# TECHNICAL PLAN

# PROJECT RULISON

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TABLE OF CONTENTS

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# PROJECT RULISON TECHNICAL PLAN

## I: INTRODUCTION

Project Rulison has been proposed as a joint Industry-Government sponsored nuclear gas stimulation experiment in the Plowshare series. It has been designed as a demonstration of the commercial feasibility of stimulating a natural gas reservoir using a nuclear explosive. The project is proposed by Austral Oil Company Incorporated of Houston, Texas, as operator, together with CER Geonuclear Corporation of Las Vegas, Nevada.

This is the first project proposed in a gas reservoir that could support commercial nuclear exploitation. This reservoir is not commercially productive using conventional completion techniques.

The Mesaverde Formation appears to be productive under 50, 000 acres at Rulison Field and contains an estimated 8 trillion standard cubic feet of gas in place. If this reservoir can be successfully stimulated, it will have sufficient capacity to supply pipeline needs for western Colorado for more than a decade.

Successful nuclear stimulation at Rulison Field will not only add to the gas reserves of the country but, since over 50 per cent of the acreage is on Federal Government leases, the Government would derive significant royalties from the production of gas from this field.

Project Rulison is planned as the first experiment in a field where full-scale commercial development may require multiple explosions in each well to fracture the majority of the productive intervals in the Mesaverde Formation. The total thickness of the Mesaverde at Rulison ranges from 2,500 to almost 4,000 feet.

Project Rulison is located in an area of low population density about 12 miles southwest of the town of Rifle in Garfield County, Colorado (see Figure 1). The site area is remote, but easily accessible from the city of Grand Junction approximately 40 miles to the west. The combination of a remote site and the proximity to an adequate logistical support base make this an attractive area for an experiment.

## II: BACKGROUND

Austral Oil Company Incorporated became interested in the use of nuclear explosions to stimulate gas reservoirs in early 1965, and began evaluating properties which might be amenable to this approach. They found that the Mesaverde Formation in the Rulison Field of west central Colorado appeared to be a suitable area for nuclear stimulation. From known drilling and testing information, it seemed to have adequate gas in place[1] but had so little permeability that conventional production stimulation methods appeared impractical and uneconomical.

Austral initially acquired approximately 20,000 acres from other operators and options on an additional 20,000 acres. At Austral's request CER conducted a surface site tour in the early winter of 1965-66 which indicated that the site had the potential for a nuclear stimulation due to its remoteness and the depth of the formation in which the nuclear explosive would be detonated. Work was immediately started on the preparation of a detailed nuclear stimulation feasibility study, additional leases were obtained, and two test wells were drilled. Upon completion of these wells in the spring of 1966, Austral/CER carried out an extensive well testing program to verify earlier calculations of gas in place and more accurately define the producing characteristics of the Mesaverde reservoir.

In July of 1966, Austral/CER submitted a formal letter of intent to the Atomic Energy Commission along with a detailed report,[2] entitled "The Project Rulison Feasibility Study."

Project Rulison

In September 1966, Austral met with the United States Geological Survey to discuss a unit agreement for the Rulison Field, which would provide for development through the use of nuclear stimulation.

In December of 1966, Austral/CER made a formal presentation of Project Rulison to the Atomic Energy Commissioners. On February 17, 1967, Austral reiterated to The Joint Committee on Atomic Energy their complete commitment to this project.

In the spring and summer of 1967, Austral/CER and Lawrence Radiation Laboratory personnel discussed the criteria for the actual site selection, inspected the proposed site area, and evolved drilling specifications.

On October 4, 1967, Austral and the United States Geological Survey signed a unique nuclear stimulation agreement. This Rulison unit agreement recognizes the experimental nature of the project and the time frames necessary to complete the experiment. The unit as approved encompasses in excess of 50,000 acres.

In late summer of 1967, a road was built from Morrisania Mesa to the project site. The contract for drilling the first exploration hole for Project Rulison was signed on November 1, 1967, and drilling operations were started November 9, 1967. This well, Hayward 25-95, is currently being tested according to the plan presented for the R-EX well in this document.

The development of this Technical Plan has been aided by discussions at a number of meetings between Austral/CER and Lawrence Radiation Laboratory personnel. Earlier drafts of the Technical Plan have been reviewed by members of the U. S. Geological Survey, the U. S. Bureau of Mines, and AEC Nevada and San Francisco Operations Offices. Thus, this document was prepared in close consultation between members of the technical organizations of the Atomic Energy Commission, Department of the Interior, Austral Oil Company, and CER Geonuclear Corporation.

## III: OBJECTIVE

The objective of the Rulison Project is to provide information that can be used to determine the potential of nuclear stimulation for the commercial development of the Rulison Field. Specifically, information is needed in regard to:

1. Pre- and post-shot gas production characteristics from the site area:
   a. The pre- and post-shot net productive interval in the nuclear-stimulated portion of the reservoir.
   b. The post-shot environmental characteristics important in gas reservoir stimulation such as effective height and volume of the chimney and the effective radius of the fracture zone as determined by production testing.
   c. The pre- and post-shot flow capacity.
   d. The change (if any) of the effective flow capacity of the fractured zone with time and decreasing reservoir pressure.
2. The degree and species of radioactive contamination present in the gas from the nuclear environment and the performance of a program to produce a saleable gas.
3. Seismic effects on cultural features to provide information for planning optimum yields for field development.

4. Determine the costs pertaining to the experiment. These costs should be divided into three categories:

   a. Costs associated with phases of the project necessary because this experiment is a part of the Plowshare program to develop nuclear technology into engineering practice.

   b. Costs associated with fielding a contained nuclear event in the Rulison area. During future commercial applications, these costs could be amortized over all the shots in the area.

   c. Costs associated with the mechanics of fielding any individual shot, such as cost of the emplacement and production well, cost of the explosive service, etc.

Since the Rulison area is typical of many gas fields that probably would be promising nuclear stimulation prospects, i.e., the moderately deep, lenticular, thick, low permeability sequences of the Mesaverde, Wasatch, Fort Union, Lewis, and Erickson Formations, the information obtained from Rulison could have important implications about the commercial possibilities of nuclear gas stimulation in other areas.

# IV: EXPERIMENTAL SITE DATA

## A. GEOGRAPHIC LOCATION

The Rulison Project location is in the southern part of the Rulison gas field, Garfield County, Colorado. The nearest town is Grand Valley, Colorado, approximately six miles to the northwest. This town has a population of 245, and is located on a highway which at this point is Interstate 70, U. S. 6 and 24, and Colorado State 789. The highway and the Denver Rio Grande Western Railway parallel the Colorado River at Grand Valley. The nearest city with commercial airline connections is Grand Junction, population approximately 20,000, which lies approximately 40 miles to the southwest (Figure 1).

The site is located on the upper reaches of Battlement Creek, on the north slope of Battlement Mesa. The site elevation is approximately 8,200 feet and the valley walls extend upward to above 9,600 feet on the east, south, and west, see Figure 2A.

The region is covered with grass, cedar, Engleman spruce, fir, and aspen on the upland which give way to sagebrush and range grass in the lower elevations.

A more comprehensive description of the area is presented in the "Project Rulison Feasibility Study"[(2)].

## B. GEOLOGY

Rulison Field is in the Piceance Creek Basin. The relative position of the field to the basin is shown in Figure 3. The field is on the southwest limb of the Basin structure, see Figure 4. Upper Cretaceous beds in this area dip towards the northeast at the rate of approximately 150 feet per mile. Tertiary age beds are relatively flat lying.

The surface geology of the Rulison Field and surrounding area is portrayed by Figures 2A and 2B. The geology as shown on these figures was mapped from aerial photograph interpretations and reconnaissance-type field work. More detailed surface studies in the site area have been made by the U. S. Geological Survey, and open file reports of these investigations are available.[3, 4] In addition, a surface geological study of the area within a few miles of the site was made by Austral, CER, and LRL geologists. No surface faults were found in the Battlement Creek area.

An evaluation of the sandstone lens geometry of the Mesaverde Formation in the general area was presented in the Project Rulison Feasibility Study.[2]

The average Mesaverde Formation characteristics obtained from an analysis of logs, core, and production data from existing wells in the field are summarized in Table I. For comparison, these same average characteristics from the initial evaluation of data from R-EX (Hayward 25-95) are presented in Table II.

## TABLE I

### AVERAGE RESERVOIR PROPERTIES, RULISON FIELD, COLORADO

| Sandstone Lens Property | Average Value |
|---|---|
| Porosity | 9.7 % |
| Permeability | .5 md |
| Water Saturation | 45 % |
| Gas Saturation | ~ 54 % |
| Oil Saturation | < 1 % |
| **Estimated Reservoir Properties at 8,500 feet (subsurface datum at site)** | |
| Initial Bottom Hole Pressure | 2,500 psia |
| Maximum Reservoir Temperature | 205 °F |
| **Basis for Volumetric Calculations** | |
| Net Sand | 500 feet |
| Base Pressure | 15.025 psia |
| Base Temperature | 60 °F |
| Initial Gas Deviation Factor (Z) | .88 |
| Gas-in-Place | 90 - 125 billion scf/640 acres |

TABLE II

AVERAGE RESERVOIR PROPERTIES,
R-EX (HAYWARD 25-95) DATA

| Sandstone Lens Property | Average Values: Core | Average Values: Log |
|---|---|---|
| Porosity | 8.7 % | 7.8 % |
| Permeability | .11 md | -- |
| Saturation | | |
| Water | 44 % | 38 - 55 % |
| Gas | ~ 55 % | 45 - 62 % (Gas + Oil) |
| Oil | < 1 % | |
| Estimated Reservoir Temperature | | 190 °F |
| Estimated Net Sand | | 400 feet |

A more detailed discussion of reservoir conditions at Rulison Field will be found in the ". . . Feasibility Study."[2]

C. STRATIGRAPHY

Rocks ranging in age from recent alluvial fill in the valleys to pre-Cambrian "basement" are present in the Rulison area. The sequence of rocks present and their relation to the general stratigraphy of the Piceance Creek Basin is shown in Figure 5.

The predominant surface rocks in the Rulison Field area are the Wasatch and Green River Formations of Tertiary age. There are a number of Quaternary age alluvial deposits in the valleys of the Colorado River and its tributaries and in terraces on the lower slopes of Battlement Mesa. In addition, "mud flow" type deposits are present in some of the higher valleys. Details of the surface geology are presented in Appendix F.

The "bedrock" at the Project Rulison site is lower Green River Formation. The Green River-Wasatch contact occurs at approximately 1, 700 feet. Relatively impermeable, Wasatch and Fort Union shales and siltstones were encountered by R-EX in the interval from approximately 1, 700 feet to 6, 134 feet. The basal Tertiary Ohio Creek Formation that occurs between the Fort Union and the Mesaverde, is water bearing in some areas in Rulison Field. This zone does not appear to be water productive in the project area, based on testing in R-EX.

The Mesaverde Formation in the Rulison Field area was deposited in a near shore environment that included marine, flood-plain and coastal swamp conditions. This depositional setting resulted in lenticular sandstones that from available data have limited areal extent. The lenticularity of the Mesaverde sandstone reservoirs is the cause of entrapment of gas in Rulison Field. The general character of the Mesaverde Formation in Rulison Field, as displayed by electrical logs, is illustrated by Figure 6. Logs run in the R-EX well disclosed a potential net pay equivalent to the 500-foot average found in the developed portion of the field. The productivity of the reservoir in the project area must await additional testing in R-EX.

The Mesaverde Formation in Rulison Field ranges in thickness from 2, 500 to 4, 000 feet. It is underlain by the Mancos shale which is part of a sequence of Lower Cretaceous shales and sandstones having a thickness of approximately 2, 500 feet.

## D. HYDROLOGY

The Colorado River and its larger tributaries in this area flow on alluvial deposits. Some limited coring by the Ground Water Branch of the United States Geological Survey shows that the sub-alluvial floors of the valleys are approximately 80 to 100 feet below the flowing stream levels.[(2)]

Most of the precipitation in this area is carried into the Colorado River by small streams, or flows and percolates to the river through the alluvial fill or terraces. A few springs are present where the underflow in the alluvium is deflected to the surface by relatively impermeable bedrock.

The residents of Morrisania Mesa and the village of Grand Valley obtain water for both domestic and agricultural purposes from shallow wells drilled into the alluvium or from cisterns and ponds fed by the intermittent creeks or by springs. Some of this water originates in the Battlement Creek drainage area.

There are some sandy zones in the lower Green River Formation which appear to be water bearing. At the site area these zones occur above an elevation of approximately 6,600 feet above sea level and are remote from permanent habitation.

In general, the Wasatch Formation underlying the alluvial deposits is relatively impermeable and is not used as a ground water source. There are some sandy zones near the top of the Wasatch and the middle Wasatch. But because of the general flat-lying nature of the Wasatch beds, it is felt that very little active ground water movement occurs in this formation.

The Ohio Creek Formation, which occurs between the Wasatch and the Mesaverde Formations, while water productive in some areas of Rulison Field, was impermeable at the R-EX well and did not produce water when tested.

A water-producing upper Mesaverde sandstone was encountered while air drilling R-EX. Since the Mesaverde sands are quite lenticular and since similar water production has not been found in other Mesaverde wells at Rulison, this is believed to be a local phenomenon. However, the productivity and storage capacity of this and other high water saturation zones will be evaluated by subsequent testing in R-EX.

E. SITE RECONNAISSANCE SUMMARY

1. The site is addequately served by a 16-foot wide graveled road that connects with the county-maintained road near the Morrisania Mesa Community Center.
2. Radio fire equipment and power supply locations can be developed at a number of points adjacent to the access road. Suitable locations are also available for a recording trailer park.
3. Radio repeating towers can be located on Doghead Mountain or on the east-west trending nose northeast of the site if a radio fire system is used. Either of these locations is line-of-sight to Grand Valley and could be used for the later full-scale commercial development in the area.

4. Grand Valley could serve as a CP location if radio is used for timing and firing. This location is logistically attractive since Grand Valley is located on the railroad and Interstate 70 - U. S. 6 - 24. If a hard wire system is used, a CP location can be established on Morrisania Mesa.

5. Power lines of sufficient capacity to serve the project are present on Morrisania Mesa and in the Colorado River Valley (Grand Valley area). Commercial telephone service is available at Grand Valley and has been extended to the site area.

