Principal drill stem test database (UBDST) and documentation: analysis of Uinta Basin, Utah gas-bearing Cretaceous and Tertiary strata

by

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Introduction

Analysis of 78 drill-stem tests (DST) from oil and gas wells in the Uinta Basin of northeastern Utah (Figures 1 & 2) resulted in the construction of a comprehensive hydrogeologic and engineering database (UBDST). The information in this database constitutes part of a set of data that has been developed as part of an effort to characterize the basin's impermeable gas reservoirs and to assess their resources. UBDST contains a wide variety of analyses and interpreted information concerning the hydrogeologic and petroleum engineering-related properties of the lower Tertiary and Upper Cretaceous gas- and oil-bearing rocks that underlie the basin.

This report and database is availible in several digital formats (see Appendix A). Hydrogeologic and engineering data can be related to core, formation top, and other geologic or geochemical data in other databases that use of American Petroleum Institute (API) numbers or congressional survey locations.

Most information in this data base relates to the evaluation of impermeable strata whose permeability values, exclusive of fracture permeability, generally fall below 0.1 millidarcy (md). Our DST determinations and interpretations of strata are consistent with the interpretations of Boardman and Knutson, 1981. They investigated permeability structure of Uinta gas-bearing units at both the large stratigraphic interval and small individual-bed scale.

Comparison of UBDST data with analyses from other oil and gas lower Tertiary and Upper Cretaceous hydrocarbon producing domains in the Uinta Basin indicate that natural fractures provide a mechanism to move fluids (and gases) to the wellbore in otherwise very low-permeability strata without artificial stimulation (Wesley, 1990; Fouch and others, in press) (Figs: 2 and 3). An apparent lack of significant

