APPENDIX I

Interpretation of Geophysical Logs to Select Stratigraphic Horizons Within the Rustler Formation

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INTERPRETATION OF GEOPHYSICAL LOGS TO SELECT STRATIGRAPHIC HORIZONS WITHIN THE RUSTLER FORMATION

Depth and Thickness Information

Geophysical logs from various boreholes for the WIPP project have been interpreted to represent the following stratigraphic markers: Rustler/Salado contact; base and top of Culebra Dolomite Member; base and top of Magenta Dolomite Member; and Rustler/Dewey Lake contact. For the Tamarisk Member, the contacts at the top of the lower anhydrite (A2) and base of upper anhydrite (A3) show regional thickness changes in a halite/mudstone unit of geological significance; we include these data as well (Ch. 4). Here we discuss the bases of our log interpretation for both stratigraphic and lithologic information and some factors that affect the accuracy and precision of the interpretations. The stratigraphy of the Rustler Formation is based on Vine (1963). Details of the Rustler vary, based on shaft mapping (Holt and Powers, 1984, 1986a) and this work.

The basic geophysical log for interpreting the Rustler stratigraphy is the natural gamma ray log (Fig. 4.1). Throughout much of the northern Delaware Basin, the contacts and members can be picked with confidence and good precision based on this log alone. In some areas, acoustic or sonic logs, for example, provide a sharp and significant response where the gamma log is not as sharp. In these interpretations, the gamma ray log was used as consistently as possible because it is the most comon usable log and to avoid small registration problems that occur between logs, especially if the final log was a composite of two logs obtained at different times.

Lithologic Information

Specific lithologies may be interpreted through cross-plots of geophysical data for an interval. This procedure is well-known within the petroleum industry, and is adapted for computer with modern borehole geophysical records. A similar, though less mechanical, approach has been used for this report because we have only analog records. For more detailed lithological interpretation, we combined the natural gamma log with acoustic or sonic logs, density logs, or neutron logs, permitting most of the common lithologies to be discriminated. For the Delaware Basin proper, gamma ray-sonic was used nearly exclusively. Over parts of the Central Basin Platform, combined gamma ray-neutron logs are much more common. Gamma

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ray-density logs are much less common in the region than at the site and were sparingly used. The common lithologies and their signatures for the Rustler are given in Table 1.

In the vicinity of the WIPP site, log signatures may be matched with descriptions from shafts (Holt and Powers, 1984, 1986a), basic data reports (e.g. Sandia National Laboratories and U. S. Geological Survey, 1980), and redescribed cores from holes with geophysical logs. Examples of the match between detailed logs and core and shaft descriptions form a "type" against which most log interpretations were made. Some of the interpretations here vary from those made previously (Borns and Shaffer, 1985; Griswold, 1977) because of differences in criteria and the details of lithology now available (Ch. 5).

Accuracy and Precision

For stratigraphic interpretation, copies of logs at a scale of 1" = 100 feet were most commonly available and were used, providing a consistent data base. Lines drawn to mark contacts cover about 1 foot, and precision associated with these lines can probably be no better than about 1 foot. The numbers presented are visual interpolations representing a variation estimated at about $\pm$ 1 ft., not allowing for other sources of "error".

The sum of geologic variations and "errors" has been assessed empirically by examining the cluster of data points in T.25S., R.32E. (Ch. 4). The isopachs of four members and part of one member provide data to calculate average thickness as well as sample standard deviation s (Table 2). A plot of thickness vs s partially reveals the effects of these errors (Fig. 1). The relative standard deviation generally decreases as thickness increases. This reflects the compensating effects of sedimentation over time for small, possibly random, local variations in depositional processes. The standard deviation is less than 10 % of the total thickness for the four thicker intervals. For the two intervals averaging less than 25 ft thickness, the standard deviation exceeds 10%. A least squares regression of s (Y) on average thickness (X) (Fig. 1) provides an intercept (b_o) of 3.5 on Y. This intercept is consistent with "errors" of about $\pm$ 1 foot on each contact as previously described. The remaining difference (that part > 3.5 ft) is more likely attributable to geological processes. Though a linear regression of standard deviation on thickness has been calculated, the data points are probably also consistent with the idea expressed above that greater thickness is related to exponentially smaller standard deviations as a consequence of compensating sedimentologic conditions over a longer period of time.