6. An adequate road net is present on Morrisania Mesa for safety considerations.

7. Typical cultural features of interest from a seismic evaluation standpoint are tabulated in Appendix C.

## V: PREDICTED EXPLOSION EFFECTS

The experiment is currently designed to use a 60 $\pm$ 20 kiloton thermonuclear explosive. The yield is believed large enough to provide sufficient guarantee of chimney collapse, and small enough so that seismic motion will be within acceptable limits.

The detonation point will be selected so that the chimney-fracture zone will occur within the gas-bearing section of the Mesaverde Formation. A sufficient buffer zone will be left so that possible fracture communication with overlying water-bearing sands will be improbable. While such communication would not contaminate any water supply, an influx of large quantities of water into the chimney and fractured zone would compromise the gas well testing program and complicate post-shot evaluation of the stimulated reservoir.

For purposes of these calculations, it is assumed that the depth of the explosion will be 8, 000 feet. This assumption is based on an extrapolation of geologic parameters from other wells in the area and initial data from R-EX. This assumption yields a scaled depth of burial of 2, 040 ft/kt$^{1/3}$, about 5 times greater than that considered necessary for containment.

The following representative geologic and physical properties, based on data from other wells in the field,[(2)] were used in predicting the effects of the Rulison explosion:

| | | | |
|---|---|---|---|
| 1. | Depth of explosive burial | = | 8,000 feet |
| 2. | Medium porosity | = | 9.7 % |
| 3. | Water saturation | = | 45 % |

4. Average overburden density = 2.35 gm/cc

5. Average core grain density = 2.67 gm/cc

Cavity radius was calculated from the correlation of Higgins and Butkovich;[5] chimney height and fracture dimensions were estimated from the data of Boardman, et al.[6]

1. Cavity radius ($r_c$) = 80 ± 10 feet

2. Effective fracture radius and chimney height = 370 ± 70 feet

These predictions may be modified as more data become available from the pre-shot well program. Data and results from previous gas stimulation projects will be used to the fullest extent possible in revising these calculations and, if possible, estimates will be made of the extent and values of reservoir permeability that might result from the nuclear explosion. One facet of this problem is the evaluation of depth of fracturing below the W. P.* This will be considered as part of the alternative program.

*Working Point

# VI: TECHNICAL PROGRAM

## A. PHASE I - SITE ACCEPTABILITY

Site acceptability will be established and documented at the end of Phase I with respect to meeting both the project technical objectives and the project safety requirements. The project technical objectives are outlined in this report. The safety program will be prepared by the AEC. Information obtained by the following technical program as well as additional AEC safety studies will be used as input to the site acceptability report.

### 1. Construction:

An all-weather access road has been constructed from the county-maintained Morrisania Mesa road to the site area. This road runs along the east side of Battlement Creek and terminates at the R-EX drilling mat in the northeast quarter of the southwest quarter of Section 25, Township 7 South, Range 95 West.

The R-EX well (Hayward 25-95) is located at an elevation of 8,171 feet, 1,695 feet from the south line and 2,236 feet from the west line of Section 25, Township 7 South, Range 95 West, Garfield County, Colorado. This location is shown in Figure 7 and indicated by an arrow on Figure 2B.

The R-EX well was drilled to a total depth 8,516 feet. Representative intervals of the Wasatch and Ohio Creek Formations were cored and tested. All of these intervals were found non-productive. The well was cased through the Ohio Creek to a depth of 6,367 feet with 7-5/8 inch O.D. pipe. A 6-1/8 inch hole was air and mud drilled in the Mesaverde Formation from the intermediate casing point to a TD of 8,516 feet. Representative cores and a comprehensive suite of logs were obtained in this Mesaverde section. A 5-1/2 inch O.D. casing liner was cemented through the Mesaverde section to a depth of 8,514 feet.

The Rulison exploratory well, R-EX, has been completed. In addition to providing geologic and hydrologic information to aid in the site acceptability decision, the results of the gas production tests which are in progress will establish a basis for evaluating the degree of stimulation achieved by the explosion.

The detailed well drilling and testing program for R-EX is presented in Appendix A.

2. Testing and Reservoir Analysis:

A series of short-term isochronal tests will be run on the gas producing interval in the R-EX well in order to evaluate the flow capacity in the immediate area of the well. Subsequently, a long-term constant rate production and buildup test will be run to verify the lack of faulting, to ascertain the average flow capacity, and to provide an estimation of the continuity of the sand bodies.

The well testing data will be used to calculate reservoir parameters, such as effective flow capacity, well-bore radius, turbulence coefficient, and effective porosity-feet. These values would then be used to construct a mathematic model of the pre- and post-shot reservoir in the vicinity of the emplacement area.

The pre-shot model will be used to match long-term production history in the Rulison area and further to predict how a non-stimulated well would perform. The post-shot model will utilize the reservoir parameters that are used in the pre-shot model, and, in addition, a chimney and fractured area of high conductivity will be superimposed over the pre-shot model. Because of the lack of data on fracture extent and flow capacity, a series of cases will be run using a grid of fracture extents and capacities which will range from conservative to optimistic. These cases will be compared to the non-stimulated case to determine the additional amount of gas that could be recovered over a given time span. A more detailed discussion of this model will be found in the ". . . Feasibility Study."(2)

Once the well has been stimulated and retested, the predicted performance will be checked and the model altered to incorporate the effective chimney size and fracture extent. This final model will be used to predict the deliverability of the stimulated well for different production practices. This model can also be used to predict the potential of nuclear stimulation for other locations in Rulison Field, as well as providing insight to the potential of nuclear stimulation in other similar areas.

3. Preliminary Weather Data:

A weather data acquisition program was started in the Rulison area during October, 1967. Four recording weather stations were located on a line extending from Morrisania Mesa to near the top of Battlement Mesa. The locations of these stations are indicated by black ticks on Figure 2A. The strip charts from these recording weather stations are collected and filed with ESSA/ARL every six weeks. The wind direction, wind run, temperature, and precipitation data which are recorded on the charts are summarized by ESSA/ARL and this information is distributed to the other interested government agencies.

B. PHASE II - OPERATIONAL PHASE

After the site has been accepted, the second or operational phase will begin. This phase will include major construction, emplacement of the explosive, and detonation.

1. <u>Construction:</u>

The emplacement hole, R-E, will be drilled approximately 285 feet northwest of R-EX, see Figures 7 and 8. This large diameter well will be uncased and drilled to a depth approximately 100 feet below the proposed working point. The specific diameter will be determined by canister dimensions that are not currently available. Formation characteristics will be carefully documented during drilling operations, and if required, a core will be cut from 40 feet above to 40 feet below the working point. A suite of wet hole logs will be run at the conclusion of drilling operations.

Details of the R-E well program are presented in Appendix B.

The bulk of the on-site activities will be started after completion of R-E.

2. <u>Seismic:</u>

Cultural features in the general project area will be documented and locations for seismic instrumentation will be developed. The technical seismic program is discussed in Appendix C.

3. Explosion Effects:

The laboratory explosion effects program is intended to improve the capability to predict for any environment and yield the cavity and chimney dimensions and severity, frequency and extent of shot-induced fractures. Core from R-EX will be furnished the laboratory to aid the general program of comparing rock characteristics with nuclear effects. In addition, geophysical logs, including density and compressional and shear velocity, will be run to aid in formation characterization.

The resulting data will serve as input for calculational models which predict explosion effects. Dynamic measurements at shot time and post-shot investigation of the effects will be used to evaluate the validity of the predictions.

4. Instrumentation:

At shot time, dynamic measurements will give data related to shock wave characteristics, fracturing, and chimney collapse. This program involves the following instruments; (see Figure 8):

a. Two peak pressure gauges or two velocity slifers in R-E. Either will provide a check on explosive yield.

b. Two stress history gauges near the predicted maximum extent of shock fracturing in R-E.

c. Two collapse slifers in R-E in the zone of expected chimney collapse.

Phase II will terminate shortly after detonation with the recovery of surface instruments and records from the site area.

C. PHASE III - POST-SHOT INVESTIGATIONS

The post-shot program is designed to be flexible enough so that a maximum amount of information can be retrieved at a minimum cost.

The post-shot program basically will consist of:

1. Evaluation of post-shot reservoir production characteristics.
2. Evaluation of chimney and fracture zone geometry.
3. Evaluation of seismic motions in the Rulison area, i.e., Morrisania Mesa, Colorado River Valley, etc.
4. Evaluation of possible radioactive contamination in gas and "cleanup" techniques.
5. Confirmation of explosive yield.
6. (Alternate) An evaluation of fracture density and vertical extent from data obtained in a second post-shot well will be considered if necessary funding is available.

The reservoir production characteristics will be determined by production tests in PS-1, a re-entry of R-E to the top of the chimney. Analysis of the test results should permit not only a determination of the stimulated well's productive capacity, but also an estimate of chimney volume and the effective fracture permeability outside the chimney.

The seismic evaluation will involve a comparison of any reported structural response with measured ground motions. These motions will be analyzed in the context of local geological conditions.

Explosive performance information will come from instrumentation at shot time on the surface and in R-E and the subsequent chimney volume measurement.

If an alternate program can be funded and is deemed appropriate, the physical effects could be studied in a second post-shot well. This well, PS-2, could be a re-entry of R-EX, passing alongside the chimney and extending several hundred feet below it. The fracture density and vertical extent could be evaluated by packer-spinner tests, core, and logs. This well could also evaluate the initial fracture flow capacity at one point in the reservoir, and monitor any reduction in flow capacity (fracture closing or healing) with time and decreasing reservoir pressure. These alternative programs are presented in separate sections and appendices.

1. <u>Initial Evaluation Program:</u>

The first Rulison post-shot well, PS-1, will be a re-entry of the emplacement hole. It is planned to lower the nuclear explosive in R-E at the end of a 7-inch casing string. On re-entry, the casing will be cleaned out as far as possible, a window milled in the wall, if required, and the well deflected out alongside the initial emplacement hole. The well will be drilled approximately vertically into the top of the chimney. If conditions allow, the extent and orientation of fracturing above the chimney will be investigated by logs, photography, and packer spinner surveys.

The returning air or gas stream from the PS-1 drilling operations will be monitored for total radioactivity. A recirculating air/gas system may be required during drilling into the fractured zone and chimney. The return gas stream will be periodically sampled and these samples analyzed chromatographically. Upon completion of the well, the chimney gas will be sampled and analyzed for components and total radioactivity. Based on the results of these analyses, a test frequency will be selected which will yield four to six samples prior to the safe testing period.

Post-shot production testing will start when gas test results show that previously determined criteria for safe testing have been met.

Production testing will be accomplished in three phases. The first phase would be very short-term transient testing to evaluate chimney volume. The second series of tests would be intermediate term isochronal tests to evaluate apparent chimney-fracture zone volume and apparent fracture radius. The final long-term production test would evaluate the flow capacity and producing characteristics of the nuclear-stimulated well.

From these tests, an estimate of the fracture flow capacity, chimney volume, fracture volume, and effective fracture extent can be determined. Using these data, a mathematical reservoir simulator model will be used with the post-shot determined chimney size and fracture extent to predict deliverability and economics for various production practices, and the nuclear stimulation potential of the Rulison area.

A program will be initiated during long-term production testing to produce a marketable gas. This could probably be accomplished by 1) separating solid particles and liquids from the gas stream, 2) venting and dispersion of the most radioactive chimney gas, and 3) subsequent diluting the low level radioactive gas with other gas in a pipeline to produce a usable product.

Additional details of the post-shot program are presented in Appendix D.

2. Alternate Evaluation Program:

If the pre-shot geologic program indicates the necessity of producing gas from the lower portion of the cavity because of liquid drop-out or water entry, the following alternate post-shot program will be initiated, see Appendix E.

After the re-entry into the top of the cavity as described above with well PS-1, the Rulison exploratory hole, R-EX, will be re-entered as PS-2 and the plugs drilled out from near the bottom of the 7-5/8 inch casing. If the 5-1/2 inch liner can then be successfully penetrated, production tubing can be installed to the working point depth and the liquid stabilized at a low level in the cavity by producing from the tubing in PS-2.

If the liner in R-EX cannot be successfuly penetrated then a plug can be placed at the top of the liner and PS-2A drilled by milling a window in the 7-5/8 inch casing and drilling a hole alongside the chimney to the working point datum of approximately 8,000 feet. Tubing would then be run to approximately

8,000 feet and the long-term production tests would be carried out in PS-2A.

If the physical effects evaluation program is undertaken then PS-2A could be drilled to approximately 8,500 feet and fracture extent and density evaluated with packer spinner surveys, logs, and representative cores. The recirculating air/gas system, discussed in conjunction with drilling PS-1, may be required for drilling the lower section of PS-2A.

The detailed well program for this alternate post-shot drilling program will be found in Appendix E.

## VII: SITE ACCEPTABILITY CRITERIA

The particular site chosen for the project must meet certain pre-determined criteria to be acceptable. The data and interpretation pertinent to the acceptance criteria will be collected and documented in a report for review by the project participants before the site is formally accepted. These criteria include:

A. The technical data enumerated in the Project Objective can be obtained at this site.

B. The hydrologic situation is such that it is not probable during the post-shot testing and production of the reservoir that water, either from overlying aquifers or edge water, will be introduced into the chimney environment in such quantities as to compromise the experiment.

C. The reservoir rock at the site will contain reserves of at least $30 \times 10^9$ standard cubic feet of gas in place per 640 acres, as determined by the analyses of core, logs, and production test results from the pre-shot drill hole, R-EX.