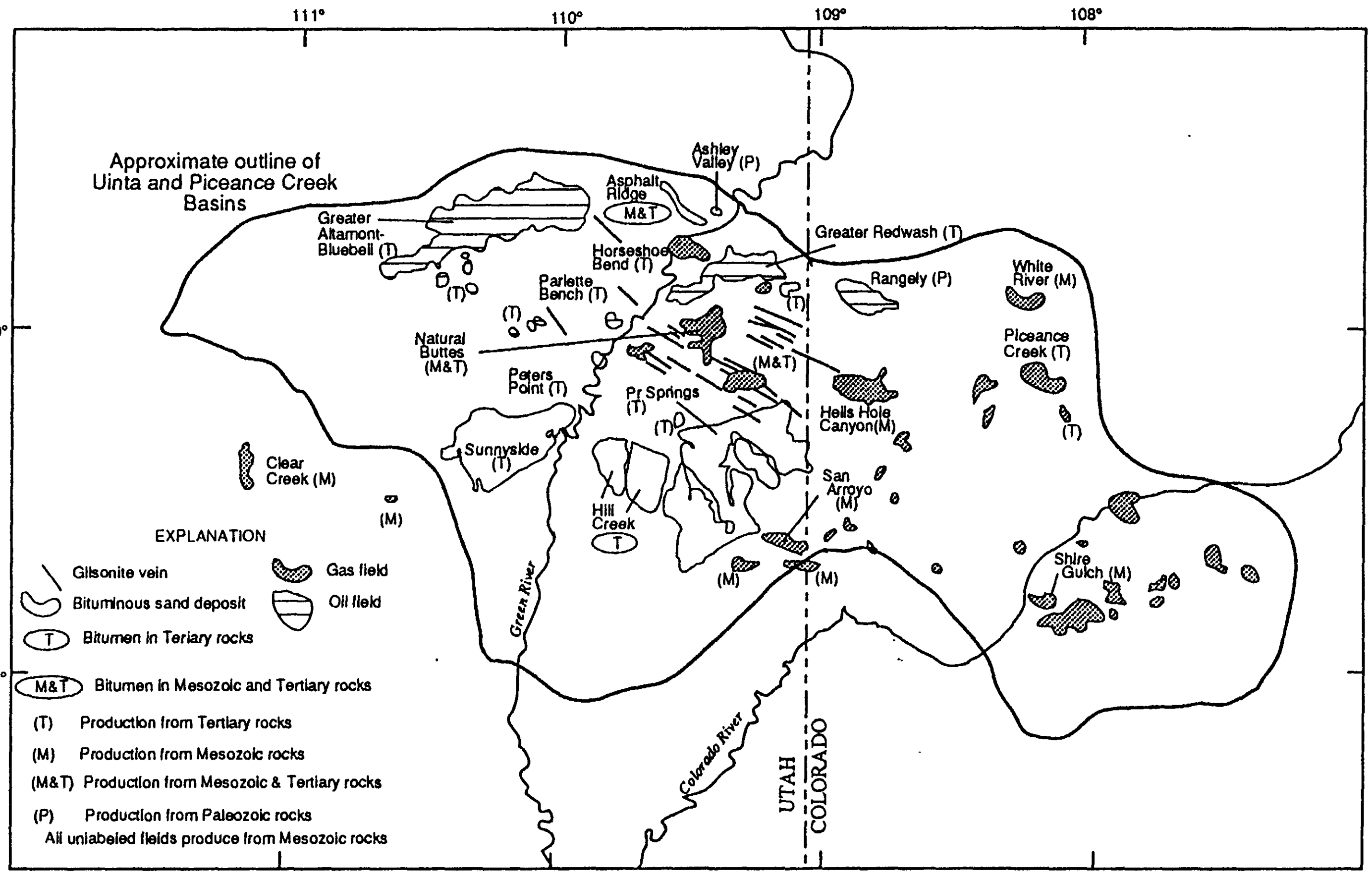

Figure 1: Map of the Uinta and Piceance Creek basins showing principal hydrocarbon accumulations.

