	--	--				185	1000	800
--	--	--			NR	NR	NR	10
--	--	--						0
--	--	--	NR	NR	NR	Confid.	Confid.	Confid.
--	--	--				0	NR	NR
--	--	--			NR	Confid.	Confid.	944
--	--	--						
--	--	--						

Appendix I (continued). Building stone data table of Sanpete County sites from Boleneus (2008)

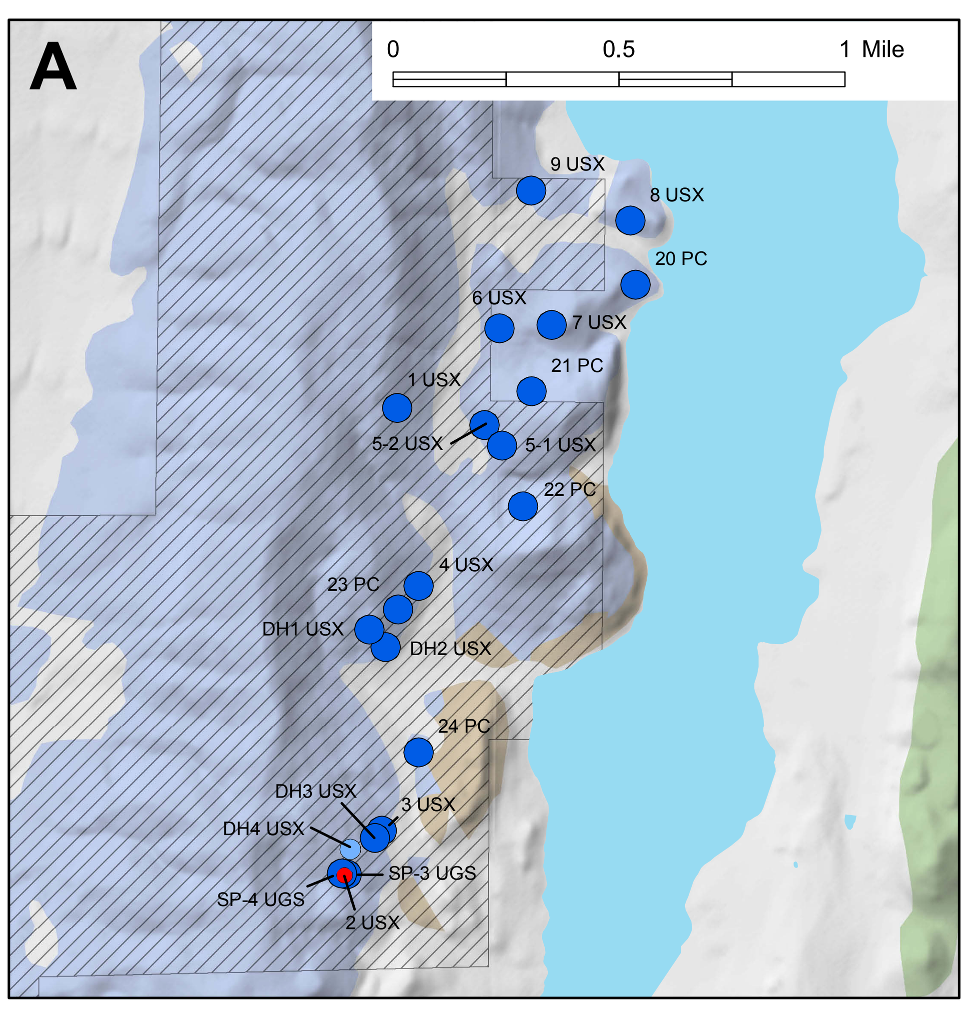
Prod_2001 (tons)	Prod_2002 (tons)	Prod_2003 (tons)	Prod_2004 (tons)	Max_prod (tons)	Comments
833	2500	3000	2600	3000	Landowner, Gerald Willden, Mayfield, UT SITLA production data here is CONFIDENTIAL
413	405	NR	NR	413	--
205	400	400	286	1000	Landowner, Joe Frischknecht SITLA production data here is CONFIDENTIAL
50	50	121	116	121	--
NR	0	0	NR		Opened in 2000; inventory of 180 pallets in yard in 1999; webstie bhstonesupply.com ID Nos. 191 and 218 appear as same property.
NR	NR	NR	NR	Confid.	SITLA production data here is CONFIDENTIAL
NR	NR	NR	NR		Opened in 2000 ID Nos. 191 and 218 appear as same property.
Confid.	NR	NR	NR	Confid.	SITLA production data here is CONFIDENTIAL
	Confid.	Confid.	Confid.	Confid.	SITLA production data here is CONFIDENTIAL
Confid.				Confid.	SITLA production data here is CONFIDENTIAL

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources



Sample Locations and MgCO3 Content

- 0.0–39.0% $MgCO_3$
- > 39.0% $MgCO_3$



Sample Locations and CaCO3 Content

- 0.0–93.0% $CaCO_3$
- 93.0–95.0% $CaCO_3$
- 95.0–100.0% $CaCO_3$
- Township Boundary
- Primary Road
- Lake

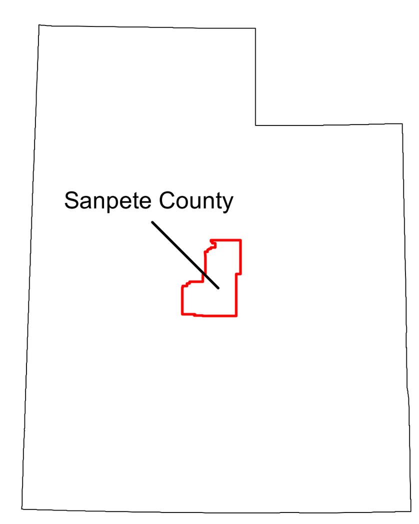
Carbonate sample label shows sample number and sampler:
PC - Pratt and Callaghan (1970)
USX - U.S. Steel (1957)
UGS - Utah Geological Survey, this study

Geologic Units

- Eocene Green River Formation
- Paleocene-Eocene Flagstaff Limestone
- Upper Cretaceous-Paleocene North Horn Formation

Land Ownership

- U.S. Bureau of Land Management
- Private
- U.S. Forest Service
- State Sovereign Lands
- SITLA Surface Rights



0 5 10 15 20 Miles

0 5 10 15 20 Kilometers

N

CARBONATE SAMPLE LOCATIONS IN SANPETE COUNTY, UTAH

by

Andrew Rupke

2011

Geology is from Hintze and Davis (2005), Witkind and others (2006), and Witkind and Weiss (2002).
Land ownership information and base map are provided by the Utah Automated Geographic Reference Center.
Elevation data from National Elevation Dataset 10m resolution.

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