

# **GOLD OCCURRENCE IN THE CRETACEOUS MANCOS SHALE, EASTERN UTAH**

*by*

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Mancos Shale, Eastern Utah**  
By Gordon Marlatt

## **INTRODUCTION**

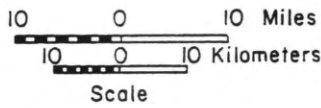
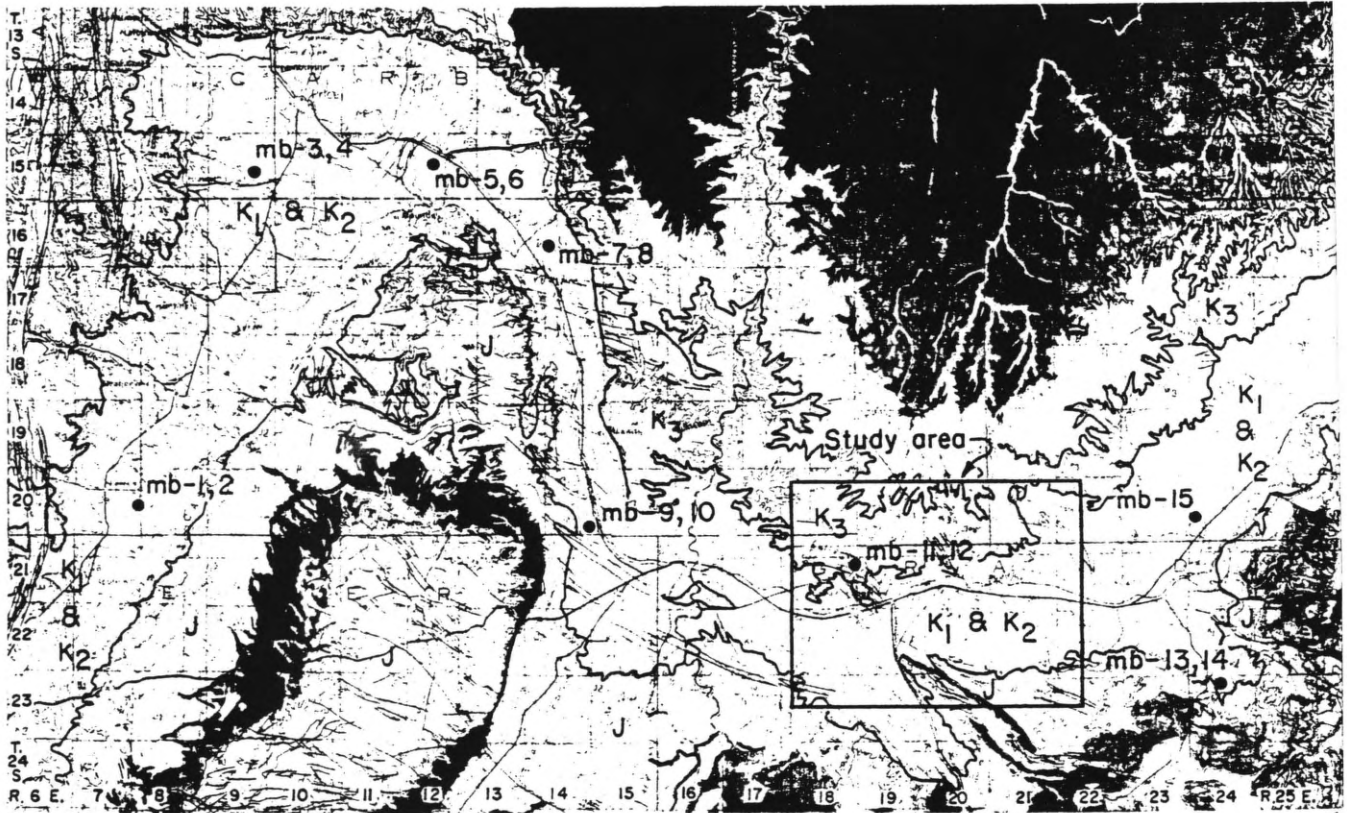
The Cretaceous Mancos Shale of eastern Utah (Fig. 1) covers several thousand square miles. It is a thick, homogenous, organic-rich shale, and like many black shales is enriched in metals. Persistent rumors of high grade gold mineralization throughout the entire section have been reported for many years. This report is an effort to evaluate these reports and to try to establish whether gold exists in commercially extractable quantities.

## **STRATIGRAPHY AND LITHOLOGY**

The study focused on the Mancos Shale. During deposition it appears to have acted as a sink for various metals. It is enriched in uranium, copper, silver, vanadium, mercury, arsenic and, to a certain extent, gold. The metals were probably deposited contemporaneously with the shale, coming in with the volcanic tuffs that compose much of the Mancos itself. The Mancos is underlain by the Dakota Sandstone and is overlain by shales and sandstone of the Mesaverde Group (Fig. 2).

### **DAKOTA SANDSTONE**

The Dakota Sandstone underlies the Mancos Shale and forms a thin, fairly resistant sandstone which is conformable with the overlying shale. In the study area it rests unconformably on siliceous sandstones and green mudstones of the lower Cretaceous Cedar Mountain Formation. The Dakota is composed of friable to indurated sandstones with considerable interbedded shale. The sandstones range from light grey to brown to white and occasionally contain interstitial limonite or kaolinite. In places the sandstone has been silicified and forms a hard grey to brown quartzite. The Dakota also contains interbedded conglomerate and shale. The shales are commonly greenish grey to dark grey and are usually slightly carbonaceous (Fisher, D.J., 1936). The Dakota is fairly thin in the study area; some 60-100 feet thick. The lower contact, which is unconformable with the underlying Cedar Mountain Formation is usually well exposed. The upper contact, conformable with the overlying Mancos



**EXPLANATION**

- Contact
- mb-15 Sample numbers and location

- UPPER JURASSIC
- CRETACEOUS
  - K<sub>3</sub> Mesaverde Group
  - K<sub>2</sub> Mancos Shale
  - K<sub>1</sub> Dakota Sandstone and Cedar Mountain Formation
- J Morrison Formation



**Study Area Location Map  
mb samples**

Figure 1.

