National Uranium Resource Evaluation
INTEGRATION OF NURE AND OTHER DATA SETS
WITH EMPHASIS ON THEIR UTILIZATION IN
GENERATING EXPLORATION MODELS IN THE
LUBBOCK, TX 1° x 2° QUADRANGLE

by: Marian M. Lankston and Robert W. Lankston

G-Cubed Incorporated

Spokane, Washington

May 1979

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Resource Applications
Grand Junction Office, Colorado

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This report is a result of work performed by G-Cubed Incorporated through a Bendix Field Engineering Corporation Subcontract as part of the National Uranium Resource Evaluation. NURE is a program of DOE's Grand Junction Office to acquire and compile geologic and other information with which to assess the magnitude and distribution of uranium resources and to determine areas favorable to the occurrence of uranium in the United States.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States Department of Energy, nor any of their employees, nor any of the contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus product or process disclosed, or represents that its use would not infringe privately-owned rights.

INTEGRATION OF NURE AND OTHER DATA SETS
WITH EMPHASIS ON THEIR UTILIZATION IN GENERATING EXPLORATION MODELS
IN THE LUBBOCK, TX 1° x 2° QUADRANGLE

✓ Marian M. Lankston
✓ Robert W. Lankston

G-Cubed Incorporated
Spokane, Washington

950 9885

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

May 1979

Prepared for the U.S. Department of Energy
Assistant Secretary for Resource Applications
Grand Junction Office, Colorado
Under Contract No. DE-AC13-76GJ01664
and Bendix Subcontract No. 78-176-S.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ABSTRACT

A year-long study using NURE Program data was made. The objective of the study was to integrate the NURE data with other data sets to determine if the data were of sufficient quality and quantity to be used as an aid to exploration in more than a regional sense. The study reviewed the geology of the region covered by the Lubbock, Texas 1° x 2° NTMS Quadrangle. The geology was integrated with NURE aerial radiometric data that had been recorded before the study was undertaken. Detailed, manual integration of the geology and aerial radiometry indicate that several of the geologic units in the area have recognizable radiometric signatures. These signatures were checked and substantiated by two ground radiometric survey systems, one truck-mounted and one hand-held.

Ground checking of outcrops and contacts and the results of chemical analyses of soil and rock samples were integrated into the interpretation of the radiometric data. Disequilibrium analyses added breadth to the spectrometer assays. Results of analyses for total U_3O_8 content and microscopic analyses were also incorporated.

The radiometric signatures, coupled with ground checking, allowed judgments to be made about the quality of the published geologic map of the region. Numerous areas were seen which suggested that areas had been mismapped, that recent wind or stream action had modified the surface exposure of units, or that the radiometric data acquisition systems were able to detect surface units which were too small to be

presented at the scale of the published geologic map.

Two exploration models for the Lubbock region are proposed. The first and most obvious model involves basal Dockum (Triassic) sandstone. This is a zone which has been known for twenty years as a potentially economic uranium zone. Thus, the modern data do not contradict earlier studies in this case. The second model is more speculative but illustrates that a model can be derived from the NURE data. By integrating subsurface geologic data, NURE HSSR data, and ground and airborne radiometric data, a band of anomalies is seen extending in a generally north-south direction at the edge of the maximum eastern subsurface extent of Cretaceous rocks. Related to this band of anomalies is the group of very high radiometric anomalies over the Pleistocene lake basins in the southwestern corner of the study area. The basins also may be potential exploration targets.

The conclusion is that the NURE data sets, when coupled with data which would normally be integrated in an exploration program, can be used to generate exploration models, but not necessarily drilling or mining locations. The conclusion is somewhat site specific in that similar studies conducted in areas with different geologic structure, rock types, topography, climate and vegetation might lead to a different conclusion regarding the utility of the NURE data sets.

CONTENTS

	<u>Page</u>
ABSTRACT	ii
PREFACE	1
INTRODUCTION	4
<u>General Information</u>	4
<u>Physiography</u>	6
<u>Geologic History</u>	6
<u>Geology</u>	8
The Permian System	8
The Dockum Group	14
The Cretaceous System	25
The Ogallala Formation	30
The Blanco Formation	37
The Tule Formation	38
Windblown Cover Sand	40
The Tahoka Formation	40
Playas	45
Terrace Deposits	47
Windblown Sands	47
Quaternary Alluvium	47
DATA REDUCTION	49
<u>Aerial Data</u>	49

	<u>Page</u>
<u>Truck-Mounted Spectrometer Data</u>	51
<u>Hand-Held Spectrometer Data</u>	52
<u>Hydrogeochemical and Stream Sediment Reconnaissance Data</u>	52
<u>Geologic-Topographic Data</u>	52
DATA PRESENTATION	54
<u>Aerial Data</u>	54
Radiometric Data	54
Altimetry Data	57
Aeromagnetic Data	58
<u>Truck-Mounted Spectrometer Data</u>	58
<u>Hand-Held Spectrometer Data</u>	60
<u>Texas Water Development Board Geochemical Data</u>	60
<u>Other Geochemical Data</u>	61
<u>Geologic-Topographic Profiles</u>	61
DATA INTERPRETATION	63
<u>Aeromagnetics</u>	63
<u>Smoothing of Aerial Radiometric Data</u>	65
<u>Validity of Truck-Mounted Spectrometer Data</u>	72
<u>Comparison of Aerial Radiometric Data and Truck-Mounted Spectrometer Data</u>	74
<u>Altimetry Plots as Pseudo-topographic Profiles</u>	76
<u>Radiometry and Geochemistry</u>	81
Stages of Interpretation	81
Obvious Radiometric Features	82

	<u>Page</u>
Detailed Interpretation	84
<u>The Permian System</u>	88
Choza Formation	88
San Angelo Formation	89
Blaine Formation	91
Whitehorse Sandstone and Cloud Chief Gypsum	97
Quartermaster Formation	99
<u>The Dockum Group</u>	106
<u>The Cretaceous System</u>	113
<u>The Ogallala Formation</u>	113
<u>The Blanco Formation</u>	124
<u>The Tule Formation</u>	129
<u>Windblown Cover Sands</u>	133
<u>The Tahoka Formation</u>	137
<u>The Playas</u>	143
<u>Terrace Deposits</u>	145
<u>Windblown Sand</u>	146
<u>Quaternary Alluvium</u>	147
Integration of NURE Data Sets	148
<u>Summary of the Interpretation Technique</u>	156
Display of the Data	156
Ground Truth	157
Integration of Data Sets	157
CONCLUSIONS	159
RECOMMENDATIONS FOR FUTURE WORK	162

	<u>Page</u>
ACKNOWLEDGEMENTS	164
BIBLIOGRAPHY	165
APPENDIX A. Site Descriptions for Hand-Held Spectrometer Readings and Geochemical Analysis Samples . .	A-1
APPENDIX B. Hand-held Spectrometer Assays and Station Locations	B-1
APPENDIX C. Soil and Rock <u>C</u> hemical and Radiochemical Analyses	C-1
APPENDIX D. Thin-Section Analyses	D-1
APPENDIX E. Symbols and Abbreviations	E-1
APPENDIX F. Summarization of the Detailed Interpretation . .	F-1
APPENDIX G. Items Delivered to BFEC But Not Included in the Present Report	G-1

FIGURES

<u>Figure</u>	<u>Page</u>
1 Lubbock 1° x 2° Quadrangle location	2
2 Physiography of the High Plains and Osage Plains	5
3 Major structural features of the Lubbock 1° x 2° Quadrangle and surrounding areas	9
4 Generalized north-south cross section	16
5 Dockum Basin at onset of Dockum sedimentation	18
6 Location of anomalous uranium recorded in Dockum Group sediments	20
7 Distribution of Cretaceous sediments in the subsurface	26
8 Elevation of the base of the Cretaceous in Lynn County, Texas	28
9 West-east cross section across the High Plains	29
10 Elevation of the base of the Ogallala Formation	32
11 Distribution of carbonate in the cap rock at .9m (3 ft) depth	35
12 Elevation of the water table on the High Plains	36
13 Elevation of the top of the Cretaceous in Lynn County, Texas	43
14 Paleodrainage pattern of pluvial lake basins in the Lubbock 1° x 2° Quadrangle	44
15 Playa lake basin cross sections	46
16 General location of airborne survey lines	50
17 15-minute quadrangles within the Lubbock 1° x 2° Quadrangle	56
18 Single-record ²¹⁴ Bi data in the T-O Creek, et al., Quadrangle area	67

<u>Figure</u>		<u>Page</u>
19	Comparison of smoothed and unsmoothed ^{214}Bi data over sands (Recent) along flight line ML-4, T-O Creek, et al., Quadrangle	68
20	Comparison of smoothed and unsmoothed ^{208}Tl data over Ogallala (To) sediments (Pliocene) along flight line ML-2, New Lynne, et al., Quadrangle	69
21	Comparison of smoothed and unsmoothed ^{214}Bi data along flight line ML-6, Double Lakes area	70
22	Comparison of smoothed and unsmoothed ^{214}Bi data along flight line ML-4 in the Guthrie Lake area, Double Lakes, et al., Quadrangle	71
23	Comparison of hand-digitized and inverted altimetry topography along flight line ML-2	78
24	Unexpected differences between altimetry and hand-digitized topography	80
25	$^{214}\text{Bi}/^{208}\text{Tl}$ anomaly over Blaine sediments along flight line ML-8	93
26	^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies in lower Dockum (Triassic) - upper Quartermaster (Permian) along flight line ML-1, T-O Creek, et al., Quadrangle	101
27	Typical ^{208}Tl and ^{40}K responses over Ogallala (Pliocene) sediments along flight line ML-6	115
28	Typical ^{208}Tl and ^{40}K responses over Ogallala (Pliocene) sediments along flight line ML-11	116
29	^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ anomaly at the base of Blanco Formation (Pliocene-Pleistocene) and top of the Ogallala Formation (Pliocene) along flight line ML-17	118
30	^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ anomaly over base of the Blanco Formation (Pliocene-Pleistocene) and top of the Ogallala Formation (Pliocene) along flight line ML-19	126
31	Change in $e\text{Th}$ background observed in the truck-mounted spectrometer data over the High Plains from south to north in the Lubbock $1^\circ \times 2^\circ$ Quadrangle	134
32	$e\text{U}$, $e\text{Th}$, and K values over Double Lakes along traverse L-NW-104 - L-NW-021	141

TABLES

<u>Table</u>		<u>Page</u>
1	Stratigraphic units exposed in the Lubbock 1° x 2° Quadrangle	7
2	List of known uranium occurrences in the Lubbock 1° x 2° Quadrangle	21
3	Size of large basins in Lynn County, Texas	42
4	Statistics calculated from the airborne radiometric data in the Lubbock 1° x 2° Quadrangle	55
5	Effect of applying new calibration coefficients to radiometric data collected by the truck-mounted spectrometer during July and August 1978	59
6	Effective Sample Size	75

PLATES

Plate

- 1 Index Map
- 2 Geology
- 3 Known Uranium Occurrences
- 4 Bendix Truck Spectrometer Survey Line Locations
- 5 Hand-Held Spectrometer and Geochemical Sample Station Locations
- 6 Airborne Radiometric Profiles, Bismuth, Flight Lines ML-1 through
ML-23
- 7 Airborne Radiometric Profiles, Thallium, Flight Lines ML-1 through
ML-23
- 8 Airborne Radiometric Profiles, Potassium, Flight Lines ML-1
through ML-23
- 9 Airborne Radiometric Profiles, Bi/Tl, Flight Lines ML-1 through
ML-23
- 10 Airborne Radiometric Profiles, Bi/K, Flight Lines ML-1 through
ML-23
- 11 Airborne Radiometric Profiles, Tl/K, Flight Lines ML-1 through
ML-23
- 12 Airborne Radiometric Profiles, Bismuth, Flight Lines TL-1 through
TL-10
- 13 Airborne Radiometric Profiles, Thallium, Flight Lines TL-1 through
TL-10
- 14 Airborne Radiometric Profiles, Potassium, Flight Lines TL-1
through TL-10
- 15 Airborne Radiometric Profiles, Bi/Tl, Flight Lines TL-1 through
TL-10

Plate

- 16 Airborne Radiometric Profiles, Bi/K, Flight Lines TL-1 through TL-10
- 17 Airborne Radiometric Profiles, Tl/K, Flight Lines TL-1 through TL-10
- 18 Hand-held Spectrometer and Geochemical Analysis: Uranium Values
- 19 Hand-held Spectrometer and Geochemical Analysis: Thorium Values
- 20 Aeromagnetic Profiles and Interpretation
- 21 Obvious Radiometric Features
- 22 Proposed Exploration Models Derived from NURE Program Data
- 23 Obvious Bi and Bi/Tl Anomalies and Extent of Cretaceous Rocks
- 24 Bi/Tl Profiles, Kiowa Peak NW, et al., with HSSR and Hand-Held Spectrometer Data
- 25 Bi/Tl Profiles, Aspermont, et al., with HSSR and Hand-Held Spectrometer Data
- 26 Bi/Tl Profiles, Peacock, et al., with HSSR and Hand-Held Spectrometer Data
- 27 Bi/Tl Profiles, Guthrie NW, et al., with HSSR and Hand-Held Spectrometer Data
- 28 Bi/Tl Profiles, Slaton, et al., with HSSR Data and Outline of Margin of Cretaceous Rocks
- 29 Bi/Tl Profiles, New Lynn, et al., with HSSR Data and Outline of Margin of Cretaceous Rocks
- 30 Bi/Tl Profiles, Lubbock, with HSSR Data and Outline of Margin of Cretaceous Rocks
- 31 Geologic Profiles Along Flight Lines ML-7 through ML-12, Slaton, et al., Quadrangle

Plate

32 Geologic Profiles Along Flight Lines ML-13 through ML-18, Lubbock

Quadrangle

33 Bendix Truck Spectrometer Survey, Line 11

34 Bendix Truck Spectrometer Survey, Line 14

35 Bendix Truck Spectrometer Survey, Line 15

36 Bendix Truck Spectrometer Survey, Line 16

37a Bendix Truck Spectrometer Survey, Line 21, Miles 0-24.66

37b Bendix Truck Spectrometer Survey, Line 21, Miles 23.67-42.4

38 Bendix Truck Spectrometer Survey, Line 23

39a Bendix Truck Spectrometer Survey, Line 24, Miles 0-24.66

39b Bendix Truck Spectrometer Survey, Line 24, Miles 24.0-39.8

40 Bendix Truck Spectrometer Survey, Line 25

41 Bendix Truck Spectrometer Survey, Line 26

42 Bendix Truck Spectrometer Survey, Line 31

43 Bendix Truck Spectrometer Survey, Line 34

44 Bendix Truck Spectrometer Survey, Line 35

45 Bendix Truck Spectrometer Survey, Line 41

46 Bendix Truck Spectrometer Survey, Line 42

47 Bendix Truck Spectrometer Survey, Line 43

48 Bendix Truck Spectrometer Survey, Line 45

49 Bendix Truck Spectrometer Survey, Line 47

50 Bendix Truck Spectrometer Survey, Line 48

51a Bendix Truck Spectrometer Survey, Line 51, Miles 0-23.67

51b Bendix Truck Spectrometer Survey, Line 51, Miles 22.69-41.4

52a Bendix Truck Spectrometer Survey, Line 52, Miles 0-24.66

52b Bendix Truck Spectrometer Survey, Line 52, Miles 23.67-49.3

Plate

- 52c Bendix Truck Spectrometer Survey, Line 52, Miles 48.33-52.3
- 53 Bendix Truck Spectrometer Survey, Line 55
- 54 Bendix Truck Spectrometer Survey, Line 61
- 55 Bendix Truck Spectrometer Survey, Line 61.1
- 56 Bendix Truck Spectrometer Survey, Line 62
- 57 Bendix Truck Spectrometer Survey, Line 62.1
- 58 Bendix Truck Spectrometer Survey, Line 63
- 59 Bendix Truck Spectrometer Survey, Line 65
- 60 Bendix Truck Spectrometer Survey, Line 66
- 61 Bendix Truck Spectrometer Survey, Line 67
- 62 Bendix Truck Spectrometer Survey, Line 71
- 63 Bendix Truck Spectrometer Survey, Line 72
- 64 Bendix Truck Spectrometer Survey, Line 73
- 65 Bendix Truck Spectrometer Survey, Line 75
- 66 Bendix Truck Spectrometer Survey, Line 76
- 67 Bendix Truck Spectrometer Survey, Line 78
- 68a Bendix Truck Spectrometer Survey, Line 81, Miles 0-24.66
- 68b Bendix Truck Spectrometer Survey, Line 81, Miles 23.67-38.6
- 69 Bendix Truck Spectrometer Survey, Line 82
- 70 Bendix Truck Spectrometer Survey, Line 85
- 71a Bendix Truck Spectrometer Survey, Line 91, Miles 0-24.66
- 71b Bendix Truck Spectrometer Survey, Line 91, Miles 23.67-41.43
- 72 Bendix Truck Spectrometer Survey, Line 92
- 73 Bendix Truck Spectrometer Survey, Line 101
- 74a Bendix Truck Spectrometer Survey, Line 111, Miles 0-24.66
- 74b Bendix Truck Spectrometer Survey, Line 111, Miles 23.67-35.4

Plate

- 75a Bendix Truck Spectrometer Survey, Line 113, Miles 0-24.66
- 75b Bendix Truck Spectrometer Survey, Line 113, Miles 23.67-39.6
- 76a Bendix Truck Spectrometer Survey, Line 121, Miles 0-24.66, 7-24-78
- 76b Bendix Truck Spectrometer Survey, Line 121, Miles 23.67-31.5, 7-24-78
- 77 Bendix Truck Spectrometer Survey, Line 121, 7-25-78
- 78 Bendix Truck Spectrometer Survey, Line 121, 7-26-78
- 79 Bendix Truck Spectrometer Survey, Line 121, 7-27-78
- 80 Bendix Truck Spectrometer Survey, Line 121, 7-28-78
- 81 Bendix Truck Spectrometer Survey, Line 121, 7-29-78
- 82 Bendix Truck Spectrometer Survey, Line 121, 7-31-78
- 83 Bendix Truck Spectrometer Survey, Line 122
- 84 Bendix Truck Spectrometer Survey, Line 123
- 85 Bendix Truck Spectrometer Survey, Line 132
- 86 Bendix Truck Spectrometer Survey, Line 133
- 87 Bendix Truck Spectrometer Survey, Line 145
- 88a Bendix Truck Spectrometer Survey, Line 151, Miles 0-24.66
- 88b Bendix Truck Spectrometer Survey, Line 151, Miles 23.67-49.32
- 88c Bendix Truck Spectrometer Survey, Line 151, Miles 48.33-57.2
- 89 Bendix Truck Spectrometer Survey, Line 152
- 90 Bendix Truck Spectrometer Survey, Line 153
- 91a Bendix Truck Spectrometer Survey, Line 171, Miles 0-24.66
- 91b Bendix Truck Spectrometer Survey, Line 171, Miles 23.67-48
- 92a Bendix Truck Spectrometer Survey, Line 182, Miles 0-24.66
- 92b Bendix Truck Spectrometer Survey, Line 182, Miles 23.67-49.32
- 92c Bendix Truck Spectrometer Survey, Line 182, Miles 48.33-53.3
- 93 Bendix Truck Spectrometer Survey, Line 191

Plate

- 94a Bendix Truck Spectrometer Survey, Line 201, Miles 0-24.66
- 94b Bendix Truck Spectrometer Survey, Line 201, Miles 23.67-39
- 95a Bendix Truck Spectrometer Survey, Line 221, Miles 0-24.66
- 95b Bendix Truck Spectrometer Survey, Line 221, Miles 23.67-49.32
- 95c Bendix Truck Spectrometer Survey, Line 221, Miles 48.33-73.98
- 95d Bendix Truck Spectrometer Survey, Line 221, Miles 72.99-83
- 96 Bendix Truck Spectrometer Survey, Line 222
- 97 Bendix Truck Spectrometer Survey, Line 223
- 98 Bendix Truck Spectrometer Survey, Line 224
- 99 Bendix Truck Spectrometer Survey, Line 321
- 100 Geologic Profile, Line 321
- 101 Bendix Truck Spectrometer Survey, Line 322
- 102a Bendix Truck Spectrometer Survey, Line 371, Miles 0-24.66
- 102b Bendix Truck Spectrometer Survey, Line 371, Miles 23.67-31
- 103a Bendix Truck Spectrometer Survey, Line 421, Miles 0-24.66
- 103b Bendix Truck Spectrometer Survey, Line 421, 23.67-49.32
- 103c Bendix Truck Spectrometer Survey, Line 421, Miles 48.33-70
- 104 Bendix Truck Spectrometer Survey, Line 441
- 105a Bendix Truck Spectrometer Survey, Line 451, Miles 0-24.66
- 105b Bendix Truck Spectrometer Survey, Line 451, Miles 23.67-37.4
- 106 Bendix Truck Spectrometer Survey, Line 452
- 107 Bendix Truck Spectrometer Survey, Line 461
- 108 Bendix Truck Spectrometer Survey, Line 462
- 109 Bendix Truck Spectrometer Survey, Line 471
- 110 Bendix Truck Spectrometer Survey, Line 472
- 111 Bendix Truck Spectrometer Survey, Line 491

Plate

- 112 Bendix Truck Spectrometer Survey, Line 504
- 113 Bendix Truck Spectrometer Survey, Line 508
- 114 Bendix Truck Spectrometer Survey, Line 518

PREFACE

The present report documents a year-long study of National Uranium Resource Evaluation (NURE) data available in the area of the Lubbock, Texas 1° x 2° Quadrangle (Fig. 1). The data evaluated included aerial radiometric and magnetic data collected by Geodata International, Incorporated in 1975, Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) data collected by Oak Ridge National Laboratory in 1976 and 1977, ground spectrometer data collected by a truck-mounted system operated by Bendix Field Engineering Corporation (BFEC), hand-held spectrometer data collected by G-Cubed Incorporated, and rock and soil samples collected by G-Cubed Incorporated and tested by a variety of methods.

These data have been analyzed and integrated in an attempt to define the utility of such data sets for uranium exploration purposes. The objective of the NURE program as initially conceived was to evaluate the uranium resource potential of the United States. However, when the various NURE datasets began to be made publicly available, exploration companies started trying to use the data for prospect generation. Much misunderstanding of the data sets existed, and it is presumed that a certain amount of misuse of the data sets occurred.

The primary objective of the present study was to determine if the NURE data could be used in any manner as a prospect finding tool. Further, are certain portions of the NURE data more valuable than others for this purpose? A number of subsidiary questions arises from these

Figure 1. Location of the Lubbock, TX, 1° x 2° Quadrangle.

two basic queries, and some of these were investigated during the research. The methods used in the Lubbock area have general applicability in any area in the United States. However, because of geologic and topographic differences in other areas, the details of the methods suggested in this report will vary.

The investigation comprised three tasks. These were:

- 1) evaluate the airborne data (magnetic and radiometric),
- 2) evaluate the HSSR data, and
- 3) integrate the data sets to define favorable and unfavorable uranium localities and test the localities with ground follow-up.

A philosophy was used through the course of the investigation. That was, how should a uranium exploration company proceed to find uranium targets given the data at hand? This philosophy stands midway

between what an exploration company would do and what a research-only organization would do. Realization of this stance is necessary to put the present report into perspective. In a typical exploration effort, particularly in the early stages of evaluating an area, only a few basic data sets would be available to the explorationist. Furthermore, time and financial resources may limit what analyses, specifically computerized analyses, of the existing data can be undertaken. The explorationist may have to rely upon data sets and data displays such as are evaluated and presented in this study. This is neither to say that the more in-depth numerical methods are overkills for exploration work, nor does it say that the limited types of analyses discussed in the present report are sufficient in all areas.

INTRODUCTION

General Information

The Lubbock, Texas $1^{\circ} \times 2^{\circ}$ Quadrangle is bounded by 100° and 102° West longitude and 33° to 34° North latitude (Pl. 1). The climate in this area is a semi-arid continental type. Rainfall averages 50 cm (20 in) per year, and most of the precipitation falls as spring and summer downpours. Normal maximum summer temperatures are 32° to 35° C (90° to 95° F) and normal winter maximum temperatures are 7° to 13° C (45° to 55° F). Wind direction is predominately southwesterly, and wind speed ranges from 19 to 26 km per hr (12 to 16 mi per hr) (Brown, 1956; Wendorf, 1975).

The Lubbock $1^{\circ} \times 2^{\circ}$ Quadrangle largely comprises irrigated agricultural land and range land. In addition, there are many oil fields scattered throughout the area. The city of Lubbock is the population center within the Lubbock Quadrangle, and there are many small towns in the area supported by the agricultural industry.

Physiography

The area covered by the Lubbock $1^{\circ} \times 2^{\circ}$ Quadrangle comprises portions of two physiographic provinces (Fig. 2). The High Plains (or Llano Estacado), found in the western half of the quadrangle, is separated from the Osage Plains on the east by an erosional escarpment which trends roughly northeast-southwest. The High Plains is the southern portion of the Great Plains, and the Osage Plains belongs to the

Figure 2. Physiography of the High Plains and Osage Plains (after Wendort, 1975).

central Lowlands Province (Brown, 1956; Cronin, et al., 1973).

The High Plains, a remnant of the Rocky Mountain piedmont plain, formed during Pliocene time (Reeves, 1970; Wendorf, 1975). The High Plains is bounded on the north by the Canadian River, on the west by the Pecos River, and on the east by an erosional escarpment, and merges with the Edwards Plateau on the south (Barker and Scott, 1958; Wendorf, 1975). Elevation of the High Plains in the Lubbock Quadrangle ranges from 885 to 1065 m (2900 to 3500 ft) above sea level, and the relatively flat surface slopes gradually to the southeast approximately 1.5 to 1.9 m per km (8 to 10 ft per mi).

Headward erosion of the Brazos River and other streams produced the eastern escarpment of the High Plains and shaped the Osage Plains in this area (Wendorf, 1975). Elevation of the gently rolling Osage Plains ranges from approximately 490 to 820 m (1600 to 2700 ft) above sea level in the Lubbock Quadrangle. Several mesas and other erosional remnants appear on the Osage Plains.

Geologic History

The oldest geologic units exposed in the area of the Lubbock Quadrangle are Permian in age (Table 1). The marine Permian units were laid down in the Midland and the Palo Duro Basins which were formed by the folding of pre-Permian rocks (Cronin, 1961). The Midland Basin began forming as a rapidly subsiding feature during Late Mississippian or Early Pennsylvanian time. During Wolfcampian (Pennsylvanian) time, "the positive features of the Matador Arch reached their maximum

TABLE 1. STRATIGRAPHIC UNITS EXPOSED IN THE LUBBOCK 1° x 2° QUADRANGLE.