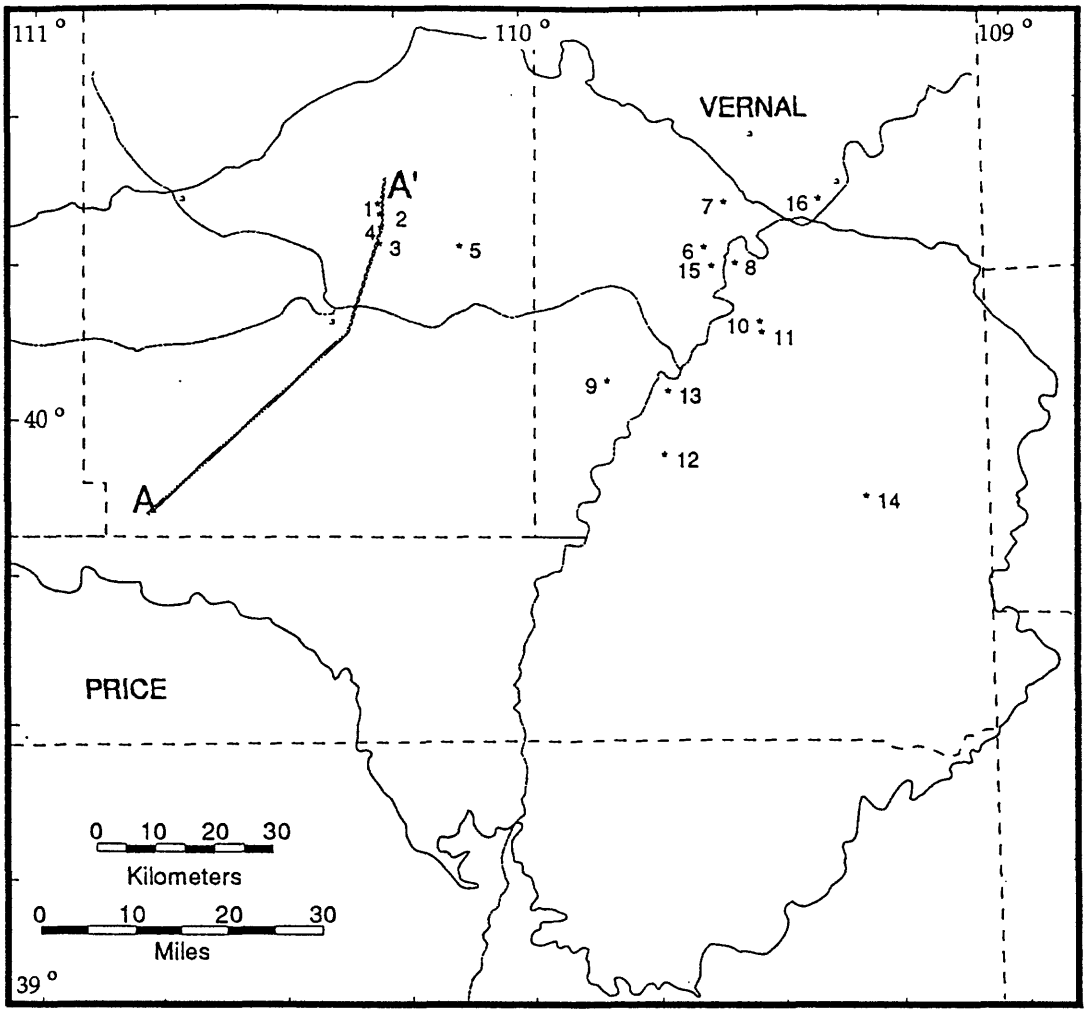

Figure 2: Map of the Uinta Basin, Utah showing location of drill holes that contain drill stem tests analyzed in this report.

1 – 1 Miles, Shell Oil
2 – 1-3 Shell-Tenneco-E, Shell Oil
3 – 1-14-B4 Shell Brotherson, Shell Oil
4 – 1-11-B4 Brotherson, Shell Oil
5 – 1-16 Gulf-Ute, Diamond Shamrock
6 – 1 Government, Gose Petroleum
7 – 1 Govt.-Dicarlo, King-Stevenson
8 – 1 Rowe-Govt., McLish H. P.
9 – 6 Pariette Bench, Pan American Petroleum
10 – 2 Wonsits-Federal, Gulf Oil
11 – 5 Federal-Wonsits Unit, Gulf Oil
12 – 3 Island Unit, Mountain Fuel Supply
13 – 1 River Junction, Phillips Petroleum
14 – 7 Southman Canyon, Shell Oil
15 – 1 Gose-Government, McLish H. P. Etal
16 – 1Stewart-Fee, Walton Paul T.

open and natural fracture systems in impermeable Cretaceous and Tertiary strata such as that in the Natural Buttes field area of the southeastern part of the Uinta Basin has resulted in very low permeability gas-bearing strata. DST-derived permeability values for intervals (large scale) of impermable gas-bearing strata in rocks of this area are very similar to core-derived permeability values for individual samples (small scale). This is presumably due to the lack of natural fractures in tight-gas formations which if present, would most likely provide larger scale, higher permeability flow conduits.

Many tested zones in the deeply buried rocks below 10,000 ft at Altamont-Bluebell oil field are fractured naturally. The permeability and radius of investigation in these rocks are relatively high, and the Horner-plot slope is low. Horner plots from DST's in and north of the large Red Wash field in the northeast Uinta Basin, and especially shallower alluvial rocks, exhibited high permeability - associated low slopes.

METHODS

Data Base Structure

Hydrogeologic, geologic, and engineering data can be related to information of other databases by use of American Petroleum Institute (API) numbers and areal locations to match records. Seventyeight one-line records respectively contain analyzed and interpreted data from a single DST gauge that was recorded during a "reliable" or successful DST measurement. These records are grouped into four data groups (Appendix A), 1) English petroleum engineering, 2) metric hydrology, 3) English calculations and comments and 4) Well location and name information. Each group consists of 78 one-line records with information from 16 drill holes in each. One-line records for a well comprise a group of reliable DST measurements and resulting interpretations at different depths within the well.

The individual one-line records within the database contain fields which consist of: 1) measured, 2) calculated, and 3) interpreted data on a single DST guage at depth within a well. Records were identified by and can be related to each other by the API number of the well, areal location, and depth.