Geologic age		Group and formation	Member	Character	Thickness (feet)			
Quaternary	Recent			Sandy alluvium along stream courses; the larger areas occur only along the Green River.				
	Pleistocene			Terrace deposits of gravel along the Green River. Remnants of alluvial-fan gravel deposits capping benches of Mancos shale sloping away from the Book Cliffs; recognized at three levels.	25 ±			
Unconformity								
	Tertiary (Eocene)	Wasatch formation		Varicolored, predominantly purplish-red shales with heavy cliff-forming gray sandstones. Basal portion carries a conspicuous conglomerate at many places. Fresh-water fossils.	250 ± to 4,000 ±			
Unconformity (?)								
	Tertiary (?)	Tuscher formation		Light-colored sandstones with minor interbedded shales. No fossils.	130 (?) to 600.			
Unconformity (?)								
Upper Cretaceous		Mesaverde group	Price River formation	Farrer non-coal-bearing member.	Sandstones with gray shales.	410 to 1,095 (average 690).		
				Neslen coal-bearing member.	Alternating sandstones and shales.	250 to 410 (average 350).		
				Sego sandstone member	Massive sandstone.	140 to 210.		
				Buck Tongue of Mancos shale.	Tongue of the Mancos shale.	0 to 350.		
				Castlegate sandstone member	Cliff-forming sandstone.	0 to 190 (averages 90 feet east of the Green River).		
			Blackhawk formation	Upper member	Sandstone.	70+ to 230.		
				Middle sandstone member	Massive sandstone.	100 to 245.		
				Middle shale member	Tongue of the Mancos shale.	100 to 160.		
				Lower sandstone member	Quartz sandstone.	150 to 170.		
					Mancos shale.		Gray marine shales with relatively minor beds of sandstone and limestone at varying horizons at different localities. Upper contact is gradational, with a tongue arrangement, the shale tongues pointing to the west, and the top of the formation rising stratigraphically to the east. Ferron sandstone member locally present in lower part.	5,000+
					Dakota (?) sandstone		Quartzitic sandstone and conglomerate with interbedded gray shale and limestone lenses.	2 to 126
Unconformity								
		Cedar Mountain	Cedar Mountain shale	Shale, some sand lenses	100 ±			
Unconformity								
Jurassic		Morrison formation	Brushy Basin shale	Shale, with few conglomeratic sandstone beds.	400 ±			
			Salt Wash sandstone	Sandstone, gray with interbedded red and green mudstone	200 ±			

Figure 2. Stratigraphic column of study area, east-central Utah. After Fisher, D.J., 1936, and Clark and Million, 1956.

shale is commonly buried by weathered shale and where exposed tends to be gradational. The unit seems to be fluvial in origin at the base, grading upward into a marine environment. Consequently the lithologic character of the unit can change abruptly both horizontally and vertically.

#### **MANCOS SHALE**

The Mancos Shale is of upper Cretaceous age. It comprises grey marine shales with relatively minor beds of sandstone and limestone which can show rather abrupt facies changes over fairly short distances. The lower contact is gradational, lying conformably on the Dakota sandstone. The upper contact is also gradational with the shale intertonguing with the overlying sandstones and shales of the Mesaverde Group. The sandstone tongues prograde eastward from a depositional source well to the west so that the upper Mancos-Mesaverde contact rises and progrades to the east. The Mancos includes equivalents of the Benton, Niobrara and much of the Montana Formations, through the Pierre shale, formations found in the northern and eastern Rockies (Clark, F.R., 1928). The thickness of the formation ranges from 3,450 feet to more than 5,000 feet.

Lithologically the Mancos is composed of slightly bluish, medium to dark grey marine shale which weathers to a drab, earthy grey when dry (Plate 1). Included are horizons which are tan or buff or pale yellow in color and massive in habit and appear to be composed of montmorillinite clay. These horizons can be as much as 75 feet thick. Outside of these horizons the Mancos is generally limey and gritty occasionally with pronounced fissility (mostly at the base and near the top of the unit). The bulk of the unit may be considered massive, soft and friable, however. The Mancos carries veinlets of gypsum and calcite and shows streaks of evaporite salts, usually some form of sodium sulphate, on some weathered surfaces. Included in the Mancos are thin beds of sandstone which vary in thickness and stratigraphic position.



Plate 1. Outcrop of the Mancos Shale shows the fissile nature of the formation. The location is south of Cisco, Utah, near the base of the Mancos. The height of the outcrop is about 8 feet.

Of these, the Ferron Sandstone Member, in the lower part of the section and recognized west of the study area, is the most extensive. Thin beds or lenses of dense limestone are also present. Marine invertebrates and fish teeth have been found in many horizons and localities (Fisher, D.J., 1936).

Topographically the Mancos Shale also forms the broad valley paralleling the Book Cliffs to the south. Locally it is known as Castle Valley, Clark Valley, Gunnison Valley and Grand Valley. It does not, however, form a valley for a single stream system. Approximately the upper 500 feet of the formation forms the basal slope of the Book Cliffs beneath which badlands are commonly present.

#### **BLACKHAWK FORMATION**

The Blackhawk Formation over-lies the Mancos in the study area. It is part of the Mesaverde Group. It is 650-700 feet thick and is subdivided into 5 units. In ascending order they are: 1) a lower shale member containing the underlying Aberdeen Sandstone Member; 2) a lower sandstone

member (brackish-water origin) not present east of Green River; 3) a middle shale member which becomes the Mancos Shale east of Green River; 4) a middle sandstone member which is a massive cliff-forming sandstone; not present east of Floy; 5) an upper member which consists of an upper cliff-forming sandstone and lower shale (Holmes, C.N., Page, B.N., 1956). East of Floy it also grades into the Mancos Shale. Only the upper-most sandstone member is present near the study area where it is the basal cliff-forming unit overlying the Mancos.

The sandstone members of this formation were formed as fluvial, costal plain deposits extending out from the western highlands eastward into the Mancos seas. The particle-size fines to the east where they grade into the Mancos Shale. The depositional environment changes eastward from fresh-water to brackish-water and finally to shallow water marine (Clark, F.R., 1928). Each sand unit was deposited farther east out into the Mancos sea than the preceding one and was subsequently buried by shales of the Mancos. Like the interbedded sands the westernmost extent of the shales is east of the next lower one as the shore-line prograded eastward. These sandstone carry many coal seams several of which are commercial. The coal mined at Sunnyside, Utah, is from this formation. No coal seams are present in this formation east of the Green River, however.

#### **PRICE RIVER FORMATION**

Overlying the Blackhawk Formation is the upper Cretaceous Price River Formation. The Price River is capped by the Tertiary Tuscher Formation which is a light-colored sandstone. Separating the Cretaceous and the Tertiary units in the map area is an unconformity marked by a basal Wasatch conglomerate. The Price River Formation is about 1,350 feet thick though it thickens westward and can be divided into four members. The Castlegate Sandstone Member is considered a separate formation elsewhere. The units, in ascending order are: 1) the Castlegate sandstone; 2) the Segoe sandstone; 3) the Neslen coal-bearing member; and 4) the Farrer non-coal-bearing member (Holmes, C.N., Page, B.N., 1956).