D. The nuclear explosive can be detonated with all reasonable assurance that it will be completely contained.

E. The other AEC safety criteria will be met.

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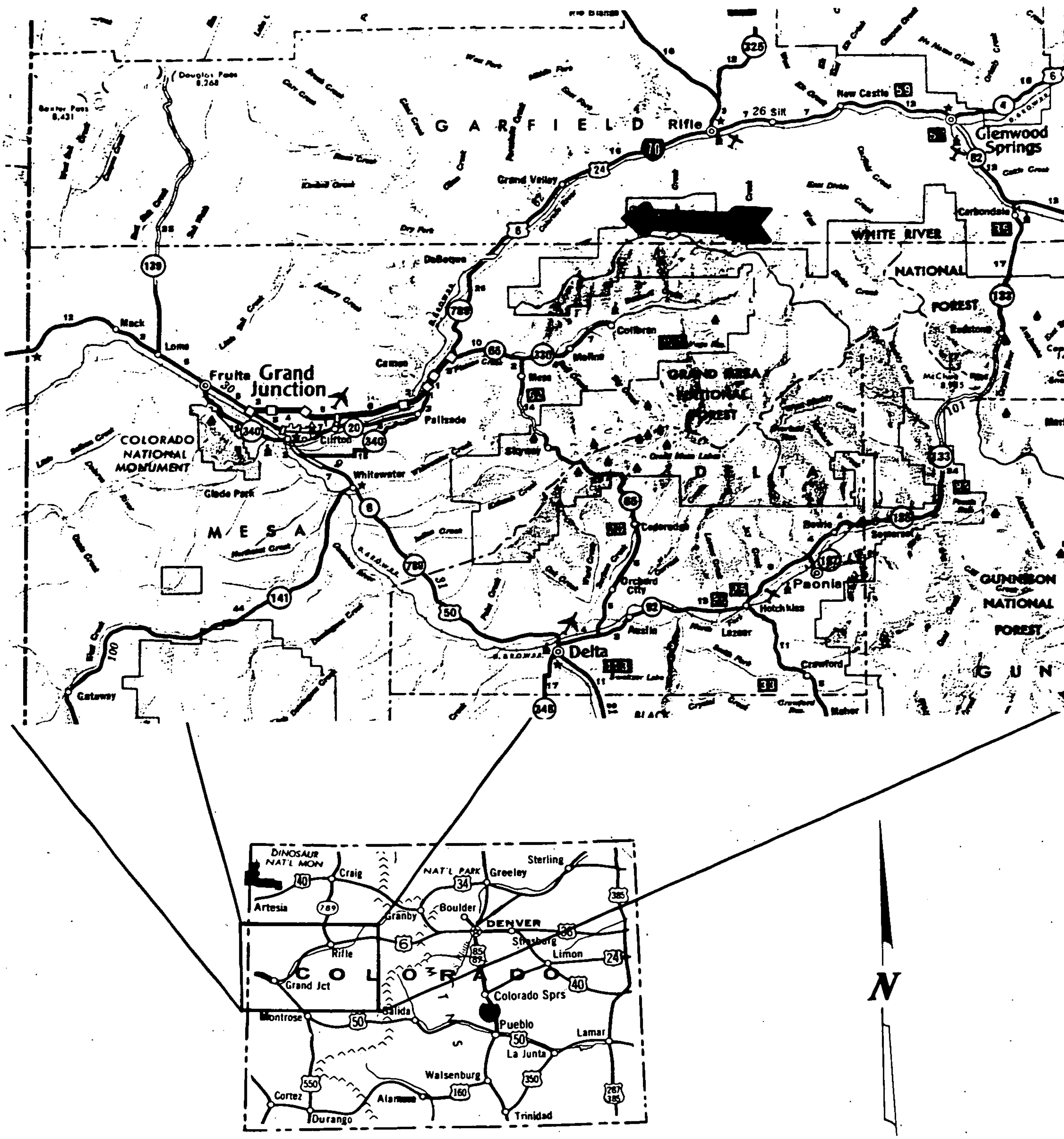
## ABBREVIATIONS

| | |
|---|---|
| AEC | Atomic Energy Commission |
| bbl | Barrel |
| BHC | Bore hole compensated |
| BHP | Bottom hole pressure |
| CER | CER Geonuclear Corporation |
| cp | Centipoise |
| CP | Control point |
| DST | Drill stem test |
| FSL | From the South Line |
| FWL | From the West Line |
| gm/cc | Grams per cubic centimeter |
| GZ | Surface of the ground directly above the nuclear explosive |
| H | Depth of shot point subsurface |
| ID | Inside diameter |
| IES | Induction electrical survey log, consisting of induction, short normal, and self potential curves |
| kh | Flow capacity, average permeability (millidarcys) multiplied by feet of net pay |
| kt | Kiloton |
| kw | Kilowatt |
| LRL | Lawrence Radiation Laboratory |
| md | Millidarcy |
| OD | Outside diameter |

ABBREVIATIONS - continued

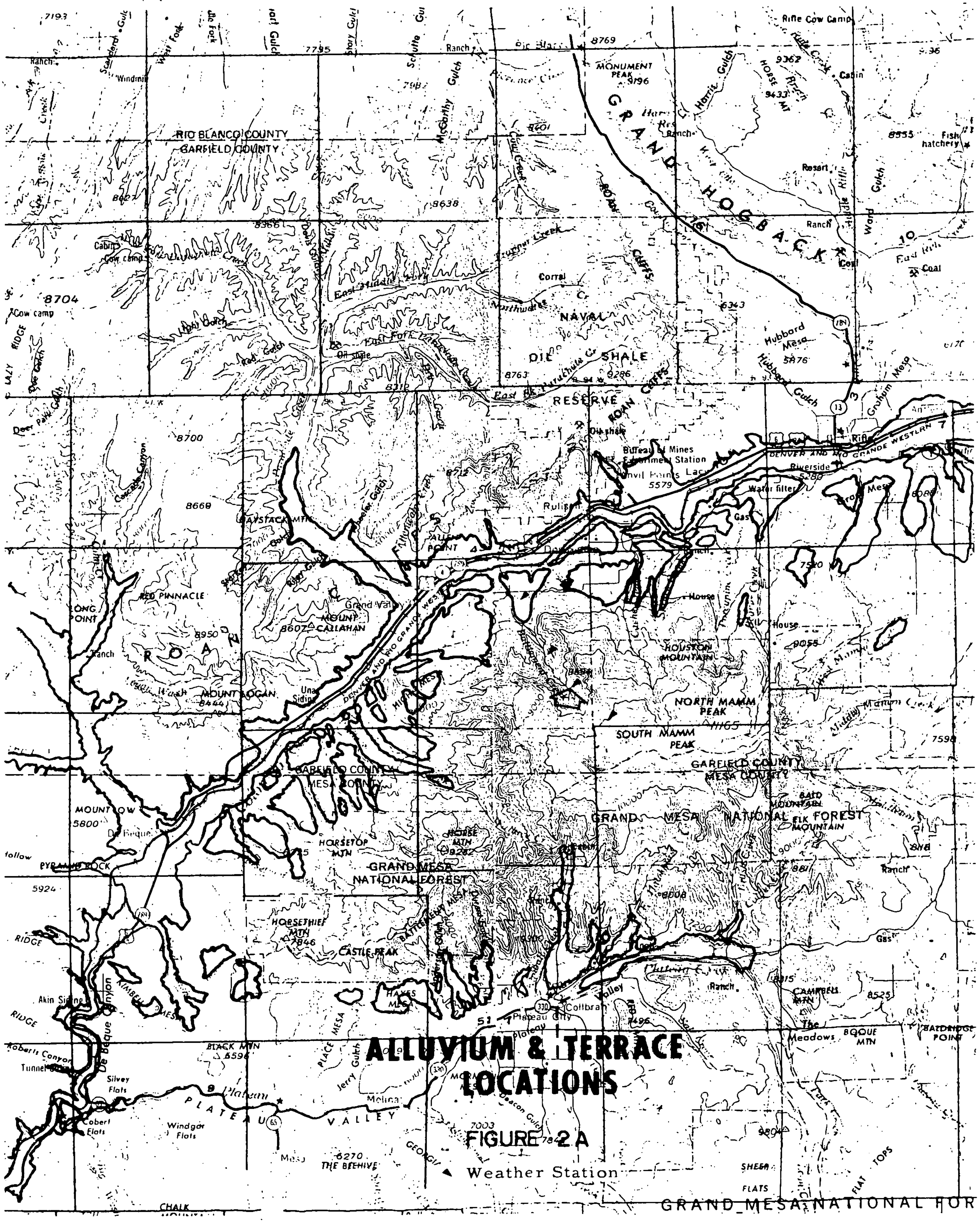
| | |
|---|---|
| psi | Pounds per square inch |
| RAMS | Remote Area Monitoring Station |
| $r_c$ | Cavity radius |
| R-E | Emplacement well. Well in which nuclear explosive will be lowered, stemmed and detonated |
| R-EX | Rulison exploratory well |
| R-PS 1 | Post-shot re-entry well number one |
| R-PS 2 | Post-shot re-entry well number two |
| RTTS | Halliburton's retrievable test-treat-squeeze tool |
| RVT | Halliburton's retrievable valve tester |
| R95W | Range 95 West |
| scf | Standard cubic feet |
| SP | Self potential log |
| TD | Total depth of well |
| TWX | Teletype service |
| T7S | Township 7 South |
| USGS | United States Geological Survey |
| VDL | Variable density sonic character log |
| W | Explosive yield, kilotons |
| WP | Working point - location of nuclear explosive |
| 3-D | Type of sonic character log |
| $^{o}F$ | Degrees Fahrenheit |