We may not truly generalize about thicknesses of individual members for the region from the example above, as as it is obvious that some units (e.g. between A2 and A3 of the Tamarisk) vary greatly over the region compared to T.25S., R.32E. However, the "error" associated with picking an individual contact is estimated. An "error" of the type where a mistake in elevation or zero point occurs is not analyzed in this example, as the data are the difference between two successive contacts and will be immune to those two types of errors.

Powers (1986) examined geophysical logs from hydrologic holes at and near the WIPP site, showing that interpreted stratigraphic picks of a horizon from various logs of the same borehole usually vary by 2 feet or less. There is no assurance in some of these cases which is the more accurate depth. For the most part, these small variations from log to log can be attributed to several types of factors such as differences in zero depth point. This kind of variation is usually unimportant for geological interpretations of either isopachs or structure contours. A $\pm$ 2 ft variation on both contacts could conceivably result in an 8 ft discrepancy in thickness between adjacent boreholes. This is unlikely, as common practice here and elsewhere is to compare adjacent logs frequently to minimize such discrepancies. Elevation/depth discrepancies are more important to resolve for the subtle questions of possible hydrologic transport in the Rustler.

Lithologic interpretations are not significantly affected by questions of accurate depths. A more important, and difficult to consider, problem is registration, especially if the log associated with gamma is a composite. Where there is no obvious problem with this particular log, the gamma ray with compensated acoustic (sonic) or compensated density is chosen as the standard over the combination gamma ray with neutron because the lithologic information from the first two combinations is usually more helpful than with neutron.

Geophysical logs contain inherent uncertainties. Stretch in the cable is usually predictable, about 1 foot/1000 feet. This is the same order of magnitude as the resolution for the tools (e.g. natural gamma and acoustic) which operate over a discrete interval or sample a certain volume. The

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sharpness of a log response to a sharp change in geophysical properties is a function of this interval, the rate at which the tool is drawn through the borehole, and time constants for data acquisition. Gradual lithologic transitions decrease the sharpness of the response further. In general, lithologic transitions and sampling interval have been dealt with arbitrarily by picking a contact at the midpoint of the geophysical response, and by attempting to make a consistent log response the standard for each "pick." Inconsistent application of standard log signature or criteria leads to error. All logs were interpreted by one person (DWP) to minimize operator to operator inconsistencies in establishing the intervals and contacts, though operator bias may be unchecked by this procedure.

Several "random" factors contribute to errors. Incorrect placement of the logging tool relative to a reference elevation (the zero point referred to above) appears to have occurred on some logs (e.g. compensated neutron, gamma ray for H-9c; Powers, 1986). Incorrect base elevations and locations may occur, but only gross errors will be detected in this study. Log reading errors may occur; they are most easily found through multiple logs of a single borehole and through structure contour and isopach map anomalies.

Further Remarks

No attempt has been made to rectify differences with other interpretations. Minor differences on picks are here of little consequence. Major anomalies may be resolved as necessary by re-examining logs and picks or by obtaining additional logs from the vicinity of the anomaly.

Geophysical well log data are used routinely within industry to infer rock properties. Doveton (1986) summarizes common approaches to log interpretations, but the limitations and problems associated with precision and accuracy of interpretation are not well addressed. The mechanical precision associated with the geophysical tool is commonly considered. For the hydrological studies of the WIPP, the uncertainties beyond mechnical precision can be important, and here we have presented information and analysis of log information that should provide perspective on this problem. Baker (1987) examines methods of quantitative interpretation that integrate geological and geophysical log data. Such approaches will be very helpful in assessing data, and the associated uncertainties, that will be used in complicated numerical codes for hydrologic modeling.