West of the study area the upper Blackhawk sandstone and the Castlegate Sandstone are separated by a 10 to 20 foot thickness of Mancos shale. Consequently the two sands occasionally appear as one (Plate 2). The upper Blackhawk sand is about 100 feet thick while the Castlegate Sandstone is about 85 feet thick. The two units grade together near the west edge of the study area. The Castlegate is generally light grey to white on fresh surfaces weathering to tan or brown on outcrop. It is medium to fine-grained, normally non-calcareous and contains minor feldspar, mica and mafic minerals.

In the study area the Sejo Sandstone is a littoral marine sandstone which varies from a medium-bedded, medium-grained buff sand to a thin-bedded, silty, grey sand with shale partings (Fisher, D.J., 1936). The upper contact is sharp and conformable with the overlying Neslen Member while the lower contact is gradational with the underlying Buck Tongue of the Mancos Shale which separates it from the basal Castlegate sand.



Plate 2. View of Book Cliffs looking north. The cliff-forming sand is the Castlegate Sandstone. The Mancos Shale forms the slopes below the sandstone cliffs.

The Neslen coal-bearing member consist of coaly, lignitic shales, light grey to purple and brown shales and grey lenticular sandstones. It is capped with a white medium-grained sandstone. Coal beds are prominent in the lower part of the member and occasionally show signs of burning. The upper contact with the Farrer member is conformable and usually gradational (Young, R.G., 1955). The coal mines of Sego Canyon are developed in the Palisades coal zone of this formation.

The Farrer non-coal-bearing member is a cliff-forming unit. It is composed of yellowish-brown, olive-green, purple, grey and white sandstones with minor interbedded grey-green shales. It contains minor coal and lignitic shale near the base of the formation. The contact with the lower Neslen coal-bearing member rises stratigraphically to the east as do all of the units overlying the Mancos Shale. The Farrer member is unconformably overlain by the Tertiary Tuscher Formation (Abbot, W.O., and Lipscomb, R.L., 1956).

The Mancos is underlain by sediments which were deposited in fluvial and lacustrine environments. The Dakota-Mancos contact represents the marine incursion over these continental-type sediments and is relatively sharp. The Mancos is overlain by littoral sandstones which intertongue with the Mancos shales. These tongues represent continental shoreline facies which developed eastward out into the Mancos sea. These sandstone tongues may represent pulses of tectonic movement or possibly lowstands of the sea. During early Mancos deposition, the western depositional shoreline was far to the west. The shoreline prograded eastward over time so that the upper contact of the Mancos rises stratigraphically and topographically from west to east. From Price, Utah to Grand Junction, Colorado the Mancos/Blackhawk contact is progressively younger.

In the study area the Mancos Shale represents a depositional column of marine muds about 20,000 feet thick which were deposited in an anoxic environment. To a great degree these muds were derived from infalling volcanic ash. Since the Mancos is now about 5000 feet thick this represents a loss of about 15,000 feet of thickness. This was principally water. The bulk of this water found its way back

to the sea shortly after deposition but some, probably about 1/3 (30%), was retained until lithification. Given a final lithified porosity of 5%, a 5,000 foot water column must have been expelled during lithification. This includes the water expelled during dehydration and clay inversion reactions. Because of the nature of the overlying sediments most of the water would have had to move downward out of the shale. This is borne out by field data. The sands at the base of the Mancos show evidence of severe chemical reaction. Many limestones are replaced by silica and calcite matrix in the sandstones is absent. Many sands are choked with diagenetic kaolinite or are cemented with silica. The sands overlying the Mancos, however, show few signs of ever having had reactive water moving through them.

## **EXPERIMENTAL**

### **INTRODUCTION**

Much of the controversy regarding gold in the Mancos Shale centers around assay techniques used to identify the metal in the shale samples. Owners of gold claims in the Mancos state that conventional assay procedures work poorly or not at all and the gold assay results are much too low. When referring to fire assay methods they feel that the gold is in a form that volatilizes at high temperatures and so escapes from the sample in the firing process. In regard to atomic absorption (AA) techniques they feel that the gold is complexed by naturally occurring organic compounds that are not dissolved by the acid solutions and consequently the gold is not seen in assay. To address these problems I explored the use of various assay techniques to insure the assay results were correct. The experimental work is confined to the use of AA analysis as that is the type of analytical process available.

The assay procedure used for gold is as follows: Samples are ground to -85 mesh in a small hammermill-type grinder. A 10 gram sample is weighed out from the larger sample and put into a 250 ml. sample container; 10 ml. of distilled water is added to the dry sample and the entire sample is wet by the water. Thirty (30) ml. of concentrated hydrochloric acid (HCl) and 10 ml. concentrated nitric acid (HNO<sub>3</sub>) is added. The samples are boiled in a water bath for 2 hours and cooled. The samples are

filtered to remove all particulate matter, then 10 ml. of methyl isobutyl ketone (MIBK) is added and the samples are agitated vigorously for 3-5 minutes. Distilled water is added to bring the sample volume to 250 ml. and the solvent and MIBK are allowed to separate. The MIBK rises into the mouth of the bottle on separation. If silica slimes are present at the interface between the now dilute acid and the MIBK, several drops of concentrated hydrofluoric acid (HF) are added to dissolve the slimes thus allowing complete separation. The MIBK is then analyzed by AA spectroscopy for gold. The lower detection limit for gold using this procedure is 50 ppb.

Base metal and silver analysis procedure is quite similar. The procedure is as follows. Samples are ground to -85 mesh. Ten (10) grams of sample are weighed into 125 milliliter (ml.) polypropylene bottles. Ten ml. of water and 40 ml. of concentrated nitric acid are added. The samples are boiled for 2 hours and allowed to cool. Volume is brought to 50 ml. The liquid is analyzed by atomic absorption standardized with a blank, 5 ppm and 10 ppm standards. The dilution of the liquid with respect to the sample is a factor of 5 giving a full scale response of 50 ppm. Detection limit for silver and copper is 0.5 ppm.

Eight Mancos Shale samples from 5 widely separated locations, one kaolinite/calcite sample and one sandstone sample not from the Mancos Formation constituted the group used in amenability experiments. The first sample run was on raw (unroasted) samples. These samples were difficult to filter due to the very fine particle size of the samples which plugged the filters. The 10 samples of the experimental group were assayed with the standard technique and were found to be barren.