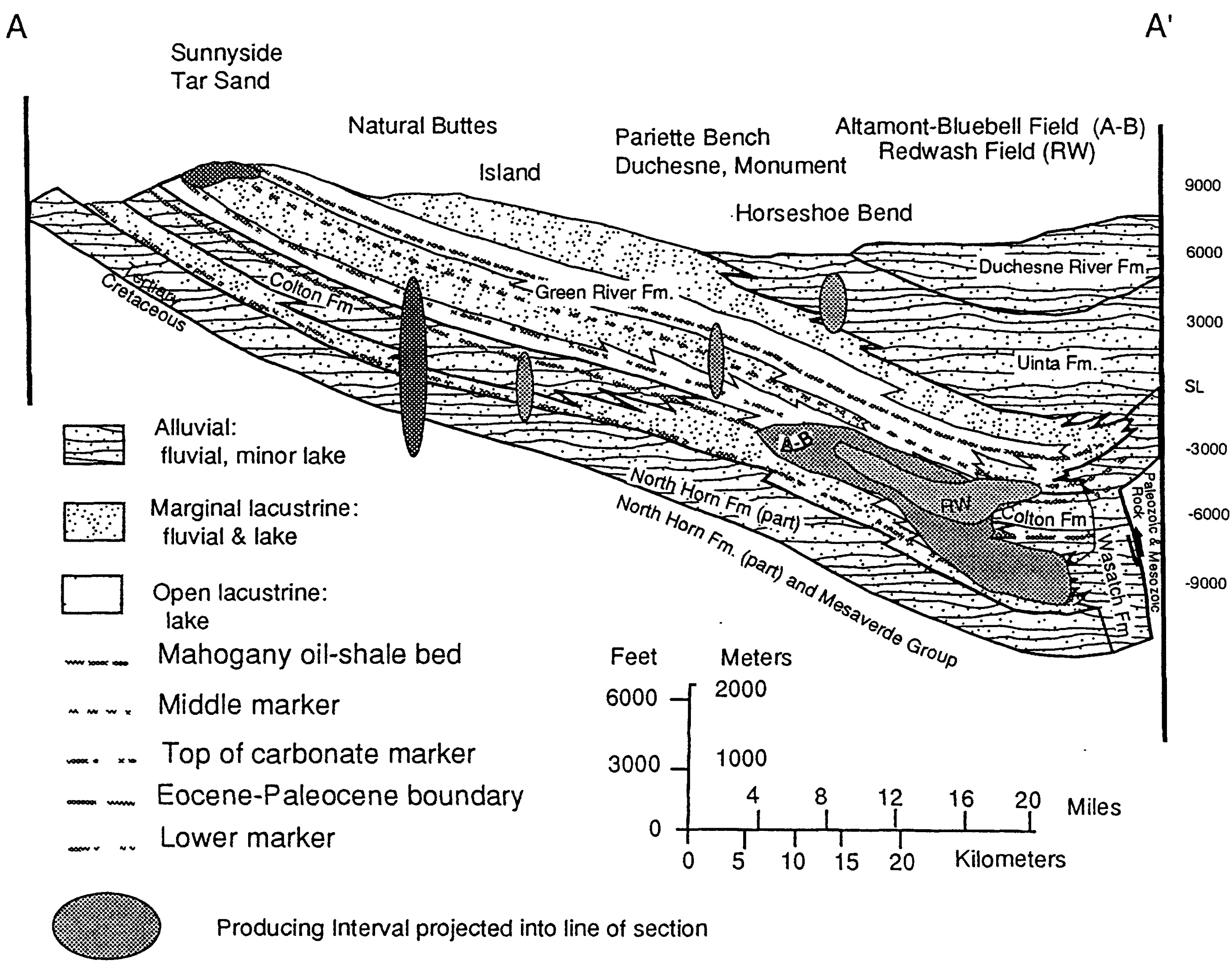

Figure 3: Indian Canyon-Altamont cross section of basin showing producing intervals from principal fields projected into line of section.

Utilization of personal-computer database management systems facilitated rapid DST calculations and interpretations. Calculation of many of the data fields made use of information in other fields thereby limiting error inherent in manual calculations.

Well-header segment precedes the hydrogeologic and engineering portion of the UBDST database record. It in turn is followed by information on depth of the DST (metric and U.S. customary units), and detailed hydrogeologic and engineering measured, calculated, and interpreted data fields (U.S. customary and metric). Some fields are recorded twice with one record expressed in U.S. customary units and one in metric. Most fields contain measured, calculated, and interpreted information about fluid pressure, permeability, hydraulic conductivity and transmissivity, production characteristics, DST radius of investigation, and other hydrogeologic and engineering properties.

DRILL STEM TESTS

Accuracy of DST Analysis and Assumptions

Seventyeight of the reliable DST's in the Uinta basin were analyzed and interpreted in this study, and the results of these DST interpretations were calculated using the database. Appendix A details the mechanics of assumptions and problems inherent in interpretation of DSTs, and the most important methods used in interpreting the DST data are outlined with references. Interpretation of gas-producing DSTs requires some additional calculations which were not addressed for simplicity, however, the calculations for gas DSTs are shown with the database.