SYSTEM	SERIES	UNITS	ABBREVIATION FOR MAPS AND PROFILES	THICKNESS
Quaternary	Recent	Alluvium Windblown sand	Qal Qs, Qsd	0-15'
	Pleistocene	Fluviatile terrace deposits Playa deposits Tahoka Formation Windblown cover sand Tule Formation Blanco Formation	Qt Qp Qta Qcs Qtu Qb	0-150'
Tertiary	Pliocene	Ogallala Formation Bridwell Member Couch Member	To	0-250'
Cretaceous	Comanche	Washita Group Duck Creek Shale Fredericksburg Group Kiamichi Shale Edwards Limestone Comanche Peak Limestone Walnut Formation Trinity Group Antler Sand	Kdk Kk Ke Kc Kcwa Kecwa	0-200'
Triassic		Dockum Group Trujillo Formation Tecovas Formation	Rd	0-400'
Permian	Guadalupe	Quatermaster Formation Whitehorse Group Pease River Group Blaine Formation San Angelo Formation	Pq Pwh Pb Psa	1600 - 1850
	Leonard	Clear Fork Group Choza Formation	Pch	100'

Compiled from Barnes (1967), Cronin (1961), McKee and Oriel (1967) and Smith (1974).

development" (Schmitt, 1956). The Matador Arch bounds the Midland Basin on the north and trends generally east-west across the northern edge of the Lubbock Quadrangle (Fig. 3). Development of the Midland Basin continued until Middle or Late Permian time although long stable periods interrupted the subsidence (Nicholson, 1956). In later Permian time, the sea withdrew generally to the southwest probably accompanied by uplift of the Lubbock area (Cronin, 1961).

Several depositional hiatuses followed the Permian sedimentation. Continental Late Triassic sediments were deposited over the Permian. Jurassic time appears to have been an erosional period. Marine sediments were deposited beginning in the Early Cretaceous as the sea transgressed over the area from the southeast. During the Tertiary (probably beginning in the Pliocene), piedmont plain deposits were laid unconformably over the Triassic and Cretaceous units and probably also over parts of the exposed Permian. A variety of Quaternary continental materials have been deposited over all of the earlier units (Cronin, 1961).

The erosional scarp which separates the High Plains from the Osage Plains appears to have formed in the Pleistocene during "intervals of accelerated erosion interrupted by long intervals of relative stability" (Evans, 1974).

Geology

The Permian System

The Permian System, exposed on the Osage Plains in the eastern half of the Lubbock Quadrangle (Pl. 2), comprises interbedded red

Figure 3. Major structural features of the Lubbock 1° x 2° Quadrangle and surrounding areas (after Cronin, 1961).

sandstones and shales with numerous gypsum and shale layers (Cronin, 1961). Five Permian formations are exposed in the area: the Choza, the San Angelo, the Blaine, the Whitehorse Sandstone and the Cloud Chief Gypsum, and the Quartermaster (from oldest to youngest) (Barnes, 1967). The Choza Formation (Middle Permian) is part of the Clear Fork Group of the upper Leonardian Series, and the San Angelo and Blaine Formations (Middle Permian) belong to the Pease River Group of the Guadalupian Series (Smith, 1974). The Whitehorse Sandstone and Cloud Chief Gypsum (Middle or Upper Permian?) are part of the Whitehorse Group of the Guadalupian Series. The Quartermaster Formation (Middle or Upper Permian?) is the youngest formation in the Guadalupian Series (McKee and Oriel, 1967).

Exposures of the Choza Formation in the Lubbock Quadrangle are limited to Stonewall and King Counties in the southeast corner of the area. The Choza Formation comprises interbedded sands and shales. The Merkel Dolomite marks the top of the unit. The bluish-green and red shales are locally sandy, and the gray sandstone layers are fine-grained, massive, moderately-indurated, and locally calcareous (Barnes, 1967). Light gray reduction spots are found throughout the formation. Both gypsum nodules and selenite are present in the Choza. The Merkel Dolomite is approximately 0.6 m (2 ft) thick, and it is missing in the Old Glory area in Stonewall County (Smith, 1974). Thickness of the Choza Formation is about 30 m (100 ft) (Barnes, 1967).

The San Angelo Formation lies both conformably and unconformably over the Choza Formation. It crops out in a thin strip along the southeastern margin of the Lubbock Quadrangle in Stonewall and King

Counties (Barnes, 1967). The San Angelo consists of equal portions of sandstone and mudstone which complexly intertongue. The unit is divided into two informal members: the lower Duncan and the upper Flowerpot. The Duncan Member comprises interbedded mudstones, siltstones, and sandstones and the unit is about 14 to 20 m (45 to 65 ft) thick. The sandstones generally consist of white to reddish-brown illitic clay and contain quartz sand and silt. The contact between the Duncan and the Flowerpot is gradational. The Flowerpot is approximately 8 to 19 m (27 to 63 ft) thick and it primarily contains easily erodable light gray and reddish-brown mudstones and siltstones. The unit also has some light gray sandstones. Gypsum nodules can be found in the mudstone beds. As with the Duncan mudstone, illite is the primary clay mineral and quartz sands and silts are found in the Flowerpot. The upper Flowerpot is marked by the presence of barite nodules, dolomicrite, and calcareous shales beds (Smith, 1974).

The contact between the San Angelo and Blaine Formations is gradational (Smith, 1974). Blaine exposures cover a broad area extending continuously from the north end of the Lubbock Quadrangle to the south end (Barnes, 1967). A 0.3 m (1 ft) thick gypsum bed is generally found in the basal Blaine (Smith, 1974). The Blaine comprises interbedded fine-grained, moderately-indurated red quartz sandstones, silty alternating gray and red shales, white to bluish-gray to pink gypsum beds, and locally argillaceous, calcitic or oolitic gray dolomites. Total unit thickness is 200 to 213 m (650 to 700 ft) (Barnes, 1967).

The Whitehorse Sandstone and Cloud Chief Gypsum which overlie the Blaine both belong to the Whitehorse Group (McKee and Oriel, 1967). Whitehorse beds crop out in a wide band from the north end of quadrangle to the south end. These units comprise interbedded sands, sandstones, shales, gypsum, and dolomite. The friable fine-grained quartz sands and sandstones and the sandy shales are various shades of red. The thin dolomites are gray, and the massive gypsum is white to pink. Average unit thickness is 200 m (650 ft) (Barnes, 1967).

The Quartermaster Formation is the youngest Permian unit in the Lubbock Quadrangle and overlies the Whitehorse Sandstone and Cloud Chief Gypsum. The Quartermaster crops out in a broad north-south trending band across the Lubbock Quadrangle. This unit comprises interbedded sandstones, shales, dolomites, and gypsum. The fine-grained sandstone contains frosted grains. The silty shale contains numerous 5 to 10 cm (2 to 4 in) thick evenly-bedded veins and interbeds of satinspar. Gypsum and dolomite beds are relatively rare and are 0.3 to 0.6 m (1 to 2 ft) thick (Barnes, 1967). Abundant green reduction haloes can be found in the Quartermaster (Jones, 1974). The unit is 76 to 107 m (250 to 350 ft) thick (Barnes, 1967). The boundary between the Quartermaster (Permian) and the Dockum (Triassic) is often unclear. The Triassic tends to be deep maroon in color, conglomeratic, and micaceous. The Permian generally is light, brick red in color (Cronin, 1961).

In northeast Kent and northwest Stonewall Counties, several salt flats appear along the tributaries of the Salt Fork of the Brazos River and cover Permian strata. Most of the salt is halite. Dove Creek salt

flat, located along Dove Creek, is the largest of these. Short Croton and "Hot Springs" salt flats occur along Croton Creek. The flats form in generally flat areas where the tributary gullies have widened to 400 m (1300 ft) or more. There is no vegetation on these flats. The salt generally overlies red silts which contain some gypsum and gypsiferous shale beds (Blank, 1956).

Permian sediments in west Texas vary from continental to marine and include salt, gypsum, and anhydrite. In general, marine sedimentation decreased in later Permian time and an "intermittent but progressive withdrawal of the sea," generally to the southwest, is indicated by increased deposition of non-marine sediments and evaporites (Cronin, 1961). More specifically, the Choza Formation was deposited on a low relief coastal plain consisting of a subtidal shelf, a mud-rich intertidal flat, and a sabkha. Much of the Choza was deposited in the tidal flat environment. Deposition of the San Angelo Formation occurred in fluvial-deltaic and tidal flat environments. In the Lubbock Quadrangle, lower San Angelo (Duncan) deposition occurred in the Old Glory fluvial-deltaic system and the Buzzard Peak sand-rich tidal flat system. The Old Glory system is a high-constructive lobate delta, and it crops out from approximately 5.6 km (3.5 mi) south of the north border of Stonewall County into Fisher County south of Lubbock. The Buzzard Peak system occurs north of the Old Glory system. The sediment supplied to the fluvial-deltaic systems was generally from the west. When the sediment supply was cut off, Duncan sandstone deposition ended. Flowerpot deposition began when long shore currents from the south began to supply mud to the Cedar Mountain mud-rich tidal

flat system. Gradual uplift of the area combined with progradation of the tidal-flat led to the termination of Flowerpot deposition (Smith, 1974).

The Blaine Formation consists of interbedded sabkha and tidal-flat deposits. Thin sabkha deposits were laid down during regressive episodes, while the thin tidal-flat sediments were deposited during transgressive episodes of the Permian sea (Smith, 1974).

The Permian rocks on the Osage Plains are neither primary nor secondary aquifers. Groundwater production is limited to small quantities of poor quality water. The water is contaminated by the gypsum, salt, and anhydrite found in the Permian strata (Cronin, et al., 1973).

Eargle and McKay (1955) evaluated the uranium potential of Permian strata in northern Texas and southern Oklahoma. The Hennessey Shale (Oklahoma Choza Formation equivalent) contained some uranium minerals in claystones found near the top of the unit. Uranium minerals were reported in thin sandstone and siltstone beds in the Cloud Chief Formation in Oklahoma. In addition, high radioactivity was noted in thin gray to yellow carbonaceous sandstones which are bounded in red shales near the base of the Quartermaster Formation in Oklahoma.

The Dockum Group

The primary exposures of the terrigenous Dockum Group (Triassic) in the Lubbock Quadrangle occur along the erosional escarpment which marks the eastern margin of the High Plains. The Dockum also crops

out as outliers on the Osage Plain (Barnes, 1967). Dockum Group rocks generally dip to the southeast at about 1.5 m per km (8 ft per mi) (Cronin, 1961). Progressively older Permian rocks underlie Dockum sediments from the north end of the Dockum Basin to the south end (Finch, 1975).

The Dockum Group comprises two formations: the basal Tecovas and the upper Trujillo (Finch, 1975; McGowen, 1978). The basal conglomerate of the Tecovas Formation has been named the Camp Springs Conglomerate. Deposits of this quartz and chert pebble conglomerate are restricted to south of the Matador Arch (Fig. 4). Most of the siliceous pebbles found in Dockum sediments are found in this unit. The Camp Springs Conglomerate has a maximum thickness of 30 m (100 ft) and it is fairly continuous. The remainder of the Tecovas Formation consists primarily of lacustrine and deltaic deposits which include locally bentonitic mudstones, siltstones, and sandstones. Maximum thickness of the Tecovas is 84 m (275 ft) and the unit pinches out over the Matador Arch. The Trujillo Formation comprises interbedded fluvial sandstones and conglomerates and deltaic and lacustrine mudstones. The Trujillo conglomerates have claystone and limestone clasts. Maximum thickness of the unit is 76 m (250 ft). The mudstones thin over the Matador Arch while the sandstones do not appear to be affected by the structure (Finch, 1975). Roth (1949) notes the presence of some volcanic ash in the Dockum.

Deposition of the Triassic Dockum Group occurred in a basin that covered parts of New Mexico, Kansas, Colorado, and Oklahoma as well as Texas. The climate was in general more humid during Dockum deposition time than during the Permian. In some places, the Dockum lies

Figure 4. Generalized north-south cross section (see Figure 2 for approximate location) (after Finch, 1975).

unconformably over Permian units while in other areas the contact is conformable. Dockum sedimentation appears to have been initiated by the climatic change induced by the opening of the Gulf of Mexico (Kehle, 1972) which also led to uplift of the Ouachita Mountains and subsidence of the Dockum Basin. The Dockum Basin in Texas and New Mexico (Fig. 5) appears to have filled with sediments derived from Paleozoic material largely from New Mexico, Texas and Oklahoma. The basal Dockum generally accumulated as progradational deposits comprising, from bottom to top, "a basal lacustrine-deltaic mudstone-siltstone sequence, a thin deltaic sequence, and a thick fluvial sandstone" (McGowen, 1978). The rest of the Dockum is characterized by cyclic sedimentation induced by alternating pluvial and arid conditions. A cycle consists of one high lake level and one low lake level. During humid periods, the lake level would be high and sediments were primarily deposited in meandering streams, alluvial fans, progradational deltas, and lakes. The base level during humid periods was relatively stable and most of the sediments were probably derived as eroded and redeposited Dockum material. Most of the red sandstone and conglomerate deposits in the Dockum appear to have been deposited during arid periods. Thin reddish-brown mudstones are also found in low stand deposits. Abrupt vertical and lateral textural changes characterize the low-lake-level-cycle deposits (McGowen, 1978).

Dockum deposits largely comprise distributary deltas and meandering streams in Crosby, Dickens, Garza, and Kent Counties, Texas. Meandering streams provided the major source of sediment from the west and the east while streams with a higher gradient and with fan deltas

Figure 5. Dockum Basin at onset of Dockum sedimentation (from McGowen, 1978).

and alluvial fans fed the north and south ends of the basins (McGowen, 1978).

Anomalous uranium occurrences have been reported in Dockum Group sediments by a number of investigators (Eargle and McKay, 1955; Finch, 1975; McGowen, 1978). Figure 6 illustrates the location of recorded anomalous uranium occurrences in the Dockum. Finch (1975) evaluated the uranium potential of the formations in the Dockum Group. Uranium deposits grading from .003 to .08% U_3O_8 have been reported in the Camp Springs Conglomerate (Table 2 and Pl. 3) in the Post District (Kent and Garza Counties, Texas). The mineralized zones in this unit are localized. The mineralization is in either clayey or sandy zones and is sometimes associated with silicified and carbonized wood. Uranium deposits in the Tecovas Formation are located in claystones from the Post District north to the Canadian River. These deposits are generally associated either with cuprous nodules or carbonaceous plant material. Ore-grade mineralization has largely been found in the Trujillo Formation generally in the Post District. The most common host rock in the Trujillo Formation is a limestone-clast conglomerate with carbonaceous plant material or areas of humic impregnation. This host rock is rated by Finch as the best host for larger uranium deposits in the Dockum Group. Uranium deposition in the Trujillo also occurs in calcareous sandstones. Poor preservation conditions lessen the possibility of finding large uranium deposits in the Trujillo Formation. The formation has been leached and dissected by eastward-flowing ground and surface waters. Volcanic and granitic source rocks do not appear to be prevalent (Finch, 1975).

Figure 6. Location of anomalous uranium recorded in Dockum Group sediments. $\mathbb{D}$ = Dockum Group, undifferentiated, deposits; $\mathbb{Ccs}$ = Camp Spring Conglomerate deposit; $\mathbb{Tte}$ = Tecovas Formation deposit; and $\mathbb{Ttr}$ = Trujillo Formation deposit (after Finch, 1975).

TABLE 2. LIST OF KNOWN URANIUM OCCURRENCES IN THE LUBBOCK 1° x 2° QUADRANGLE.

County--Name	Location	Stratigraphic Unit	Production	Description
Lubbock County 1. Benson Lake	approx. 33°32'N 101°41'W	Ogallala	occurrence	From Benson Lake upstream for 1500 m to Lake No. 3 anomalous radioactivity is noted near the top of the caliche. At Lake No. 3 a conical hill of caliche 6 m high and 80 m in diameter is uniformly radioactive. Grab samples at caliche showed 0.014 to 0.017% uranium in near equilibrium.
Crosby County 2. Unnamed	approx. 33°50'N 101°15'W	Blanco	occurrence	Anomalous radioactivity in the Pleistocene units are deposited in shallow basins developed in cap rock.
3. Negro Hill	approx. 33°31'N 101°10'W	Tecovas	occurrence	Uranium is associated with sparse cuprous nodules averaging one cm across that are scattered through a 2 m thick zone for about 15 m along a mudstone outcrop. Analysis showed 0.03% U, 7% Cu, and 0.1% V.

Table 2. (Continued)

County--Name	Location	Stratigraphic Unit	Production	Description
Crosby County				
4. Wood Ranch	approx. 33°30'N 101°32'W	Ogallala	occurrence	Upper 10 m of caliche anomalous for about 30 m along the outcrop. Channel samples of "hot spots" showed 0.023 and 0.0025% U.
5. Eubank Ranch	approx. 33°24'N 101°19'W	Trujillo	shipped 365 tons @ .11% U ₃ O ₈ (cert. no. 824)	Deposits in the basal sequence of limestone pebble conglomerates and thin interbeds of sandstone consist of small, irregular, discontinuous bodies in a single horizon. Primary ore consists of sparse uraniferous carbonized plant remains, but mostly of uraniferous microscopic organic (humic) impregnations, as rims in calcareous mudstone cement around the limestone pebbles, pellets, and grains. Sparse amounts of tyuyamunite and metatyuyamunite core joints and bedding surfaces.
Dickens County				
6. Unnamed	approx. 33°48'N 101°00'W	Pearlette Ash Type 0	occurrence	Anomalous radioactivity in Pleistocene units deposited in small shallow basins are developed in the cap rock.

Table 2. (Continued)

County--Name	Location	Stratigraphic Unit	Production	Description
Kent County				
7. McArthur Ranch	approx. 33°23'N 101°01'W	Camp Springs Conglomerate	shipped 33 tons @ .01% U ₃ O ₈	Carnotite associated with carbonized and silicified fossil wood in clayey and sandy parts of the quartz-chert conglomerate.
Garza County				
8. Garza Co. Exploration/ Swenson Ranch	approx. 33°21'N 101°15'W	Trujillo	shipped 13 tons @ .08% U ₃ O ₈ cert. no. D-319	Carnotite in sandstone.
9. Crown (Long Ranch)	approx. 33°19'N 101°24'W	Trujillo	shipped 54 tons @ 0.22% U ₃ O ₈ cert. no. 1002	Carnotite in sandstone channel fill. Reserves estimated to be 1240 tons @ 0.2% U ₃ O ₈ .
10. Twin Rattler (Long Ranch)	approx. 33°19'N 101°24'W	Trujillo	shipped 133 tons @ 0.14% U ₃ O ₈ cert. no. 1002	Carnotite in sandstone channel fill. Stockpiled 200 tons @ 0.15 - 0.20% U ₃ O ₈ . Reserves estimated at 9500 tons @ 0.21% U ₃ O ₈ .
11. Hillside (Long Ranch)	approx. 33°19'N 101°24'W	Trujillo	shipped 38 tons @ 0.20% U ₃ O ₈	Carnotite in bedded sandstone channel fill. Stockpiled 100 tons @ 0.15 - 0.20% U ₃ O ₈ .

Table 2. (Continued)

County--Name	Location	Stratigraphic Unit	Production	Description
Garza County				
12. Sanderson Ranch	approx. 33°17'N 101°08'W	Dockum (?)	occurrence	Uranium mineral identified in a sandstone.
13. Roddy Ranch	approx. 33°14'N 101°11'W	Dockum (?)	occurrence	Uranium in a sandstone.
14. Rattleweed/ Post Estate	approx. 33°08'N 101°23'W	Trujillo	occurrence	Carnotite in bedded sandstones. Reserves estimated to be 125 tons @ 0.20% U_3O_8 .
15. Yellow Cub-- Sec. 4 (Kirkpatrick Ranch)	approx. 33°08'N 101°23'W	Trujillo	shipped 186 tons @ .43% U_3O_8 cert. no. 871	Carnotite in sandstone channel fill. Reserves estimated to be 25 tons @ 0.15% U_3O_8 .
16. Adams Prospect	approx. 33°07'N 101°07'W	Camp Springs Conglomerate	shipped 13 tons @ 0.08% U_3O_8	Uranium mineralization in pebbly claystone.
17. Cap rock Prospect/ Slaughter Ranch	approx. 33°03.5'N 101°33'W	Trujillo	occurrence est. reserves 125 tons @ .2% U_3O_8	Carnotite in sandstone channel fill.

From: Bement, et al., (1977).

Eargle and McKay (1955) describe anomalous uranium mineralization near the base of the Dockum in Briscoe County, Texas, located just north of the Lubbock 1° x 2° Quadrangle. The host rock is a "cross-bedded pale-red to gray micaceous sandstone" which contains plant fragments and clay pellets.

McGowen (1978) analyzed 400 samples at 93 localities of Dockum Group sediments for uranium concentration. Of the 400 samples analyzed, approximately 10% contained at least 5 ppm U_3O_8 . These include 9 fluvial deposit samples, 1 valley fill sample, 21 deltaic deposit samples and 10 lacustrine deposit samples. The most significant uranium mineralization in Dockum Group sediments appears to be in the fluvial channel-lag deposits. McGowen feels three factors contribute to a favorable depositional environment in these deposits: 1) a high sandstone and conglomerate content; 2) the presence of a reducing environment caused by plant material; and 3) high porosity and permeability. The high lacustrine U_3O_8 values are localized in burrow-fills in sandstone. The mineralized deltaic deposits are generally in sandstones which were deposited during humid times.

The Cretaceous System

Surface exposures of Cretaceous material in the Lubbock Quadrangle are limited to the flanks of the large playa basins, to the canyons cut by the Double Mountain Forks of the Brazos River, and to Double Mountain (Barnes, 1967). The subsurface distribution of Cretaceous material is largely restricted to the southwest portion of the Lubbock area (Fig. 7). The dip of the Cretaceous strata, which lies

Figure 7. Distribution of Cretaceous sediments in the subsurface (after Brand, 1974).

unconformably over older beds (Fig. 8), is 1.3 to 1.5 m per km (7 to 8 ft per mi) to the southeast. Structures in underlying Triassic and Paleozoic sediments were not imparted to the Cretaceous material. The upper surface of the Cretaceous is an erosional surface. The irregular nature of the upper and lower boundaries of the Cretaceous is illustrated in Figure 9. A blue-green reduction halo is often present at the top of the Dockum Formation (Triassic) when the Triassic and Cretaceous units are in contact (Brand, 1953; Van Siclen, 1957).

The Cretaceous System in the High Plains is divided into three groups: the Trinity, the Fredericksburg, and the Washita (Table 1). The lower group, the Trinity, consists of a basal sand called the Paluxy sandstone by Brand (1953, 1956) and the Antler Sand by Barnes (1967). The Antler Sand comprises poorly-bedded, light-gray to purple sands, sandstones, and conglomerates. Average thickness is 9 m (30 ft). The Fredericksburg Group consists of (from oldest to youngest) the Walnut Formation, the Comanche Peak Limestone, the Edwards Limestone, and the Kiamichi Shale. Interbedded fossiliferous sandstones, shales, and limestones characterize the Walnut Formation which has a maximum thickness of 8 m (25 ft). The Comanche Peak Limestone, averaging 12 m (40 ft) in thickness, has fossiliferous thin shales interbedded with thick fossiliferous limestones. The Edwards Limestone contains rudistids and has a maximum thickness of 11 m (35 ft). The Edwards contains hard limestones, and in southern Garza County it forms the High Plains cap rock. The Kiamichi Shale is exposed in the Lubbock Quadrangle only along the flanks of the large playa lakes in Lynn County. The unit is composed of interbedded limestones, sandstones,

Figure 8. Elevation of the base of the Cretaceous in Lynn County, Texas (after Reeves, 1966).

Figure 9. West-east cross section across the High Plains (after Cronin, 1961). Refer to Figure 10 for location.

and shales. The Duck Creek Shale of the Washita Group comprises interbedded shales and limestones which are also exposed around the deep playas in Lynn County (Brand, 1953, 1956; Barnes, 1967).

The Cretaceous System is not considered a major aquifer of the High Plains. In a few areas, caverns or fractures in the Cretaceous limestones hold enough water to supply wells. The water is highly mineralized, and recharge is suspected to be from the Ogallala (Tertiary) Formation (Cronin, 1961).

Reports of uranium occurrences in Cretaceous rocks have been sparse. Uranium has been noted in Cretaceous material in West Texas only in Upton County about 280 km (175 mi) south of Lubbock. The host rock is the Edwards Limestone and deposits appear to be joint-controlled. The source appears to be Recent mineralized ground water which moved through fractures and deposited the uranium on joint surfaces (Eargle, 1956; Finch, 1975).

The Ogallala Formation

The Ogallala Formation (Pliocene) crops out in the Lubbock Quadrangle along the erosional escarpment which separates the High Plains from the Osage Plains, along the flanks of the valleys cut by the Brazos and White Rivers, and in the large playa basins in the southwest part of the quadrangle (Pl. 2). In addition, there are a few scattered outcrops of Ogallala exposed through windows in the windblown cover sands on the High Plains (Barnes, 1967). The Ogallala lies unconformably over Triassic and Cretaceous rocks on an erosional

surface (Fig. 9) and dips less than 1° to the southeast (Van Siclen, 1957; Evans, 1974). Figure 10 presents the elevation of the irregular surface upon which the Ogallala was deposited.

Reeves (1966) dates Ogallala deposition as Late Miocene and Early Pliocene while Evans (1974) dates it as Lower and Middle Pliocene. The Ogallala sediments primarily comprise clays, sands, and gravels which were deposited by meandering streams. The sediments were derived from the mountains to the west and were deposited on a piedmont plain surface. Unit thickness varies from 15 to 107 m (50 to 350 ft) and is influenced by the pre-Ogallala topography. The last stream deposition on the High Plains appears to have occurred in Middle Pliocene (Evans, 1974).

The Ogallala Formation has two members: the older Couch Member and the younger Bridwell. Evans (1974) suggests the Ogallala should be elevated to the rank of group and the Bridwell and Couch should be elevated to formations.

Erosional unconformities bound both the top and the bottom of the Couch (lower Pliocene). The base of the Couch consists of cross-bedded shallow channel sands and gravels which filled east-west trending valleys. As the pre-existing valleys were buried by Ogallala deposition, the Ogallala sediments coalesced and covered large expanses (Frye, 1974; Evans, 1974). The upper Couch consists of unbedded, pinkish-gray "well-sorted, semi-consolidated calcareous and clayey sands" (Evans, 1974). This unit is jointed and homogeneous and probably comprises stream sediments sorted and redeposited by the wind.

Figure 10. Elevation of the base of the Ogallala Formation (after Cronin, 1961).

The uppermost Couch contains a locally siliceous secondary carbonate-enriched zone. The type locality of the Couch is 11.3 km (7 mi) east of Crosbyton,, and the unit is well exposed in Lubbock and Crosby Counties. Vertebrate fossils are present (Evans, 1974).

The Middle Pliocene Bridwell unconformably overlies the Couch and Cretaceous and Triassic sediments. The basal Bridwell is in general a sand and gravel channel deposit which contains clay balls. The remainder of the Bridwell is a heterogeneous unit composed of bedded unconsolidated sands and clays locally with channel deposits. The flood plain and channel sediments of the Bridwell were deposited by broad aggrading streams. The Bridwell is reddish-brown and becomes lighter in color up section. Vertebrate fossils are present in the Bridwell (Evans, 1974).

The upper Bridwell is characterized by a well-indurated gray calcareous cap rock which covers the entire High Plains (Brown, 1956). This cap rock caliche is a zone of secondary calcium carbonate which developed in Late Pliocene after stream deposition had ended (Evans, 1974). Cap rock thickness normally ranges from 3 to 19 m (10 to 50 ft) (Reeves, 1976), and the cap rock has a pisolitic surface (Barnes, 1967). The caliche generally rests on Ogallala material. However, where the Ogallala is missing, the cap rock lies on older material (Brown, 1956). Reeves (1970) proposes that the first caliches over the Ogallala formed at the end of the Pliocene in a semi-arid environment. Desert loess from the west constituted the principal calcium carbonate source. During dry periods the loess accumulated. During moist periods, the surficial carbonate went into solution then precipitated at depth while

the silica at depth went into solution. The clastic content of the caliche consists almost entirely of frosted quartz floating in a matrix. The caliche cement is a combination of silica and calcium carbonate. Figure 11 illustrates the distribution of carbonate material in the cap rock. Caliche permeability is virtually zero and porosity is 25 to 40% (Brown, 1956).