A second 10 gram portion of these samples was taken. This portion was roasted at 500°C for 2 hours to oxidize any carbon and sulphide present in the samples. Upon reweighing after roasting it was found that the samples high in clay lost about 10% of the original weight in the samples. The sandstone sample lost about 2%. This weight loss is assumed to be due to dehydration of clays as well as oxidation of organics, volatilization of contained water and decarboxilization of carbonates. These samples were

evaluated by the standard procedure. The samples were barren of gold. It was found that the samples filtered much quicker after being roasted. This is probably because of fusing of the finest clay particles into slightly larger particles on heating.

A third 10 gram cut was of the study sample group was taken. These samples were covered with a sodium bicarbonate ( $\text{NaHCO}_3$ ) cap of approximately 8 grams. This was done to eliminate the problem of losing gold during roasting by loss to volatilization. These samples were roasted for 2 hours at  $500^\circ\text{C}$ . A problem developed in some of the samples in that the  $\text{NaHCO}_3$  acted as a high pH flux. This allowed the sample to partially melt forming a glass which in some cases adhered to the crucibles. This made it difficult to remove some of the samples and ruined some crucibles as well as some samples. Those samples were rerun. The samples were analyzed for gold by the standard procedure and found to be barren.

To discover if the organic-rich shales would, in fact, tie up gold in insoluble organic complexes or allow the gold to be volatilized during roasting, a 10 gram portion of each sample was taken and a standard addition procedure was done. Ten ml. of gold standard was added to each 10 gram sample giving a theoretical concentration of 1 ppm in the samples. The samples were thoroughly mixed and allowed to dry. They were roasted and assayed for gold. The results are as follows:

Sample No.	Sample Type	Au PPM
P-1	Kaolinite/Calcite from Colorado Plateau, Co.	0.75
P-2	Sandstone with $\text{MnO}_2$ ; Colorado Plateau, Co.	1.00
P-3	Mancos Shale, near Floy, Utah	1.00
P-4	Mancos Shale, near Floy, Utah	0.94
P-5	Mancos Shale, near Ferron, Utah	0.96
P-6	Mancos Shale, near Ferron, Utah	0.95
P-7	Mancos Shale soil sample near Sunnyside Junction	0.96
P-8	Mancos Shale near Green River, Utah	0.98
P-9	Mancos Shale near Green River, Utah	0.96
P-10	Mancos Shale, Price, Utah	1.02

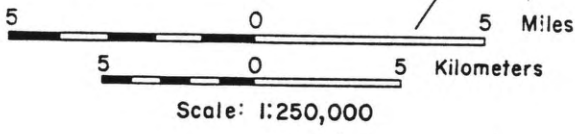
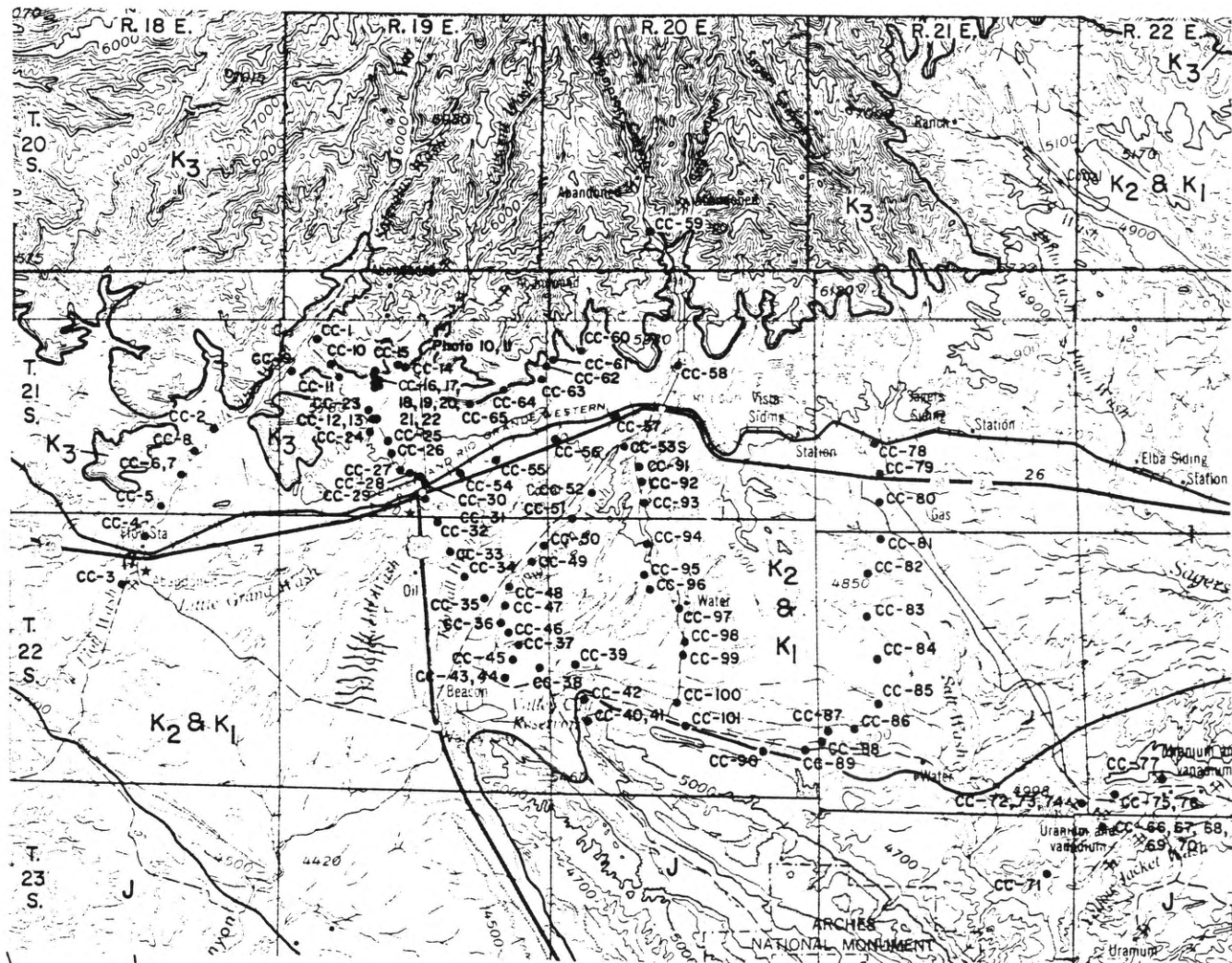
The results are all near 1.0 ppm indicating that the gold is not volatilized by roasting nor tied up in organic complexes. Since roasting the samples facilitated processing, the rest of the samples from the study area were roasted then assayed by wet chemistry and AA.