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TABLE 1

General Log Responses for Rustler Lithologies

lithology	natural gama (std API units)	sonic travel time (micro-sec/ft)	neutron (API units)
anhydrite	low (<10 API)	high (50)	high
salt	low (<10 API)	medium (70)	variable
dolomite	variable (10-50)	variable (50-90)	variable
siltstones	variable (10-50)	low (>70)	low
gypsum	low (<10)	medium (70-80)	low
polyhalite	very high (50-150)	med to high (50)	med to low

TABLE 2

Statistical Summary of Isopach Data, T.25S., R.32E.

Isopach Interval Name	Number of Data Points	Average Thickness (ft)	Sample Standard Deviation(s)
Forty-niner	83	63.7	4.12
Tamerisk	82	102.8	8.55
A2-A3 of Tamerisk	78	13.0	4.58
Culebra	83	24.5	2.76
1. unnamed mbr.	82	151.9	12.3
Rustler	82	364.6	16.8

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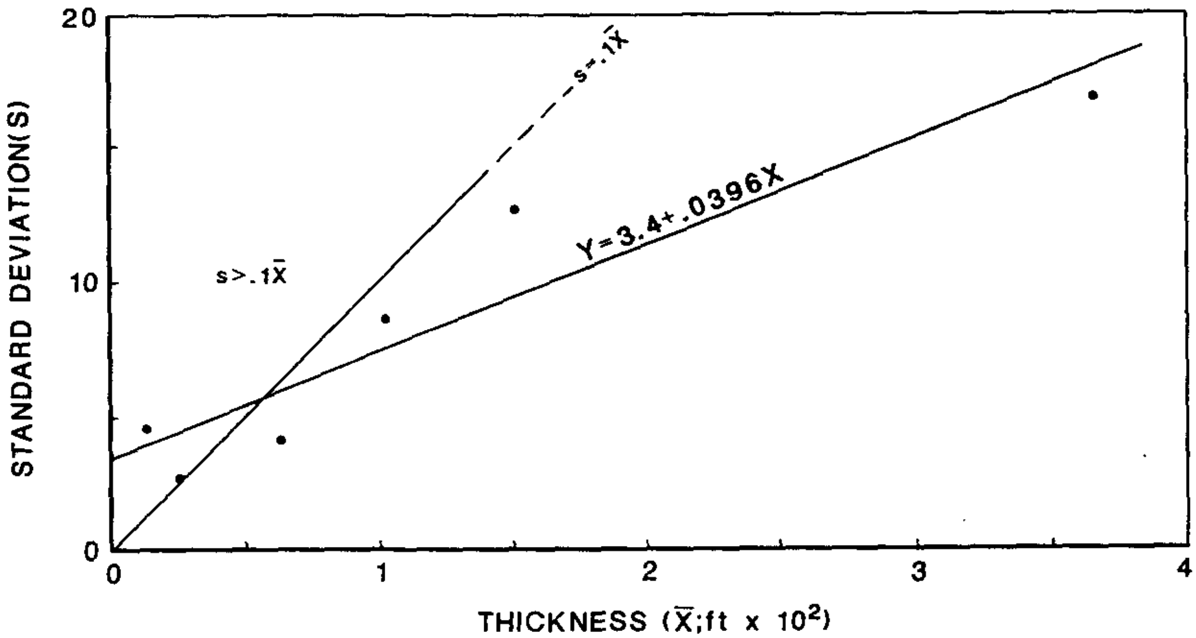
STANDARD DEVIATION(S)
THICKNESS ($\bar{X}$;ft x 10^2)
s=.1$\bar{X}$
s>.1$\bar{X}$
Y=3.4+.0396X
0
10
20
0
1
2
3
4

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