The Ogallala is the major aquifer of the High Plains. A number of factors, such as the topographic relief of the pre-Ogallala surface, the strike of the valleys filled with Ogallala material, and buried soils and other hydrologic barriers (Frye, 1970), influence the aquifer's hydrologic properties. Most of the water in the Ogallala Formation is located in sand and gravel pore spaces (Cronin, et al., 1973; Wyatt, et al., 1976). The Ogallala is basically a water table aquifer with the base of the aquifer generally at the base of the Ogallala. Ground water flow through the Ogallala is to the southeast (Fig. 12), and the aquifer is principally recharged by precipitation on the High Plains in Texas with minor recharge from New Mexico (Cronin, et al., 1973). The Ogallala is relatively free of contamination from any highly mineralized water which may be contained in underlying Triassic (Barker and Scott, 1958). Cronin (1961) notes a change in ground water quality when the Ogallala is underlain by Cretaceous material. Of 42 ground water samples, 25 had over 500 ppm dissolved solids and 22 of these were underlain by Cretaceous sediments.

Anomalous radioactivity in the Ogallala cap rock caliche has been reported from two locations. The localities (the Benson Lake area and the Wood Ranch) are along the North Fork of the Double Mountain Fork of

Figure 11. Distribution of carbonate in the cap rock at .9 m (3 ft) depth (after Reeves, 1976).

Figure 12. Elevation of the water table on the High Plains (after Cronin, 1961).

the Brazos River (Finch, 1975) (Pl. 3). Finch feels "the depositional history of the Ogallala has some analogies to the host rocks at Yeelerie" in western Australia.

Uranium content in the ground water appears to increase down gradient due to the increased length of time that the water has been in the Ogallala aquifer. Highly mineralized evaporite zones, which may include uranium salts, in permeable or semi-permeable depressions and playa bottoms may account for local radioelement anomalies in the ground water. Percolating waters may dissolve the salts from the playas and produce local anomalies (Barker and Scott, 1958).

The Blanco Formation

Exposures of the Blanco Formation in the Lubbock 1° x 2° Quadrangle are restricted to two localities. The type locality of the Blanco Formation crops out at the confluence of Crawfish Creek with White River approximately 14 km (9 mi) north of Crosbyton. The second locality occurs about 10 km (6 mi) northeast of Crosbyton, east of the White River (Barnes, 1967).

The Blanco Formation comprises fine-to medium-grained, bedded to massive, white to gray quartz sands, bentonitic and partially calcareous sandy and silty clays, and thin-bedded limestones (Barnes, 1967). At the type locality the upper Blanco consists of "white to red-brown laminated caliche which is highly contorted" and "is separated by an erosional disconformity from the overlying eolian cover sands" (Pierce, 1974). The Blanco beds are finer toward the center of the basin with

coarser clastics which include caliche gravels and limestones at the basin margins. Pierce (1974) notes the presence of the Blanco Ash in the northwest portion of Blanco basin 9 to 10 m (30 to 33 ft) below the top of the Blanco. This ash contains high iron and low potassium and has not been dated. The Guaje Ash which correlates with the Bandelier Tuff of New Mexico is found in the eolian sands overlying the Blanco.

The Blanco Formation weathers white and contains both vertebrate and molluscan fossils. Maximum thickness of the Blanco is 23 m (75 ft) (Barnes, 1967). Average Blanco bed thickness is 15 m (50 ft) (Evans, 1948).

The Blanco Formation is a lacustrine deposit (Pierce, 1974; Reeves, 1966; Van Siclen, 1957) which lies disconformably over the Bridwell Formation (Pliocene). Mineralogic and paleontologic evidence suggest deposition of the Blanco occurred in Late Pliocene or Early Pleistocene (pre-Nebraskan time) in a semi-arid to arid climate. Evans (1948) postulated continuing deposition in a playa similar in size to the large pluvial basins found on the High Plains today. However, Pierce (1974) and Reeves (1966) feel the depositional basin was a closed playa basin with two periods of deposition. The basin began by erosion of an existing shallow "abandoned Pliocene drainage channel" which was later enlarged by deflation (Pierce, 1974).

The Tule Formation

Exposure of the lacustrine Tule Formation (Quaternary) in the Lubbock 1° x 2° Quadrangle occurs only at the head of the Double Mountain Fork of the Brazos River (Barnes, 1967) in the old Spring

Creek Basin (Evans, 1974). The sediments which comprise the Tule were deposited during Kansan time in a shallow basin which trends N60°E and has dimensions of approximately 16 km (10 mi) by 6 km (4 mi) (Evans, 1974). Maximum thickness of the Tule is about 26 (85 ft) (Barnes, 1967). Much of the Spring Creek Basin fill has been removed by erosion (Evans, 1974).

The Tule Formation comprises thin- to massive-bedded, fine- to medium-grained quartz sands which are locally silty and contain some caliche nodules, and indistinctly bedded silts and locally bentonitic clays. Gravel is found at the base of the unit, and vertebrate and molluscan fossils have been found within the unit. Sand color varies from white to grayish-red; the silts and clays are various shades of gray (Barnes, 1967). Volcanic ash deposits have been reported in Tule Canyon located north of the Lubbock Quadrangle in Briscoe County, Texas (Brown, 1956).

Reeves (1966) classifies Tule deposits as lake deposits which filled the basin mainly during one pluvial period and which breached the cap rock. The basin is along a Pleistocene drainage channel, at the intersection of regional lineaments (Reeves, 1970), and is associated with a Cretaceous topographic high (Evans, 1974).

A uranium discovery which assayed from 0.60% to 1.45% U_3O_8 was reported in 1955 in Tule Canyon in Briscoe County north of Lubbock (Hayes, 1956). Finch (1975) notes the occurrence of anomalous radioactivity in the Tule Formation in the Spring Creek Basin as well as in Tule Canyon.

Windblown Cover Sands

The majority of material exposed on the High Plains in the Lubbock area consists of Quaternary windblown sands. This cover sand is described (Barnes, 1967) as a fine- to medium-grained, silty, calcareous quartz sand with caliche nodules. It is a massive, grayish-red unit whose soil profile is well-developed. The age of the deposit is Illinoian although there may be some younger material contained within the deposit.

Thickness of the cover sand is about 8 m (25 ft), locally feathering out (Barnes, 1967). Reeves (1966, 1971) has noted that the sands are thickest on the northeast portion of the High Plains due to the southwesterly winds which began 4000 to 5000 years B.P. (post-Illinoian time). The surface of the High Plains and, consequently the surface of the windblown sands, slopes 1.5 to 1.9 m per km (8 to 10 ft per mi) to the southeast. Pierce (1974) notes the presence of the 1.4 ± 0.2 m.y. old Guaje Ash in the cover sands near Blanco Canyon.

The Tahoka Formation

In Lynn County in the southwest corner of the Lubbock 1° x 2° Quadrangle, lacustrine Tahoka Formation deposits (Quaternary-Wisconsinian) outcrop in Double Lakes, Twin Lakes, Tahoka Lake, and Guthrie Lake Basins. In addition, there is a Tahoka Formation exposure along the southern border of the Lubbock Quadrangle at the Lynn-Garza County line (Barnes, 1967).

The large depressions which form the lake basins are restricted to relatively thin, less than 30 m (100 ft) thick, accumulations of Ogallala Formation (Tertiary) material. The size of the large basins in Lynn County varies considerably (Table 3). Tahoka clays, usually covered with younger lacustrine deposits which in turn are covered with eolian sand, form the main part of the lake basins. Cretaceous deposits underlie most of the large pluvial depressions on the High Plains (Reeves, 1966; Harbour, 1975).

The Tahoka deposits comprise particles which range in size from clay to gravel and which are coarser toward the margins. The bluish-gray clays are gypsiferous and calcareous, and the sands are gray. The predominant clay mineral is illite (Harbour, 1975). Bedding is indistinct, unit thickness is 8 m (25 ft), and mollusk and vertebrate fossils are present (Barnes, 1967).

The lake basins appear to have formed during Pleistocene pluvial periods primarily by end-current erosion with deflation occurring during the more arid interpluvial periods. Double (also called T-Bar), Tahoka, and Guthrie lake depressions are at the head of Cretaceous valleys (Fig. 13). Twin Lakes (also called Three Lakes) does not appear to follow this pattern (Reeves, 1966). Tahoka Formation deposition probably ranged from 35,000 to 16,000 years B.P. when the climate was cooler than it is at present and a boreal forest covered at least 50% of the High Plains.

The base of the pluvial basins appears to be controlled by the more resistant Edwards Limestone (Cretaceous). Harbour (1975) believes that

TABLE 3. SIZE OF LARGE BASINS IN LYNN COUNTY, TEXAS (FROM REEVES, 1966).

	Length of Depression	Width of Depression	Length of Playa	Width of Playa	Playa Area	Depression Area
Guthrie	16.1 km (10.0 mi)	8.0 km (5.0 mi)	2.9 km (1.8 mi)	0.8 km (0.5 mi)	3.08 km ² (1.19 mi ²)	77.7 km ² (30.0 mi ²)
Double	8.9 km (5.5 mi)	2.7 km (1.7 mi)	6.8 km (4.2 mi)	0.8 km (0.5 mi)	3.99 km ² (1.54 mi ²)	22.48 km ² (8.68 mi ²)
Tahoka	6.4 km (4.0 mi)	2.4 km (1.5 mi)	3.4 km (2.1 mi)	0.6 km (0.4 mi)	1.68 km ² (0.65 mi ²)	18.26 km ² (7.05 mi ²)
Three Lakes	5.6 km (3.5 mi)	3.2 km (2.0 mi)	1.6 km (1.0 mi)	0.3 km (0.2 mi)	0.52 km ² (0.20 mi ²)	13.86 km ² (5.35 mi ²)

Cretaceous marine shales are the principal sediment sources for Tahoka deposition. In Tahoka and Double Lakes basins deflation has exposed the Tahoka-Cretaceous contact. Tahoka deposits in these basins are generally thin with approximately 3 m (9 ft) of Tahoka material found in the southwest corner of Tahoka Lake and about 2 m (5 ft) of Tahoka material found at the north end of Double Lakes. A 61 cm (24 in) test pit dug on the floor of Double Lakes revealed 51 cm (20 in) of "alternating brown and slightly humic medium-grained sand resting on green Cretaceous shale" (Harbour, 1975).

The drainage pattern of the Pleistocene lakes is not completely understood. Mound Lake, located northwest of Twin Lakes (Three Lakes), may have drained into Twin Lakes which then may have drained into Double (T-Bar) Lakes (Fig. 14). Both the Tahoka and Double Lakes Basins appear to be located along the same Cretaceous valley. However, they do not appear to have been connected. The Tahoka basin drained to the southeast into the Spring Creek (Tule Formation) basin, which is now

Figure 13. Elevation of the top of the Cretaceous in Lynn County, Texas (after Reeves, 1966).

Figure 14. Paleodrainage pattern of pluvial lake basins in the Lubbock 1° x 2° Quadrangle (after Reeves, 1966).

filled. This drainage channel is still used during periods of run-off. Double Lakes and Guthrie basins may have been connected. The Guthrie depression, also drained to the southeast (Reeves, 1966).

A lake basin also existed in Yellow House Canyon (Wendorf, 1975). This lake, called Lubbock Lake, developed at least 13,000 years B.P. and was almost completely filled by the late 1800's. A basin was present in approximately the same area during Nebraskan time (Reeves, 1966).

Playas

The High Plains geologic province which makes up most of the western part of the Lubbock 1^U x 2^U Quadrangle consists primarily of windblown sands (Quaternary) with many small playas (Quaternary-Wisconsinian) which are generally covered by a thin veneer of recent sediments (Barnes, 1967).

Reeves (1971) has noted that there are several types of playas in the southern High Plains. Some of the playa basins are underlain by Pliocene "cap rock" caliche (calcrete) while others bottom in the Ogallala Formation (Pliocene) below the cap rock (Fig. 15). Those which are underlain by the cap rock comprise small blow-outs which become larger and deeper in the northeast part of the High Plains, animal wallows, ancient dune swales, and basins which are caused by undulations in the underlying cap rock. Those basins which are not underlain by the cap rock are the pluvial lake basins and the deep and large deflation basins. These deflation basins usually have a fringing dune or basal remnant (Reeves, 1971). Caliche presence in the playas depends upon the basin thickness and the windblown cover sand thickness. The caliche

Figure 15. Playa lake basin cross sections (after Reeves, 1976).
 (a) Playa underlain by Pliocene caliche. Lofton series soils and Randall clays exposed on the surface are both products of clayey material. Randall clays are found in playa bottoms while Lofton soils surround playa lakes (Blakely and Koos, 1974). (b) Playa which bottoms in Ogallala Formation (Pliocene) below cap rock.

found in the playas is younger material than the cap rock caliche. Because the sand sheets are thickest in the northeast part of the High Plains, due to prevailing southwesterly winds in Pleistocene time, cap rock underlies more large basins in the northeast part of the High Plains (Reeves, 1971).

Terrace Deposits

At least three levels of fluviatile terraces (Quaternary-Pleistocene) have been mapped in the Lubbock 1° x 2° Quadrangle. The terrace deposits are silts, quartz sands, and gravels with chert, igneous and metamorphic rock fragments, and caliche cobbles and pebbles. Gryphaea fragments can be found at higher terrace levels. Sediment color ranges from reddish-brown to light gray (Barnes, 1967).

Windblown Sands

Large sheets of sand and silt (Quaternary-Recent) cover portions of both the High Plains and the Osage Plains. These deposits are eolian, and locally they form dunes and dune ridges (Barnes, 1967).

Quaternary Alluvium

Flood-plain deposits (Quaternary-Recent) are found along the drainages which cross the Lubbock 1° x 2° Quadrangle. These drainages are primarily on the Osage Plains in the eastern part of the quadrangle. However, in a few places the High Plains has been incised by headward erosion of the Brazos and White Rivers, and Quaternary alluvium has been deposited in these river valleys. Quaternary alluvial deposits can

also be found in and around the large playa basins in the southwest corner of the Lubbock Quadrangle (Barnes, 1967).

DATA REDUCTION

Aerial Data

The aerial radiometric, the aeromagnetic, and the altimetry data analyzed in this study were collected by Geodata International Incorporated during May and June 1975. Twenty-three east-west flight lines spaced approximately 4.8 km (3 mi) apart were flown over the Lubbock 1° x 2° Quadrangle along with 10 north-south tie lines which were spaced approximately 19.3 km (12 mi) apart (Fig. 16). Each data point represents a one-second integration period. The airborne magnetic survey sampling period was also one second. A combination of Doppler navigation and flight path films provided aircraft positioning information. Geodata reduced the radiometric data using "matrix operator data multiplication, instrument live time and radiation background correction, calculation of airborne ^{214}Bi concentration and removal of the ^{214}Bi airborne contribution . . . , and altitude correction to a constant 400 feet above the surface elevation" (Geodata, 1975).

Radiometric profiles for the present study were plotted by the Applications Branch of the Computer Services Division, Oak Ridge National Laboratory (ORNL). Horizontal positioning for the data points was obtained from latitude-longitude information on the data tape. The flight line positioning could not be verified because of nonavailability of the flight path films. The value of each radiometric data point was calculated using a simple 7-point running average of the single-record

Figure 16. General location of airborne survey lines.

data. The equation for this calculation is of the form:

$$C_n = \frac{1}{7} \sum_{j=n-3}^{n+3} B_j \quad (1)$$

Where C_n is the average ("smoothed") value in counts per second at the n th point and B_j is the single-record value in counts per second at the j th point. Throughout this report, aerial radiometric parameters are denoted by ^{214}Bi , ^{208}Tl , ^{40}K , $^{214}\text{Bi}/^{208}\text{Tl}$, $^{214}\text{Bi}/^{40}\text{K}$, and $^{208}\text{Tl}/^{40}\text{K}$. This notation is used to emphasize that the airborne data acquisition system was not calibrated. In Equation 1, ^{214}Bi , ^{208}Tl , or ^{40}K count rates can be substituted for B_j . For the ratios, $^{214}\text{Bi}/^{208}\text{Tl}$, $^{214}\text{Bi}/^{40}\text{K}$, and $^{208}\text{Tl}/^{40}\text{K}$, the prescribed division was performed on a point-for-point basis and the series of quotients was then smoothed by Equation 1.

Truck-Mounted Spectrometer Data

A truck-mounted, calibrated spectrometer operated by Bendix Field Engineering Corporation (BFEC) surveyed approximately 2600 line-km (1600 line-mi) in the Lubbock $1^\circ \times 2^\circ$ Quadrangle in July and August 1978 and January and February 1979. The data were collected along selected state, county, and private roads at approximately 160 m (0.1 mi) data point spacings (Pl. 4). The recording system integrated 30 seconds of data per data point, and the truck speed was approximately 14 km (9 mi) per hour. The data were stripped by BFEC to yield ppm eU, ppm eTh, and % K and standard deviations for the three radioelements.

Profiles of the single-recorded ("unsmoothed") truck-mounted spectrometer data were plotted by G-Cubed Incorporated. The values for ppm eU, ppm eTh, and % K were obtained from the data tape supplied by BFEC. The eU/eTh and eU/K values were computer-calculated by G-Cubed Incorporated from the BFEC data tape.

Hand-Held Spectrometer Data

G-Cubed Incorporated personnel used a Geometrics Model GR-410 spectrometer with a 0.35 l (21 cu in) crystal to collect additional radiometric information at selected localities in the Lubbock 1° x 2° Quadrangle in July, August, and September 1978 and January 1979 (Pl. 5). The sample time for each station generally was 4 minutes. The data were reduced by G-Cubed Incorporated to ppm eU, ppm eTh, and % K including standard deviations and eU/eTh and eU/K using stripping constants provided by Geometrics.

Hydrogeochemical and Stream Sediment Reconnaissance Data

No data processing was performed on the reported Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) data (Nichols, et al., 1976; Nichols, et al., 1977). These data were used in a secondary manner with respect to the radiometric data.

Geologic-Topographic Data

Geologic profiles at a horizontal scale of 1:62,500 were constructed by G-Cubed Incorporated along all airborne survey flight lines and tie lines as well as along selected truck survey lines and hand-held spectrometer survey lines. The topography for these profiles

was hand-digitized from 116 7½-minute NTMS maps which were photographically reduced to 1:62,500 and from 3 15-minute (1:62,500) maps. Geologic information for these profiles was hand-digitized from the 1:250,000 scale Geologic Atlas of Texas, Lubbock Sheet (Barnes, 1967) which was photographically enlarged to a scale of 1:62,500.

DATA PRESENTATION

Aerial Data

Radiometric Data

Two base map scales were used for presentation of the airborne radiometric data: 1:250,000 and 1:62,500. Data at the 1:250,000 scale were presented on 1° x 2° maps which encompassed the entire Lubbock Quadrangle. Data for each radioelement were displayed on two maps: one map for map lines and one map for tie lines (Pl. 6 through 17). The flight lines were used as reference lines for the radiometric data. The displacement (A_n) of each point from the flight line was calculated from the equation:

$$A_n = \frac{(C_n - \text{Adjusted Mean}) \times \text{Scale}}{\text{Adjusted Standard Deviation}} \quad (2)$$

where n is the nth point along the line, C_n is the average ("smoothed") value in counts per second at the nth point, adjusted mean is the mean calculated for the entire quadrangle, the adjusted standard deviation is the standard deviation calculated from the adjusted mean, and scale is 0.2" per adjusted standard deviation. Table 4 lists the statistics calculated from the radiometric data in the Lubbock Quadrangle.

The Lubbock 1° x 2° Quadrangle was divided into 32 15-minute quadrangles for display of the 1:62,500 scale aerial radiometric data. Figure 17 is an index map of the 32 quadrangles and the names which were

TABLE 4. STATISTICS CALCULATED FROM THE AIRBORNE RADIOMETRIC DATA IN THE LUBBOCK 1° x 2° QUADRANGLE

	²¹⁴ Bi (cps)	²⁰⁸ Tl (cps)	⁴⁰ K (cps)	²¹⁴ Bi/ ²⁰⁸ Tl	²¹⁴ Bi/ ⁴⁰ K	²⁰⁸ Tl/ ⁴⁰ K
Mean	84.9	54.5	195.0	1.62	0.45	0.28
Standard Deviation	36.1	15.7	50.1	0.76	0.24	0.07
Adjusted Mean	84.9	54.5	195.0	1.62	0.45	0.28
Adjusted Standard Deviation	36.1	15.7	50.1	0.76	0.24	0.07
Minimum Value	0.3	0.9	1.4	0.01	0.00	0.08
Maximum Value	1253.1	109.0	410.0	32.68	15.29	2.47

assigned to them by ORNL. The names were derived from the names of the 7½-minute quadrangles located in the northwest quadrant of each of the 15-minute quadrangles. Six maps were constructed for each 15-minute quadrangle with data for one radioelement being plotted on each map (e.g., Pl. 24). The flight line positions were indicated on each map and used as reference lines as was done with the 1:250,000 scale maps. The displacement (A_n) of each point from the flight line was calculated using Equation 2. A scale of 0.4" per adjusted standard deviation was used for the 1:62,500 parameter profile maps.

As a test, single-record ("unsmoothed") data for each radioelement and ratio were plotted at a scale of 1:62,500 for the Double Lakes, et al., New Lynn, et al., Post West, et al., Justiceburg NW, et al., T-O Creek, et al., and Clairemont East, et al., Quadrangles. The vertical

Figure 17. 15-minute quadrangles within the Lubbock 1° x 2° Quadrangle.

scale for the parameter traces was 0.25 in per adjusted standard deviation. The data were plotted as displacements from the mean. The mean was the position of the flight line. The data were also plotted at 1:250,000. The vertical scale for the traces was 0.25 in per one adjusted standard deviation.

Altimetry Data

The Applications Branch of the Computer Services Division at ORNL prepared single-record plots of the altimetry data for six of the 1:62,500 scale quadrangles. These were prepared with the intention of comparing the altimetry with hand-digitized topographic profiles. The six quadrangles were Double Lakes, et al., New Lynn, et al., Post West, et al., Justiceburg NW, et al., T-O Creek, et al., and Clairemont East, et al. The computer-drawn altimetry traces were presented as the height above the ground at a scale of one inch equals 100 feet (1:1200). This vertical scale is the same as was used for the hand-drawn topographic profiles discussed in a later section. Because the altimetry data were to be compared to the hand-drawn topographic profiles, before a comparison could be made, the altimetry profiles had to be inverted. In doing the inversion, the trough which appeared in the altimetry trace because the aircraft was closer to a ridge top was inverted so that it indeed looked like a ridge and thus compared with the ridge shape extracted from the topographic map and plotted by hand on the topographic profile.

Aeromagnetic Data

The Applications Branch of the Computer Services Division at ORNL plotted the aeromagnetic data at a scale of 1:250,000. Two maps were generated, one with the east-west flight lines and the other with the north-south tie lines. The vertical scale for the magnetic data was 2000 gammas per inch. The flight line position was chosen as the reference level for the plotting of the magnetic data. The reference level was 52,581 gammas. The plots delivered by ORNL showed numerous spikes on the data profiles. These were probably remnants of noise from the raw data tapes. No attempt was made to deal with these spikes. In most areas, the general shapes of the magnetic anomalies were not obscured by the spikes.

Truck-Mounted Spectrometer Data

The truck-mounted spectrometer data were presented as single-record (unsmoothed) data at a scale of 1:62,500. Each line was plotted separately with ppm eU, ppm eTh, % K, eU/eTh, and eU/K data for each line being presented on a single plot. Error bars indicate plus or minus one standard deviation at each data point. Arbitrarily chosen vertical scales were as follows: for eU and eTh, 2 ppm per inch; for K, 0.5% per inch; for eU/eTh 1.0 per inch; and for eU/K, 4.0 per inch.

Bendix Field Engineering Corporation computed new calibration coefficients for the truck-mounted spectrometer after the first part of the survey was run and after the data tape was issued to G-Cubed Incorporated. Table 5 illustrates the effect of the recomputation. The result of the recomputation was to spread the eU values; that is, the

TABLE 5. EFFECT OF APPLYING NEW CALIBRATION COEFFICIENTS TO
RADIOMETRIC DATA COLLECTED BY THE TRUCK-MOUNTED
SPECTROMETER DURING JULY AND AUGUST 1978.

Line Number	Mile	Initial Value					Recomputed Value				
		K (%)	eU (ppm)	eTh (ppm)	$\frac{eU}{K}$	$\frac{eU}{eTh}$	K (%)	eU (ppm)	eTh (ppm)	$\frac{eU}{K}$	$\frac{eU}{eTh}$
111	29.72	1.14	1.6	6.1	1.4	.3	1.10	0.9	7.0	.8	.1
62	1.64	0.61	2.0	3.4	3.3	.6	0.56	1.8	3.9	3.2	.5
132	11.08	0.46	2.2	2.9	4.8	.8	0.41	2.1	3.4	5.1	.6
81	0.95	1.02	2.5	5.1	2.5	.5	0.96	2.1	5.9	2.2	.4
21	14.07	1.60	2.9	10.1	1.8	.3	1.53	1.8	11.6	1.2	.2
132	14.60	0.55	3.0	3.1	5.5	1.0	0.48	2.9	3.6	6.0	.8
121	10.05	0.95	3.7	5.7	3.9	.7	0.86	3.4	6.6	4.0	.5
121	11.02	1.07	4.0	6.1	3.7	.7	0.98	3.6	7.0	3.7	.5
15	13.96	1.26	4.0	8.7	3.2	.5	1.17	3.3	10.1	2.8	.3
15	12.44	1.21	5.0	10.4	4.1	.5	1.10	4.2	12.0	3.8	.4
61	4.70	1.09	5.6	5.6	5.1	1.0	0.97	5.5	6.5	5.7	.9
15	12.34	1.60	6.0	10.8	3.8	.6	1.46	5.2	12.5	3.6	.4
61	5.93	1.09	6.2	5.3	5.7	1.2	0.95	6.2	6.2	6.5	1.0
67	0.09	1.10	6.5	6.2	5.9	1.1	0.96	6.4	7.2	6.7	.9
21	8.91	1.30	8.4	6.3	6.5	1.3	1.11	8.6	7.4	7.8	1.2
21	8.71	1.23	12.4	4.6	10.1	2.7	0.95	13.4	5.5	14.1	2.4
35	9.52	1.51	15.0	7.4	9.9	2.0	1.17	16.0	8.8	13.7	1.8
47	20.80	1.36	18.5	7.5	13.6	2.5	0.95	19.9	9.0	21.0	2.2

low eU values from the original computation became lower when recomputed and the higher eU values became higher. The original eU values were within 1 ppm of the new values except for values greater than 15 ppm. Values for eTh increased when the new calibration coefficients were applied to the data. Thus the eU/eTh ratios calculated from the new eU and eTh values decreased between 0.1 and 0.3 per data point. K values decreased when recomputed. However, the eU/K ratio increased in some cases and decreased in others. The values on the truck plots in the present study were from the original data tape.

Hand-Held Spectrometer Data

The hand-held spectrometer data were presented in four forms. A tabulation of the data appears in Appendix B with the sample site descriptions tabulated in Appendix A. The data were plotted on the 1:62,500 scale truck-mounted spectrometer plots in selected instances to show the comparison between the two data sets. In addition, some of the data were plotted at a scale of 1:62,500 and were presented as traverses. The same vertical scales were used for plotting the hand-held spectrometer data as were used for plotting the truck-mounted spectrometer data. The eU and eTh values recorded by the hand-held spectrometer are posted on Plates 18 and 19, respectively.