### Study Area

Because outcrops of the Mancos Shale cover such a large area it was decided that a study area should be chosen which would be representative of the Mancos as a whole. It also seemed most logical to use an area which had reported gold occurrences. To satisfy these criteria, an area near Crescent Junction, Utah was chosen. The approximate boundaries were as follows: The western boundary was Floy Wash, west of Crescent Junction. The north boundary was the Castlegate Sandstone at the top of the Book Cliffs. The eastern boundary was Thompson Canyon and Bootlegger Wash, but included the Parco Mining district in T 23 S, R 22 E. The southern boundary was the lower Cretaceous/upper Jurassic ridges which form the northern edge of Arches National Park and the southern edge of the Mancos outcrop. This comprises an area of about 100 square miles. A further advantage of this area is that the dip of the Mancos is steeper than normal (15 degrees) so the outcrop width is only about 10 miles. This allowed the full section of the Mancos shale to be examined. However, here as on most areas of flatlying Mancos, the shale is covered by a thin soil horizon making outcrops fairly rare.

### Sampling

Good outcrop exposures exist in the upper portion of the Mancos where the upper 700 or 800 feet of the unit is exposed in the base of the Book Cliffs and the gullies leading from the cliffs. A few outcrops are found in the areas which are predominately flat. They are in stream cuts and in cut faces on hills. Another source of fairly fresh material is spoil from rodent burrows. Because of the paucity of outcrops many of the samples were either stream sediment samples or soil samples. Both of these sample types may have slightly elevated gold concentrations because of mechanical enrichment processes.



- EXPLANATION**
- Contact
  - cc-30 Sample numbers and location
  - UPPER JURASSIC CRETACEOUS**
    - K3 Mesaverde Group
    - K2 Mancos Shale
    - K1 Dakota Sandstone and Cedar Mountain Formation
    - J Morrison Formation



**Sample Location Map — CC samples  
Crescent Junction, Utah, Area**

Figure 3.

Consequently they are useful because they show areas of mineralization which would otherwise escape detection.

### Results of Sample Analysis

Sampling of fresh outcrop was biased toward the uppermost portion of the Mancos due to the relative abundance of outcrops as compared to the middle and lower portions. The sampling of the middle and lower parts was mostly soil and stream sediment samples. At least one sample of all unique lithologies, however, was taken and analyzed (Fig. 3). These included samples of all shale lithologies, evaporite salts found in salt pans and along active streams, carbon-rich zones in the Segó member, thin interbedded sands in the Mancos, and jasperoid replacement deposits in limestones (Appendix A). In all, 101 samples were taken and analyzed.

The results of gold analysis was quite uniform. Locally most lithologies carried high background in gold, but nowhere were anomalies detected above 150 ppb (Appendix A). Some curious anomalies were noted. Two samples (#43 and #53) of evaporite salts, or Mancos Shale containing abundant salts, contained detectable levels of gold. Number 43 had only a trace but #53 contained 100 ppb. A third sample (#63) of evaporite salts was barren of gold.

Fifteen bulk samples ( $\pm 10$  pounds) were taken for use in bottle roll tests and to determine the heavy mineral suite--(Fig. 1). These samples, labeled mb, were taken from widely scattered sites in the Mancos shale. The procedure used is as follows: The sample was ground to -85 mesh. One half kilogram (kg) of sample was weighed into a 5 gallon Nalgene container. Two gallons of water were added, with enough sodium hydroxide (NaOH) to bring the pH to 11. The purpose of the high pH was to break down as many organic compounds as possible. The sample was rolled for 24 hours to allow the reactions to proceed to completion. The liquid was decanted and assayed for gold. All liquids were barren. The solid sample was then panned and the heavy minerals were studied under a microscope. The major constituent in all samples was volcanic rock fragments (50%), including volcanic glass. The fragments ranged from



buff to black in color. The second most common was quartz, followed by particles of Mancos Shale. Most of the quartz was smoothly rounded indicating long transport or perhaps multiple cycle sediments. The minor constituents comprised micro-fossils, fragments of hydrocarbons, pyrite, arsenopyrite, native mercury and fragments of steel from the grinder. The micro-fossils appeared to be fragments of teeth or bone. The hydrocarbons were brown, translucent and waxy appearing; probably paraffins. The pyrite was both yellow and white (marcasite or pyrrhotite) and was mostly in anhedral form. The arsenopyrite was grey to black and identified by its unique crystal form (monoclinic but commonly twinned to produce pseudo orthorhombic crystals). It was the also most common sulfide, contributing about 60% of the total sulfide volume. The most unusual mineral in all the samples was native mercury. It occurred in small spherical beads and did not wet any part of the sample nor did it contain any native gold. The globules were clearly visible with the naked eye. Estimated concentration for the mercury and the arsenopyrite is 5 ppm to 50 ppm in the bulk sample. The most mercury appeared in sample mb 11 which was taken near the top of the Mancos section. The least was in mb 1 and 2 which came from near the bottom.

#### DISCUSSION

The Mancos Shale appears to have a significant component of volcanic-derived detritus. There are layers 1-2 feet thick which are mostly bentonite and thicker zones which have a good deal of benzonitic clay. The volcanic input, in the form of air fall and water borne tuffs, is probably the source for most of the metals seen in these samples. In particular, the arsenic, native mercury and gold seem likely to have been introduced with the volcanic debris. The arsenic and mercury are present in varying amounts in all areas and in all stratigraphic horizons of the Mancos. The wide distribution and the volatile nature of these two metals strongly suggests a volcanic, air borne source for the metals rather than a primary detrital source. The gold, silver, and uranium are probably also from this volcanic source, since there is no evidence of hydrothermal activity nearby.

The entire section contains variable amounts of organic material. Most of the organic material is in the form of kerogen in the clays. Some of it, however, is in the form of detrital hydrocarbons, probably paraffins. The presence of thermally mature paraffin minerals in the detrital mineral suite is not uncommon in organic shales. It suggests a maturation temperature of around 120°C. This corresponds to a depth of burial of  $\pm 12,000$  feet.