Drill stem-test interpretation

Drill-stem tests were interpreted for: 1) *reservoir/interval permeability,* 2) *formation pressure, 3) approximate radius of investigation, and 4) tested fluid flow rates and volumes.* The accuracy and data provided by older DSTs is usually poor while DSTs measured since the late 1950's have steadily improved in quality. Accuracy in interpretation of DSTs is found to be very dependent on the amount and reliability of the information provided by field personnel at the well site, as well as on the proper functioning of the downhole equipment.

Most DSTs in the Uinta basin (60%) contain unreliable results due to: 1) equipment failure and 2) shut-in times which were too short in rather low-permeability formations, where pressure did not even approach static reservoir pressure.

Horner-plot Analysis

Interpretation of DSTs involves plotting a semilog plot of pressure versus Horner-time (Horner, 1951) and estimation of the fluid flow rates recorded during the flow periods. Horner-time values for a point on a pressure-build-up curve are derived by adding the preceding flow time (T; in minutes) to each time increment (theta, in minutes) of pressure build-up and dividing this sum by theta (minutes). The original data from the recording instrument must be transposed to a larger scale and increments of pressure and time must be correctly marked to get accurate data.

Reliable DST data is in the form of microfiche charts which usually contain the proper information required to produce an accurate Horner plot (Horner, 1981). This analog information was fed manually into spreadsheet codes which calculated Horner-time and produced semilog Horner plots. This method of calculation was the fastest and most accurate for interpreting large numbers of DSTs.

In this study, the most valuable information that we derived from the Horner plot is the extrapolated, or static *reservoir pressure* (P*), and the slope of this line (m). We frequently obtained m using the last few points on the final pressure-buildup curve. Correct extrapolation of P* for most DST's generally only involves use of the last few data points on the buildup curve, because the measured pressure values approach static reservoir pressure with time. In many low permeability rocks, the shut-in times are usually too short to allow pressure to even approach static, and interpretation can be difficult or inaccurate

Fluid-flow rates

Fluid-flow rate calculations can be used to interpret permeability, and radius of investigation. The calculations employ information on fluid recoveries and flow times that can be obtained from the DST chart record. In this study, fluid-flow rates were calculated from a volume of fluid(s) that was measured as a height in the drill-pipe. Fluids produced were of various types: oil, gas, water, drilling mud, and combinations of the above. One can calculate a volume of fluid(s) produced over a given flow time by using parameters that describe the inner diameter of the drill-pipe and permit calculation of its volume. We converted gas production (mcf/day) to a barrels per day equivalent. We estimated a total flow rate (Qt) at reservoir conditions ("sand-face") and the average viscosity of the fluid at reservoir conditions for each test.

Net pay, permeability, and radius of investigation

One must estimate the net pay (feet) of the producing zone in order to calculate permeability of the zone. *Net pay* is a term used by industry to estimate the quantity (thickness) of the producing zone that actually contributes to the production of oil or gas. Use of net-pay values versus that of the actual footages of the tested zone is a method of weighting the permeability towards that part of the tested zone (the reservoir) which contributes the most towards production. We used net pay values which were: 1) provided by the field personnel and 2) estimated by the authors from borehole logs. Our values provide an estimate of the reservoir footage of the tested zone which would produce any fluid or gas, not simply oil or gas.

Total flow rate (Qt, barrel per day), average fluid viscosity (uavg, centipoise), Horner plot slope (m, psi/log cycle), and net pays (h, feet) are used to calculate *reservoir permeability* (k, millidarcies) according to the industry-standard equation:

k (md) = 162.6 x ((Qt)(beta)(uavg)/(m)(h))

where (beta) = 1 at sandface (reservoir) conditions. Usually a relatively permeable reservoir exhibits high flow rates and low Horner plot slopes; low permeability reservoirs usually have low flow rates and high Horner plot slopes.

An *approximate radius of investigation* of the DST was calculated by multiplying the reservoir permeability times the total flow time and taking the square root. Low permeability formations ("tight") in the Uinta basin have a small radius of investigation with a short DST flow time, and their interpretation requires slightly different interpretation techniques.