Texas Water Development Board Geochemical Data

The Texas Water Development Board provided computer-printed tabulations of water quality data from water wells which they monitor in the area of the Lubbock 1° x 2° Quadrangle. These data did not present uranium concentrations in the ground water or other parameters which

could be used directly to isolate uranium anomalies. The well location system used by the Texas Water Development Board did not always pinpoint the sample site. These data were minimally used in the study.

Other Geochemical Data

G-Cubed Incorporated collected soil and rock samples from the Lubbock area for chemical analysis. Fifty-one samples were analyzed for uranium disequilibrium, and eight samples underwent microscopic analysis. Nine samples were collected and analyzed by BFEC for total U_3O_8 . The geochemical data were used to assist in evaluating the radiometric data and in generating the exploration models discussed in a later section. The geochemical data are tabulated in Appendix C and on Plates 18 and 19.

Geologic-Topographic Profiles

The geologic profiles along the airborne survey flight lines were presented at a horizontal scale of 1:62,500 and a vertical scale of 1:1200. The geologic and topographic information for the flight lines was digitized along the flight path and then projected to a straight line. The geologic profile maps were designed as overlays for the 1:62,500 airborne radiometric profile and altimetry profile plots. Therefore, 32 geologic profile maps containing map-line profiles and 32 maps containing flight-line profiles were constructed for the Lubbock 1° x 2° Quadrangle. The longitude of the end points of the geologic profiles along the map lines was indicated but the latitude was not. The reverse was true for the tie lines.

In this report, two of the geologic profile maps are included (Pls. 31 and 32). In addition, excerpts from many of the hand-digitized geology and topography maps are presented in Figures 19 through 30.

Geologic and topographic information for the truck-mounted and hand-held spectrometer survey lines was digitized along the survey lines and plotted as the actual distance along the line at a scale of 1:62,500.

DATA INTERPRETATION

Aeromagnetism

Two presentations of the aeromagnetic data were interpreted. The Oak Ridge National Laboratory (ORNL) provided the aeromagnetic data on two 1:250,000 scale maps, one for tie lines, one for flight lines. The magnetic data presented in the Geodata International report (1975) were also reviewed. On the maps provided by ORNL, numerous spikes were seen in the magnetic profiles (Pl. 20). The origin of these spikes is not known. The spikes do not appear on the profiles presented in the Geodata report.

Three positive magnetic anomalies stand out in the Lubbock study area. The smallest one (Anomaly 1, Pl. 20) is located at approximately 33°40'N., 100°30'W. (Pl. 20). Applying Peter's half-slope method (1949), depth to the top of the mass causing this anomaly is estimated to be 3,350 m (11,000 ft). This magnetic feature is approximately on the axis of the Matador Arch. No other significant magnetic feature can be correlated with the Matador Arch.

The second of the three significant anomalies is an anomaly complex which is not entirely within the Lubbock Quadrangle. It appears to be centered along the eastern limit of the quadrangle at a latitude of approximately 33°20'N. (Anomaly 2, Pl. 20). Several small amplitude anomalies in the complex give depth estimates of 2,150 m (7,000 ft) below the flight level.

The third anomaly is entirely within the Lubbock Quadrangle and is centered at approximately 33°20'N., 101°15'W. The estimated depth to this anomalous mass is 6,700 m (22,000 ft) below the flight level (Pl. 20). The depth estimates for the three anomalies are consistent with the general shape of the northern part of the Midland Basin (Fig. 3) and are thus interpreted as features that do not penetrate into the sedimentary section.

In the case of the third magnetic anomaly, a geographical relationship can be seen between the interpreted outline of the anomalous mass (Pl. 20) and the outline of the High Plains Escarpment in the area west and north of the anomaly. The axis of the magnetic anomaly is generally parallel to the trend of the escarpment. It is also interesting to note that over the area of the large anomaly are exposures of the Dockum (Triassic) which contain the highest radiometric anomalies seen in the Dockum. Where the Dockum is exposed to the north of the magnetic anomaly, the radiometric values are lower. Related to this observation is the fact that most of the high ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies are south of an east-west line extending past the northern edge of the magnetic anomaly. Another geographical relationship is that projections of the topographic linears which correlate to Blanco Canyon and Yellow House Canyon would bracket the interpreted limits of the anomalous mass on the northeast and the southwest sides, respectively. That these geographical relationships can be used as an aid in the uranium exploration effort in this area is not established. It is possible that the large anomalous igneous mass in the subsurface is related to an area from which reducing agents could

escape. The igneous mass could have undergone some slight diapiric activity during which the overlying sediments became more fractured thereby allowing the reducing agents to move more freely toward the surface.

The magnetic profile data were scanned to determine if any high frequency anomalies existed (other than the spikes mentioned above). If such high frequency anomalies existed, these could perhaps have been related to geologic features closer to the surface and perhaps related to radiometric features. No such anomalies were seen.

In the Lubbock area, the aeromagnetic data are not significantly valuable in defining prospective uranium exploration areas. In other areas where the magnetic anomalies were related to geologic features closer to the surface, the value of the magnetic data could be much greater.

Smoothing of Aerial Radiometric Data

The aerial radiometric data collected during the Geodata survey were smoothed using a seven-point running average (Eq. 1). In the present study, the unsmoothed single-record data were compared with the smoothed data to determine what effects the smoothing might have on the interpretation.

The single-record data were expectably noisy. In an area like the T-O Creek, et al., Quadrangle for example, where the smoothed ^{214}Bi values varied considerably along flight lines, only a general idea of areas of high or low ^{214}Bi could be obtained from the unsmoothed

profiles (Fig. 18).

Detailed analysis of smoothed airborne radiometric data collected over the sands (Recent) showed ^{214}Bi , ^{208}Tl , and ^{40}K values which consistently fell below the mean. This pattern was not as obvious in the unsmoothed data (Fig. 19). With the single-record data, about all that could be determined was that the ^{214}Bi , ^{208}Tl , and ^{40}K values over the sands (Recent) generally fell below the mean. Similarly the low ^{208}Tl values recorded over Ogallala (Pliocene) sediments were not as sharp in the single-record plots (Fig. 20) as in the smoothed parameters plots. Thus the single-record plots are judged to be less valuable in determining radiometric contacts than the smoothed data.

The single-record data were also evaluated to determine if applying the seven-point running average affected the lateral extent of anomalies. The ^{214}Bi anomalies were observed in the smoothed data in the Double Lakes Basin and Guthrie Basin. In the Double Lakes Basin, a strong ^{214}Bi anomaly was observed in both the smoothed and the unsmoothed (single-record) data (Fig. 21). The application of the smoothing function did not significantly alter the lateral extent of the ^{214}Bi anomaly in this area. In Guthrie Basin, the ^{214}Bi anomaly observed in the single-record plot is not as obvious as in the smoothed data plot due to the large variation in signal amplitude in the unsmoothed data (Fig. 22). The application of the smoothing function created a small peak in the center of Guthrie Lake Basin where probably none existed. The effect of the operator on the width of the Guthrie Lake Basin anomaly is not clear.

Figure 18. Single-record ^{214}Bi data in the T-O Creek, et al., Quadrangle area.

Figure 19. Comparison of smoothed and unsmoothed ^{214}Bi data over sands (Recent) along flight line ML-4, T-O Creek, et al., Quadrangle. (See Table 1 and Appendix E for abbreviations.)

Figure 20. Comparison of smoothed and unsmoothed ^{208}Tl data over Ogallala (To) sediments (Pliocene) along flight line ML-2, New Lynn, et al., Quadrangle. (See Table 1 and Appendix E for abbreviations.)

Figure 21. Comparison of smoothed and unsmoothed ^{214}Bi data along flight line ML-6, Double Lakes area (Pl. 1). The extent of the anomaly did not spread much with the application of the smoothing operator to the data. (See Table 1 and Appendix E for abbreviations.)

Figure 22. Comparison of smoothed and unsmoothed ^{214}Bi data along flight line ML-4 in the Guthrie Lake area, Double Lakes, et al., Quadrangle (Fig. 17, Pl. 1). (See Table 1 and Appendix E for abbreviations.)

Qualitatively, the seven-point running average operator, a form of low pass filter, would be expected to have more effect on narrow anomalies than on wider anomalies. This effect is generally seen in comparing the smoothed and unsmoothed data, and because the smoothed data are easier to relate to the surface geology, the smoothed data are preferred for the present interpretation.

Validity of Truck-Mounted Spectrometer Data

The repeatability of the data collected by the truck-mounted spectrometer was tested in two ways. First, one mile of Line 121 was surveyed on seven different days (Pl. 76a, 77 through 82). Although the actual radiometric values varied slightly from day to day for the three parameters respectively, a striking similarity was observed in curve shape (Pl. 77 through 82). The similarity was most striking on the eTh and K curves. Plate 76a did not compare well when mile 0.0 was matched with the other mile 0.0's. However, if mile 1.1 on Plate 76a was compared with mile 0.0 on the other figures the same curve shape was observed. Therefore, it was assumed that the starting point of Line 121 on July 24, 1978 (Pl. 76a) was not at the same location as on the other days.

The second test of the repeatability of the data comprised resurveying portions of lines from the July and August 1978 survey during the January and February 1979 survey. Portions of Lines 81 (Pl. 68a), 47 (Pl. 49), and 182 (Pl. 92a) from the first survey were rerun as Lines 508 (Pl. 113), 504 (Pl. 112), and 518 (Pl. 114), respectively (Pl. 4). According to the data tape, mile 7.14 of Line 508

was at the same point as mile 3.18 of Line 81. With these two points matched, the correlation between Line 81 (Pl. 68a) and Line 508 (Pl. 113) was poor. However, if Line 81 was shifted slightly so that mile 3.5 of Line 81 was equivalent to mile 7.14 of Line 508, the curve shapes were similar. This 0.5 km (0.3 mi) error is not surprising for two surveys run six months apart. The levels of the eTh and K values recorded on Lines 81 and 508 were nearly identical. The eU values recorded during the second survey were approximately 1 to 1.5 ppm higher than those recorded during the first survey, and consequently, the eU/eTh and eU/K ratios were higher along 508 than along Line 81.

The correlation between Line 47 (Pl. 49) and Line 504 (Pl. 112) is not as good as the correlation between Line 81 and Line 508. The eTh and K curves have similar shapes. However, the actual values for the eTh are lower in the second survey than the first. The eU curves are significantly different. An equipment malfunction in the uranium channel is suspected in the first survey along Line 47, and Line 504 is interpreted to have a more realistic shape. Line 47 was recorded on August 18, 1979. Other lines recorded August 18-20, 1978 (the last three days of the summer 1978 survey) are suspected of having this same instrument problem. These lines include 47, 67 (Pl. 61), 16 (Pl. 36), 26 (Pl. 41), and 35 (Pl. 44). Lines 48 (Pl. 50) and 145 (Pl. 87) were recorded August 19 and 20, 1978 respectively but may not have been affected by the problem. High eU values from the truck survey of greater than 5 ppm in areas of low aerial ^{214}Bi readings and low hand-held spectrometer readings are the most significant clue to the instrument problem.

The third resurveyed line, Line 182 (Pl. 82a), shows a similar curve shape to Line 518 (Pl. 114) when mile 8.2 of Line 182 is matched with mile 5.72 of Line 518. As with the Line 81 - 508 comparison, the eTh and K levels are similar in both surveys while the eU is higher in the second survey.

The striking similarity in radiometric curve shapes observed in both tests supports the validity of the data sets. The background eU appears to have been higher in the January and February 1979 survey. The January and February 1979 survey was run under high moisture conditions while the July and August 1978 survey was run under arid conditions. This implies that while the ground moisture may have affected the actual levels of the radioelements (particularly the eU, probably by radon entrapment in the soil) the relative levels remain unchanged and consequently the shapes of the curves remain unchanged.

Comparison of Aerial Radiometric Data and Truck-Mounted Spectrometer Data

The truck-mounted spectrometer survey was run in the Lubbock 10 x 20 Quadrangle in order to verify the reliability of the airborne spectrometer data. Several fundamental differences exist between the airborne radiometric survey data set and the truck-mounted spectrometer survey data set. These differences include sample area, survey line location, and data processing methods and should be considered when comparing the data sets.

The airborne spectrometer integrated a larger surface area (sample volume) than the truck-mounted spectrometer (Table 6). The

TABLE 6. EFFECTIVE SAMPLE SIZE.

Analysis Method	Sample Size*
Airborne Spectrometer	10^{11} gm
Truck-Mounted Spectrometer	10^8 gm
Hand-Held Spectrometer	10^6 gm
Geochemical Sample	10^2 gm

* Assumes soil density of 2.0 gm/cc and 0.3 m (1 ft) of soil is penetrated by gamma radiation.

truck-mounted spectrometer survey line locations overlapped the airborne flight lines in only a few areas because the truck was constrained by the location of roads in the study area. Consequently, while the airborne survey was able to sample the entire Lubbock Quadrangle without bias, the truck-mounted spectrometer survey could not. The result was an abundance of truck survey data over some units, such as the windblown sand (Pleistocene) in the southwest corner of the map, and a sparsity of data over some other units, primarily those exposed in the eastern half of the quadrangle (Pl. 4). The dependence upon roads made it impossible for the truck survey to verify some ^{214}Bi anomalies observed in the airborne radiometric survey due to lack of access.

A line-to-line, point-to-point comparison of the truck data and the aerial data was difficult because of the above-mentioned considerations. However, the truck data were valuable in verifying trends observed in the airborne spectrometer data. For example, the sands (Recent) exhibit a characteristic response in the airborne radiometric data of low ^{214}Bi ,

low ^{208}Tl , and low ^{40}K . This, and other characteristic responses discussed in detail in a later section, is observed in the truck-mounted spectrometer data, and thus confirm the validity of the airborne radiometric data set.

Altimetry Plots as Pseudo-topographic Profiles

As a test, the aircraft altimetry data from six quadrangles (Double Lakes, et al., New Lynn, et al., Post West, et al., Justiceburg, NW, et al., T-O Creek, et al., and Clairemont East, et al.) were plotted. As discussed in a previous section, the altimetry traces were inverted to yield pseudo-topographic profiles. The vertical scale for the inverted altimetry plots was the same as for the hand-drawn topographic-geologic profiles, 1:1200. The objective of the test was to determine if the altimetry trace could be used in place of the hand-drawn topographic-geologic profile, thereby saving time in the overall interpretation effort. Secondly, it was desired to integrate the altimetry and the Geodata digitized geology to determine if the data provided by the initial contractor could completely replace the hand-drawn geologic profiles thus providing faster and cheaper interpretation of the airborne radiometric data in light of the known surface geology. The geologic data could not be plotted by ORNL in the time frame of the present study so the entire test was not completed.

In comparing the altimetry plots (pseudo-topographic plots) with the hand-drawn topographic plots, numerous differences were seen between the two data sets. It was expected that where the topography was changing slowly, the airplane would have been able to follow the

topography and thus no variation would be seen in the altimetry trace. On the other hand, where the topography changed more rapidly, such as over gullies or isolated hills, the altimetry trace was expected to mirror the topography better. In general these two expectations were satisfied (Fig. 23).

Cases do occur where the altimetry trace does not behave as might be expected from looking at the hand-digitized topography (Fig. 24). One likely explanation for this is that the altimetry information is related to radar signals. Though it is often assumed that the radar signal returns from a point vertically below the aircraft, the time recorded by the radar is actually the minimum travel time of the radio beam to a reflecting point and back again. Thus, the distance which the data acquisition system recorded as an altitude could in some cases be diagonal distance to the side of a hill or gully ahead or behind the aircraft, or even more problematic, from one side or the other of the aircraft's path.

Using the altimetry trace is not recommended as a way of generating topographic profiles. The hand-drawn profiles have less ambiguity than the altimetry-generated topographic profiles. The geology, both surface and subsurface, is more readily integrated on the hand-drawn topographic profiles. In the present study, numerous cases were found where a simple linear scaling and plotting of the geology onto the topography did not work. Recent creek deposits would plot at the top of hills away from the obvious creek bottom or an older unit, such as Dockum (Triassic) would plot higher on a hillside than a younger unit such as Ogallala (Pliocene). The geologist was able to identify these problems and make

Figure 23. Comparison of hand-digitized and inverted altimetry topography along flight line ML-2 (Fig. 16). At the west end of this profile, the inverted altimetry trace mirrors the true topography relatively well. Approximately 5 km (3 mi) of the eastern limit of this profile, the altimetry flattens. This indicates the aircraft was able to follow the topography closely.

Figure 24. Unexpected differences between altimetry and hand-digitized topography. Relative positions of peaks and troughs are shifted probably as a result of the radar beam direction not being vertical. Line is taken from T-O Creek, et al., Quadrangle, flight line ML-1 (Figs. 16 and 17).

an adjustment. A computerized process would not be expected to be able to make such adjustments.

Radiometry and Geochemistry

Stages of the Interpretation

The interpretation process applied to the aerial radiometric data basically comprised three stages. The first stage involved evaluation of the 1:250,000 scale parameter plots in terms of obvious radiometric features. The ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ plots were used to initially localize anomalous uranium areas ("anomaly chasing"). For example, the lower Dockum Group (Triassic) exposure area stood out because of consistently high ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ values. In addition to the more extensive anomalous areas, other localized areas, such as those observed in the southwest corner of the quadrangle, can be pinpointed for more detailed evaluation.

Other obvious features, such as the response over large expanses of sand (Recent), could also be mapped using the 1:250,000 scale ^{214}Bi , ^{208}Tl , and ^{40}K plots. Coloring the peaks and troughs of the parameter plots aided greatly in the recognition of the large scale features. It is believed that the actual amplitude levels for applying the color is not critical. The important point is that the color focuses the geologist's attention faster than the uncolored waveform.

The second stage in the interpretation of the aerial radiometric data consisted of a detailed evaluation of the data to determine the radiometric response of the various geologic units. This comparison of geology and aerial radiometry was done on the 1:62,500 scale maps on a

line-to-line basis by overlaying the aerial radiometry with the corresponding geologic profiles.

After completion of the detailed evaluation of the aerial radiometry, a set of criteria was established. In the third stage of the interpretation, these criteria were used to make additional interpretations of the 1:250,000 and 1:62,500 scale maps, and the 1:62,500 scale truck spectrometer survey profiles, and, upon integration with other data sets, to propose uranium exploration models in the Lubbock study area.

Obvious Radiometric Features

The 1:250,000 scale single-element radiometric plots were used to map obvious radiometric features and contacts. The primary radiometric feature used was signal amplitude although signal shape was a secondary factor.

One of the most obvious features observed on the ^{214}Bi (Pls. 6 and 12), ^{208}Tl (Pls. 7 and 13), and ^{40}K (Pls. 8 and 14) plots were large areas where the radiometric response for all three parameters was very low (Pl. 21). These areas correspond roughly to areas mapped by Barnes (1967) as windblown sand (Recent) (Pl. 2). Some of these low ^{214}Bi , ^{208}Tl , and ^{40}K areas also occur over mapped alluvium (Quaternary) and terrace deposits (Quaternary). The areas of very low ^{214}Bi , ^{208}Tl , and ^{40}K are interpreted to be areas covered by sand (Recent) or alluvium (Recent).

A prominent north-south trending radiometric contact was observed in the northern half of the ^{208}Tl map (Pls. 7, 13, and 21). This contact corresponds roughly to the top of the erosional escarpment separating the High Plains from the Osage Plains (Pl. 2). The contact is interpreted to separate the windblown sands (Pleistocene) (higher ^{208}Tl) on the west from the Ogallala (Pliocene) (lower ^{208}Tl) on the east at the top of the escarpment. An increase in background response of ^{208}Tl was observed in the western part of the quadrangle over the windblown sands (Pleistocene) from the south end of the quadrangle to the north end (Pls. 7 and 13). This accounts, in part, for the Pleistocene-Pliocene contact being more obvious in the north than in the south of the study area.

Generally north-south trending strips of high ^{208}Tl (Pls. 7 and 13) and ^{40}K (Pls. 8 and 14) were observed in the eastern half of the Lubbock $1^\circ \times 2^\circ$ Quadrangle (Pl. 21). The orientation of those strips is most easily seen if the peaks and troughs of the parameter maps are colored. These areas are interpreted to be Permian shales or siltstones.

Higher ^{214}Bi (Pl. 6) and $^{214}\text{Bi}/^{208}\text{Tl}$ (Pl. 12) values were recorded in the south-central portion of the Lubbock Quadrangle. Although these anomalies were not the highest amplitude anomalies in the Lubbock area, they stood out because of their broad extent (Pl. 21). These areas correspond generally to lower Dockum (Triassic) - upper Quartermaster (Permian) exposures (Pl. 2).

Scattered ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies were observed in the southwest corner of the quadrangle (Pl. 21). There was no apparent pattern to these anomalies except that they were over material other

than the windblown sands (Pleistocene). However, these anomalies stood out because of their high amplitude.

Detailed Interpretation

The following sections describe in detail the characteristic radiometric responses over each geologic unit exposed within the area of the Lubbock 1° x 2° Quadrangle. The comparison of the aerial radiometric data and the hand-drawn geologic profiles essentially composed the second stage of the overall interpretation effort. Also reported in the next sections are the radiometric responses seen in the truck-mounted spectrometer surveys and the hand-held spectrometer surveys. Where samples were analyzed for total U_3O_8 or disequilibrium, the results of the analyses are also presented.

The comparison of the aerial profile data and the hand-drawn geologic profiles was a time-consuming task. The careful comparison of these two data sets is the heart of the present study, and, though a rudimentary geologic technique, it is one which is not unique to the Lubbock study area. It is one which can be implemented by any geologist in any study area.

The comparison of the two data sets was complicated by ambiguities in the geologic map (Barnes, 1967) from which the geologic profiles were extracted. The ambiguities in the geologic map are not perceived as an indication of poor mapping in the Lubbock area. It is believed that much of the original mapping was at a scale of 1:62,500 (Noel Waechter, personal communication). In compiling the 1:62,500 geologic maps, small features certainly became obscured or eliminated. For the purposes for

which the 1:250,000 scale geologic map was prepared, these omissions are not critical. However, in photographically enlarging the 1:250,000 scale map to 1:62,500 scale, any small positioning errors in the 1:250,000 scale data become magnified. Of course, any data omitted in the 1:250,000 scale map was not recovered in the enlargement. The interpreter in the present study needed to make decisions about the probable locations of some contacts, such as along hillsides, and whether units existed at all in an area.

In the following sections are cases in which it is suggested that the geology is mismapped. Based upon the interpretation of the aerial radiometric data, such statements are correct. However, it is realized that the absence of a unit on the geologic map or the lateral translation of a contact may be a function of the initial processes used in publication of the geologic map and that the radiometric signal recorded could have been affected by talus or other surface cover.

The manner of displaying the data sets used in the comparison is important. The radiometric data presented by the original radiometric contractor (Geodata International, 1975) are not in an ideally usable format for this form of interpretation. The horizontal scale of 1:500,000 allows only the obvious radiometric features to be seen; i.e., stage one of the interpretation process. In order to see the more subtle relationships, the aerial radiometric data need to be displayed at horizontal scales of at least 1:125,000. The scale 1:62,500 used for the present study would be recommended as a good working scale for the detailed comparison. Use of scales larger than 1:62,500 (e.g., 1:24,000) are not recommended because of the reduction in the number of flight

lines on each map. The desired horizontal scale could be obtained by photographically enlarging the original contractor's profiles. The present study used 1:62,500 scale maps which were computer-plotted by ORNL.

The original airborne contractor presented the data in what is commonly referred to as "stacked" profiles (Geodata International, 1975). That is, for a given flight line, all of the parameters (radioelements, ratios, geology, altimetry, and magnetics) are presented on the same axes. This form of display does not lend itself to ready evaluation of the responses over a given geologic unit. Another disadvantage of stacked profile displays is that they make mapping contacts more difficult. Contacts can be more readily seen if the data are in a map, as opposed to a profile, form. The displays used for the present study combined the idea of a map and a profile. The parameter plots or profile maps (Pls. 6 through 17), minimize the problems of using the stacked profile displays. When it is necessary to view more than one parameter at a time, the appropriate profile maps can be overlain, and the interpreter can readily see how more than one parameter is changing in space.

As in the case of mapping the obvious radiometric features, the ^{214}Bi and the $^{214}\text{Bi}/^{208}\text{Tl}$ parameters were used to indicate potential uranium-bearing surface rock units. All of the parameters were used to map geologic contacts though, from unit to unit, one or more parameters might be better than others as indicators of the contact. The Geodata International report (1975) presented tables of the average count rates for each geologic unit along each flight and tie line. Also, the report

presented frequency plots of the count rates observed over the various units. Extensive use of these graphs and tables was not made in the present study because the Geodata International report (1975) was not clear as to how the geology was digitized. Therefore, in cases where small outcrops of one unit could not be distinguished from an adjacent unit, the count rates over the smaller unit might have been included in the Geodata statistics. The original aerial contractor's report illustrates an automated method for determining the typical response over the various units. The present report describes a manual technique for developing the same information. The automated method has problems of positioning and unit segregation while the manual method has problems with subjectivity and time consumption. This is an obvious area where a combination of the computer method and the manual method could lead to faster development of better working relationships for the radiometric responses over the various units.

Once working ideas were formulated for the typical radiometric responses over a given unit, the ideas were tested with the truck-mounted spectrometer survey data. These data were presented at a scale of 1:62,500. Unfortunately, few cases occurred in which the truck-recorded data could be directly overlain with the aerial data. Ratios of the eU to eTh and of the eU to K were calculated and presented on the truck profile plots (e.g., Pl. 33). Because the truck traversed river valleys, ridges, and open plains and no provision for monitoring the geometry of the earth which the spectrometer crystal was "seeing," the ratios became a more important anomaly isolating tool. By taking the ratio of the radiometric parameters, the effect of the geometry

was normalized out of the radiometric value. Therefore, the ratio can be more readily compared along a line than the absolute values of eU and eTh. In principle, the same rationale holds for the aerial data. However, the change in geometry for the airborne crystal from point to point is significantly less than for the ground-based system.

A variable which cannot be removed from the truck survey data is the effect of paving material. It is entirely possible that some anomaly highs or lows are actually a result of road aggregate composition.

The detailed study of the radiometric data on a unit-by-unit basis may in itself isolate exploration locales or lead to uranium exploration models. This perhaps is the case with the Dockum (Triassic) discussed later. This level of interpretation may be sufficient for the exploration purposes at hand. However, a thorough understanding of the usual radiometric responses over each geologic unit is necessary for laying the foundation for the more speculative effort described in stage three of the interpretation effort.

The Permian System

Choza Formation

The aerial radiometric data collected over the Choza Formation (Permian) generally showed a ^{214}Bi response of less than +2%. (Standard deviations reported are based on data for the entire quadrangle not for each unit.) The $^{214}\text{Bi}/^{208}\text{Tl}$ ratio was generally between +1% and -1%. The exception occurred along flight line ML-8 where the ^{214}Bi rose to

+4.5C (Pl. 6) and the $^{214}\text{Bi}/^{208}\text{Tl}$ rose to +4C (Pl. 24). This anomaly occurred along one line only and was at the edge of the quadrangle so it is difficult to evaluate whether the anomalous response is geologic or related to some cultural feature such as an oil field. The peak of this broad anomaly occurs over terrace deposits (Pleistocene) to the west of the Choza exposures. The aerial radiometry in the adjoining quadrangle should be studied before any conclusions concerning the source of this anomaly are drawn. ^{40}K values are generally above the mean (Pls. 8 and 14). The higher ^{40}K values were expected as a result of the presence of weathered shales in the unit. The Merkel Dolomite which marks the top of the Choza Formation (Barnes, 1967) could not be delineated radiometrically and may be absent in at least part of the Lubbock Quadrangle (Smith, 1974).