Prior to generation of hydrocarbons many types of organic acids invert from the kerogen or proto-kerogen (Surdam, et al 1985). The presence of solid hydrocarbons indicates that conditions did exist for the formation of organic acid-rich saline waters. Laboratory experiments indicate that most metals are soluble and mobile in various organic acids intrained in saline water solutions (Marlatt, 1989). Organic acids will complex most metals they come in contact with, so, as they invert in the organic muds, they tend to become saturated with complexed metals.

During compaction and heating prior to lithification, organic acids evolve from the organics in the muds. They are water soluble dissolve in the pore fluids. The permeability of the muds is low so the pore fluids are unable to migrate as rapidly as compaction pressure increases. This results in overpressure in the muds during burial. The overpressure causes the fluids to migrate laterally because the permeability within the mudstone units is biased about 100/1 laterally to vertically. The overpressured fluids migrate continually during sedimentation and the pressure may not be relieved until lithification of the muds (and occasionally not then). Over pressure is bled off at lithification because the formation becomes brittle which allows fracturing of the rock to take place. The fractures form fluid conduits for the pore fluids. There is also a sudden (relatively) pressure increase as the formation approaches lithification conditions due to dehydration reactions of various minerals. Due to the combination of these two factors, permeability pathways extending upward, or more likely downward, allow the fluids to exit the shale.

Upon exiting the shale, the fluids contain many complexed elements and are quite corrosive. They react readily with carbonates and other minerals in the sandstones which may lie in contact with the shales. This reaction, which destabilizes the organic-acid complex, causes deposition of the contained elements. If metals are present in large enough quantities, ore bodies are formed. Silver Reef silver deposit of southern Utah is an example. The Gilman lead/zinc deposit of northern Colorado is another.

Unlike the arsenic and mercury anomalies within the Mancos shale, the gold anomalies are spotty. Gold ranges from a trace (30 ppb) to 100 ppb. Background gold concentrations in this environment should be in the range of 5-10 ppb so these anomalies are clearly above background levels. Whether the anomalies are primary or due to secondary mobilization can only be established at some sites. The anomalies found in stream sediment samples are clearly secondary as are those associated with evaporite salts. The implication of the stream sediment samples is that some gold particles are large enough to be concentrated by mechanical means though no gold particles were panned during the field work.

The implication of finding gold in the evaporite salts is that the gold is complexed into a water soluble form. The gold may be in chloride, sulfide or organic complexes, all of which are water soluble. The conditions required to form these complexes vary widely. A strongly oxidizing, acid environment or an extremely concentrated chloride brine is required to form the gold oxychloride complex. This type of environment was probably never present in the Mancos. Gold may also form a sulfide complex under high pH conditions if the sulfide ion ( $S^{2-}$ ) is available. However gold is quite unstable when complexed in this form. Mercury and arsenic should form sulfide complexes at the same time, however, when mercury is released from this complex it forms mercury sulfide, not mercury metal as found in the Mancos (Krauskopf, 1967). The wide, homogenous distribution of mercury and arsenic suggests that they have never been mobilized, whereas the variable occurrences of gold and other metals suggest that they have. This argues against complexing by the sulphide ion. A fairly low pH, organic-acid-rich, saline formation water will also complex gold but complex arsenic and mercury to a much lesser degree. This

could result in the observed gold concentrations. It could also explain the other metal and non-metal concentrations or lack of concentrations. This includes the late-stage mobilization of the gold by formation water and concentration in an evaporite phase since the organic complexes are water soluble. Further study is needed to define the exact form in which the gold occurs. Finding gold in detectable quantities in an evaporate salt, however, does establish the presence of gold in a water soluble, mobile phase in the Mancos Shale.

Due to the nature of the chemistry and the hydrodynamic systems characteristic of the Mancos and other shales, significant metal deposits probably would not form in the shale itself. This is because the organic acids which complex the metals and which begin to form soon after burial of the organic-rich sediments, are expelled from the mudstone by compaction along with the pore fluids. The element-rich fluid migrates into overlying, or more likely, underlying formations. Destabilization of organic acids by calcite or oxygen causes deposition of the minerals in these formations. The probable source of gold anomalies in the shale and in the evaporite salts is the trapping of the complexed gold-rich fluids within the Mancos Formation by physical means. A more complicated hydrodynamic scheme involving organic-acid and metal-rich formation waters being expelled from the compacting muds downward, probably resulted in the metal and alteration anomalies found in the sandstones immediately beneath the Mancos shale (Grunder, J.W., 1956, Adler, H.H., Sharp, B.J., 1956, Clark, E.L., Million, I., 1956). This <sup>proposed</sup>~~proposed~~ origin is speculation at this point as little investigation of the underlying sands has been done.

Organic acids, also known as carboxylic acids (CAA), which normally form in organic shales follow an evolutionary pathway based on the composition of the original organic material and the burial and heat flow regimes. These evolutionary and acid inversion pathways are, as yet, poorly understood. However, since various metals are susceptible to complexing by certain acids and not susceptible to others, certain inferences as to the types of acid species which were active, can be drawn by the metals which were mobilized in and near the Mancos Shale and those which were not. Mercury, arsenic, gold

and quartz, as well as some other metals, are normally mobilized by a higher pH CAA species. Gold and quartz are also somewhat soluble in certain low pH CAA species, as are silver, uranium and copper. Arsenic and mercury are not particularly soluble in these lower pH species. Since the mobile elements in the Mancos appear to be gold, silver, uranium, copper and silica, it appears that the complexing agent was the lower pH species. These low pH, organic acid species also react rapidly with calcite leading to deposition of minerals and calcite depleted zones within the Mancos Shale. The low level metal anomalies in the shale itself are probably just due to closed permeability pathways which trapped some of the complexed metals within the shale.

## CONCLUSIONS

Sample analyses of the Mancos Shale shows anomalous amounts of several metals. These include gold, silver, copper, arsenic and mercury. The shale also contains a large component of volcanic material, mostly altered air-fall tuffs. It is hypothesized that the metals were introduced into the Mancos from the tuffs. The processes which are a normal part of diagenesis of an organic-rich mud as it undergoes compaction and lithification served to redistribute some of the metals. The elements which were preferentially mobilized were gold, silver, aluminum, uranium and silica. Elements not mobilized were mercury and arsenic as the distribution of mercury and arsenic is currently widespread and at roughly the same level throughout the Mancos. The remobilized elements have been depleted in some areas, and concentrated in others. This is most easily seen with gold.