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.c1.APPENDIX A

FORMAT DOCUMENTATION

The files with a (.DAT) extension are fixed ascII format. There are text headings at the top of each table which label the fields and their unit of measure. Maximum row length is 132 characters.

File: DSTLOC.DAT

DSTLOC.DAT contains the well location information for all of the associated DST records. There is a unique API number at the beginning of each record which can be used to link the records in any of the other files. There are 16 records in this file.

File Format:
API number consisting of the following codes (state 2 characters, county 3 characters, id characters 5.
Fieldname -- Name of oil or gas field such as Altamont.
Twndir -- Township direction N or S.
Twnnum -- Township number.
Rngdir -- Range direction.
Rngnum -- Range number.
Section -- Section number.
Spot -- Quarter section location.
Wellnumber -- Well number.
Leasename -- Lease name.
Operator -- Well operator.

Note that well information may be truncated or abbreviated. Also note that rounding occurs in some real number fields.

DATA FILES:

FILE: DST1.DAT
API number consisting of the following codes (state 2 characters, county 3 characters, id characters 5.
Elev -- Elevation of reference datum from sea level, in this case kelly bushing.
RF -- Elevation reference measured or estimated from kelly bushing.
Gauge depth -- DST gauge depth in feet below elevation reference.
Gauge from Sea Lv-- Distance of gauge from sea level in feet (from DST chart).
Temp -- Temperature in degrees farhenheit (measured or calculated).
DST Top Depth -- Depth to top of DST test zone in feet.
DST Base Depth -- Depth to base of DST test zone in feet.
DST Mid-pt Depth -- Depth to mid-point of DST test zone in feet.
DST Mid-pt Sea level-- Distance from sea level to mid point of DST in feet.

Extrap Fluid Press -- Extrapolated fluid pressure from Horner plot.
Fluid Press Grad -- Fluid pressure gradient.
Net Pay -- Thickness of pay zone in feet.
Total Flow-- Total flow in barrels per day.
Ave Vis -- Average viscosity in centipoise.
Slope PSI -- From Horner plot.
Reservoir Permeability -- Reservoir permeability in millidarcies.

FILE: DST2.DAT

API number consisting of the following codes (state 2 characters, county 3 characters, id characters 5.
Elev. -- Elevation of reference from sea level in meters.
RF -- Elevation reference measured or estimated from kelly bushing.
Gauge Depth -- DST gauge depth in feet below elevation reference in meters.
Gauge Depth to Sea Level-- Distance of gauge from sea level in meters (from DST chart).
Temp -- Temperature in degrees centigrade (measured or calculated).
Depth to DST Mid-Point -- Mid-point of DST zone in meters.
Sea Level to DST Mid-point -- Distance from sea level to mid-point of DST zone in meters.
Net Pay -- Thickness of pay zone in meters.

File: DST3.DAT

API number consisting of the following codes (state 2 characters, county 3 characters, id characters 5.
Fresh Water Dens.-- Fresh water density in gm/cc, (from Hewlett Packard fluids pac).
Fresh Water Visc. -- Fresh water viscosity in centipoise.
Reservoir Hydraulic Conductiv. -- Reservoir hydraulic conductivity in meters per second.
Reservoir Hydraulic Conductiv. -- Reservoir hydraulic conductivity in meters per day.
Reservoir Transmisi. -- Reservoir transmisivity in square meters per second.
Reservoir Transmis. -- Reservoir transmisivity in square meters per day.
Oil Potential -- Oil potential in meter feet.
Ground Water Potential -- Ground water potential in meter feet.
Potentiometric_Surface-- Potentiometric surface.in meters.
Radius of Investigation -- Radius of DST investigation in meters.

FILE: DST4.DAT

API number consisting of the following codes (state 2 characters, county 3

characters, id characters 5.
Oil -- Oil flow rate in barrels per day.
Mud -- Mud flow rate in barrels per day.
Water -- Water flow rate in barrels per day.
Gas -- Gas flow rate in barrels per day (requires special conversion!).
Total -- Total flow of oil, mud, water, and gas in barrels per day.
Comments -- Comments on individual DST's.

ALTERNATE FILE FORMAT:
There are also four files with a (.TAB) extension. These files contain the same data as the files with the (.DAT) extension except there are no header records. The files with the (.TAB) extension are tab delimited for direct loading into a variety of spreadsheets and databases that accept tab delimited formats.