Truck-mounted spectrometer Line 48 (miles 12.7 through 14.6) (Pl. 50) traversed Choza material less than 1.6 km (1 mi) north of flight line ML-4. Uranium values along this section of the truck line were between 3.1 and 4.4 ppm and eU/eTh ratios were between 0.5 and 0.8.

The generally low ^{214}Bi , eU, $^{214}\text{Bi}/^{208}\text{Tl}$ and eU/eTh (App. F) values recorded over Choza material suggest that the Choza Formation in the Lubbock Quadrangle does not contain significant uranium occurrences. However, the anomaly recorded along flight line ML-8 should be investigated further to determine its cause.

San Angelo Formation

^{214}Bi values recorded over San Angelo sediments (Permian) in the Lubbock 1° x 2° Quadrangle did not rise above +2C and the higher ^{214}Bi

values were generally accompanied by higher ^{208}Tl values so that the $^{214}\text{Bi}/^{208}\text{Tl}$ ratios registered between +10 and -10. As with the Choza Formation, ^{40}K values tended to be above the mean. The $^{208}\text{Tl}/^{40}\text{K}$ ratios over San Angelo material were consistently above the mean unlike the overlying Blaine sediments and the underlying Choza Formation sediments (Pls. 11 and 17).

Truck-mounted spectrometer Lines 48 (Pl. 50) and 67 (Pl. 61) traversed sediments mapped by Barnes (1967) as San Angelo. Along Line 48, eU, eTh, and K values were all low over the section mapped as San Angelo, and these values were probably affected by cover sands (Recent). Line 67 showed eU values in the 3.5 to 6.5 ppm range, eTh values in the 4.5 to 8 ppm range, and K values generally between 1 and 1.8%. The eU/eTh ratios were between 0.5 and 0.9. The eU values recorded over portions of the San Angelo were higher than would be expected from the radiometric data and the higher values may be the result of a malfunction in the uranium channel of the truck-mounted spectrometer system.

Hand-held spectrometer Station L-RE-102 sampled the upper San Angelo Formation (Pl. 5). L-RE-102 comprised highly weathered red carbonaceous clays and silts (App. A). The eU and K values recorded at this station were similar to those recorded by the truck-mounted spectrometer (App. B). However, the truck-mounted spectrometer recorded eTh values which were approximately half what the hand-held system recorded (Pl. 50).

The relatively low ^{214}Bi concentrations and the low $^{214}\text{Bi}/^{208}\text{Tl}$ and eU/eTh ratios (Apps. F) recorded by the airborne, truck-mounted, and hand-held spectrometer surveys suggest the San Angelo Formation has poor potential as a uranium host rock.

Blaine Formation

Although no extremely high ^{214}Bi values were found in the airborne spectrometer survey data over Blaine Formation sediments (Permian), values between +1 and +2σ were common, particularly in the "middle" Blaine (Pls. 2 and 6). Because ^{208}Tl (Pl. 7) values tended to be relatively high, the $^{214}\text{Bi}/^{208}\text{Tl}$ (Pl. 9) ratios calculated for Blaine sediments generally were between +1σ and -1σ. However, in the "middle" Blaine, $^{214}\text{Bi}/^{208}\text{Tl}$ ratios commonly were in the +2σ to +1σ range, and along flight line ML-8 the $^{214}\text{Bi}/^{208}\text{Tl}$ ratio rose to +4σ near the Salt Fork of the Brazos River (Fig. 25). The lateral extent of this anomaly was limited. A large expanse of windblown sand (Recent) was mapped, (Barnes, 1967) just west of this anomaly. The airborne radiometric response indicated that the sand extended to the edge of the anomaly instead of 1.6 km (1 mi) to the west as it was mapped. Thus, the anomalous area may have a larger lateral extent than indicated by the airborne radiometric survey.

^{40}K responses recorded by the airborne survey ranged from +3.5σ to -2σ. High ^{40}K values marked the "upper" Blaine (Pls. 2 and 8). Drainages generally traverse those parts of the "upper" Blaine which did not exhibit high ^{40}K responses. Readings over those areas may have been contaminated by the effects of alluvium (Recent) and terrace deposits (Pleistocene). The low ^{40}K values tended to be clustered in the "middle" Blaine, primarily in the northern half of the quadrangle. The higher ^{40}K responses are interpreted to indicate units of higher shale (clay) and lower evaporite and sand content.

Figure 25. $^{214}\text{Bi}/^{208}\text{Tl}$ anomaly over Blaine sediments along flight line ML-8 (Fig. 16). The low ^{214}Bi , ^{208}Tl , and ^{40}K responses on the western part of this flight line are characteristic of the sands (Recent). Profiles are smoothed data.

Several truck survey lines traversed Blaine Formation sediments (Pls. 2 and 4). Lines 48 (Pl. 50), 66 (Pl. 60), 67 (Pl. 61), 145 (Pl. 87), 182 (Pls. 92a-c), and 224 (Pl. 98) were run during the July and August 1978 survey, while Lines 151 (Pl. 88a), 152 (Pl. 89), and 421 (Pls. 103a-c) were run during the January and February 1979 survey. In general, eU values recorded over Blaine sediments during the first survey were between 2.5 and 3.5 ppm while those recorded during the second survey were in the 4 to 5.5 range (App. F). The truck spectrometer data do not support the observation in the airborne data that the uranium values (^{214}Bi) are higher in the "middle" Blaine. The eU curve appeared relatively flat along Lines 151 (Pl. 88a), 152 (Pl. 89), and 145 (Pl. 87) which traversed most of the Blaine Formation east of Guthrie. Line 421 (Pls. 103a-c), which traversed the Blaine Formation in a north-south direction showed a slight decrease in eU values to the north (from "middle" to "upper" Blaine) but the bulk of the eU values along this line fell between 4 and 5 ppm.

The only anomalous eU readings over Blaine sediments recorded in the truck survey occurred along Line 48 (Pls. 25 and 50) where the eU values rose to about 6 ppm for a short distance and along Line 67 (Pl. 61) where eU values of 5 to 7 ppm were recorded. The higher eU readings along Line 48 were near flight line ML-4 where common Blaine ^{214}Bi values of +15 to +25 were recorded. A malfunction in the uranium channel of the truck-mounted spectrometer is suspected along truck line 67.

eTh values recorded over the Blaine Formation appeared to decrease slightly to the north and generally fell between 4 and 7.5 ppm. K values

ranged from 1 to 2% with the higher K values recorded in the "upper" Blaine.

Hand-held spectrometer data (App. B) were collected at ten locations in the Blaine Formation (Pl. 5). Samples from six of the ten locations were analyzed for total U_3O_8 content (App. C). Four sites were investigated between flight lines ML-7 and ML-8 over "middle" Blaine exposures in the valley of the Salt Fork of the Brazos River (Pl. 24). At station L-JE-101, the hand-held spectrometer assays over an exposure of unconsolidated, fine red sand (App. A) recorded 2.0 ppm eU while the laboratory analysis yielded 13 ppm U_3O_8 . At station L-JE-102, located about 0.8 km (0.5 mi) north of L-JE-101, the hand-held spectrometer reading over an outcrop of highly-weathered, interbedded gypsum yielded 11 ppm U_3O_8 . No explanation is offered for this magnitude of disagreement between the hand-held spectrometer readings and the laboratory analyses. Two hand-held spectrometer stations made north of L-JE-102 showed higher eU with assays of 2.6 ppm eU at station L-JE-103 and 3.1 ppm eU at station L-JE-104. Total uranium analyses were run by Bendix on three samples, one a red shale, one a gray-green shale, and one a green siltstone, from site L-JE-104 (App. A). Each sample showed 3 ppm U_3O_8 .

Site L-RE-104 in the "middle" Blaine (Pl. 5) was close to the location of flight line ML-4 where low ^{214}Bi , ^{208}Tl , and ^{40}K responses were recorded. The hand-held spectrometer data support this with assays of 4.6 ppm eTh, 2.2 ppm eU, and 0.6% K.

"Upper" Blaine sediments generally showed low eU hand-held spectrometer readings (App. B) and low total uranium analyses (App. C). The "upper" Blaine units which were sampled tended to be highly-weathered and were often water-saturated. Two hand-held spectrometer stations west of Aspermont (L-QE-101 and L-QE-107) were near the location of flight line ML-4 (Pl. 26). These hand-held spectrometer stations showed low uranium values of 2.1 and 1.1 ppm, respectively. Analysis for U_3O_8 on red-brown clayey soil collected at L-QE-101 yielded 1 ppm. Two other stations in the "upper" Blaine near Guthrie were investigated. These showed 2.8 ppm eU (L-GE-101) and 3.2 ppm eU (L-GE-102) and 1 ppm U_3O_8 and 3 ppm U_3O_8 , respectively (Pl. 27).

The spring and well water data collected by the HSSR study in the Blaine Formation (Nichols, et al., 1977) showed several locations with uranium concentration of greater than 20 ppb (Pls. 24, 25, and 26). These anomalies are not substantiated by the airborne, truck-mounted, or hand-held radiometric surveys. Only two of the eight geochemical analyses of Blaine sediments in the present study yielded anomalous amounts of U_3O_8 (L-JE-101, L-JE-102), neither of which were near HSSR uranium anomalies.

Several ambiguities exist in the radiometric data collected over mapped Blaine sediments (App. F). Neither the high $^{214}Bi/^{208}Tl$ ratio observed along ML-8 (Fig. 25) nor the higher $^{214}Bi/^{208}Tl$ ratios observed in the airborne data in the "middle" Blaine are confirmed by the ground data. The ground spectrometer data agree well with the total U_3O_8 except for two samples and suggest that the Blaine has limited uranium concentration. The HSSR data, however, do not support this, and

the Blaine merits further study to resolve the ambiguities between the data sets. One possible explanation is that the anomalies are caused by leaching of uranium from the Dockum (Triassic) which has then contaminated the spring and well water in some areas in the Blaine or that remnant Dockum is present in some areas mapped as Blaine.

Whitehorse Sandstone and Cloud Chief Gypsum

^{214}Bi values recorded by the airborne radiometric survey over sediments mapped by Barnes (1967) as Whitehorse Sandstone and Cloud Chief Gypsum (Permian) were between $+2\sigma$ and -2σ except for one small area along flight line ML-23 where the ^{214}Bi rose to $+3\sigma$ for a short distance (Pl. 6). ^{208}Tl values largely were $+1\sigma$ or less and tended to be near the mean. The lower ^{208}Tl values stood out in contrast to the higher ^{208}Tl values observed in the airborne radiometric data in the underlying Blaine Formation (Permian) and the overlying Quartermaster Formation (Permian). Because of the lower ^{208}Tl values, a number of small $^{214}\text{Bi}/^{208}\text{Tl}$ "anomalies" were observed in the airborne radiometric data over the Whitehorse Sandstone and Cloud Chief Gypsum.

^{40}K responses of the Whitehorse Sandstone and Cloud Chief Gypsum recorded by the airborne radiometric survey tended to be at or above the mean, occurring between $+2\sigma$ and -1σ . Although $^{214}\text{Bi}/^{40}\text{K}$ ratios were generally low, there was no apparent pattern to the ratios (Pls. 10 and 16). However, the $^{208}\text{Tl}/^{40}\text{K}$ (Pls. 11 and 17) ratios over the Whitehorse Sandstone and Cloud Chief Gypsum were consistently at or below the mean.

The truck spectrometer survey supported the low uranium concentrations observed in the airborne radiometric survey. High eU

values were observed in the truck-mounted spectrometer data along Lines 16 (Pl. 36), 26 (Pl. 41) and 35 (Pl. 44) but a malfunction in the uranium channel is suspected to account for these anomalous values. eU values recorded during the summer 1978 survey generally were between 2.5 and 3.5 ppm except for a 2.4 km (1.5 mi) stretch along Line 66 (Pl. 60) which had eU values in the 4 to 4.5 ppm range. During the January and February 1979 survey, eU values over the Whitehorse Sandstone and Cloud Chief Gypsum sediments ranged between 4 and 4.5 ppm. eTh values over these sediments were largely in the 4.5 to 7.5 ppm range, and K values tended to be between 1.0 and 1.8%.

Hand-held gamma ray spectrometer assays were made over the Whitehorse Sandstone and Cloud Chief Gypsum west of Aspermont (L-QE-102 through L-QE-106, L-QE-108, and L-QE-109) and west of Guthrie (L-GE-103 through L-GE-105) (Pl. 5). These readings were made over gypsums, dolomites, sandstones, siltstones, and unconsolidated clays and silts. The ground was saturated at the time of the survey. The readings near Aspermont all showed eU values of less than 2.5 ppm (App. B). Disequilibrium analysis of a siltstone from station L-QE-109 yielded only 1.5 ppm U and suggested the sample was not in equilibrium (App. C). The eTh and K values recorded by the hand-held spectrometer appeared to be affected by the amount of gypsum and dolomite present: the higher the percentage of evaporites at a location, the lower the amount of eTh and K recorded by the spectrometer. West of Guthrie, eU values of 4.0 to 5.2 ppm were recorded. Total U_3O_8 analysis performed on a sample of unconsolidated sand and silt from station L-GE-103 (in situ assay of 4.0 ppm eU) yielded only 2 ppm U_3O_8 .

The HSSR well and spring water and stream water data showed anomalous amounts of uranium in portions of Whitehorse Sandstone and Cloud Chief Gypsum exposures (Nichols, et al., 1977) contrary to the airborne, truck-mounted, and hand-held spectrometer data.

The low ^{214}Bi and eU values observed in the airborne, truck-mounted, and hand-held spectrometer data and in the disequilibrium and total U_3O_8 analyses (App. F) suggest that the Whitehorse Sandstone and Cloud Chief Gypsum do not contain significant amounts of uranium. The small $^{214}\text{Bi}/^{208}\text{Tl}$ "anomalies" observed are a reflection of the lower ^{208}Tl units (primarily evaporites) rather than of high ^{214}Bi units. Numerous eastward-flowing streams traverse the Whitehorse Sandstone and Cloud Chief Gypsum. These streams head along the High Plains Escarpment in an area which is largely devoid of any ^{214}Bi or $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies. The areas of "higher" ^{214}Bi in the Whitehorse Sandstone and Cloud Chief Gypsum may in part be explained by the leaching of uranium from the Triassic and Tertiary sediments in the northern part of the Lubbock Quadrangle and partial precipitation of some of the uranium over Whitehorse Sandstone and Cloud Chief Gypsum units. Additionally, the scattered higher ^{214}Bi readings may occur at locations with remnant traces of basal Dockum (Triassic) sandstones.

Quartermaster Formation

The airborne radiometric response recorded over Quartermaster Formation sediments (Permian) varied considerably from the upper to lower Quartermaster and from north to south in the study area. In the lower Quartermaster, ^{214}Bi values were generally below the mean in the

southern part of the quadrangle and slightly above the mean (between 0 and +20 calculated for the entire quadrangle) in the northern part (Pls. 2 and 6). However, in the upper Quartermaster in the southern half of the quadrangle, ^{214}Bi values of +40 to +50 were common and the ^{214}Bi response rose to as much as +8.50 in one area. In the northern half of the quadrangle, both the upper and lower Quartermaster exhibited similar ^{214}Bi responses.

^{208}Tl values varied over a wide range, from +2.50 to -20. In general, the ^{208}Tl responses over the Quartermaster sediments were above the mean and the lower values were probably associated with unmapped cover sands (Recent). As with the other Permian units, the ^{40}K responses over the Quartermaster Formation were above the mean, rising to as much as +4.250 in the southern third of the quadrangle. A number of $^{214}\text{Bi}/^{208}\text{Tl}$ and $^{214}\text{Bi}/^{40}\text{K}$ anomalies were observed in the upper Quartermaster. These anomalies may be associated with the overlying Dockum Group (Triassic) in some cases. Cronin (1961) notes that the Triassic-Permian boundary is often unclear so some of the areas mapped as upper Quartermaster which exhibit high ^{214}Bi , $^{214}\text{Bi}/^{208}\text{Tl}$, and $^{214}\text{Bi}/^{40}\text{K}$ may actually be mismapped Dockum sediments. In addition, geologic profiles constructed along the flight lines show that areas of high ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ over Quartermaster deposits are often down relatively steep slopes from Dockum sediments which exhibit anomalous uranium concentrations (Fig. 26). These anomalous areas may be affected by the leaching of uranium from the Dockum or by downslope movement of eroded Dockum material. Except for the southwest quadrant of the Quartermaster Formation in western Kent County, the $^{214}\text{Bi}/^{40}\text{K}$ ratios

Figure 26. ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies in lower Dockum (Triassic) - upper Quartermaster (Permian) along flight line ML-1 (Fig. 16), T-O Creek, et al., Quadrangle (Fig. 17).

over the Quartermaster were less than +1σ and were generally below the mean.

A number of truck survey lines traversed Quartermaster Formation sediments (Pl. 4). Although high ^{214}Bi values were recorded by the airborne radiometric survey over the upper Quartermaster in the central and southern parts of the quadrangle, the truck data did not always verify this. For example, along Lines 24 (Pl. 39a), 52 (Pl. 52a and b), 76 (Pl. 66), and 113 (Pl. 75a), from the July and August 1978 survey, eU values recorded over these sediments were average to somewhat above average, in the range of 3.5 to 5.5 ppm. This is not interpreted to be an instrumental problem. However, in some areas, the readings might have been affected by road bed material.

Along Line 123 (summer 1978 survey), higher eU values of 4.5 to 5.5 ppm (Pl. 84) were noted. This line was near an airborne survey line which showed large ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies. Lines 151 (Pl. 88a), 182 (Pl. 92a) and 222 (Pl. 96) were in areas over which the airborne radiometric data did not show any strong positive anomalies and the data along these truck lines substantiate that observation. Lines 441 (Pl. 104) and 451 (Pl. 105a and b) were run during the January and February 1979 survey over areas which showed average ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ values, and the eU values recorded by the truck survey were also average for the winter survey, generally in the 4 to 6 ppm range. The eTh values recorded by the truck survey followed the same pattern as those observed in the airborne survey of a slight decrease to the north and generally ranged from about 5 to 10 ppm. In many cases, a sharp decrease in the K was noted at the interpreted Quartermaster-Dockum contact. This

decrease is probably a result of decreased clay content in the Dockum with respect to the Permian (Pl. 84).

In situ hand-held gamma ray spectrometer assays were made in 18 locations mapped by Barnes (1967) as Quartermaster (Pl. 5). Disequilibrium analyses were performed on samples collected at 2 of these locations. Stations L-EE-101, L-FE-104, L-GE-108, L-HW-003, L-JW-006, L-ME-003, L-ME-004, and L-ME-005 were located in areas which, though mapped as Quartermaster, are probably covered by sands (Recent) or terrace deposits (Pleistocene). The range of eU concentrations at these stations was 1.5 to 4.2 ppm. Disequilibrium analysis of a sample of reddish-gray soil from the Brazos River Valley from station L-JW-006 yielded 6.7 ppm U while the hand-held spectrometer assay showed 4.2 ppm. The sample was determined to be in disequilibrium (Ra-226/U-238 ratio of .8; Pb-210/Ra-226 ratio of .2) and the discrepancy between the geochemical and the hand-held spectrometer analyses is qualitatively expected from the disequilibrium results (Apps. B and C). The sample is probably from material younger than the Quartermaster and the daughter products have not had time to reach equilibrium; thus the lower uranium determination by the spectrometer. This sample is probably from a terrace deposit (Pleistocene) whose source material was the Quartermaster and the Dockum. That some areas that are mapped as Quartermaster are actually small exposures of terrace deposits or even mismapped Dockum helps to explain the discrepancy mentioned above between the truck spectrometer data and the airborne spectrometer data.

Hand-held spectrometer measurements taken over Quartermaster Formation exposures showed different readings than those over the

covered Quartermaster areas. Four locations of Quartermaster sandstones, some with selenite layers were assayed east of Dickens. These stations (L-GE-106, L-GE-107, L-GE-109, and L-GE-110) (Pl. 5) showed between 3.8 and 4.9 ppm eU (Pl. 18), 5.7 and 8.3 ppm eTh (Pl. 19), and .7 to 2.6% K. The lowest K value was at station L-GE-109 and reflects a low clay content in the outcrop. The outcrop contained a coarse-grained, friable sandstone with a conglomerate layer and is interpreted to be basal Dockum. The aerial radiometric data in the area of these stations did not show high amounts of ^{214}Bi so the low eU values were expected.

Thin-section analysis of a sample from station L-GE-110 showed the specimen consisted of 54% silicate grains. Quartz is the dominant silicate mineral although other silicates, including glauconite, are present (App. D). The rock contains 40% gypsum in the form of cement and as selenite layers and 2% carbonate. Because of the presence of the carbonate, gypsum, and glauconite, deposition of this rock is interpreted to be in a shallow marine environment with restricted circulation.

Stations L-JW-001 (red sands and silts), L-JW-002 (coarse-grained, well-sorted micaceous sandstone), L-JW-003 (coarse-grained, well-sorted sandstone), L-ME-001 (well cemented sandstone), and L-NE-001 (red sandstone and shale) were all in the southern half of the quadrangle (Pl. 5) where the airborne radiometric data showed ^{214}Bi highs in areas which Barnes (1967) has mapped as Quartermaster. The eU values recorded by the hand-held gamma ray spectrometer ranged from 3.6 ppm over the red sands and silts to 11.3 ppm at L-ME-001 (Pl. 18). The high value of 11.3 ppm was made on a hilltop and because of the mineralogy (App. A),

is interpreted to be basal Dockum. Disequilibrium analyses on a sample from this station (App. C) yielded 23.7 ppm U in near equilibrium. In addition, Cronin (1961) notes that the basal Dockum sandstones tend to be micaceous so samples L-JW-002 and L-JW-003 may actually be basal Dockum.

Station L-NE-002 (pale gray clays) was also located in the southern part of the quadrangle (Pl. 5). This station was located in an area which Barnes (1967) has mapped as Dockum (Triassic) although the radiometry (App. B) and mineralogy (App. A) suggest this was a Quartermaster Formation exposure. The hand-held spectrometer recorded eU values of 4.1 ppm and K values of 2.9%. The high K value is expected because of the high clay content in the sample.

The HSSR data (Nichols, et al., 1977) showed areas of high uranium concentration in the stream water samples, particularly in the upper part of the Quartermaster Formation. The well and spring water data also showed other high uranium concentrations scattered throughout the formation.

The high ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ and relatively high eU values recorded by the hand-held spectrometer survey over the upper Quartermaster Formation in the southern half of the Lubbock Quadrangle (App. F) indicate this area has potential uranium deposits. Many of the anomalies observed over mapped Quartermaster may be a result of leaching and downslope movement of Dockum material or they may actually be Dockum deposits. However, the area is interpreted to be favorable for uranium deposition.

The Dockum Group

The airborne radiometric response over Dockum Group (Triassic) exposures varied from the north end of the Lubbock 1° x 2° Quadrangle to the south end. The ^{214}Bi recorded over Dockum sediments did not rise above +1.5σ north of flight line ML-16 and did not rise to +3σ north of flight line M-13. South of ML-13 vast areas of Dockum exposures had ^{214}Bi values of +3σ or greater, and ^{214}Bi values of +5σ to +8σ were common (Pls. 6 and 12). ^{208}Tl values also tended to be higher in the south than in the north (Pls. 7 and 13). North of ML-13, ^{208}Tl responses over Dockum sediments were less than +0.5σ while ^{208}Tl readings of +1σ to +3σ (based on σ calculated for the entire quadrangle) were common south of ML-13.

The basal Dockum in the southern part of the Lubbock Quadrangle stood out because of broad areas which displayed high $^{214}\text{Bi}/^{208}\text{Tl}$ (Pls. 9 and 15) and high $^{214}\text{Bi}/^{40}\text{K}$ (Pls. 10 and 16) as well as high ^{214}Bi . These areas were distinct enough to be considered obvious radiometric features (Pl. 21). The high $^{214}\text{Bi}/^{208}\text{Tl}$ ratios were generally not observed in most of the remainder of the Dockum exposed in the southern half of the quadrangle because of the higher ^{208}Tl values as well as lower ^{214}Bi values (still above the mean) in the upper Dockum in this area.

^{40}K values recorded over mapped Dockum sediments were generally low, seldom rising above +1.5σ. This is a result of the low clay (shale) content of the Dockum. As noted in the previous section on the Quartermaster Formation (Permian), the ^{40}K plots could often be used to

map the Dockum Group - Quartermaster Formation contact.

Many truck-mounted spectrometer survey lines traversed areas mapped by Barnes (1967) as Dockum (Pls. 2 and 4). The truck-mounted spectrometer data tended to verify the anomalies observed in the airborne radiometric data. However, the amplitudes of the anomalies observed in the truck data were not as high as might have been expected compared to the amplitudes of the anomalies observed in the airborne radiometric data. Comparisons of truck and airborne data from other units usually showed that areas of "average" ^{214}Bi were in the 3 to 4 ppm range which is only a few ppm lower than many of the anomalous areas in the Dockum. Areas of anomalous ^{214}Bi over lower Dockum sediments observed in the airborne radiometric survey often showed only 5 to 6.5 ppm eU in the summer 1978 truck survey although values of 6.5 to 10 ppm were observed along some of the lines. For example, eU responses in the 5 to 10 ppm range were observed along 2 miles of Line 15 (Pl. 35) while the rest of the line showed eU responses in the 4 to 4.5 ppm range. Line 14 (Pl. 34), which sampled the upper part of the Dockum west of Line 15, displayed only 3.5 to 5.5 ppm eU. As with the airborne survey, these values were high for the truck survey but not as high as over the lower part of the Dockum, and the eU/eTh over the upper part was only about .5 while ratios as high as 1.6 were observed in the lower part of the Dockum Group. eTh and K values were in the 7 to 10 ppm and 1 to 1.6% ranges, respectively.

eU and eU/eTh anomalies were also observed along Lines 45 (Pl. 55), 75 (Pl. 65), 113 (Pl. 75a and b), 123 (Pl. 84), and 321 (Pl. 99). The anomalous eU and eU/eTh responses observed along Line 123 are in the

vicinity of White River Reservoir (Pl. 1) where the airborne radiometric survey also recorded high ^{214}Bi (Pl. 6) and $^{214}\text{Bi}/^{208}\text{Tl}$ (Pl. 9). In this area the truck survey recorded values in the 4 to 6.5 ppm range while values of 3 to 4 ppm were recorded along this line over the Dockum west of the reservoir. eU/eTh ratios were in the 1 to 2 range over the basal Dockum near White River Reservoir (Pl. 1) while the upper part of the Dockum along Line 123 had eU/eTh ratios in the .4 to .7 range. In addition, an anomaly interpreted as basal Dockum occurs between 0 and 0.5 miles along Line 123.

The advantage of constructing geologic profiles along the radiometric survey lines is illustrated with Line 321 (Pl. 99) which shows two eU and eU/eTh anomalies of short lateral extent in the Dockum in an area which might be interpreted as upper Dockum upon a cursory inspection of the geologic map. However, the geologic profile (Pl. 100) shows that the anomalies occur in a drainage which cuts deeply into the Dockum, exposing lower Dockum sediments. This suggests that the areas of anomalous uranium concentration in the basal Dockum extend farther to the west than indicated by surface geologic map and that the younger sediments which cover the basal Dockum may be masking anomalous areas of uranium concentration.