# ROAD MAP OF NORTHWEST COLORADO

0 5 10 15
SCALE IN MILES

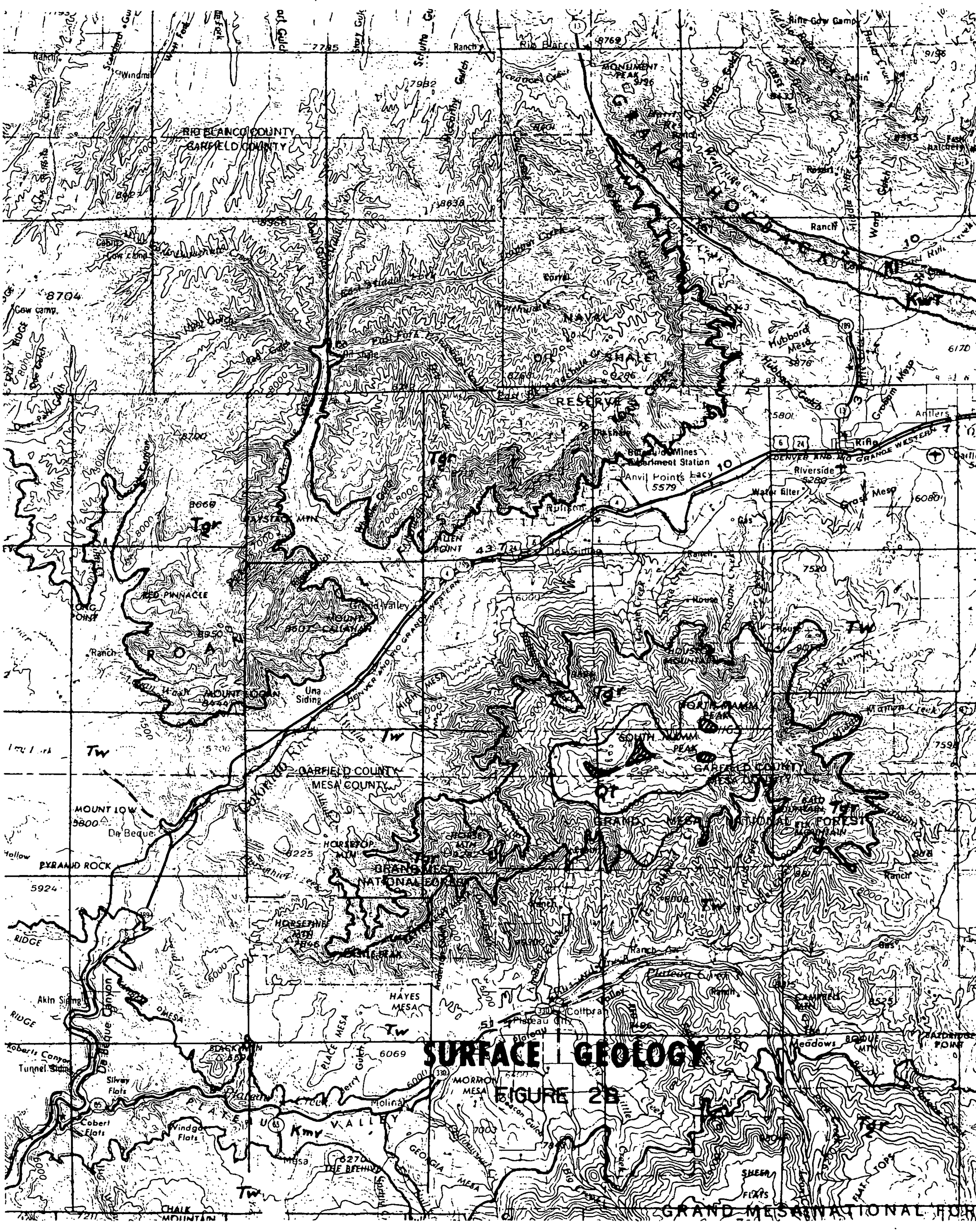
Figure




ALLUVIUM & TERRACE LOCATIONS

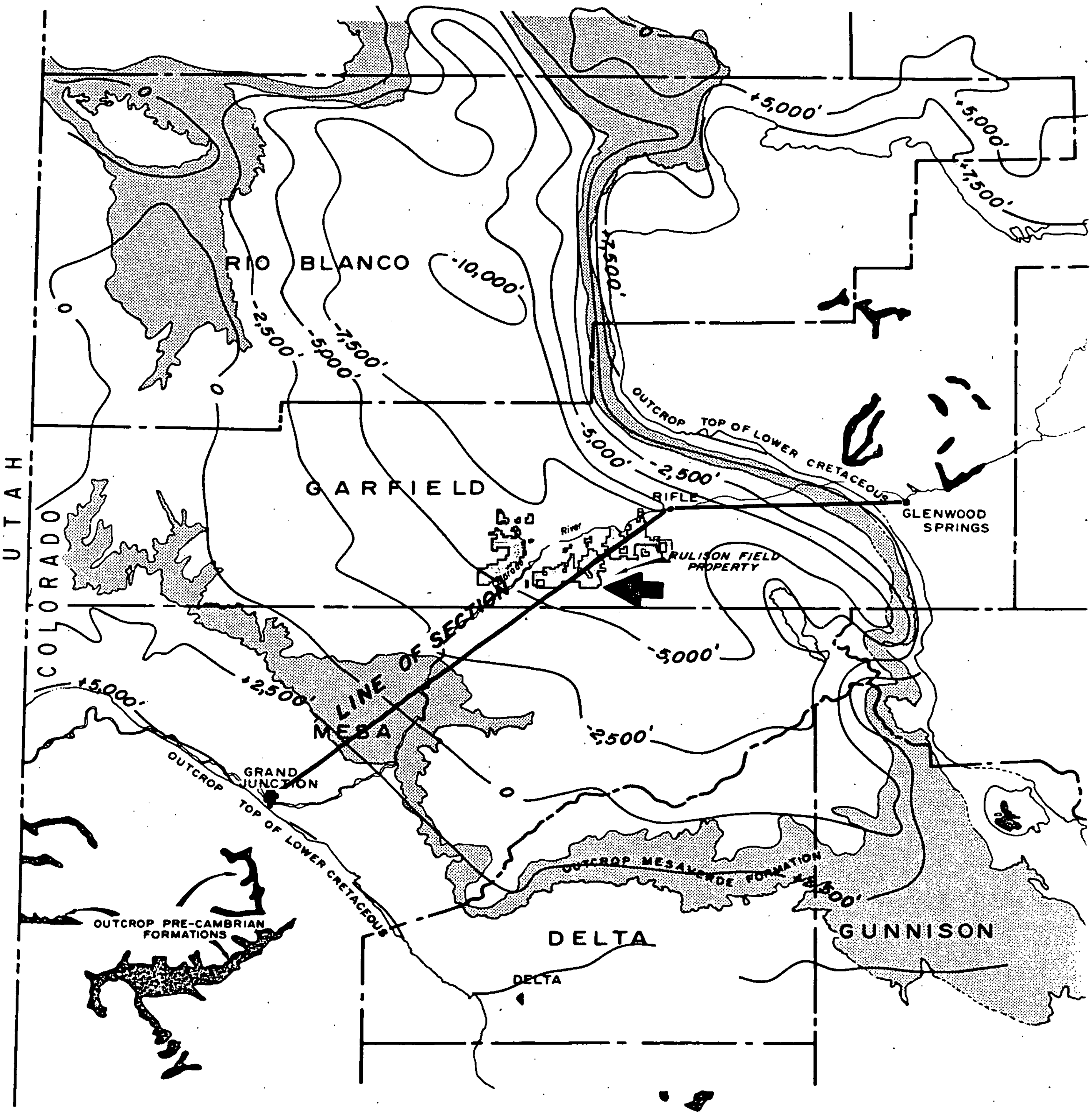
FIGURE 2A

▲ Weather Station




SURFACE GEOLOGY

FIGURE 2B




REGIONAL MAP AND STRUCTURAL INTERPRETATION CONTOURED ON TOP OF LOWER CRETACEOUS AND SHOWING THE POSITION OF RULISON FIELD PROPERTIES RELATIVE TO SURFACE EXPOSURES OF MESAVERDE AND PRE-CAMBRIAN FORMATIONS

FIGURE 3

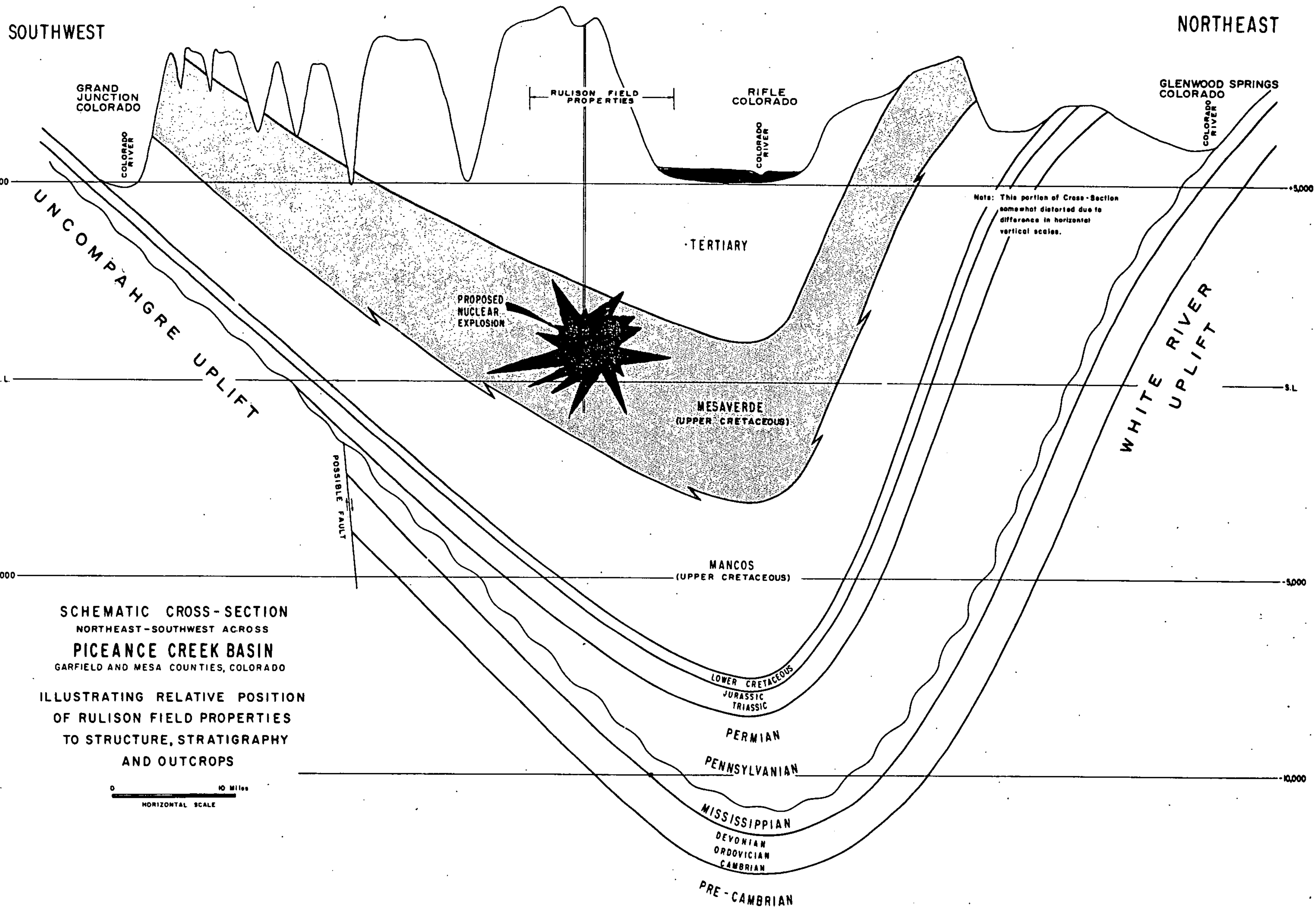

SOUTHWEST
NORTHEAST
GRAND JUNCTION COLORADO
COLORADO RIVER
RULISON FIELD PROPERTIES
RIFLE COLORADO
COLORADO RIVER
GLENWOOD SPRINGS COLORADO
COLORADO RIVER
+5,000
+5,000
Note: This portion of Cross-Section somewhat distorted due to difference in horizontal vertical scales.
TERTIARY
UNCOMPAHGRE UPLIFT
PROPOSED NUCLEAR EXPLOSION
S.L.
S.L.
MESAVERDE (UPPER CRETACEOUS)
WHITE RIVER UPLIFT
POSSIBLE FAULT
-5,000
MANCOS (UPPER CRETACEOUS)
-5,000
SCHEMATIC CROSS-SECTION
NORTHEAST-SOUTHWEST ACROSS
PICEANCE CREEK BASIN
GARFIELD AND MESA COUNTIES, COLORADO
ILLUSTRATING RELATIVE POSITION
OF RULISON FIELD PROPERTIES
TO STRUCTURE, STRATIGRAPHY
AND OUTCROPS
0
10 Miles
HORIZONTAL SCALE
LOWER CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
PENNSYLVANIAN
-10,000
MISSISSIPPIAN
DEVONIAN
ORDOVICIAN
CAMBRIAN
PRE-CAMBRIAN

FIGURE 4

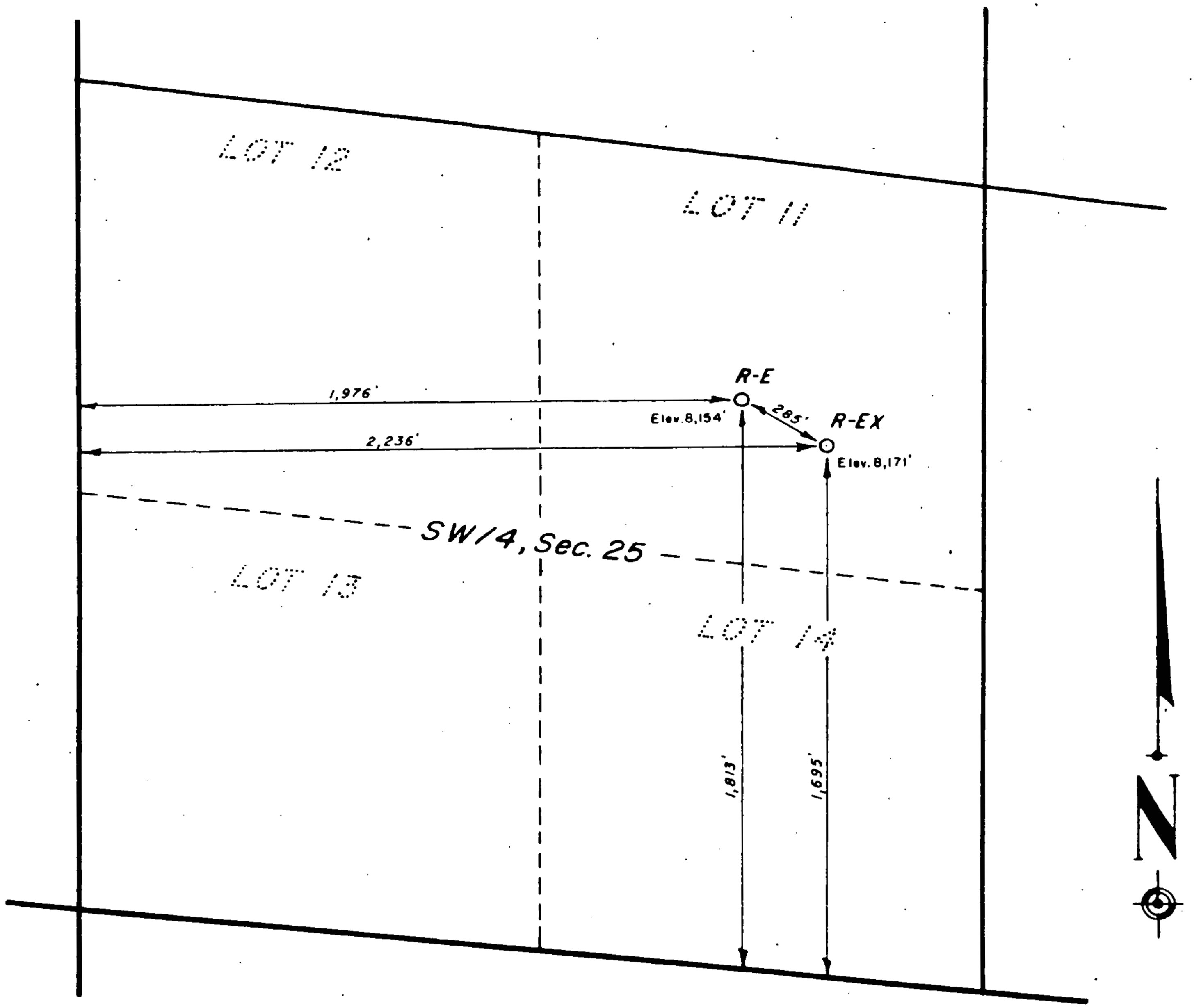



FIGURE 7

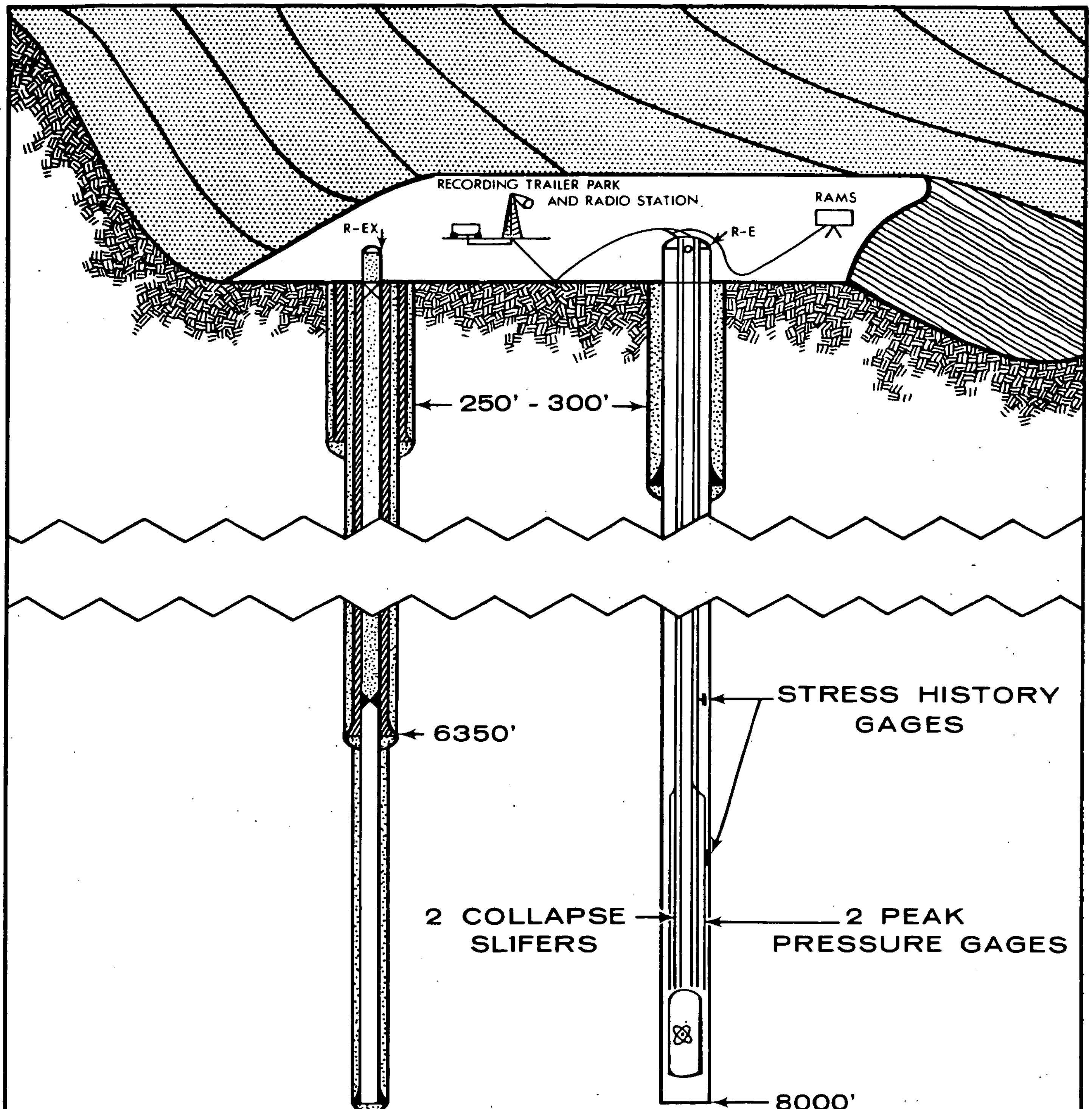
AUSTRAL OIL COMPANY
INCORPORATED
HOUSTON TEXAS

PROJECT RULISON
WELL LOCATION PLAT

GARFIELD COUNTY, COLORADO
T-7-S, R-95-W OF THE 6TH. P.M.