As the organic-rich muds achieved a burial depth of 4,000-5,000 feet, the base of the section began to lithify. Lithification was accompanied by fracturing and dewatering of the lithified zone. The process of lithification was accompanied by the expulsion of water from various crystal lattices. This, in turn, results in overpressure of pore water. The water was prevented from rising upward through the shale horizon by the thick impermeable, non-lithified, overlying muds. Since organic shales are much more permeable laterally than vertically, the reaction of the formation water to overpressure would be

to move laterally and then downward. Since compaction driven overpressure occurs at the deepest point (depo-center) of the basin first the fluid would tend to move outward away from the basin center and locally downward through fractures or other permeability pathways into the underlying formation. The lateral migration of waters was responsible for the mobilization and slight concentration seen in gold in the Mancos. The other elements are more soluble in the organic-rich, saline waters and continued in solution as the waters exited the shales downward into the underlying sandstones. The organic-acid-rich waters then reacted with various components of the formation, usually calcite or oxygen within the limestones and sandstones causing alteration and precipitation of various elements. This reaction is responsible for the alteration and the precious metal anomalies in the limestones and sandstones of the Dakota and Brushy Basin Formations and probably the uranium ore bodies in the Jurassic Salt Wash sand.

Gold concentrations of economically exploitable grade seem unlikely to occur in the Mancos Shale for reasons given above. While gold is present in the Mancos in amounts above background and has definitely migrated and been reconcentrated by diagenetic fluids, it is unlikely that conditions needed to form orebodies were ever present. The missing elements include permeable, reactive, open-ended host zones in the Mancos. However, the number of samples collected in this study represent only limited coverage of the entire Mancos so local zones of ore-grade gold may exist which were not found by this study.

## REFERENCES

- Abbot, W.O., Liscomb, R.L., 1956, Stratigraphy of the Book Cliffs East-central Utah in Geology and Economic Deposits of East Central Utah, 7th Annual Field Conference Guidebook, Intermountain Association of petroleum Geologists, pp. 155-160.
- Adler, H.H., Sharp, B.J., 1967, Uranium ore rolls-occurrence, genesis and physical and chemical characteristics in Guidebook to the Geology of Utah, no. 21, (Utah Geologic Society), pp. 53-77.
- Carter, W.D., 1956, The Burro Canyon-Dakota Contact in the Mt. Peale No.1 Quadrangle, Western Colorado and Eastern Utah in Geology and Economic Deposits of East Central Utah, 7th Annual Field Conference Guidebook, Intermountain Association of Petroleum Geologist, pp. 113-115.
- Clark, E.L., Million, I., 1956, Uranium Deposits in the Morrison Formation of the San Rafael District in Geology and Economic Deposits of East Central Utah, 7th Annual Field Conference Guidebook. Intermountain Association of Petroleum Geologists, pp. 155-160.
- Clark, F.R., 1928, Castlegate, Wellington and Sunnyside Quadrangles, Carbon County, Utah. USGS Bul. 793.
- Craig, C.L., Dickey, D.D., 1956 Jurassic Strata of Southeastern Utah and Southwestern Colorado in Geology and Economic Deposits of East Central Utah. Intermountain Association of Petroleum Geologists, 7th Annual Field Conference Edition, pp. 93-104.
- Fisher, D.J., 1936, The Book Cliffs Coal Field in Emery and Grand Counties, Utah. USGS Bulletin 852.
- Grunder, J.W., 1956, Mineral Associations in the Continental-Type Uranium Deposits of the Colorado Plateau and Adjacent Areas in Geology and Economic Deposits of East Central Utah, 7th Annual Field Conference Guidebook, Intermountain Association of Petroleum Geologists, pp. 151-154.
- Holmes, C.N., Page, B.N., 1956, Geology of the Bituminous Sandstone Deposits near Sunnyside, Carbon County, Utah in 7th Annual Field Conference Guidebook, Intermountain Association of Petroleum Geologists. pp. 171-177.
- Krauskopf, K.B., 1967. Introduction to Geochemistry. McGraw-Hill Book Company, New York.
- Marlatt, G., Davis, R.W., 1989. Sandstone Gold Potential of Wyoming Basins with Emphasis on In situ Mining Methods for Recovery in Proceedings of Insitu All Mineral Symposium, American Institute of Mining Engineers.
- Surdam, R.C., Boese, S.W., Crossey, L.J., 1985, The Chemistry of Secondary Porosity.
- Surdam, R.C., Crossey, L.J., 1985, Organic-inorganic reactions during progressive burial: Key to Porosity and permeability enhancement and preservation. Phil. Trans. R. Soc. Lond. A-315, pp. 135-156.
- Walton, P.W., 1956, Structure of the North Salt Valley-Cisco Area, Grand County, Utah in 7th Annual Field Conference Guidebook, Intermountain Association of Petroleum Geologists, pp. 186-189.
- Wolfbauer, C.A., 1973, Criteria for Recognizing Paleoenvironments in a Playa-lake Complex: the Green River Formation of Wyoming. Wyoming Geological Association, 25th Field Conference, pp. 87-91.
- Young, R.G., 1955, Sedimentary Facies and Intertonguing in the Upper Cretaceous of the Book Cliff, Utah-COLORADO. GSA Bulletin, vol. 66, February, pp. 170-202.

## APPENDIX A

Sample No.	Sample Description	Au PPB	Cu PPM	Comments
cc- 1	sh; grey, sub-calc., gyp.	ND	ND	
cc- 2	sh; calc., minor Fe. st.	ND	ND	
cc- 3	soil sample; red	ND	ND	
cc- 4	ss.; fg., Fe stain, trace recrystlized feld.	ND	ND	
cc- 5	sh.; grey red, org., silicified	ND	13	
cc- 6	soil sample; red	ND	ND	
cc- 7	sh; clay-silt, red	50	ND	
cc- 8	soil sample; red, variable grain size	ND	2	
cc- 9	clay; buff-grey, montmorillinite	ND	13	Mont. clay after volcanics
cc-10	ss.; buff, fg, clean, no matrix	ND	13	
cc-11	sh./clay; red, fissle	ND	ND	
cc-12	sh./clay; red, fe-rich	50	ND	
cc-13	sh.; grey, calc., 2ndry gyp.	ND		zone w/abunt. volcanics
cc-14	sh.; grey, calc, 2ndry gyp.	ND		abunt vol. debris
cc-15	sh/ss; grey, brn, calc., gyp. 60			thinbedded ss.& sh.
cc-16	silt stn.; gr.-blk., carb., sub-silicified	ND		Contains minor dolo stringer, hard
cc-17	silt stn.; gr.-blk., carb., gyp., soft	ND		
cc-18	silt stn./mudstn.; buff-gr., gyp.	ND		very finely lam.
cc-19	md stn.; carb., gr.-olive	ND		contains partitioned tar and paraffin
cc-20	md stn.; carb., blk., platey, abunt. gyp.	ND		
cc-21	sh.; sub-carb., Fe. st., tr. gyp.	Tr		bentonite (after vol. debris)
cc-22	sh., carb., fissle, some gyp.	Tr		
cc-23	silt; grey, very fine-grained	ND		base of silt layerin stock pond
cc-24	sh.; blk-gr., carb., fissle	ND		
cc-25	ss.; gr., fg., qtzose., gyp.	ND		
cc-26	soil sample; Qal. outwash	ND		outwash from Mancos slopes
cc-27	soil sample; Qal outwash	ND		as above
cc-28	sh.; blk, fissle, evaporite salts	ND		most fissle outcrops have evap.
cc-29	stream sed. sample	ND		
cc-30	soil sample; sandy	ND		
cc-31	silt sample; bottom of dry pond	ND		
cc-32	soil sample; sandy	ND		top of Mancos knob
cc-33	stream sed. sample; base of cong.	ND		Qal. outwash stream w/placer workings
cc-34	stream sed. sample; sand/silt	ND		modern stream
cc-35	soil sample, sandy, lay soil	ND		cattle trail marker
cc-36	stream sed. sample; sand	150		modern stream
cc-37	stream sed. sample; silt	ND		
cc-38	stream sed. sample; carb., clay	ND		from clay-rich zone in Mancos shale