The anomalous area along Line 21 (Pls. 37a and b), which appears to be over Dockum, may actually be over younger sediments. Field checking revealed that the Ogallala (Pliocene) exposure along the flanks of the Double Mountain Fork of the Brazos River Valley may extend farther down slope than indicated by the geologic map.

Sand cover (Recent) may be masking anomalous concentrations of uranium in the Dockum in the airborne and the truck-mounted survey. These areas of sand cover do not always appear on the geologic map. For example, Line 52 (Pl. 65) shows areas of relatively high eU values which are bordered by areas of low eU, eTh, and K interpreted to be unmapped sand cover.

The lack of anomalies in the northern part of the Lubbock Quadrangle over sediments mapped as Dockum (Barnes, 1967) was verified by the truck-mounted spectrometer data. Along Line 182 (Pl. 92a) eU values over Dockum sediments were only about 3 ppm and eTh and K values were in the range of 5 to 6.5 ppm and 1.3 to 1.5%, respectively. No anomalies were observed over Dockum sediments along Lines 151 (Pls. 88a and 88b) and 461 (Pl. 107) which are located in the northern part of the Lubbock Quadrangle.

Ground-checking revealed that a number of areas mapped as Dockum were in fact covered by sands as the airborne and truck survey data suggested. The sands may be masking anomalous areas of uranium concentration. Hand-held gamma ray spectrometer assays at stations L-HW-004, L-HW-006, L-JW-005, L-RW-001, and L-RW-002 (Pl. 5), were all over exposures of red-brown soils, some of which were plowed fields. The maximum eU at any of these stations was 2.6 ppm (App. B).

Station L-JW-002, L-JW-003, and L-ME-001, discussed in the previous section concerning the Quartermaster Formation are interpreted to be basal Dockum sandstones. The assays at these stations all showed high eU values, both in hand-held spectrometer analyses and in the

disequilibrium analyses. In addition, lower Dockum sediments in the southern part of the Lubbock Quadrangle were sampled at station L-JW-004, L-RW-003, and L-RW-004 (Pl. 5). Disequilibrium analysis of a coarse-grained, well-sorted micaceous sandstone from station L-JW-004 yielded 7.7 ppm U in near equilibrium and 12.2 ppm Th. The hand-held spectrometer assay at station L-RW-003 showed 4.3 ppm eU and 9.8 ppm eTh. Disequilibrium analysis of a sample from station L-RW-003 yielded almost identical amounts of U (4.3 ppm) and Th (9.9 ppm) but the Ra-226/U-238 and Pb-210/Ra-226 ratios indicated the sample was not in equilibrium. At station L-RW-004 the coarse-grained, cross-bedded sands and gravels with organic material which were sampled yielded 6.2 ppm eU and 10.6 ppm eTh in situ while the disequilibrium analysis showed 5.1 ppm U in near equilibrium and 8.3 ppm Th. The low U-234/U-238 ratio reported (0) is a function of imprecision in the geochemical analysis technique (Paul Nordstrom, personal communication) and thus U-234 could not be accurately determined.

Thin-section analyses of rocks from stations L-JW-002, L-JW-003, and L-NE-001 were made to determine if any clues to the deposition of uranium in these samples could be obtained (App. D). The thin-section analysis of sample L-JW-003, which showed 9.9 ppm U in the disequilibrium analysis (App. C), showed 65% silicate grains. The cement for this friable sandstone comprises limonite which amounts to 1% of the rock. Because of the high porosity of this sample, it is structurally favorable for trapping uranium. However, the sample is lacking in reducing agents for precipitating uranium.

Analysis of a rock sample from station L-JW-002 (eU of 7.1 ppm measured by hand-held spectrometer, U of 10.9 ppm by disequilibrium analysis) yielded 49% silicate (App. D) which has been partially replaced by calcite. This rock contained authigenic hematite in a calcite cement which indicated that it was deposited in an alkaline oxidizing environment. Thin-section analysis of a sample from L-NE-001 yielded 22% silicate (dominantly quartz) and 75% carbonate (App. D). The microscopic analysis indicates this rock was deposited in quiet water. Pervasive red limonite cement suggests deposition under oxidizing conditions. The thin-section analyses on these three samples suggests that uranium concentration generally appeared to be directly related to silicate percentage. This suggests that the uranium contained within these sandstones may have been contained within the source rocks which contributed to these sediments.

In the valley of the Double Mountain Fork of the Brazos River, three stations were located over exposures which are mapped as upper Dockum. These stations are in the vicinity of Line 21 (Pl. 37a). The stations L-PW-007 (red-brown shale possibly containing gypsum), L-PW-008 and L-PW-009 (both yellow-gray fine-grained sands with mica and possibly gypsum), showed low eU in situ assays of 1.3, 2.5, and 3.2 ppm, respectively (App. B). These low values were expected based on the airborne and truck survey data from the area.

In the northern part of the quadrangle an exposure of red-brown to gray, well-rounded cobbles and cemented gravels with thin-bedded sands sampled at station L-HW-005 yielded only 2.2 ppm eU and .7% K with 8.6 ppm eTh. Station L-HW-103 (highly-weathered coarse, brown sand with

small pebbles) showed a higher eU content (4.6 ppm) while a terrace (Pleistocene) in contact with the Dockum exposure at L-HW-103 yielded 4.4 ppm eU. The source material for this terrace is interpreted to be Dockum sediments. L-GE-109, interpreted to be basal Dockum (App. A), yielded 4.9 ppm eU, 5.7 ppm eTh, and .7% K. The eU values are average for their respective surveys. (Sample numbers which begin with "0" were collected in July and August 1978; those which begin with "1" were collected in January 1979 when the eU background was higher.)

The HSSR well and spring water data and the HSSR stream water data (Nichols, et al., 1977) indicate the Dockum contains favorable areas of uranium mineralization. These favorable areas appear to be confined to the southern two-thirds of the Lubbock Quadrangle, in agreement with the airborne, truck-mounted, and hand-held spectrometer data (Pl. 22). Some of the high values noted in the HSSR data are located in areas where the basal Dockum is covered by younger sediments and tends to support to the idea that anomalous concentrations of uranium in the Dockum extend farther west than where the basal Dockum is exposed.

The high ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ observed in the airborne radiometric data, the relatively high eU and eU/eTh values observed in the truck-mounted and hand-held spectrometer data, and the high uranium values observed in the geochemical analyses (App. F) indicate that the basal Dockum south of about latitude $33^{\circ}40'\text{N}$. is a favorable area for uranium exploration in the Lubbock Quadrangle. This horizon is one from which uranium has been produced for a number of years (Table 2; Pl. 3) (Eargle and McKay, 1955; Finch, 1975; Bement, et al., 1977; and McGowen, 1978). The airborne radiometric data, as well as the

other data sets confirm the presence of a well-known uranium-bearing rock.

The Cretaceous System

The limited exposures of Cretaceous rocks in the Lubbock 1° x 2° Quadrangle made it difficult to evaluate their radiometric response. In general, however, the airborne ^{214}Bi , ^{208}Tl , and ^{40}K values recorded over Cretaceous sediments tended to be moderate, falling between +1σ and -1σ.

Although the Cretaceous was sampled by the truck-mounted spectrometer in a few locations, it was again difficult to evaluate the unit for any characteristic radiometric responses. No eU anomalies were recorded over Cretaceous material by the truck survey.

Hand-held spectrometer station L-FW-101 was made at an exposure of highly-weathered and fractured yellowish-tan interbedded Cretaceous siltstone and fossiliferous limestone with minor shale seams. The reading at this location yielded low eU (3.3 ppm), eTh (2.9 ppm), and K (.2%).

The airborne, truck-mounted, and hand-held spectrometer survey data indicate that anomalous uranium is not contained within Cretaceous strata surveyed.

The Ogallala Formation

A distinctive radiometric signature was noted in the airborne radiometric data collected over Ogallala Formation (Pliocene) sediments.

Most significantly, both the ^{208}Tl and the ^{40}K values consistently occurred at or below the mean in the Lubbock $1^\circ \times 2^\circ$ Quadrangle. Figures 27 and 28 illustrate typical ^{208}Tl and ^{40}K responses over Ogallala sediments. In those places where the ^{208}Tl and ^{40}K responses were not at or below the mean (calculated for each radioelement for the entire survey) often either the surface geology could be questioned or the application of the seven-point smoothing operator was responsible for widening the "high" in the ^{208}Tl or ^{40}K channel.

The ^{214}Bi values over the Ogallala generally ranged from $+1.5\sigma$ to -1.5σ over most of the quadrangle (Pls. 6 and 12). The maximum ^{214}Bi variation along any Ogallala exposure was generally on the order of $+2\sigma$. However, in places, the ^{214}Bi jumps to as much as $+12\sigma$ over sediments mapped as Ogallala. The $^{214}\text{Bi}/^{208}\text{Tl}$ and $^{214}\text{Bi}/^{40}\text{K}$ ratios for Ogallala material were also between $+1.5\sigma$ and -1.5σ with considerably higher ratios in small localized areas.

Along flight lines ML-12 and TL-8 (approximately $33^\circ 25' \text{N.}$, $101^\circ 30' \text{W.}$), the ^{214}Bi rose to approximately $+12\sigma$ (Pls. 6 and 12). The $^{214}\text{Bi}/^{208}\text{Tl}$ and $^{214}\text{Bi}/^{40}\text{K}$ ratios in this area also rose to at least $+12\sigma$. This anomaly, although limited in extent, is strong enough to be considered an obvious radiometric feature (Pl. 21). The anomaly occurs in the area of the Slaton (Wood Ranch) anomaly (Table 2) mentioned by Finch (1975). The anomaly peak occurred on the south side of Yellow House Canyon. This area was not ground-checked because of lack of access.

Figure 27. Typical ^{208}Tl and ^{40}K responses over Ogallala (Pliocene) sediments along flight line ML-6 (Fig. 16). Where ^{40}K rises above mean, Tahoka clays (Pleistocene) may cover Ogallala. Profiles are smoothed data. (Refer to Table 1 and Appendix E for abbreviations and symbols.)

Figure 23. Typical ^{208}Tl and ^{40}K responses over Ogallala (Pliocene) sediments along flight line ML-11 (Fig. 16).

Another significant ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ anomaly was observed along flight line TL-9 (approximately $33^{\circ}30'\text{N.}$, $101^{\circ}45'\text{W.}$) where the ^{214}Bi rose to $+10.5\sigma$ (Pl. 12) and the $^{214}\text{Bi}/^{208}\text{Tl}$ rose to about $+20.5\sigma$ (Pl. 15). This anomaly occurred over an Ogallala exposure on the south side of Yellow House Canyon. Finch (1975) describes an anomaly in this area and names it the Benson Lake anomaly.

In a few other places along the erosional escarpment, the ^{214}Bi values recorded over Ogallala exposures were greater than $+2\sigma$. These higher ^{214}Bi values were found along flight line ML-2 ($+4\sigma$) and along ML-3 ($+2.5\sigma$), in the canyon of the Double Mountain Fork of the Brazos River, and along ML-17, in Blanco Canyon ($+3\sigma$), and were associated with higher peaks over the Pleistocene lake sediments in contact with the Ogallala (Pls. 1 and 6). Figure 29 illustrates the Ogallala Formation anomaly in Blanco Canyon.

Along the northern part of the erosional escarpment low ^{214}Bi values were observed. The ^{214}Bi responses recorded over Ogallala sediments in this area were generally lower than those observed over the windblown cover sands (Quaternary) exposed to the west of the escarpment.

In the large lake basins in the southwest corner of the quadrangle, the aerial radiometric data recorded over Ogallala exposures were largely devoid of anomalies. However, in the Double Lakes Basin, ^{214}Bi anomalies were observed along flight lines ML-6 (Pl. 6) and TL-10 (Pl. 12). The ^{214}Bi anomaly peak of about $+5\sigma$ along ML-6 occurred over Ogallala material near the Ogallala-Tahoka

Figure 29. ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ anomaly at the base of the Blanco Formation (Pliocene-Pleistocene) and top of the Ogallala Formation (Pliocene) along flight line ML-17 (Fig. 16).

Formation (Pleistocene) contact. The $^{214}\text{Bi}/^{208}\text{Tl}$ anomaly of +180 (Pl. 9) was shifted slightly to the east and occurred over the Takoka Formation exposure (Fig. 27). On the north side of Tahoka Lake Basin a small ^{214}Bi anomaly of +20 was recorded along flight line TL-9 (Pl. 12). This anomaly was related to Tahoka Formation deposits. The remainder of ^{214}Bi responses over Ogallala sediments exposed in the large pluvial basins were between +20 and -20.

The ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ responses over the Ogallala exposed through windows in the cover sand (Pleistocene) were higher than the responses recorded over the sands. However, ^{214}Bi responses over Ogallala windows still ranged from only +10 to +20.

The truck-mounted spectrometer survey traversed Ogallala Formation outcrops in many areas (Pl. 4). Few eU anomalies over Ogallala sediments were observed in the truck-mounted spectrometer data. Along the erosional escarpment, no eU anomalies were observed in the truck survey data over the Ogallala Formation. The low to moderate eU values of 2.5 to 4 ppm were expected along most sections of the escarpment surveyed by the truck because the aerial radiometric data did not record ^{214}Bi anomalies along the escarpment in the same areas. During the January and February 1979 survey the eU values recorded were in the 3.5 to 4.5 ppm range which were only average eU values for the survey. As was observed in the airborne survey, eU values over the windblown cover sands (Pleistocene) were higher than over the Ogallala exposed along the erosional escarpment in the northern part of the quadrangle (Pl. 92a).

In Blanco Canyon, however, the truck-mounted spectrometer observed a small anomaly over Ogallala sediments near the contact with the Blanco Formation (Pliocene-Pleistocene) along Line 191 (Pl. 93). This is similar to what was observed in the airborne radiometric data along flight line ML-17 (Fig. 29).

Ogallala Formation deposits in all of the modern lake basins (Double, Twin, Tahoka, and Guthrie Lakes) in the Lubbock Quadrangle were sampled with the truck-mounted spectrometer (Pl. 4). In Double Lakes Basin moderate eU and eU/eTh anomalies were observed over Ogallala sediments. eU values of about 5.5 ppm were recorded in the vicinity of mile 1.5 of Line 62 (Pl. 56). eU values of approximately 4.5 ppm were recorded along miles 9 to 9.2 of Line 62.1 (Pl. 57) while eU values of 3 to 3.5 ppm were common along the rest of the line. eU values of 4 to 5 ppm were observed along Line 42 (Pl. 46) in the Guthrie Lake Basin. No anomalies were observed over Ogallala sediments in the truck survey data from Twin Lakes and Tahoka Lake Basins.

Slightly higher than average eU values were recorded along Line 73 (Pl. 64) over Ogallala material exposed through a window in the cover sand (Pleistocene) at about miles 9 to 11.5. No other anomalies were observed in the truck survey data over cover sand windows.

As was the case with the airborne and truck-mounted survey data, few areas of anomalous uranium concentration were found in the Ogallala Formation in the hand-held spectrometer surveys and in the geochemical assays. As mentioned previously, some areas which showed anomalous amounts of uranium in the airborne survey were not ground-checked

because of lack of access.

Some of the areas ground-checked were found to be covered by sands (Recent) or terrace deposits (Pleistocene). Samples L-DE-001, L-DE-002, L-DE-004, L-DE-101, L-DE-102, L-DE-103, L-HW-008, and L-HW-009 are interpreted to be either sand contaminated or terrace deposits. None of these samples had more than 2.6 ppm eU (App. B, Pls. 5 and 18). Sample L-DE-101, a bright red, very fine-grained sand and silt with thin gravel and pebble lenses, which is interpreted to be a terrace deposit, was analyzed for total U_3O_8 . The hand-held spectrometer recorded 2.6 ppm eU while the total U_3O_8 analysis showed only 1 ppm. Location L-NW-021 was over an exposure mapped as Ogallala but is interpreted to be covered by windblown sand (Pleistocene).

The Ogallala was sampled northwest of the Slaton (Wood Ranch) anomaly in the Yellow House Canyon (Pl. 3). Traverse L-LW (Pl. 5) was made on a butte and sampled the entire Ogallala Formation. The highest uranium concentration was recorded at station L-LW-002 where the in situ survey yielded 3.7 ppm eU. Disequilibrium analysis of a sample from this station yielded 2.9 ppm U and may suggest that U-238 had recently been removed from the system. Station L-LW-002 sampled a light-tan to milky-white hard caliche. Microscopic examination of the cap rock from this station (App. D) showed that the rock contained 90% very fine-grained clear calcite with a typical grain size of about 5 microns. The rock also contained 5% detrital grains which were primarily quartz with minor accessory minerals and rock fragments. The remaining 5% of the sample consisted of pore spaces in the .1 to .3 mm range. The silicate grains are uniformly distributed throughout the calcite and

are floating in carbonate.

A sand and caliche layer at station L-LW-001, up section from L-LW-002, yielded 2.8 ppm eU in situ and 1.7 ppm U in the disequilibrium analysis with a suggestion that Ra-226 has been introduced into the system (App. C). At station L-LW-003, the caliche was reddish instead of milky in color. The eU response recorded by the hand-held spectrometer at L-LW-003 dropped to 1.9 ppm and only 1.4 ppm was assayed by the disequilibrium analysis. Down section from station L-LW-003 a series of sandstone layers with caliche were sampled. These stations showed less than 2.5 ppm eU with the hand-held spectrometer and 1.5 ppm U in the disequilibrium analysis.

The cap rock was also sampled at stations L-LW-101 and L-LW-102 on the south side of Yellow House Canyon. Again, low eU values of 1.9 and 1.7 ppm, respectively, were assayed over the cap rock (App. B). The eTh and K values recorded over these stations and in traverse L-LW previously mentioned were all low for the Lubbock Quadrangle with the eTh values generally below 5 ppm and K below .8%.

Other stations which sampled the cap rock were in the northern part of the quadrangle. Station L-AW-102 was located on the east side of Blanco Canyon and was over cap rock which was in contact with Blanco sediments. An eU response of 3.0 ppm was observed here with an eTh of 3.5 ppm and K of .4% (Pl. 93). Station L-DE-006 was along Line 221 (Pl. 92c) and the low eU response of 1.5 ppm is expected based on the data collected by the airborne and truck-mounted surveys. Station L-HW-010 was also in an area in which the Ogallala did not show anomalous amounts of uranium and hand-held spectrometer and disequilibrium

determinations support this. As with the other cap rock samples, the disequilibrium analyses (App. C) suggest that the cap rock is Ra-226 enriched or U-238 deficient. Microscopic analysis of the sample from station L-HW-010 (App. D) yielded 90% calcite just as sample L-LW-002 did. However, the calcite in sample L-HW-010 was extremely fine-grained dark brown, turbid calcite with most grains less than 1 micron. The sample also contained 3% detrital grains and 7% pore space.

Samples L-DE-003, L-DE-005, L-DE-104, L-HW-001, L-HW-007, and L-HW-101 were all collected in parts of the Ogallala other than the cap rock and comprised unconsolidated to moderately-consolidated sands, some of which contained caliche pebbles. Some of these samples may also be contaminated by sand or terrace cover. None of the samples show anomalous uranium concentrations (App. B). In addition, sample L-FW-102 and L-FW-103 were collected in the basal Ogallala in Yellow House Canyon immediately above an exposure of Cretaceous material. The hand-held spectrometer determination at station L-FW-102 yielded 4.4 ppm eU and the disequilibrium analysis, which recorded 4.5 ppm U, suggested that the sample may not be in equilibrium (App. C).

The highest uranium value measured in the Ogallala by the hand-held survey was in the valley of the Double Mountain Fork of the Brazos River down section from an exposure of the Tule Formation (Pleistocene). The white cap rock and the caliche nodules sampled at station L-PW-005 yielded 4.3 ppm uranium in situ (Pl. 18). The geochemical assay, however, showed 8.7 ppm U in a uranium-enriched environment. Down section from L-PW-005, at station L-PW-006, the yellow-red, cemented, unsorted gravel and caliche appeared to be slightly uranium-enriched

(App. C).

The HSSR spring and well water data (Nichols, et al., 1977) showed anomalous concentrations of uranium in the Ogallala Formation. Cronin (1961) has noted that the Ogallala is the major aquifer on the High Plains and Barker and Scott (1958) note that the concentration of uranium in the Ogallala aquifer waters increases down the hydraulic gradient. The uranium in Ogallala waters is interpreted to be leached from the Ogallala and perhaps from younger sediments, and, in the absence of a reductant, is generally being washed through the aquifer. This is not inconsistent with the other data sets. The anomalous uranium concentrations observed in the Ogallala Formation appear to be in the less permeable cap rock, and not in the underlying permeable sands.

The airborne and ground radiometric survey data and the laboratory analyses indicate that, although some high ^{214}Bi anomalies are observed over the Ogallala Formation (App. F), much of the unit exposed at the surface cannot be considered to have favorable uranium concentrations. The anomalous uranium appears to be confined to portions of the cap rock. The Ogallala may be a good source and host rock. Quaternary volcanic ashes may be leached and yield uranium minerals into the Ogallala. The Ogallala itself may provide uranium minerals from Pliocene ashes.

The Blanco Formation

The Geodata (1975) aerial reconnaissance spectrometer survey recorded radiometric information about the Blanco Formation (Pliocene-Pleistocene) along flight lines ML-17 and ML-19. No tie lines cross the

Blanco Formation. Flight line ML-19 was over the type locality of the Blanco Formation at the confluence of Crawfish Creek with White River (Pls. 1 and 2). Only Blanco exposures on the west side of White River were sampled by airborne survey line ML-19. A maximum ^{214}Bi reading of about +1.5σ was recorded over Blanco sediments along this line. This maximum value occurred at the base of the Blanco, and the peak of this ^{214}Bi "anomaly" was over an exposure of Ogallala material (Pliocene) in a small valley whose walls contained Blanco sediments (Fig. 30). Along flight line ML-17, Blanco sediments exposed on the east side of White River were sampled (Fig. 29). As with flight line ML-19, basal Blanco near the Ogallala-Blanco contact yielded the highest ^{214}Bi values, rising to +2.5σ at the easternmost exposure of Blanco along M-17.

The ^{208}Tl responses over Blanco sediments recorded by the airborne survey were below the mean (calculated for the entire survey) except for one exposure along ML-19 which showed a radiometric response more characteristic of windblown sand (Pleistocene) (+1σ) and the area was thus interpreted to be sand-covered (Fig. 30). Finch (1975) noted low thorium values in the Blanco Formation which the aerial ^{208}Tl readings supported. All Blanco-related ^{40}K values were at or below the mean. Because of the low ^{208}Tl and ^{40}K recorded over the Blanco, $^{214}\text{Bi}/^{208}\text{Tl}$ and $^{214}\text{Bi}/^{40}\text{K}$ ratios for Blanco sediments were above the mean. The highest ratios were found at the base of the Blanco with the peaks of the $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies generally occurring over the Ogallala sediments (Figs. 29 and 30).

Truck-mounted spectrometer Lines 191 (Pl. 93) and 472 (Pl. 110) traversed Blanco Formation exposures about 1.6 km (1 mi) north and about

Figure 30. ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ anomaly over the base of the Blanco Formation (Pliocene-Pleistocene) and top of the Ogallala Formation (Pliocene) along flight line ML-19 (Fig. 16). High ^{208}Tl over western exposure of the Blanco suggests windblown sand (Pleistocene) cover.

1.6 km (1 mi) south of flight line ML-19, respectively (Pl. 4). The western exposure of Blanco along Line 191 was approximately 1.2 km (0.75 mi) north of ML-19. A relatively high eU value of 6 ppm was recorded by the truck survey over this exposure while the eTh and K values were low. On the east side of White River along Line 191, the eU values over Blanco sediments were lower than on the west side of the river while the eTh and K values were similar on both sides of the valley. The eU/eTh and eU/K ratios calculated for Blanco material along Line 191 were generally higher than background readings. However, on the east side of White River, the highest eU/eTh and eU/K ratios were recorded over Ogallala sediments east of the Blanco exposure (Pl. 93).

This is an example of a case in which the eU/eTh and eU/K values could be used to reduce uncertainties caused by the geometry which the spectrometer crystal "sees." Because of the roadcuts and the small creek valleys in this area, the normalization of the geometrical effects facilitated recognizing the anomalies as being in basal Blanco or Ogallala sediments. This provides better agreement with the interpretation based upon airborne data.

Blanco sediments on the south side of Crawfish Creek (Pls. 1 and 2) were sampled by truck-mounted spectrometer around mile 7 of Line 472 (Pl. 110). This exposure of Blanco showed the characteristic low eTh and K values observed in other localities although the eU values were also low. In this area, the Pleistocene cover sands showed higher eU readings than the Blanco. Field checking revealed that the Blanco exposures were not as prominent in this area as on the north side of Crawfish Creek and on the east side of the White River.

Hand-held spectrometer station L-HW-002 was located over the Blanco Formation 0.4 km (0.25 mi) south of flight line ML-17 (Pl. 5). Field checking of this area showed that Blanco talus extended down slope (to the west) and covered Ogallala sediments. Two hand-held spectrometer assays were made over Blanco sediments in this area. One reading was made over Blanco talus while the other reading was over Blanco outcrop. Both readings showed low eTh (Pl. 19) and K (App. B) just as the airborne survey indicated. However, the hand-held spectrometer showed only 2.4 ppm and 2.1 ppm eU (App. B) while the airborne survey recorded high ^{214}Bi values over Blanco sediments along ML-17. Disequilibrium analysis of caliche gravels and sands and limestone from site L-HW-002 showed low uranium (2.5 ppm) and thorium (1.2 ppm) (App. C).

That the hand-held spectrometer determination and the uranium concentration determined in the disequilibrium analyses are similar for sample L-HW-002 is probably fortuitous. Assuming that the two analyses are of good accuracy, the disequilibrium analysis would lead to two proposed events, both of which probably occurred in Blanco Canyon. The Ra-226/U-238 and Pb-210/Ra-226 ratios (App. C) suggest either an introduction of radium or a leaching of uranium in the Blanco lake.

Two hand-held spectrometer determinations (L-AW-101 and L-AW-104) were made along truck Line 191 over Blanco sediments (Pl. 93). In general, eU, eTh, and K values calculated from hand-held spectrometer data were lower than those values recorded by the truck-mounted spectrometer. The hand-held spectrometer readings may have been affected by high moisture conditions during the time of the survey. However, a comparison of hand-held spectrometer stations L-AW-101,

L-AW-102, L-AW-103, and L-AW-104 and truck Line 191 showed strikingly similar eU, eTh, and K curve shapes (Pl. 93). Both the data from truck Line 191 and the hand-spectrometer data indicated that the eU values recorded over the Blanco were higher on the west side of White River than on the east side, that eU values over the eastern exposure of the Ogallala were higher than over the Blanco on the east side of White River, and that eTh and K values over Blanco, Ogallala (Pliocene), and terrace deposits (Pleistocene) were low.

The aerial radiometric survey and the truck-mounted survey suggest that anomalous amounts of uranium may be present in the base of the Blanco (App. F). The source of the uranium found in the Blanco could have been ash falls originating in the mountains to the west which were deposited in the Blanco drainage basin. The uranium was then leached from the ashes, washed into the lake, and deposited when the reducing environment in the lake was encountered. Some ash was probably deposited directly in the lake. The uranium found in the Blanco Formation may not be economically significant because of the limited extent of the unit. However, the Blanco Formation and nearby Ogallala sediments should be investigated in greater detail to better determine the uranium potential within the unit.