SCALE: 1" = 500'

DATE: NOVEMBER 14, 1967




**RULISON HOLE LAYOUT**

DRYHOLE CASE

Figure 8.

## APPENDIX A: WELL R-EX PROGRAM

R-EX, Site Exploratory and Test Well, is located 1,695 feet FSL 2,236 feet FWL Section 25, T7S, R95W, Garfield County, Colorado.

1. Drilling Program

   a. TD: 8,516 feet subsurface, drilled about 500 feet below the anticipated location of W. P.

   b. Casing:

      Surface to 500 feet, 10-3/4 inch O. D.

      Surface to 6,365 feet, 7-5/8 inch O. D.

      5,860 to 8,516 feet, 5-1/2 inch O.D.

   c. Minimum ID:

      Surface to 5,860 feet, 6.97 inches

      5,860 to 8,516 feet, 4.78 inches

   d. Drilling Media:

      Surface to 500 feet, mud

      500 feet to 2,010 feet, air

      2,010 feet to 4,030 feet, air and foam

      4,030 feet to 6,365 feet, mud

      6,365 feet to 7,084 feet, air

      7,084 feet to 8,516 feet, mud

   e. Coring: 3-inch diameter and sidewall cores in Wasatch and Ohio Creek Formations, and 2-7/8 inch diameter in the

Mesaverde Formation. The core was wrapped on site and shipped to a commercial core laboratory for surface gamma logging, photography, porosity-permeability-water saturation determination, wrapping, and temporary storage. The cored intervals were:

| Formation | Footage | Approximate Interval |
|---|---|---|
| Wasatch | 60 | 4, 125 to 4, 177 feet |
| Ohio Creek | 60 | 6, 009 to 6, 062 feet |
| Mesaverde | 60 | 7, 060 to 7, 120 feet |
| Mesaverde | 60 | 7, 260 to 7, 320 feet |
| Mesaverde | 60 | 7, 500 to 7, 560 feet |
| Mesaverde | 60 | 7, 840 to 7, 900 feet |
| Mesaverde | 60 | 8, 000 to 8, 120 feet |
| Mesaverde | 60 | 8, 350 to 8, 410 feet |

f. Logging:

1.) Surface to 500 feet, IES, caliper-sonic

2.) 500 feet to 6, 365 feet

a.) I.E.S.

b.) Borehole compensated (BHC) sonic-caliper

c.) Variable density sonic log, (VDL)

d.) Gamma-epithermal neutron

e.) Multishot directional survey

f.) Temperature log

g.) BHC density-caliper

h.) Acoustic cement bond log

i.) 3-D cement bond log

3.) 6,367 feet to 8,516 feet

a.) BHC sonic-caliper

b.) 3-D sonic, 3, 6, 12 foot spacing

c.) VDL sonic

d.) IES

e.) Gamma-epithermal neutron

f.) BHC density-caliper

g.) Multishot directional

h.) Temperature log

i.) Cased hole gamma-epithermal neutron

j.) Acoustic cement bond log

g. Directional Control: Multishot directional surveys indicated a maximum hole inclination of 2 degrees. The bottom of the hole was 55.8 feet from the surface location on a bearing of S 29.6° E.

h. Well Completion:

1.) Well head completion hardware suitable for production tests will be furnished.

2.) New 2-3/8 inch tubing to approximately 8,000 feet is required. The tubing will not be run until after the gas entry zones have been determined.

2. Testing Program

a. Hydrologic Testing:

1.) Wireline formation sample tests were made at the following depths in the Wasatch Formation:

2,029

2,053

2,310

3,288

3,920

4,226

All tests were dry.

2.) DST's of the intervals 6,026 - 6,062 and 6,145 - 6,165 were made in the Ohio Creek Formation -- both tests were dry.

3.) Additional Hydrologic Testing: The following zones have calculated water saturations of 80-95% and are to be swab tested individually to determine their water flow capacity, if any.

| | Interval | Neutron Porosity | Water Saturation | Remarks |
|---|---|---|---|---|
| (1) | 8, 030-8, 034' | 6% | 85% | |
| (2) | 7, 614-7, 620' | 8% | 95% | |
| (3) | 7, 328-7, 336' | 7 - 10% | 85% | |
| (4) | 7, 212-7, 214' | 11% | 80% | Zone fractured |
| (5) | 7, 092-7, 096' | 10 - 11% | 85% | |
| (6) | 7, 082-7, 088' | 8 - 10% | 85% | Water entry into borehole observed while coring at 7, 084' with air. |

Note: Additional zones with calculated water saturations of 85-100% are found in the upper part of the hole in the gross interval 6, 500-6, 830 feet. However, this part of the hole was air drilled without any water influx and testing of these zones has, therefore, been eliminated.

Intervals No. 1, 2, and 3 are zones of low porosity, shaley in character, and are expected to yield negative results. Interval No. 4 is within a fractured zone and as such may test positively. Intervals 5 and 6 are expected to yield fluids based on the observations made while attempting to core them while air drilling.

Procedure:

a.) Perforate 2 holes/ft. with bullet gun (4-inch O.D.)

b.) Run RTTS-RVT (with BHP bombs)

c.) Set packer above perforations and swab. Measure recovered fluids including load water in a small rectangular tank

d.) At the conclusion of swab test, reverse out BHP bomb and observe charts

e.) At the conclusion of each test cement squeeze open perforations and prepare to test next interval above.

At the conclusion of the testing of these five zones drill out the cement plugs and clean out to bottom. Condition and treat completion fluid if necessary.

b. Gas Testing:

1.) Initial gas testing will test individual intervals in the shot affected region. The testing procedure follows:

The section from 7,300-8,500 feet has been subdivided into four intervals for gas testing purposes:

Interval #1 - 8,148-8,464' - 316' gross, 70' of perforations.

Interval #2 - 7,886-8,072' - 186' gross, 56' of perforations.

Interval #3 - 7,634-7,844' - 210' gross, 72' of perforations

Interval #4 - 7,302-7,576' - 274' gross, 52' of perforations.

Perforations of each interval will be as follows:

| Interval #1 | Interval #2 | Interval #3 | Interval #4 |
|---|---|---|---|
| 8,148-8,154' | 7,886-7,890' | 7,634-7,642' | 7,302-7,308' |
| 8,156-8,172' | 7,892-7,914' | 7,648-7,654' | 7,402-7,404' |
| 8,200-8,208' | 7,952-7,966' | 7,668-7,678' | 7,410-7,416' |
| 8,290-8,298' | 8,050-8,060' | 7,680-7,686' | 7,480-7,484' |
| 8,318-8,326' | 8,066-8,072' | 7,720-7,734' | 7,526-7,530' |
| 8,430-8,434' | | 7,776-7,782' | 7,534-7,538' |
| 8,440-8,444' | | 7,812-7,824' | 7,540-7,544' |
| 8,448-8,464' | | 7,834-7,844' | 7,550-7,554' |
| | | | 7,556-7,568' |
| | | | 7,570-7,576' |

Procedure:

a.) Connect air compressors and remove water from inside casing

b.) Perforate Interval #1, 2 holes/ft (bullet gun) in dry casing c.) Run RTTS-RVT tools (with BHP bombs). Set packer at 8,100 feet.

d.) Remove fluid influx, if any, with swab.

e.) Run short-term test through critical flow prover unit. If volume of gas flow is unusually low conclude test with a short-term BHP buildup, otherwise pull RTTS-RVT tools and observe charts.

f.) Set drillable bridge plug 20-30' above open perforations.

g.) Remaining intervals #2, #3, #4 will be perforated and tested in a like manner.

Note: The perforated intervals will be treated with chemicals, if necessary, designed to overcome the "skin" effect, which is expected to be a specific factor to be considered because of having drilled the Mesaverde section with mud in the borehole. Consideration will also be given to stimulation by hydraulic fracturing, if necessary, to obtain a sufficient gas entry that can be measured at the surface. Gas flow will be measured at the surface with the critical flow prover unit. This unit consists of an inline heater (90,000 BTU), a back pressure valve with close-tolerance pressure and temperature controls, and an orifice well tester.

After testing of the four proposed intervals has been completed, operations will then be commenced to install production tubing in the well bore and complete.

2.) After the individual interval tests have been completed, the well will be shut-in and the pressure monitored. When the approximate static pressure has been reached, the well should then be placed on production at near capacity. After approximately 48 hours a flowing temperature survey should be run. At least two complete runs should be conducted to verify the gas entry points. Each run should span the entire Mesaverde section. If feasible, a spinner survey will also be run. After completing the survey, tubing should be run in the hole so that any fluid produced can be unloaded during the subsequent constant rate tests. The well should then be shut in until static reservoir pressure is reached.

3.) Short constant rate production tests will be run using the diagrammed equipment in Figure I-A. A series of constant rate draw-down and pressure buildup tests will be made. Each test should take from 1 to 5 days depending on how long it takes to dampen out the cross-flow effects caused by layering. Each test should be at a rate higher than the previous one. The pressure buildup portion of each test should be approximately three times the flow duration. This sequence should be continued for a total of three or possibly four rates.

4.) Long-term production tests will be based on the data from the short-term tests. The long-term flow test will be run to sample the formation away from the well bore. A surface recording bottom hole pressure bomb will be run to a point near the bottom of the tubing. The subsurface pressure will be continuously recorded during the test. A flow rate should be selected that can be sustained for an adequate flow period, e.g., 30-90 days, and the rate held constant within acceptable limits. The conduct of the test can be accomplished with the equipment diagrammed in Figure 1-A. At the conclusion of the long-term flow test the well will be shut in for a buildup of sufficient duration to evaluate the reservoir characteristics.

The pressure in R-EX will be carefully monitored during and after the drilling of R-E so that any pressure pulses initiated during the drilling of R-E can be recorded in R-EX.

5.) Gas samples will be taken during the long-term testing for chemical and radiochemical analysis. A complete chemical characterization of the gas will be made for comparison with gas compositions from other experiments, for radioactivity backgrounds, and to estimate the chemical composition of cavity gas after the explosion.

3. Stemming

Consideration will be given to filling the 5-1/2 inch casing section with sand to approximately 5,850 feet. A drillable plug will be placed in the 7-5/8 inch casing above the sand fill. A 100-foot cement plug will be placed on the drillable plug and the 7-5/8 inch casing secured at the top with the well head equipment.

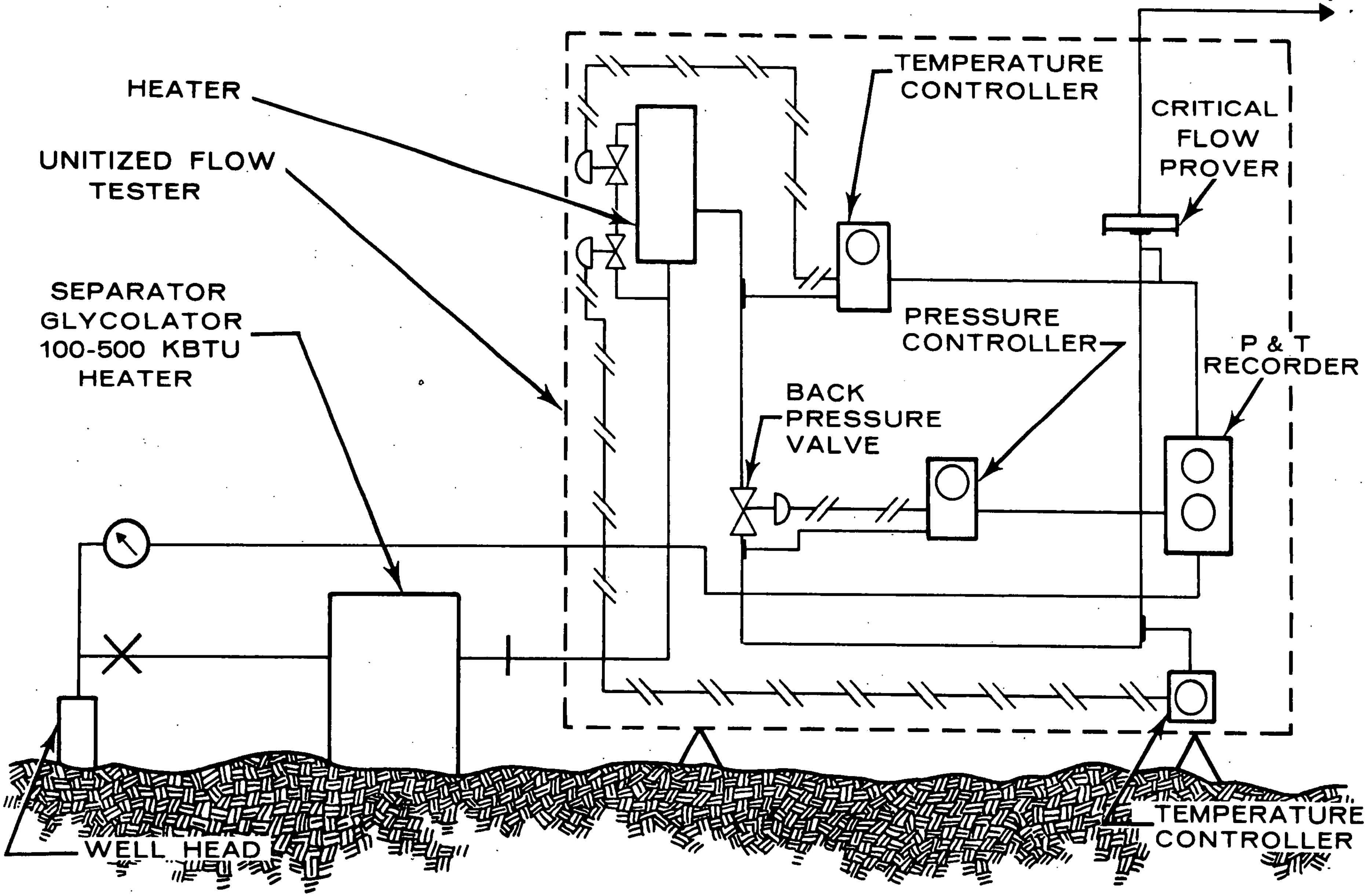



Figure 1A.