Key: ND--Not Detected.  
Tr--Trace (<50ppb)



Sample Description	Au PPB	Cu PPM	Ag PPM	Comments
stream sed. sample; sandy	ND			near base of Mancos shale
ss.; white, mg.-cg., calc.	150			Jur. Salt Wash Sandstone
ss.; brn., Fe. st., silicified	ND			Jur. Brushey Basin sandstone
jasperoid; brn-red, hem., calc.	50	25		K. Dak(?) replacing limestone
sh., abunt. evaporite salt	Tr	ND		test for H <sub>2</sub> O soluble gold
sh.; blk-gry, minor salt	ND	ND		sample just below #43
sh., blk-gry, abunt carb.	ND	125		
soil sample; clay, minor sand	ND	ND		
stream sed. sample; clay-silt	ND	75		below suspicious sh. outcrop
stream sed. sample; sand	ND	38		following stream bed,
stream sed. sample; sandy	80	50		
stream sed. sample; sandy	Tr	25		
stream sed. sample; sand-silt	ND	63		
stream sed. sample; silt-	60	75		stream wet @ this point
evaporite salt; white-buff	100	50		test for H <sub>2</sub> O soluble gold
stream sed. sample; sandy	50			
stream sed. sample; sandy	Tr			
stream sed. sample; sandy	ND			
stream sed. sample; sandy	ND			
stream sed. sample; sand-silt	ND			
ss.; Mg, brn-grey, some carb., silic.	ND			base of reduced (carb.) zone
ss.; Mg, brn-orange, Fe. st.	ND			
ss.; brn-orange, mg., Fe. st.	ND			contains lim. st. inclusions
ls. Breccia; gr-buff, qtz. frac. filling	ND			Qtz. in fractures blk-red-white
evaporite salt; white-buff	ND			caliche
ss.; brn., mg., calc., qtzose.	ND			prob. Castlegate SS
ss.; brn, mg., qtzose	ND			
clay-carb.; minor Fe. st.	100	63	15	Jur. Salt Wash Frm.
ss.; gr., silicified, fg.	ND	25	8	Jur. Salt Wash Frm.
ss.; gr-grn-brn, silic., minor calc.	60	25	ND	Jur. Salt Wash Frm.
clay-ss.; brn-gr-blk, carb., tr. evap.	70	ND	ND	Jur. Salt Wash Frm.
ss.; gr-brn (red-ox) banded carb.	50	ND	ND	Jur. Salt Wash Frm.
ss.; gr-blk (matrix, prob UO <sub>2</sub> ), qtzose	50	ND	ND	Jur. Salt Wash Frm.
ss.; gr w/dk. gr. bands, calc., sub-silicif.	ND	ND	50	Jur. Salt Wash Frm.
ss.; gr-grn., fg., kaol. matrix (2ndary)	ND	15	15	Jur. Salt Wash Frm.
qtz.; vein, gr-rd, replaces ls.	450	15	33	Jur. Salt Wash Frm.
ss.; gr-buff, silicif., blk. stringers w/Fe.	ND	ND	63	Jur. Salt Wash Frm.
ss.; gr-buff, silicif., gr-blk stringers	70	ND	ND	Jur. Salt Wash Frm.
ss.-cong.; brn-rd, abunt. kaol, calc.	ND	ND	88	Jur. Salt Wash Frm.
sh.; blk., fissle, evap. crust	ND			Mancos outcrop
stream sed. sample, sandy	ND			from drainage under road
soil sample; clay silt	ND			
stream sed. sample, sand w/silt	ND			
sh.; sandy, gr-blk, calc.	ND			
sh.; tr. silt, gry-brn, some Fe. st.	ND			
sh.; blk, fissle	ND			poor exposure

ND--Not Detected.

Tr--Trace (<50ppb)

Sample No.	Sample Description	Au PPB	Cu PPM	Ag PPM	Comments
cc-85	stream sed. sample; very sandy area	Tr			maybe Qal. seds.
cc-86	sh.; blk-gr. thin platy, Fe st.	ND			
cc-87	sh.; blk-gr. platy; Fe st. on plates	ND			
cc-88	stream sed. sample	ND			
cc-89	ss.; buff-gr. kaol matrix	ND			prob. Dakota
cc-90	Jasperoid; white-brn-red, calc.	100			replacement in Brushy Basin
cc-91	soil sample; sandy, calc.	ND			ditch beside road
cc-92	soil sample; sandy	ND			ditch beside road
cc-93	soil sample; sandy	ND			ditch beside road
cc-94	gr. massive, calc.	ND			
cc-95	ss.; fr., brn, Fe st. calc	Tr			SS. in Mancos Sh.
cc-96	sh.; blk., platy, calc., Fe. st.	ND			
cc-97	soil sample	ND			ditch beside road
cc-98	soil sample	ND			ditch beside road
cc-99	soil sample; sandy clay	ND			ditch beside road
cc-100	soil sample; sandy clay	ND			ditch beside road
cc-101	SS., buff-white, kaol., calc., Fe. st.	150			prob. Dakota ss.

Key: ND--Not Detected.  
Tr--Trace (<50ppb)