The Tule Formation

The airborne spectrometer survey recorded a wide variation in radiometric readings over the Tule Formation (Pleistocene). The ^{214}Bi ranged from approximately +0.5C (Pl. 12) over the north end of the Tule exposure along flight line TL-8 (Fig. 16) to about +8.25C (Pl. 6) over

the western exposure of Tule sediments along flight line ML-3 (Fig. 16).

²⁰⁸Tl values recorded over the Tule Formation were near the mean (calculated for the entire survey). ⁴⁰K values (Pls. 2, 8, and 14) tended to be low and were never above +0.25C.

Truck-mounted spectrometer Line 21 (Pl. 37a) traversed the Tule Formation. Nowhere do the aerial survey and the truck-mounted survey locations coincide over Tule sediments. eU values over the Tule recorded by the truck-mounted spectrometer ranged from 3 to 4 ppm except for two sites on the south side of the Brazos River Valley where eU values of 5.7 and 7.7 ppm were recorded. The eU/eTh values recorded at these points were 0.9 and 1.0, respectively. As with the airborne survey, the truck-mounted survey recorded uniform eTh values over the Tule Formation. These values ranged from about 6 to 9 ppm in the truck survey. K values were between 1.0 and 1.6%. eU/eTh ratios were between 0.4 and 0.6 except for the two anomalous points (0.9 and 1.0) near the Tule - Ogallala contact, and a ratio of 0.7 was recorded near the Tule - Cretaceous contact.

Hand-held spectrometer survey PW crossed the Tule Formation in the north end of the valley of the Double Mountain Fork of the Brazos River (Pl. 5). Four stations sampled exposures mapped by Barnes (1967) as Tule: L-PW-001; L-PW-002; L-PW-003; and L-PW-004. Station L-PW-001, was recorded over an exposure of pebble sand with minor caliche on a hill top and had a hand-held spectrometer eU reading of 3.1 ppm (App. B). Approximately 120 m (400 ft) northwest of this station at mileage 7.6 of Line 21, the truck-mounted spectrometer recorded eU values near 4 ppm. Disequilibrium analysis of a sample collected at station L-PW-001

showed the sample to be near equilibrium and yielded 4.5 ppm uranium (App. C). The higher uranium in the geochemical analysis may be expected because the sample has not had enough time to generate all the daughters which would be measured by the gamma ray spectrometer.

Stations L-PW-002, down section from L-PW-001, was made over a 3 m (10 ft) thick caliche layer (App. A) which registered an eU of 24.8 ppm, and 34.2 ppm uranium were assayed in the sample by disequilibrium analysis. Continuing down section, station L-PW-003 over a sand and caliche layer showed 15.1 ppm eU while the U determined by disequilibrium analysis showed only 7.9 ppm, and the sample did not appear to be in equilibrium (App. C). The reason for the discrepancy in the two uranium determinations is probably the same as discussed previously for sample L-HW-002 from the Blanco Formation, (i.e., introduction of Ra-226 or leaching of U-238 from the location). Station L-PW-004 was made over a caliche exposure which contained thin red and yellow sand layers (App. A). The hand-held spectrometer reading over this layer yielded 7.2 ppm eU while the disequilibrium analysis showed 13.0 ppm uranium. If sample L-PW-003 is deficient in uranium because of leaching, L-PW-004, which shows an excess of uranium, could be the zone in which the uranium has been reprecipitated. The correctness of this hypothesis is perhaps greater than that in the case of the Blanco because the uranium concentrations are higher.

Three additional in situ spectrometer assays (Post A, B, and C) were made along truck spectrometer Line 21 (Pl. 37a). Post A was

located about at truck mileage 8.65 where the Dockum (Triassic) outcrops (Barnes, 1967) at the edge of the cap rock. Post B was located at mileage 8.4, mapped as the Tule - Ogallala (Pliocene) contact, over an exposure of caliche soil on caliche outcrop, and Post C was located at mileage 8.2 over a caliche exposure mapped as Tule. Slightly higher eU and eU/eTh hand-held spectrometer determinations were recorded over these stations than were observed in the truck survey, with hand-held spectrometer eU values between 5.1 and 6.2 ppm and eU/eTh ratios between 0.6 and 1.1. The correlation between the hand-held spectrometer data and truck-mounted spectrometer data was not striking.

The airborne reconnaissance, the truck-mounted reconnaissance, and the hand-held spectrometer surveys all showed anomalously high ^{214}Bi and eU values (App. F) over portions of the Tule Formation exposure around the valley of the Double Mountain Fork of the Brazos River. Lateral inhomogeneities may explain why most of the higher values were recorded on the north side of the valley. The highest readings in this area in the hand-held spectrometer assays occurred over caliche outcrops, and the amount of eU recorded by the hand-held spectrometer and geochemical surveys appears to be directly proportional to the amount of caliche in the outcrop of rock sample. Caliche presence was reported in Tule Canyon north of the Lubbock Quadrangle (Brown, 1956) where anomalous uranium-bearing rock was discovered.

The Tule Formation in the Double Mountain Fork of the Brazos River is interpreted as a favorable area for uranium deposition although large quantities may not be present because of the limited amount of Tule present. The uranium in this area is interpreted as being trapped

in the caliche and therefore may extend into units other than Tule. The high ^{214}Bi and eU values and the high $^{214}\text{Bi}/^{208}\text{Tl}$ and eU/eTh ratios recorded in this area suggest that the Tule should be investigated in greater detail.

Windblown Cover Sands

The aerial radiometric survey data recorded over the windblown sands (Pleistocene) which cover most of the High Plains area of the Lubbock 1° x 2° Quadrangle (Pl. 2) showed low ^{214}Bi values (Pls. 6 and 12) which generally did not rise above +10. A few areas exhibited a radiometric response more characteristic of the Ogallala Formation (Pliocene). The higher ^{214}Bi values over mapped windblown sands on the High Plains are interpreted to be an effect of thinner sand cover over the underlying sediments. The ^{208}Tl recorded over the windblown cover sands showed a striking increase from the south to the north end of the Lubbock Quadrangle (Pls. 7, 13, and 21). Because the ^{214}Bi showed a slight increase to the north, the $^{214}\text{Bi}/^{208}\text{Tl}$ ratio remained relatively constant over the windblown sands across the entire quadrangle although the ratio was somewhat lower towards the north. ^{40}K values over the windblown sands were uniformly low, seldom rising above +10.

Radiometric data collected over the windblown cover sand by the truck-mounted spectrometer were evaluated to determine if the eU and eTh values increased from south to north as they did in the airborne radiometric survey (Fig. 31). The eU values recorded by the truck-mounted spectrometer survey during the summer 1978 survey were in the 2 to 3.5 ppm range in the southern part of the quadrangle and in the

Figure 31. Change in eTh background observed in truck-mounted spectrometer data over the High Plains from south to north in the Lubbock 1° x 2° Quadrangle (Pl. 4).

3.5 to 4.5 ppm range in the northern part of the quadrangle. During the January and February 1979 survey, the truck-mounted spectrometer recorded eU values in the range of 4 to 5 ppm in the northern part of the quadrangle over the windblown cover sands. The higher winter values with respect to the summer values are seen over other geologic units. The eTh values increased to the north with most eTh readings in the southern part of the area being less than 7 ppm while responses on the northern end of the quadrangle were as high as 11 ppm. eU/eTh ratios were generally in the .4 to .6 range.

As in the airborne survey, several truck lines showed slightly higher eU values over areas mapped by Barnes (1967) as windblown cover sands. Miles 3.5 to 6.5 of Line 61 (Pl. 54) and miles 8 to 18.5 of Line 81 (Pl. 68a) showed higher eU and eU/eTh ratios than the surrounding sands. Along Line 61, miles 3.5 to 6.5 showed eU values in the 4 to 6 ppm range and eU/eTh ratios in the .9 to 1.1 range and miles 8 to 18.5 of Line 81 showed eU values of 4 to 5.5 ppm and eU/eTh ratios of .7 to 1.2.

Along Lines 461 (Pl. 107) and 221 (Pl. 95c) the eU over the windblown cover sands was actually higher than over the Ogallala (Pliocene) and Dockum (Triassic) units exposed to the east. This was also observed in the airborne radiometric data and the hand-held spectrometer data.

Hand-held spectrometer stations L-AW-001, L-AW-002, L-AW-004, L-AW-005, L-DE-007, L-GW-001, L-GW-002, L-HW-011, L-MW-001, L-MW-002, L-MW-007, L-MW-008, L-MW-014, L-PW-010, and L-PW-014 (Pl. 5, App. A)

were all made over exposures of brown to red-brown sandy soil, generally in plowed fields. The maximum eU recorded by the hand-held spectrometer at any of these stations was 2.8 ppm (App. B). Disequilibrium analysis of a sample from station L-AW-001 yielded 2.9 ppm U in a nonequilibrium state and 7.3 ppm Th while the hand-held spectrometer assay at station L-AW-001 yielded 2.1 ppm eU and 11.4 ppm eTh. The increase in ppm eTh to the north over the windblown sands was also observed in the hand-held data (Pl. 19).

Hand-held spectrometer traverse DE and truck-mounted spectrometer Line 221 were along the same road (Pls. 4 and 95d). The truck survey data and the hand-held survey data both indicate that the eU is higher over the windblown cover sands (Quaternary) than over the Ogallala and Dockum sediments.

The aerial radiometric survey data, the truck-mounted spectrometer survey data, and the hand-held spectrometer survey data all indicate that the eU and eTh values over the High Plains cover sands increase to the north. The cause for this increase is not known. However, the sand thickness is known to increase to the north (Reeves, 1966 and 1971) and this could be a factor. Additionally the grain size of the sands may be smaller to the northeast because of the wind direction. Perhaps the resistates are finer-grained than the other sand material and are thus accumulated towards the northeast. The highest eTh and eU values in the cover sands of the Lubbock area are in the north-central portion of the quadrangle. This area is northeast of Blanco Canyon where Pierce (1974) has noted the presence of volcanic ash in the cover sands. The gradient observed in the eTh and eU values may be a result

of a greater accumulation of volcanic ash in the northeast than in the southern part of the quadrangle as a function of ground level aeolian transport..

Although the ^{214}Bi and eU values observed over the windblown cover sands (Pleistocene) increase to the northeast, the ppm eU remains low (App. F). Thus, the windblown sands are not considered to be significant uranium-bearing hosts and are regarded as unfavorable for exploration targets. However, because of the presence of volcanic ash, the windblown cover sands may be a source of uranium.

The Tahoka Formation

Several anomalously high ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ locations were observed in the airborne radiometric survey over Tahoka Formation (Pleistocene) deposits (Pls. 2 and 21). The ^{214}Bi over the Tahoka Formation fell below -10 only in Guthrie Lake Basin. ^{214}Bi responses as high as +5.50 were recorded in Double Lakes Basin and $^{214}\text{Bi}/^{208}\text{Tl}$ responses over Tahoka sediments rose to as much as +180. ^{208}Tl values generally occurred at or below the mean (calculated for the Lubbock Quadrangle) in the lake basins and ranged from +10 to -20. ^{40}K values also tended to cluster around the mean, ranging from +1.50 to -20.

The highest amplitude anomalies in the aerial radiometric data over Tahoka deposits were recorded in Double Lakes Basin. Flight lines TL-10 and ML-6 sampled Tahoka sediments in Double Lakes Basin. High amplitude anomalies were observed along both lines. ^{214}Bi anomalies over the Double Lakes Basin were above +3.50 and as high as +5.50 and $^{214}\text{Bi}/^{208}\text{Tl}$ ratios were in the +80 to +180 range.

Significant anomalies in the airborne radiometric data were also observed over Tahoka Lake Basin. Along flight line ML-6 the ^{214}Bi rose only to +20 and the $^{214}\text{Bi}/^{208}\text{Tl}$ ratios of +90 were recorded, while the ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ responses along TL-9 rose to +50 and +60, respectively.

Guthrie Lake Basin was sampled by flight lines ML-2, ML-3, and ML-4. The maximum ^{214}Bi values occurred along ML-4 which displayed values in the +2.50 range over Tahoka sediments along most of the line. On the east side of Guthrie Lake Basin along ML-4 the $^{214}\text{Bi}/^{208}\text{Tl}$ ratio rose to +40. No ^{214}Bi or $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies were observed along flight lines ML-2 and ML-3 over Tahoka sediments in Guthrie Lake Basin.

Twin Lakes Basin showed the lowest response of any of the pluvial lake basins in the Lubbock Quadrangle. There were no anomalies observed over Twin Lakes Basin along flight line ML-4, and the ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ values along TL-10 were only in the range of +1.50 and +30, respectively.

The only other exposure of Tahoka sediments mapped in the Lubbock Quadrangle occurs along the southern border of the quadrangle at about 101°35'W. No anomalies were observed along ML-1 which traversed this exposure.

The truck-mounted survey data did not strongly support the existence of anomalous uranium concentrations in the Tahoka Formation sediments. This could partially be explained by sampling problems (Pl. 4). That is, the truck was not able to traverse areas sampled by the airborne radiometric survey.

Double Lakes, which showed the highest anomalies over Tahoka sediments in the airborne survey, also yielded the highest eU values in the truck survey. Line 62 (Pl. 56) traversed the northern part of Double Lakes Basin (Pl. 4) and the portions of the line over Tahoka sediments showed eU responses in the 4 to 5 ppm range and eU/eTh ratios in the .8 to 1.2 range.

Guthrie Lake Basin was sampled most extensively by the truck-mounted spectrometer survey. Lines 31 (Pl. 42), 42 (Pl. 46), 43 (Pl. 47), and 491 (Pl. 111) sampled Tahoka sediments in Guthrie Lake Basin. The low eU, eTh, and K values recorded over mapped Tahoka exposures along Line 43 suggest that this area may be sand-covered (Recent). No anomalies were observed along Lines 31 and 491 over Tahoka deposits. However, eU values in the 4 to 5 ppm range were recorded along Line 42 and eU/eTh values in this area were in the .7 to .9 range.

Tahoka deposits in Tahoka Lake Basin were only sampled for a short distance along the south end of the exposure in this lake basin. No anomalies were recorded in this area and eU values were commonly in the 3 to 3.5 ppm range. No anomalies were observed in the truck spectrometer data collected in Twin Lakes Basin along Line 41 (Pl. 45), probably because of sand cover.

The Double Lakes Basin was sampled by the hand-held spectrometer near the location of airborne radiometric survey anomalies. The hand-held data verified the high uranium concentrations suggested by the airborne survey. Two traverses (Stations L-NW-004 through L-NW-013 and Stations L-NW-014 through L-NW-021) were established across Double Lakes

(Pl. 5) and three additional stations (L-NW-001, L-NW-002, and L-NW-003) were located where a small drainage flowed into Double Lakes.

High eU values were recorded by the hand-held spectrometer over station L-NW-001, L-NW-002, and L-NW-003 (App. B, Pl. 18). However, the disequilibrium analysis indicated very high uranium concentrations (App. C). A sample of caliche and evaporite at station L-NW-001 yielded 11.5 ppm eU in situ (App. B) while the disequilibrium analysis showed 95 ppm in a uranium-enriched environment (App. C). This caliche is not the cap rock caliche but a more recent caliche skin. Station L-NW-002 (caliche and evaporite, App. A) showed a slightly higher eU in situ than L-NW-001. However, the disequilibrium analysis showed less U (22.9 ppm). The analysis suggests that although the sample is uranium-enriched, it is not as uranium-enriched as L-NW-001. Sample L-NW-003 (caliche), which yielded 7.3 ppm eU in situ, also appears to be uranium-enriched and assayed at 14.9 ppm in the disequilibrium analysis.

Stations L-NW-004 through L-NW-013 traversed the north end of Double Lakes (Pl. 5). eU values along this traverse ranged from 1.7 ppm at station L-NW-008 to 11.4 ppm at L-NW-011 (App. B). eTh and K values were moderate, generally ranging from approximately 4 to 8 ppm eTh and 1 to 1.3% K. Sample L-NW-008 had low eU, eTh and K values and is interpreted to be alluvial cover (Recent) (App. A). The other stations along this traverse were over fine brown sand which contained varying amounts of caliche. The disequilibrium analysis on sample L-NW-006 yielded 14.4 ppm U in a uranium-enriched environment (App. C). L-NW-001 may be slightly uranium-enriched. The other samples (L-NW-005 and L-NW-007) did not appear uranium-enriched and showed the same or lower

concentrations of uranium in the disequilibrium analyses and the in situ assays.

The second traverse across Double Lakes was run near the north-south center of the lake. Stations L-NW-014 through L-NW-021 were evaluated with the hand-held spectrometer (Fig. 32) and with disequilibrium analyses (App. C) except for station L-NW-019 which was only evaluated in situ. The lowest uranium concentrations observed along this traverse were at the ends of the line (stations L-NW-014 and L-NW-021) where eU responses of 3.4 and 3.0 ppm were recorded by the hand-held spectrometer, respectively, and disequilibrium analyses yielded 4.3 and 3.6 ppm U suggesting that either the samples were uranium-deficient or RA-226 enriched. Samples L-NW-016, L-NW-017, L-NW-018, and L-NW-020 all yielded greater than 10 ppm U in the disequilibrium analyses and generally suggested either a uranium-enriched environment or a system near the equilibrium.

The airborne radiometric and hand-held spectrometer data indicate that anomalous concentrations of uranium exist in the large pluvial lake basins. Although the truck data do not strongly support this, it is theorized that this is largely a sampling problem. Although the areas of anomalous uranium concentration are mapped at Tahoka Formation, a more recent caliche skin on the lake sediments is interpreted to be the primary source of these radiometric anomalies. The source could be the volcanic ashes in the windblown sands (Pleistocene) and perhaps the Ogallala Formation (Pliocene). The reducing environment could be provided by organic material within the lake sediments or by Cretaceous sediments which are exposed in a number of the lake basins. Thus, the

Figure 32. eU, eTh, and K values over Double Lakes along traverse L-NW-014 - L-NW-021 (Pl. 5).

pluvial lake basins are regarded as favorable exploration targets.

The Playas

Evaluation of the aerial radiometric data over the playas (Pleistocene) was undertaken to determine if there might be some correlation between the anomaly pattern and type of playas. It was hoped that the anomaly pattern over playas which bottom in the Pliocene cap rock would be different than the anomaly pattern over playas which bottom below the cap rock and that the different anomaly patterns could then be used to evaluate the uranium potential of the underlying sediments.

The anomalies over the playas varied although the observed "anomalies" were all lower in amplitude than the major anomalies observed in the Lubbock 1° x 2° Quadrangle. The playas generally did not show ^{214}Bi values as great as +10. Therefore, analysis of the playas used a different set of criteria than was used for the total quadrangle. A qualitative evaluation of the aerial data began by tabulating the ^{214}Bi , ^{208}Tl , ^{40}K , and $^{214}\text{Bi}/^{208}\text{Tl}$ ratio of each playa which lay beneath a flight line from the 1:62,500 scale parameter plots. Values greater than approximately +0.250 were considered "high," values less than approximately -0.250 were called "low," and those which occurred between the two limits were considered "moderate." These relative values were posted on a 1:250,000 scale map. Three groups of playas were observed: those with a "high" ^{208}Tl and a "low" $^{214}\text{Bi}/^{208}\text{Tl}$; those with a "high" ^{214}Bi and a "high" $^{214}\text{Bi}/^{208}\text{Tl}$ ratio; and those which showed "moderate" or "low" ^{214}Bi , ^{208}Tl , and ^{40}K values.

Approximately 130 of the 400 playas sampled by the airborne radiometric survey showed "moderate" or "low" values of ^{214}Bi , ^{208}Tl , and ^{40}K . These playas are interpreted to have had water in them at the time of the survey though this was not verified by viewing the flight tracking photographs. Thus, the true ^{214}Bi , ^{208}Tl , and ^{40}K values of the material which comprises these playas were masked. A second map was then constructed which showed only those playas which registered a relative "high" ^{214}Bi and/or a relative "high" ^{208}Tl response. There was no apparent pattern to the distribution of playas with "high" $^{214}\text{Bi}/^{208}\text{Tl}$ ratios ("high" ^{214}Bi) and those with "low" $^{214}\text{Bi}/^{208}\text{Tl}$ ratios ("high" ^{214}Bi) and those with "low" $^{214}\text{Bi}/^{208}\text{Tl}$ ratios ("high" ^{208}Tl) and those with "low" $^{214}\text{Bi}/^{208}\text{Tl}$ ratios ("high" ^{208}Tl). Higher values of both ^{214}Bi and ^{208}Tl , following the same pattern that was observed in the windblown cover sands (Pleistocene), were observed in the northern part of the High Plains.

Ground-checking substantiated the patterns observed in the airborne radiometric survey. No eU anomalies were observed over the playas in the truck-mounted spectrometer survey. Playas from each "group" ("high" $^{214}\text{Bi}/^{208}\text{Tl}$, "low" $^{214}\text{Bi}/^{208}\text{Tl}$, and "low" or "moderate" ^{214}Bi , ^{208}Tl , ^{40}K) were sampled with the hand-held spectrometer (App. A). These playas all showed low eU in the 1.3 to 3.1 ppm range, eTh values in the 7.5 to 12.0 ppm range and K values in the 0.9 to 1.6% range (App. B). Disequilibrium analysis of a sample of a hard, gray-brown clay from station L-GW-004 yielded 2.6 ppm U, 8.1 ppm Th and suggests that uranium has been leached from the system (App. C). No obvious gradient in the eU values from south to north was observed in the hand-held spectrometer data, but this was not surprising because of the

small number of data points. K values appeared to be relatively higher (in the .9 to 1.9% range) in the playa bottoms than in the surrounding windblown sand (Pleistocene). This response was expected because of the higher clay content of the playa bottoms.

The playas sampled with the hand-held spectrometer were all dry. Thus, the lack of any distinguishable differences in the anomaly shapes between the three "groups" of playas suggests that the "anomalies" observed in the aerial radiometric data were all a function of the amount of water contained within the playas at the time of the survey. The aerial anomalies, therefore, are of minimal usefulness in predicting subsurface geology. In addition, the low eU and ^{214}Bi values recorded over the playas suggest the small playa lakes are not significant uranium-bearing units.

Terrace Deposits

Determining a characteristic radiometric response over the terrace deposits (Pleistocene) was difficult because of limited exposures with respect to the flight line coverage. The observed responses were often influenced by the responses of surrounding material. In addition, the different terrace levels (Barnes, 1967) may have different radiometric responses as a function of the material from which the terraces were derived. Because of these factors a wide variation in the radiometric signatures with no apparent pattern was recorded over the terrace deposits. There were no anomalous areas in the terraces. The ^{214}Bi values are all below +20 over the terraces.

The truck-mounted spectrometer data also indicated that no eU anomalies exist over the terrace deposits. Ground-checking of the terraces revealed that they were often difficult to distinguish from older sediments such as the Ogallala (Pliocene). Hand-held spectrometer stations L-DE-101 and L-DE-104 (Pl. 5) were made over sediments mapped as Ogallala (Pliocene) but which resembled terrace deposits (App. A). These stations showed hand-held spectrometer eU responses of 2.6 and 2.1 ppm, respectively, and laboratory analysis of a sample from station L-DE-101 yielded 1 ppm U_3O_8 . Stations L-AW-103, L-DE-105, L-DE-108, L-FE-106B, and L-HW-102 were located over sediments interpreted to be terrace deposits (App. A). A thin veneer of sand (Recent) covered the terrace deposits at stations L-DE-105 and L-FE-106B, and the readings at these stations were made at exposures of terrace deposits in road cuts. The maximum eU value at any of these stations was 3.0 ppm (Pls. 5 and 18).

The low eU and ^{214}Bi values recorded by the airborne, truck-mounted, and hand-held spectrometer surveys suggests that the terrace deposits are not uranium hosts. The apparent permeability of these deposits would be conducive for leaching of uranium from the deposits and therefore they may have uranium source potential.

Windblown Sand

The airborne radiometric response over the windblown sand (Recent) was extremely predictable and has been discussed earlier in this report. The Recent sands were characterized by ^{214}Bi , ^{208}Tl , and ^{40}K values which all fell below the mean calculated for the entire quadrangle

(Fig. 25, Pl. 21). Although the $^{214}\text{Bi}/^{208}\text{Tl}$ and $^{214}\text{Bi}/^{40}\text{K}$ ratios fluctuated greatly, the $^{208}\text{Tl}/^{40}\text{K}$ ratios were smoother and were generally below the mean.

The truck-mounted spectrometer data displayed the same predictably low eU, eTh, and K responses over the sands. During the summer 1978 truck survey, eU values of 2 to 3 ppm were common over the sands while eTh values of 2.5 to 5.5 ppm and K values of .5 to .9% were prevalent. During the second survey somewhat higher eU values were generally observed but these values were still low for the survey.

Similarly, hand-held spectrometer readings over the sands, which were often mapped as older units, displayed low eU, eTh, and K responses with eU values generally less than 2.5 ppm.

The low ^{214}Bi and eU values recorded over the cover sands (Recent) indicate they were unfavorable uranium hosts.

Quaternary Alluvium

In general the alluvium (Recent) exposed in the river valleys in the Lubbock 1° x 2° Quadrangle displayed low ^{214}Bi , ^{208}Tl , and ^{40}K responses in the aerial data similar to the windblown sands (Recent). Often the exposures of alluvium traversed in the airborne survey were limited in extent and therefore the radiometric response was sometimes affected by the response over adjoining sediments when the smoothing operator was applied.

The truck-mounted spectrometer verified the lower radiometric responses observed over the alluvium in the airborne radiometric data.

The low ^{214}Bi , and eU values observed over most of the alluvium suggest that it is not a uranium host rock. The uranium transported into the alluvium from older sediments will tend to be washed out of the area in the absence of a trapping mechanism.

Integration of NURE Data Sets

The integration of NURE and other data sets is the third stage in the interpretation process. In stage one of the interpretation process, the obvious radiometric anomalies were identified. Depending upon the geology and the uranium resources in any given area, this could be the extent to which the NURE aerial data are applied in exploration. Stage two of the interpretation process, involving more sophistication than stage one, leads to detailed information about the radiometric response of each geologic unit and an estimation of each unit's potential for uranium mineralization. Of course, stage one merges into stage two.

The Dockum Group (Triassic), which exhibited extensive areas of large ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies, is an example of an area identified after stage two of the interpretation process. Upon careful examination, the basal Dockum appeared to consistently show anomalous ^{214}Bi and $^{214}\text{Bi}/^{208}\text{Tl}$ (Pl. 22) and anomalous uranium in the HSSR groundwater analyses. Again, depending upon the geology of the area and the exploration target, stage two effort might be sufficient to define areas for ground checking or additional radiometric or other geophysical surveying. However, in the same manner that stage one merges into stage two, the effort in stage two lays the groundwork for stage three of the interpretation process.

In stage three of the interpretation process, all of the data on hand are integrated in the hope of identifying the more subtle features which could lead to the development of an exploration model for part of the region. In this context, an exploration model includes considerations of the source of the uranium, the transport and concentration of uranium minerals, and host rocks. Stage three of the interpretation process is the stage at which the question of the utility of the NURE Program data sets for exploration can be addressed. That the data can be integrated to present an exploration model for this area is a function of the geology of this area. In other areas, more or fewer models might be generated at this level of the interpretation.