**SCHEMATIC DIAGRAM**

**CONSTANT RATE FLOW CONTROL SYSTEM**

(100-200 MCF/D RATE, 90-100 PSI FLOW PROVER PRESSURE)

# APPENDIX B: WELL R-E PROGRAM

R-E emplacement hole will be located 1,813 feet FSL, 1,976 feet FWL, Sec. 25, T7S, R95W, Garfield County, Colorado, or approximately 285 feet northwest of R-EX (Hayward No. 25-95).

1. Drilling Program

   a. T.D.: Working Point (W. P.) + 100 feet. W. P. determined on basis of logs and tests in R-EX.

   b. Minimum I. D.: To be determined after canister dimensions are available.

   c. Casing: Surface casing of sufficient diameter will be run to approximately 750 feet, open hole below this depth to TD. No intermediate casing string is anticipated.

   d. Drilling Medium: Surface to T. D., mud.

   e. Coring: In pilot hole, 80 feet total, 40 feet above to 40 feet below W. P.; consideration will be given to using a "Tricore" from the full diameter hole. Cores to be wrapped, and stored by commercial core lab.

   f. Logs:

      1.) The following wet hole logs are required from surface to casing point:

         a.) Gamma-neutron

         b.) Caliper

      2.) Casing point to T. D.:

a.) Gamma-epithermal neutron

b.) Neutron lifetime log

c.) Multishot directional survey

d.) BHC density

e.) Caliper

g. <u>Directional Control</u>: Deviation shall not be greater than 5° at T.D. with maximum angular build-up less than 1°/100.

2. Testing Program

a. <u>Hydrologic Testing</u>: none

b. <u>Gas Testing</u>: none

3. Emplacement and Stemming

a. The explosive package will be run on a 7-inch casing equipped with cementing ports. Necessary cabling and instrumentation will be affixed to the outside of this pipe.

b. The proposed stemming procedure is:

1.) The casing would be cemented in the lower section of the hole through ports located just above the explosive canister. The cement top would be approximately 1,500 feet above the working point inside and outside the casing.

2.) The intermediate section of the hole could remain mud filled, e.g., 1,500 to 7,000 feet above the W. P.

3.) A cement plug would be placed below the bottom of the surface pipe, e.g., from approximately 1,000 feet subsurface to the surface.

# APPENDIX C: SEISMIC MOTION PROGRAM

The purposes of the Seismic Motion Program are: 1) to determine the amplitude of the source signal in formations comparable to the Mesaverde; 2) to determine the effect on the propagated signal of transmission through the overlying formations; 3) to assess the degree of amplification caused by mismatches of acoustic impedance between the several overlying layers; and 4) to determine the seismic motion for correlation with effects on cultural features. From the results of these investigations, a reasonable prediction can be made of the extent to which the yield of possible follow-on explosions can be increased without causing excessive damage to cultural features.

To achieve these objectives it is planned to acquire ground motion data at several locations down the Battlement Creek valley and in addition at several locations up and down the Colorado River. It is tentatively planned to use accelerographs and displacement meters at about 5 locations spaced on a radial from GZ to a point near the town of Grand Valley. Three components of motion, vertical, radial and tangential, will be recorded at each of these locations. It is planned to make velocity measurements at greater distances, up to about 40 miles from GZ. For this purpose, about 8 additional stations will be required, 4 of them spaced at significant locations up the Colorado River valley toward Glenwood Springs, the remaining 4 at significant locations downstream toward Grand Junction. At each of these locations it is planned to take geophone velocity data in three components, radial, tangential and vertical.

At about 4 selected locations, where hardrock and alluvium are both accessible, duplicate installations are planned to provide comparative data which will give an insight into the amplification effects of the valley alluvium.

Locations for each of the classes of stations have been selected primarily on the basis of map study. It is probable that a site survey will result in changes in the selections. It may be desirable, for example, to relocate or add one or more stations to provide measurements in the Plateau Creek Valley to the south of GZ. For economy of effort, station locations should be coordinated as much as possible with those required for the safety program. Tentative locations of the geophone stations for the technical program are shown in Figure C-1. The close-in station locations, as noted above, are in an array between GZ and Grand Valley.

Typical cultural features of interest from a seismic standpoint are tabulated below:

| Feature | Nearest to Surface Ground Zero | Possible Ground Acceleration in Units of Gravity |
|---|---|---|
| Gas Well | 2.7 miles | 0.95 |
| Residence | 3.3 | 0.64 |
| Railroad and Highway | 5.1 | 0.27 |
| Road Bridge | 6.0 | 0.19 |
| Town, Grand Valley | 6.0-6.5 | 0.19-0.16 |
| Power Station | 6.3 | 0.17 |

| Feature | Nearest to Surface Ground Zero | Possible Ground Acceleration in Units of Gravity |
|---|---|---|
| Anvil Points Plant | 8.1-8.5 miles | 0.054-0.048 |
| Anvil Points Mine | 8.9 | 0.042 |
| Union Carbide Plant | 11.2 | 0.056 |
| City, Rifle | 12.0-13.0 | 0.048-0.041 |
| City, Grand Junction | 39.0-41.0 | 0.0046-0.0039 |


Figure C-1. Proposed Geophone Station Locations

# APPENDIX D: POST-SHOT RE-ENTRY WELL 1

## A. PS-1, POST-SHOT PRODUCTION WELL (RE-ENTRY OF R-E)

1. Drilling Program

   a. T.D.: Approximately 7,600 feet (to top of chimney)

   b. Minimum I.D.: 6-1/8 inches

   c. Coring: None

   d. Casing: Re-entry to be made through 7-inch casing used to emplace explosive

   e. Drilling Medium: Surface to 7,000 feet - no requirements. 7,000 feet to top of chimney - air or gas. Recirculation system may be required.

   f. Direction Control: If sidetracked hole is required, sufficient directional control will be maintained to hit a 50-foot radius target centered on top of the chimney.

   g. Logging: The following dry hole logs will be required:

      1.) Gamma-neutron

      2.) Temperature

      Alternates:

      3.) Packer spinner if feasible

      4.) Casing caliper

      5.) Dry hole 3-D sonic type if available

      6.) Bore hole photography

      7.) $\Delta$ temperature

h. <u>Well Completion:</u>

1.) Well head completion hardware suitable for production tests will be furnished

2.) 2-3/8 inch tubing to be set to approximately 7,000 feet

i. Install gas monitor equipment.

2. Gas Quality and Radiation Testing

Wire line service will be required monthly to obtain gas samples at top of chimney. This sampling will continue until radioactive levels are low enough to commence production testing. Gas samples will be taken at the surface during testing.

3. Testing Program

a. <u>Hydrologic Tests:</u> None

b. <u>Gas Production Testing:</u>

1.) A series of short-term tests will be run to evaluate chimney void volume, chimney-fracture void volume, and effective fracture radius. Pressures and flow rates will be recorded continuously throughout production tests. The durations of tests will be determined at the time of testing.

2.) Following this, a series of longer-term draw-down and build-up tests will be needed to evaluate the flow capacity of the post-shot environment.

3.) The pressure and flow rates will be monitored during the producing life of the well. It will be necessary periodically to re-test the well to determine if the created volume and/or associated fracture permeability has decreased as the reservoir pressure declines.

# APPENDIX E: ALTERNATE PROGRAM - POST-SHOT WELL NO. 2

## A. PS-2, POST-SHOT ALTERNATE PRODUCING WELL (RE-ENTRY OF R-EX)

1. Drilling Program

   a. T.D.: Approximately 8,000 feet

   b. Minimum I.D.: 4-3/4 inch

   c. Coring: None

   d. Casing: Same as R-EX

   e. Drilling Media: Surface to plug at approximately 5,800 feet - no requirements. Plug to T.D. air or gas. Re-circulation system may be required.

   f. Directional Control: None

   g. Logging:

      1.) Packer spinner if feasible

      2.) Flowing temperature

      3.) Casing caliper

      4.) Gamma-neutron

   h. Well Completion:

      1.) Well head completion hardware suitable for production testing

      2.) 2-3/8 inch tubing set to approximately 8,000 feet

   i. Install gas and radiation monitoring equipment

2. Gas Quality and Radiation Testing

The return gas stream will be monitored for radiation during drilling and flow test operations. Radioactive cuttings (if any) will be handled to conform with practices consistent with radiation levels encountered.

3. Test Program

a. Hydrology Tests: none

b. Gas Testing: This well will only be completed if liquid drop-out or water entry into chimney region require that production be from near the bottom of the chimney. In this case the test program will be the same as PS-1.

B. PS-2A, (SIDETRACK OF R-EX)

This well will be considered in case it is impossible to enter the liner in drilling PS-2, or if the alternate physical effects evaluation program is initiated.

1. Drilling Program

a. T.D.: Shot point plus 500 feet (est. 8,500 feet)

b. Minimum I.D.: 6-1/8 inches if window is milled in 7-7/8 and 4-3/4 if window is milled in liner

c. Coring: Representative cores of fractured area may be cut if budget permits

d. Casing: None anticipated

e. Drilling Media: Surface window milled in casing - no requirements. Window point to TD, air or gas

f. Directional Control: Within 50 feet of R-EX well bore at 7,000 feet, and within 75 feet of R-EX well bore at T.D.

g. Logging Program:

1.) In casing: caliper

2.) Window to T.D.:

a.) Gamma-neutron

b.) Flowing temperature

c.) Directional survey

Alternates:

d.) Packer spinner if available

e.) Borehole stereo photographs

h. Well Completion:

1.) Well head completion hardware suitable for production tests required.

2.) 2-3/8 tubing set to approximately 8,000 feet

i. Install gas and radiation monitoring equipment

2. Gas Quality and Radiation Testing

The gas and cutting stream will be monitored for radioactivity during drilling and testing operations. The radioactive cuttings and core will be handled to conform with practices consistent with the radiation levels encountered and appropriate classification procedure.

3. Test Programs

a. Hydrologic Tests: None

b. Gas Testing: If PS-2A is drilled because the liner could not be penetrated in R-EX and if long-term reservoir production will be from PS-2A; then gas testing will be the same as in PS-2.

If the PS-2A is a physical effects evaluation well, then gas testing will be limited to short-term tests. Flowing temperature survey and packer spinner survey, if available, will be run to evaluate productive interval and contribution of fracture and matrix production. Then tubing will be run to evaluate flow capacity, kh, at this distance from chimney. Testing will consist of a series of short-term isochronal tests. Periodically, the well should be re-tested to evaluate the permeability decrease (if any) with increasing time and decreasing reservoir pressure.

# APPENDIX F: DETAILED GEOGRAPHICAL AND GEOLOGICAL DESCRIPTION OF THE PROJECT RULISON SITE AREA

## A. AREA GEOGRAPHY

The Rulison Field area consists of almost 60,000 acres situated largely in the south-central portion of Garfield County, Colorado, but partly overlapping into the northeast portion of Mesa County. The boundary of the approved Federal Unit area lies generally to the south of the Colorado River (see Figure F-1) and includes almost 51,000 acres, of which about 42,500 were under lease when the unit was approved. The unit extends from an elevation of about 5,200 feet near the river up the slopes of Battlement Mesa to an elevation of over 10,000 feet in a relatively inaccessible area adjacent to a portion of the White River National Forest. The tentative site of the Rulison experiment, shown as Hayward 25-95 in Figure F-1, is identified in Figure F-2 as the center of a series of concentric circles spaced at 15-mile intervals. The 45-mile circle encompasses substantial portions of four Colorado counties, as well as an essentially uninhabited portion of a fifth. The four counties of interest are Delta, Garfield, Mesa, and Rio Blanco. Their combined population (1965 estimate) is slightly over 88,000. Their combined area is about 10,700 square miles, giving an average population density of about 8.25 persons per square mile. Most of the cultural development of these counties has been confined to the valleys of the Colorado, Gunnison and White Rivers, and their tributaries at elevations of below about 6,500 feet, but some settlements largely associated with tourism are to be found at higher elevations, notably on Grand Mesa to the south and west of Battlement Mesa. In each of the valleys, irrigation systems exist which support extensive cultivation. Agricultural produce (1963 values) of the four counties amounted to about $17.3 million.

The estimated distribution of population in the Rulison area and peripheral regions is shown in Table F-1 arranged approximately in order of increasing distance from the proposed GZ. The values shown for the incorporated areas are the estimates for 1965 made by the Colorado State Planning Division. The values shown for the unincorporated areas are based on the assumption that the ratio of urban to rural population is the same within the area chosen as it is in the entire county.

CLOSE-IN CULTURE (0-15 miles)

The area within a radius of 15 miles of the proposed GZ has a population of almost 4,700, the bulk of which is distributed toward the outer limit. The nearest habitation is about 3-1/2 miles to the north and to the west, about 8 miles to the south and about 13 miles to the east. Thus, a large portion of this close-in area is uninhabited. Approximately 60 homes of predominantly frame construction exist between 3.5 and 5 miles from GZ. In the town of Grand Valley and the immediate vicinity, about 6.3 miles from GZ, there are about 150 buildings, including about 30 concrete block or plaster structures. In the town of Collbran and the neighboring unincorporated community about 11 miles from GZ, about 150 structures were mapped, as were

TABLE F-1

ESTIMATED POPULATION IN RULISON
AREA AND PERIPHERAL REGIONS

| 0-15 miles: | Distance to GZ Miles | Estimated Population |
|---|---|---|
| **Incorporated Cities and Towns** | | |
| Grand Valley | 6.3 | 245 |
| Collbran | 11 | 310 |
| Rifle | 12.5 | 2,200 |
| DeBeque | 15 | 172 |
| **Rural and Unincorporated Communities** | | |
| Garfield County (est.) | 0-15 | 1,340 |
| Mesa County (est.) | 5-15 | 420 |
| Total, 0 to 15 miles | | 4,687 |
| **15-30 miles:** | | |
| **Incorporated Towns** | | |
| Silt | 18 | 400 |
| New Castle | 24.5 | 450 |
| Palisade | 29 | 860 |
| **Rural and Unincorporated Communities** | | |
| Garfield County (est.) | 15-30 | 460 |
| Mesa County (est.) | 15-30 | 750 |
| Total, 15 to 30 miles | | 2,920 |
| **30-45 miles:** | | |
| **Incorporated Cities and Towns** | | |
| Cedaredge | 33 | 550 |
| Glenwood Springs | 34 | 4,200 |

TABLE F-1 - continued

| 30-45 miles: | Distance to GZ Miles | Estimated Population |
|---|---|---|
| Incorporated Cities and Towns - continued | | |
| Carbondale | 39 | 650 |
| Grand Junction | 40 | 22,400 |
| Orchard City (Eckert) | 41 | 1,020 |
| Meeker | 42 | 1,660 |
| Hotchkiss | 43 | 630 |
| Paonia | 43 | 1,080 |
| Rural and Unincorporated Communities | | |
| Delta County (est.) | 30-45 | 3,670 |
| Garfield County (est.) | 30-45 | 2,660 |
| Mesa County (est.) | 30-45 | 19,600 |
| Rio Blanco County (est.) | 30-45 | 920 |
| Total, 30 to 45 miles | | 59,040 |

about 90 structures in the town of DeBeque, about 15 miles from GZ. The Anvil Points Oil Shale facility, about 8 miles from GZ, contains about 100 structures, including about 15, 20,000-gallon oil and water tanks.

The city of Rifle, at a range of about 12.5 miles, contains about 1,000 structures, of which about 150 are masonry or plaster. The Union Carbide Yellow Cake plant is located to the west of Rifle. The plant includes six concrete block buildings as well as two 40-foot high silos and one 25,000 to 50,000-gallon elevated water tank.

Oil shale mine workings exist at Anvil Points and up Parachute Creek from Grand Valley. Active coal mines are known to exist near Grand Junction, Cameo, Rifle, and Glenwood Springs.

The valley is served by U. S. Highway 6-24 and by the single-track Denver, Rio Grande and Western Railway.

Communication between the main highway and the roads across the river to the Rulison unit is provided by two 10-ton capacity bridges, one near Grand Valley, the other at Rulison itself. The closest approach of the highway and railway to the proposed GZ is somewhat greater than 5 miles.

Approximate road travel distances are shown in Table F-2.

TABLE F-2

APPROXIMATE ROAD TRAVEL DISTANCES

| | Miles |
|---|---|
| Grand Junction to Rifle | 66 |
| Grand Junction to Grand Valley | 49 |
| Grand Valley to Proposed GZ | 7.5 |

TABLE F-2
(continued)

| | Miles |
|---|---|
| Rifle to Proposed GZ: | |
| via Rulison Bridge | 21 (12 unpaved) |
| via Grand Valley Bridge | 25 (7.5 unpaved) |

B. GEOLOGY

Initial geological background investigations of the Rulison area (References F-1, F-2, F-3, F-4, F-5) yielded a uniformly simple structural picture of the project area. Details of the Battlement Mesa geology were discussed with members of the USGS who had mapped in the area. John Donnell and Warren Yeend contributed a great deal of specific information, because they were in the process of completing maps and a report on the area.*

Austral had aerial photo coverage (scale about 1:24,000) flown on the Battlement Mesa area to supplement the available smaller scale aerial photographs (GS-VAAL, 1960). Stereo pairs, from Austral's coverage, were studied and linears, occurring within a mile of the proposed location, were plotted on overlays and transferred to a 1:24,000 Rulison 7-1/2° Quadrangle topographic map. (Figure F-3).

A field investigation was made of the area within approximately 1-1/2 miles of the proposed site by geologists representing Austral, CER, and LRL. Much of the bedrock in the stream valley was covered by deposits mapped by Yeend[(2)] as Quaternary slides, mud flows, and fan gravels, Qsl and Qgmf, Figure F-4. Excellent continuous exposures of bedrock, mapped by Donnell[(3)]

*References 3, 4 in the body of the document as the Parachute Creek, Tgp, and Garden Gulch, Tgg, occur in the walls of Battlement Creek Valley. These continuously exposed beds were walked and particular attention was given to areas where linears intersected the outcrops. No displacements or traces of faulting were found. The continuous beds traced in this study are traced in red on Figure F-3.

Many of the linears were found to be related to the well developed joint sets in the area. Other linears were associated with slide margins, and topographically and geologically controlled vegetation.

The dips and elevation of a bedrock marker near the base of the Parachute Creek oil shale member of the Green River Formation were used to construct a "phantom" structural map throughout the project area, Figure F-5. No discontinuity was noted across the Battlement Creek area, where the bedrock is covered by Quaternary slides, fan and mud flow material.

## REFERENCES

F-1 "Geologic History of the Piceance Creek - Eagle Basin," M. D. Quigley, AAPG Bulletin, V. 49, No. 11 (1965) p. 1924.

F-2 "Introduction to the Geology of Northwestern Colorado," J. D. Haun, RMAG Guidebook (1962) p. 7.

F-3 "The Geological Development of Northwestern Colorado," B. F. Curtis, RMAG Guidebook (1962) p. 15.

F-4 "Upper Cretaceous Stratigraphy, Colorado," R. J. Weimer, RMAG Guidebook (1959) p. 9.

F-5 "South Piceance Basin, Township 6-11 South, Ranges 93-98 West, Garfield and Mesa Counties, Colorado," R. L. Boyers, W. F. Schneeberger, H. S. Mayberry, Ball Associates Report (February 1961).

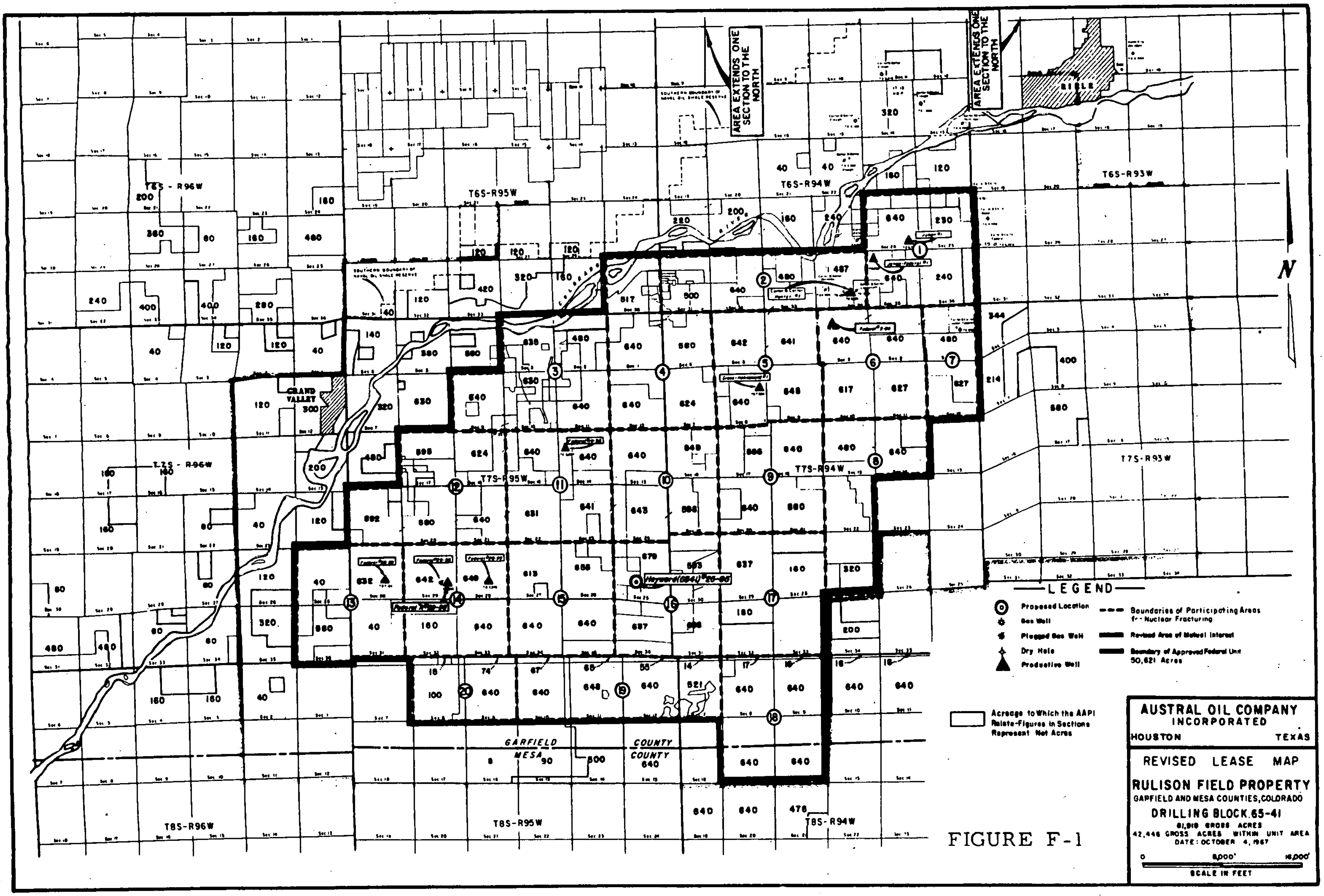

AUSTRAL OIL COMPANY INCORPORATED
HOUSTON TEXAS
REVISED LEASE MAP
RULISON FIELD PROPERTY
GARFIELD AND MESA COUNTIES, COLORADO
DRILLING BLOCK 65-41
42,446 GROSS ACRES WITHIN UNIT AREA
DATE: OCTOBER 4, 1967
SCALE IN FEET
LEGEND
Proposed Location
Gas Well
Plugged Gas Well
Dry Hole
Productive Well
Boundaries of Participating Areas for Nuclear Fracturing
Revised Area of Mutual Interest
Boundary of Approved Federal Unit 50,621 Acres
Acreage to Which the AAPI Relate-Figures in Sections Represent Net Acres
AREA EXTENDS ONE SECTION TO THE NORTH
AREA EXTENDS ONE SECTION TO THE NORTH
T6S-R96W
T6S-R95W
T6S-R94W
T6S-R93W
T7S-R96W
T7S-R95W
T7S-R94W
T7S-R93W
T8S-R96W
T8S-R95W
T8S-R94W
GRAND VALLEY
RIFLE
GARFIELD COUNTY
MESA COUNTY
N

FIGURE F-1

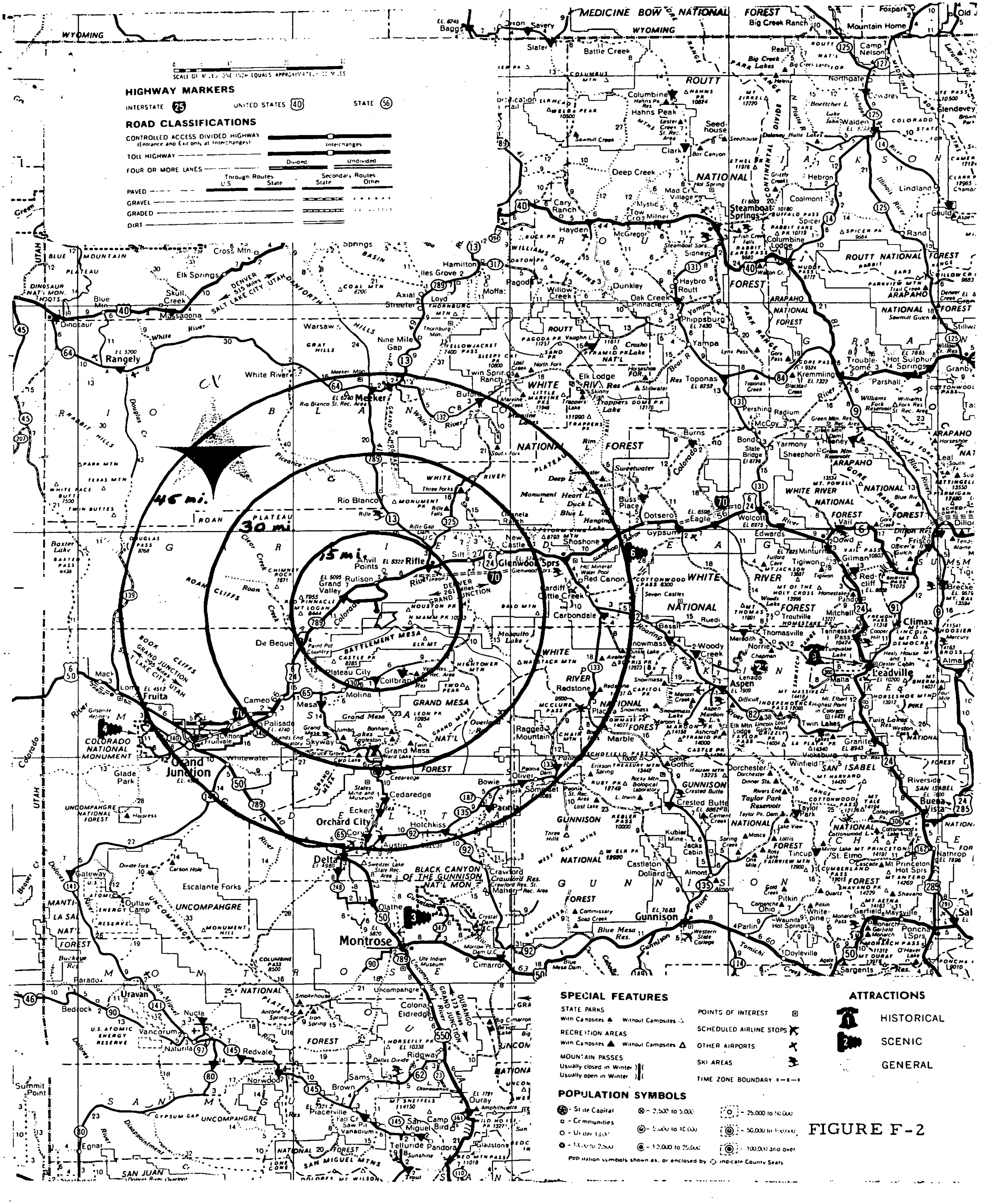
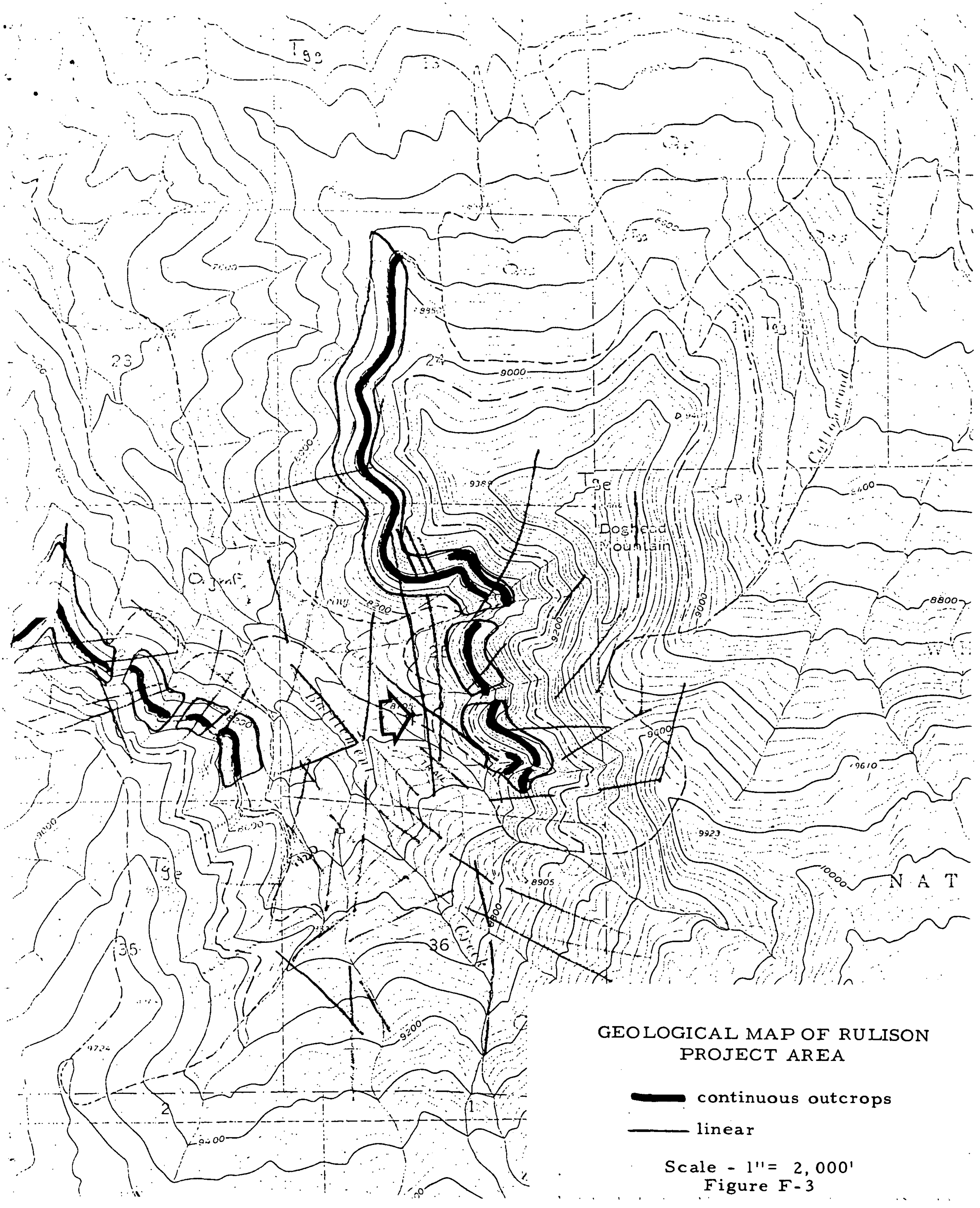

HIGHWAY MARKERS
INTERSTATE 25
UNITED STATES 40
STATE 56
ROAD CLASSIFICATIONS
CONTROLLED ACCESS DIVIDED HIGHWAY
TOLL HIGHWAY
FOUR OR MORE LANES
PAVED
GRAVEL
GRADED
DIRT
SPECIAL FEATURES
STATE PARKS
RECREATION AREAS
MOUNTAIN PASSES
POINTS OF INTEREST
SCHEDULED AIRLINE STOPS
OTHER AIRPORTS
SKI AREAS
TIME ZONE BOUNDARY
POPULATION SYMBOLS
ATTRACTIONS
HISTORICAL
SCENIC
GENERAL
45 mi.
30 mi.
15 mi.
WYOMING
UTAH
MEDICINE BOW NATIONAL FOREST
ROUTT NATIONAL FOREST
WHITE RIVER NATIONAL FOREST
GRAND MESA NATIONAL FOREST
UNCOMPAHGRE NATIONAL FOREST
GUNNISON NATIONAL FOREST
ARAPAHO NATIONAL FOREST
SAN ISABEL NATIONAL FOREST
COLORADO NATIONAL MONUMENT
BLACK CANYON OF THE GUNNISON NAT'L MON.
Grand Junction
Rifle
Glenwood Sprs
Meeker
Rangely
Rio Blanco
De Beque
Parachute
Grand Valley
Fruita
Palisade
Delta
Montrose
Aspen
Leadville
Steamboat Springs
Craig
Gunnison
Ouray
Telluride
Collbran
Plateau City
Carbondale
Paonia
Hotchkiss
Cedaredge
Orchard City

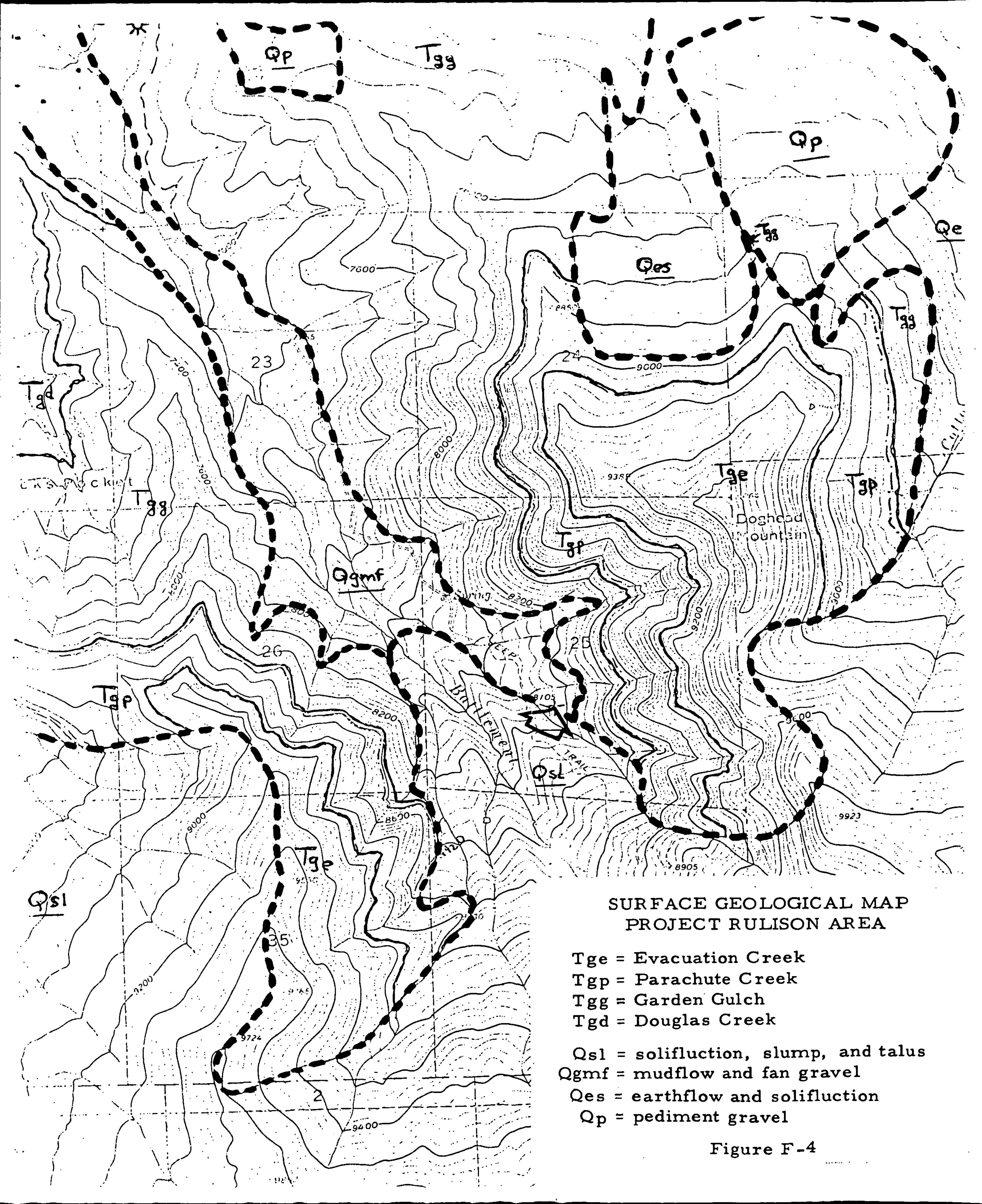
FIGURE F-2




GEOLOGICAL MAP OF RULISON PROJECT AREA

Scale - 1" = 2,000'

Figure F-3

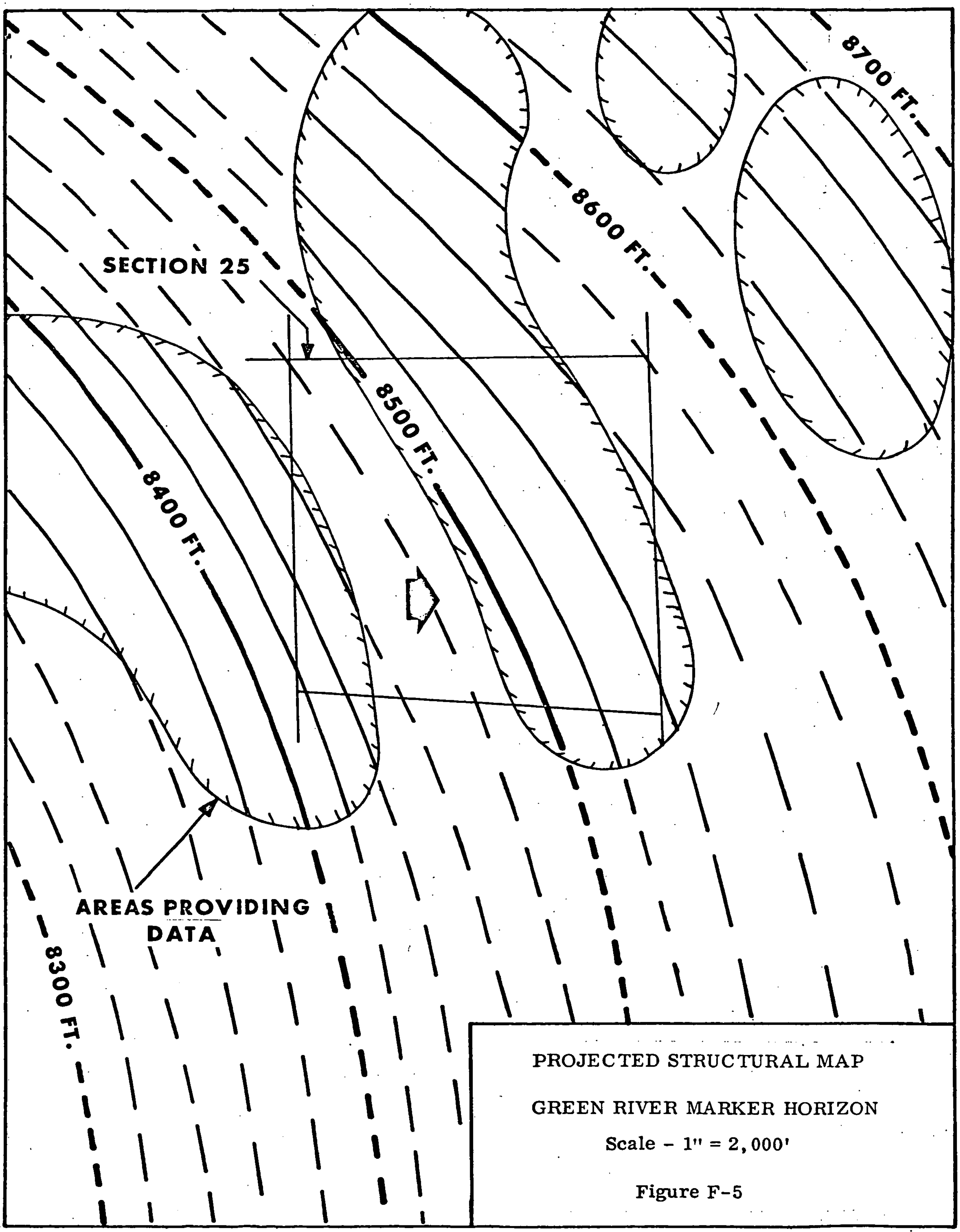



SURFACE GEOLOGICAL MAP
PROJECT RULISON AREA

Tge = Evacuation Creek
Tgp = Parachute Creek
Tgg = Garden Gulch
Tgd = Douglas Creek

Qsl = solifluction, slump, and talus
Qgmf = mudflow and fan gravel
Qes = earthflow and solifluction
Qp = pediment gravel

Figure F-4




PROJECTED STRUCTURAL MAP

GREEN RIVER MARKER HORIZON

Scale - 1" = 2,000'

Figure F-5