The process in stage three of the interpretation which leads to the definition of an exploration model starts by recognizing features in the NURE data sets which suggest uranium occurrences, in the case of the Lubbock 1° x 2° Quadrangle, high ^{214}Bi , high $^{214}\text{Bi}/^{208}\text{Tl}$, or high uranium concentrations in the HSSR samples. This recognition, essentially aspects of stages one and two of the present study, generally identifies host rock locations. The geologist works backwards from this point to find evidence for uranium source material, a transportation mode, and a concentration mechanism in order to complete the exploration model. The basal Dockum (Triassic) is an example of this procedure applied to very obvious anomalies in the NURE data sets. The Dockum contains sorted continental clastic material and organic debris and could be considered to host uranium in sandstone roll front-type deposits. The source of the uranium could be Tertiary volcanic ash falls, or as is suggested by the direct relationship between uranium concentration and silicate percentage in samples L-JW-002, L-JW-003, and L-NE-001 (Apps. B, C, D),

could be from sediment actually deposited in the Dockum basin during Triassic time. The transportation mode was via groundwater and possibly surface water, and concentration occurred at reduction fronts where organic material existed in the basal Dockum sediments or at the interface between the basal Dockum and underlying Permian shales.

The model presented in the following discussion relies upon the concept of geographical association of features more subtle than those in the case of the basal Dockum (Triassic). The features are seen in the aerial, ground, and subsurface data. The development of this model requires nothing more than the meticulous application of standard geologic methodology. The relationships upon which the model is based can be extracted from the parameter profile maps (or, with somewhat more difficulty, from the aerial contractor's presentations) and from other data displays which the geologist would normally prepare during the course of an investigation.

In preceding discussions of the radiometric and geochemical responses of the individual geologic units exposed in the Lubbock 1° x 2° Quadrangle, numerous uranium anomalies were noted generally in the southwestern quarter of the quadrangle. Many of these were seen to correspond to outcrops of basal Dockum (Triassic) sandstone and conglomerate. However, other significant anomalies were seen over the various Quaternary lake basins (Tahoka, Guthrie, Double Lakes, Spring Creek, Blanco, and Benson) (Pl. 23). Also in the southwestern quarter of the study area is the large Slaton (Wood Ranch) anomaly (Pl. 23). Of the significant non-Dockum anomalies in the southwestern quarter of the study area, the Slaton anomaly is the only large $^{214}\text{Bi}/^{208}\text{Tl}$ anomaly which does not seem to coincide with a

Pleistocene lake location (Pls. 2, 9, and 15). The significance of this will be given later.

From the NURE data sets, possible uranium host rocks were defined in non-Dockum sediments. The source for the uranium recognized in the NURE data anomalies is Tertiary and Quaternary volcanic ash deposits which various investigators have observed in the Cenozoic sediments in the Lubbock area (e.g., Pierce, 1974; Waechter, pers. comm.). The transportation mode is through the oxidizing groundwaters flowing through the Quaternary and the Tertiary sediments. All of the facets of the model are identified except for the concentration mechanism. Moreover, the data suggest more than one concentrating mechanism and thus allow a large subsurface region to be fit into the model and to be outlined for more exploration. This, of course, is the objective of defining the model.

Because the model involved a sequence of events, origin, transport, concentration, and because numerous uranium anomalies are associated with the Pleistocene lake basins, an explanation of the origin of the lakes is in order. Cretaceous rocks formed positive topographic features through the Tertiary (Figs. 7 and 10). During the more humid Quaternary, it is postulated that karst topography developed over the Cretaceous units. Collapse features evolved, the largest of which ultimately became the Pleistocene lake basins. Of the Pleistocene lake basins, the Blanco Canyon Basin is the only one not near Cretaceous rock outcrops (Pl. 2) and thus does not fit the origin pattern for the other lakes. The significance of this will be brought into perspective later.

The Pleistocene lakes are providing the concentration mechanism to complete the model. The uranium minerals are leached from the Quaternary sediments and from the Ogallala Formation (Tertiary). In part, the uranium is concentrated by evaporation in the closed basins. In addition, organic material in the lakes provides a reductant for concentrating the uranium. A second source of reducing material is proposed for the Pleistocene basins. Because of the proximity of the basins to Cretaceous rock units (Pl. 23), it is suggested that reducing agents may be issuing into the lake environments from the Cretaceous rocks. If this is the case, a key is provided for explaining the Slaton (Wood Ranch) anomaly, other anomalies in the Ogallala (Tertiary), and for extending the area for exploration to the region north of the City of Lubbock.

In order to see the extent of the Cretaceous rocks in the subsurface in the western half of the study area, Cronin's (1961) map of the elevation of the base of the Ogallala (in part presumed to indicate the top of the Cretaceous) (Fig. 10) and Brand's (1974) map of the extent of the Cretaceous rocks were combined (Pl. 23). In some areas, the eastern edge of the Cretaceous rocks appears to have a relatively steep contact with the Ogallala (e.g., Pl. 28). This steep front is probably analogous to the modern High Plains Escarpment. Comparing Plate 23 and Plate 21, the proximity of the Slaton anomaly to the front of the Cretaceous rocks is evident. The Slaton anomaly is also down the hydraulic gradient from the Cretaceous - Ogallala contact. Groundwater percolating through the Cenozoic sediments leaches the uranium and carries it toward the lakes, the valleys, and the High Plains Escarpment. Reductants in the lakes, either from Recent or Cretaceous age organic matter precipitate the uranium in the lakes (e.g., Sample L-NW-002, App. C). Waters moving slowly

through the Cretaceous rocks pick up reductants which cause the uranium to precipitate in the Ogallala sediments in a groundwater mixing zone (reduction-oxidation front) east of the limit of the Cretaceous rocks. Uranium which reaches the valleys, such as the Yellow House Canyon, is flushed downstream as is suggested by the stream water analysis in the HSSR report (Pl. 8 in Nichols, et al., 1977).

The next step is to test the hypothesized Cretaceous front model in the area where surface and subsurface control exists. Plate 23 presents the limit of the Cretaceous rocks as derived from Cronin (1961) and Brand (1974). Northwest of the Slaton (Wood Ranch) anomaly, in Yellow House Canyon, a small anomaly can be seen east of the eastern edge of the Cretaceous rocks. Farther upstream in Yellow House Canyon is the Benson Lake anomaly, not far from exposures of Cretaceous sediments. South of the Slaton anomaly, on flight line ML-10 and ML-9 (Pl. 28) east of the Cretaceous margin, are two anomalies lower in amplitude than the Slaton anomaly.

The windblown sand probably obscures many Ogallala anomalies which are related to the Cretaceous front model and thus limits the number of places where the hypothesis can be tested. On line ML-7, the sand cover is absent and Ogallala is exposed. Interestingly, the Ogallala is thin here so that the Cretaceous is close to the surface (Cronin, 1961) (Pl. 31). A high uranium response is noted at this location (Pl. 28). On line ML-8, a smaller $^{214}\text{Bi}/^{208}\text{Tl}$ anomaly is seen northeast of the anomaly on ML-7. Here, the geology map (Barnes, 1967) does not indicate that the Ogallala is exposed. However, the Cretaceous is close to the surface (Pl. 31) and a small anomaly is visible.

The Slaton (Wood Ranch) anomaly and the smaller anomalies on lines ML-7, ML-8, ML-9, ML-10, and ML-12 fit into a pattern of anomalies in Ogallala sediments which are close to the contact of the Ogallala with the Cretaceous. The Ogallala exposures would be expected to have a certain amount of uranium leached from them by the oxidizing environment at the surface. Therefore, the hypothesis that these anomalies may be clues to greater uranium concentrations generally westward from the anomalies themselves is formed. Greater concentrations to the west are suggested by the HSSR data (Pl. 28) in the Slaton, et al., Quadrangle. The HSSR data in the New Lynn, et al., Quadrangle (Pl. 29) is even more impressive, but the radiometry is not as striking as in the Slaton, et al., Quadrangle.

The exploration model which relates the Cretaceous rocks and the Ogallala Formation suggests a direction for the geologist to continue his search (Pl. 22). It does not define a drilling or mining location, but it might provide additional information for the acquisition of property or more geophysical surveying. The hypothesis can be used to extend the area for the more detailed search into the area north of the City of Lubbock. Several anomalies can be identified along flight lines ML-13, ML-16, and ML-18 in the Lubbock 1:62,500 Quadrangle (Pls. 23 and 30). These anomalies are over an area where Cretaceous rocks are shallowly buried in the subsurface. Comparison of the $^{214}\text{Bi}/^{208}\text{Tl}$ profile map (Pl. 30) and the geologic profiles map (Pl. 32) for the Lubbock 1:62,500 Quadrangle indicates that the larger of these anomalies, the ones south of the City of Lubbock on ML-13 and the one north of the city on ML-16 are not over mapped (Barnes, 1967) exposures

of the Ogallala (Pliocene). However, the sands could be thinner or absent at these locations. The few HSSR samples in this area help to support the extension of the model north of Lubbock, but the geochemical data are far from conclusive.

Comparing the approximate area in the subsurface where Cretaceous rocks occur with the ^{214}Bi and the $^{214}\text{Bi}/^{208}\text{Tl}$ 1:250,000 scale maps (Pl. 23) and the HSSR data (Nichols, et al., 1977) indicates other high count rates or high uranium concentrations near the Cretaceous rocks. The model can be extended, perhaps, at this point to include the Blanco Canyon area. Though no Cretaceous units are known at the surface or nearby in the subsurface in the vicinity of Blanco Canyon, Blanco Canyon is down the hydraulic gradient from the locations where the Cretaceous is in the subsurface.

The question of whether the NURE data can be used to generate exploration models can be answered affirmatively. In the Lubbock $1^{\circ} \times 2^{\circ}$ Quadrangle study area, a relationship appears to exist between the location of Cretaceous rocks and the location of significant aerial radiometric anomalies and HSSR anomalies. The hypothesis stemming from the observed relationship was only tested in the Lubbock study area. Other areas near the Lubbock study area could be tested to see if this is truly a regional feature or merely a relationship which appeared in this limited data set. The hypothesis could perhaps be further tested in the Lubbock area with additional subsurface data.

Summary of the Interpretation Technique

The NURE Program data sets can be used for a variety of geological activities ranging from identifying obvious radiometric features, both at a regional and local level, to generating uranium exploration models. The following summary outlines the basic elements applied in the present study and suggests their utility for similar studies in other areas.

Display of the Data

The aerial radiometric data should be presented at a horizontal scale of 1:250,000 for regional evaluations and a scale of 1:125,000 or 1:62,500 for more localized mapping. An appropriate vertical scale, in part as a function of the horizontal scale, should be selected which causes the minimum of overlapping of the data from flight line to flight line in the parameter profile map form of display. This is most easily accomplished if the data are replotted by computer. However, photographic enlargements of the aerial contractor's stacked profiles can be used. The single-parameter profile maps are more usable than the stacked profiles. Adding color to the parameter profile maps helps the interpreter to recognize relationships from line to line. This is particularly helpful in the 1:250,000 scale parameter profile maps for identifying regional features. The actual levels at which various colors are applied could be selected arbitrarily or by following statistical procedures such as presented by Saunders and Potts (1978). The display and the use of the aeromagnetic data will vary from area to area as a function of the geology and the anomalies exhibited.

Ground Truth

For each flight line, a topographic-geology profile should be constructed at the same horizontal scale as the radiometric profile. The vertical scale should be chosen in such a way that any effects of topographic changes or the surface geology are most easily seen in the aerial data. The best surface and subsurface geology available should be used in constructing the profiles. Comparison of the radiometric and the topographic-geologic profiles allow the typical response over each geologic unit to be identified. With sufficient resources, identifying the typical responses and isolating anomalies could be aided by the computer. The typical aerial radiometric response over a unit can be ground-checked with ground-based spectrometer systems. Geochemical analyses of soil, rock, and water samples and additional geologic mapping add needed detail to both airborne and ground spectrometer measurements. The geochemical analyses, HSSR and others, provide clues to disequilibrium and thereby can help to refine ideas of which radiometric responses are anomalous and which are not.

Integration of the Data Sets

Depending upon the objectives of the exploration programs, varying degrees of integration of NURE Program data sets will be needed. Overlaying of 1:250,000 scale radiometric parameter profile maps with HSSR geochemical analysis maps may be sufficient. However, for most areas, it is anticipated that careful tabulation of radiometric responses, coupled with field-checking of contacts and exposures will be needed. Moreover, incorporation of published geologic data from

sources other than the NURE Program will be needed.

The basic activity in the integration of the data sets is looking for geographical relationships between radiometric responses, geochemical anomalies, outcrop patterns, and topographic features. Data will need to be posted on secondary or interpretation maps and profiles. These themselves may undergo interpretation and further refinement. Upon combining the various data sets, patterns which evolve can be judged with regard to indicating favorable or unfavorable uranium occurrences.

CONCLUSIONS

The procedures and interpretations discussed in the preceding pages indicate some of the problems which can be encountered when using NURE data sets. Ambiguities in data always require a qualification of the interpretation based upon those same data. For the most part, the interpretations presented herein have assumed that the problems with the data are insignificant with respect to the general value of the data. The value of the data is that they can be used for exploration activities which require more areal detail than a quick look to find "hot spots" with obvious uranium anomalies. In many instances, these hot spots were detected in the 1950s. The Dockum (Triassic) has been known since the 1950s as a good potential uranium host. It is comforting that the new NURE data did detect uranium anomalies over the Dockum sediments.

The aerial data utilized in the present study are among the earliest acquired in the NURE program. Part of the incentive for the present study was to verify the quality of the aerial data. The truck-mounted spectrometer system provided a very large data set which qualitatively supported the aerial survey almost 100 percent. This is impressive considering the different effective sample volume seen by the two spectrometers. The use of the truck-mounted spectrometer system would be recommended as an effective ground follow-up system for airborne surveys in areas like Lubbock where roadways are copious. Hand-held spectrometer data provided verification for both the

truck-mounted and the airborne spectrometer systems. The hand-held spectrometer is considered an essential tool for the ground follow-up phase of a program such as the present one.

The manner in which the aerial data were presented facilitated the verification of the aerial data and the generation of exploration models. For an activity such as mapping surface radioelement distributions, the construction of single-parameter profile maps, either by computer or by photography, is critical. The careful comparison of the single-parameter profile maps with surface geology and topography is the heart of the process for interpreting aerial radiometric data and generating exploration models.

The most significant facet of the present study is the determination that the NURE data are of sufficient quality and quantity to be used to generate exploration models. Three models were derived from the data sets (Pl. 22). These involved the basal Dockum, the large pluvial lake basins, and the front of the Cretaceous. The first model suggests that the basal Dockum (Triassic) is a good exploration target. The Dockum was deposited over much of eastern New Mexico and northwestern Texas. The basal Dockum may be a good regional unit to investigate further for uranium occurrences. The pluvial lake basins are identified by large, obvious radiometric anomalies in the same way the basal Dockum is. The lake basins may be a separate province or may be an integral part of the Cretaceous front idea.

The Cretaceous front model is more speculative than the idea concerning the basal Dockum, but it does have merit. Of importance is that the model was derived from the NURE data sets and other information

in the public domain. This is a very important consideration. The largest percentage of persons involved in uranium exploration are in the nonmajor companies. These explorationists do not have the capability, for whatever reason, time, finances or background, to use highly sophisticated numerical techniques to isolate or evaluate anomalies. These persons would also, in general, rely heavily upon federal and state agencies and their publications for the data necessary to make initial and secondary decisions about an area. The use of manual techniques and public data sources was the heart of the present study. It is hoped that this report will provide encouragement for those who are endeavoring to apply the NURE data in a manual fashion, integrating them with other readily available information.

RECOMMENDATIONS FOR FUTURE WORK

A significant recommendation is that the airborne radiometric data of the NURE program be made more readily available to the smaller exploration companies in displays such as the 1:250,000 and 1:62,500 scale single-parameter profile maps used in this study. It is recommended that the NURE program offer as a standard product the single-parameter profile maps on 15' quadrangles such as were used in this study. These could then be selected and ordered from an appropriate office much as topographic and geologic maps are obtained. The data in the format of the original aerial radiometric contractor's report for this study area are not considered to be of optimum value for the detailed interpretation which will lead to generating exploration models.

Additional studies generally along the line of the present study are recommended for other regions. A number of questions raised during the present study could not be answered simply because of the geological environment of the Lubbock area. Other areas to study, applying the same manual methodology, could include areas with rugged terrain, more varied geology, and more geological structure. Other variables such as climate and vegetation cover could be secondary considerations in selecting other study areas.

The present report does not argue that the manual techniques are the best techniques to apply for the generation of exploration models. Another suggestion for future work would be to conduct a program in

which manual and computerized techniques were integrated. However, it is not proposed that a large step into computerization be taken. In the same sense, that any geologist can apply the manual techniques, many will be able to apply some computerized techniques. The medium-sized exploration companies have access to computer systems with limited graphical output capabilities either through small in-house systems or through timesharing networks.

The present study considered incorporating some tests of the basic integration of the computer and the manual techniques. This integration would have incorporated the method of statistical tabulations and graphs as presented in the Geodata International report (1975) and the manual identification of the location of geologic contacts as outlined in the present report in order to obtain a better numerical definition of the typical radiometric responses over the various geologic units. This was not done for two reasons. This was not part of the objective of the study, and the particular data set being interpreted was known to have problems on the data tape. Use of elementary computer techniques and small computer systems could compliment the establishment of smaller blocks of data, such as the 15' blocks (instead of 1° x 2° blocks) as mentioned above.

Any additional work which might be contemplated as a result of the present study and these recommendations should keep in mind that most of the persons endeavoring to use the NURE program data will not have large exploration resources to commit to a project. Any new research should be directed so that it can provide guidelines and data sets such

that these persons can make the greatest use of the data which are in the public domain to, it is hoped, provide the greatest public benefit.

ACKNOWLEDGEMENTS

G-Cubed Incorporated recognizes Bendix Field Engineering Corporation (BFEC) and the Computer Services Division of the Oak Ridge National Laboratory (ORNL) and gratefully acknowledges their assistance in this project. BFEC provided and operated a truck-mounted spectrometer system in the study area. BFEC also performed the Compton stripping of the data. BFEC collected samples and analyzed them for total U_3O_8 content and provided the results for inclusion in this report. ORNL plotted all of the aerial data utilized in the study.

BIBLIOGRAPHY

- Barker, F. G., and Scott, R. C., 1958. Uranium and radium in the ground water of the Llano Estacado, Texas and New Mexico: Am. Geophys. Union Trans. v. 39, p. 459-466.
- Barnes, V. E., (ed.) 1967, Geologic atlas of Texas, Lubbock Sheet; Texas Bu. Econ. Geol., scale 1:250,000.
- Bement, T. R., Susco, D. V., Whiteman, D. E., and Zeigler, R. K., 1977, Progress report--Geostatistics project of the National Uranium Research Evaluation Program, January - March 1977: Los Alamos Scientific Laboratory, GJBX (50)-77.
- Blakely, E. R., and Koos, W. M., 1974, Soil survey of Hale County, Texas: U.S. Dept. of Agri., Washington, D.C., 54 p.
- Blank, H. R., 1956, Salt flats of Kent and Stonewall Counties, Texas: Texas Jour. Sci., v. 8, p. 25-32.
- Brand, J. P., 1953, Cretaceous of Llano Estacado of Texas: Texas Bur. Econ. Geol. Rept. of Inves. no. 20, 55 p.
- _____, 1956, Cretaceous System, in Evans, G. L., and Brand, J. P., Eastern Llano Estacado and adjoining Osage Plains: West Texas Geol. Soc. and Lubbock Geol. Soc. Guidebook, p. 10-13.
- _____, 1974, Cretaceous System, in Meade, G. E., Evans, G. L., and Brand, J. P., Mesozoic and Cenozoic Geology of the southern Llano Estacado: Lubbock Geol. Soc. Guidebook, p. 45-49.
- Brown, C. N., 1956, The origin of caliche on the northeastern Llano Estacado, Texas: Jour. Geol., v. 64, p. 1-15.

- Cronin, J. G., 1961, A summary of the occurrence and development of ground water in the southern High Plains: Texas Water Develop. Board Bull. 6107, 104 p.
- _____, Follett, C. R., Shafer, G. W., and Rettman, P. L., 1973, Reconnaissance investigation of the Brazos River Basin, Texas: Texas Water Comm. Bull. 6310, 152 p.
- Eargle, D. H., 1956, Some uranium occurrences in West Texas: Texas Bur. Econ. Geol. Rept. of Inves. no. 27, 23 p.
- _____, and McKay, E. J., 1955, Permian and Triassic sediments in Northern Texas and Southern Oklahoma, in Geologic investigations of radioactive deposits: U.S. Geol. Survey, TEI-590, p. 257-262.
- Evans, G. L., 1948, Geology of the Blanco beds of West Texas: Geol. Soc. America Bull., v. 59, p. 617-619.
- _____, 1974, Cenozoic geology, in Meade, G. E., Evans, G. L., and Brand, J. P., Mesozoic and Cenozoic geology of the southern Llano Estacado: 1974 Lubbock Geol. Soc. Guidebook, p. 27-30.
- Finch, W. I., 1975, Uranium in West Texas--paper delivered June 3, 1975 AAPG-SEPM Rocky Mountain Section meeting, Albuquerque, NM: U.S. Geol. Survey Open File Rept. 75-356, 20 p.
- Frye, J. C., 1970, The Ogallala Formation--a review: Ogallala Aquifer Symp. Proc., Lubbock, Texas Tech. Univ., p. 5-15.
- _____, and Leonard, A. B., 1967, Buried soils, fossil mollusks and late Cenozoic paleoenvironments: Univ. Kansas Special Pub. 2, p. 429-444.
- Geodata International Incorporated, 1975, Aerial radiometric and magnetic survey of the Lubbock and Plainview geologic atlas areas of Texas: ERDA Contract No. AT(05-1)-1654, 42 p.

- Harbour, J., 1975, General stratigraphy, in Wendorf, F., and Hester, J. J. (eds.), Late Pleistocene environments on the southern High Plains: Fort Burgwin Research Center Pub. no. 9, p. 33-55.
- Hayes, W. C., 1956, Uranium prospects in West Texas, in Evans, G. L., and Brand, J. P., Eastern Llano Estacado and adjoining Osage Plains: West Texas Geol. Soc. and Lubbock Geol. Soc., 1956 Guidebook, p. 69-72.
- Jones, T. S., 1974, Permian System, in Brand, J. P., Evans, G. L., and Meade, G. E., Mesozoic and Cenozoic geology of the southern Llano Estacado: Lubbock Geol. Soc. Guidebook, p. 20-21.
- Kehle, R. O., 1972, Gulf Coast structure: origin of the Gulf of Mexico: Univ. of Texas Dept. of Geol. Sci., Lecture Notes, 152 p.
- McGowen, J. H., 1978, Triassic lacustrine basins--Texas, in Galloway, W. E., Kreitler, C. W., and McGowen, J. H., Depositional and ground water flow systems in the exploration for uranium--a research colloquium: Austin, Texas Bur. Econ. Geol., p. XI-1-XI-17.
- _____, Granata, G. E., and Seni, S. J. (in press), Depositional framework of the lower Dockum Group (Triassic), Texas Panhandle: U.S. Geol. Survey Grant no. 14-08-0001-G-153, 74 p.
- McKee, E. D., and Oriel, S. S., 1967, Paleotectonic maps of the Permian System: U.S. Geol. Survey Misc. Inves. Map I-450, 164 p.
- Nichols, C. E., Butz, T. R., Cagle, G. W., and Kane, V. E., 1977, Wide-spaced uranium geochemical survey in Plainview, Lubbock, and Big Springs Quadrangles, Texas: National Uranium Resource Evaluation Program, Rept. GJBX-73 (78), 71 p.

- _____, Kane, V. E., Browning, M. T., and Cagle, G. W., 1976, Northwest Texas pilot geochemical survey: National Uranium Resource Evaluation Program Rept. GJBX-60(76), 58 p.
- Nicholson, J. H., 1956, General geologic history of the Palo Duro Basin, Texas Panhandle, in Evans, G. L., and Brand, J. P., Eastern Llano Estacado and adjoining Osage Plains: West Texas Geol. Soc. and Lubbock Geol. Soc., 1956 Guidebook, p. 54-59.
- Nordstrom, P., 1978, personal communication.
- Peters, L. J., 1949, The direct approach to magnetic interpretation and its practical applications: Geophysics, v. 14, p. 290-320.
- Pierce, H. G., 1974, The Blanco beds, in Meade, G. H., Evans, G. L., and Brand, J. P., Mesozoic and Cenozoic geology of the southern Llano Estacado: Lubbock Geol. Soc. Guidebook, p. 9-16.
- Reeves, C. C., Jr., 1966, Pluvial lake basins of West Texas: Jour. Geol., v. 74, p. 269-291.
- _____, 1970, Origin, classification, and geologic history of caliche on the southern High Plains, Texas and eastern New Mexico: Jour. Geol., v. 78, p. 352-362.
- _____, 1971, Relation of caliche to small natural depressions, southern High Plains, Texas and New Mexico: Geol. Soc. America Bull., v. 82, p. 1983-1988.
- _____, 1976, Caliche: Lubbock, Estacado Books, 233 p.
- Roth, R., 1949, Paleogeology of the Panhandle of Texas: Geol. Soc. America Bull., v. 60, p. 1671-1688.
- Saunders, D. F., and Potts, M. J., 1978, Manual for the application of NURE 1974-1977 aerial gamma-ray spectrometer data: U.S. Energy Research and Devel. Adm., GJEX-13(78), 71 p.

- Schmitt, G. T., 1956, Summary of geologic history of the Matador Arch, in Evans, G. L., and Brand, J. P., Eastern Llano Estacado and adjoining Osage Plains: West Texas Geol. Soc. and Lubbock Geol. Soc. Guidebook, p. 60-64.
- Smith, G. E., 1974, Depositional systems, San Angelo Formation (Permian), North Texas--facies control of red-bed copper mineralization: Texas Bur. Econ. Geol. Rept. of Inves. 80, 73 p.
- Van Siclen, D. C., 1957, Cenozoic strata on the southwestern Osage Plain of Texas: Jour. Geol., v. 65, p. 47-60.
- Vick, W. E., 1951, Sedimentary structure of the Ogallala of Lubbock County, Texas (M.S. Thesis) : Lubbock, Texas Tech. Univ., 36 p.
- Waechter, N., 1978, personal communication.
- Wendorf, F., 1975, The modern environment, in Wendorf, F. and Hester, J. J., (eds.), Late Pleistocene environments on the southern High Plains: Fort Burgwin Research Center Pub. no. 9, p. 1-12.
- Wilson, W. E., 1979, personal communication.
- Wyatt, A. W., Bell, A. E., and Morrison, S., 1976, Analytical study of the Ogallala aquifer in Crosby County, Texas: Texas Water Develop. Board, Rept. 209, 63 p.

Appendix A

Site Descriptions for Hand-Held Spectrometer Readings and Geochemical Analysis Samples

Note: Station locations tabulated in Appendix B
and posted on Plate 5. Geochemical analyses
tabulated in Appendix C.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-AW-001*	Qcs	Qcs	Plowed field. Sand, brown.
L-AW-002	Qcs	Qcs	Plowed field. Sand and silt with clay, brown, fine-grained.
L-AW-003	Qp	Qp	Clay, dark brown, very hard, mud cracks.
L-AW-004	Qcs	Qcs	Plowed field. Soil, light brown, sandy.
L-AW-005	Qp	Qp	Clay and silt, brown, mud cracks.
L-AW-101	Qb	Qb	Sandstone, white, well-consolidated.
L-AW-102	To	To	Cap rock caliche, light red, hard.
L-AW-103	Qt	Qt	Soil, red, fine-grained, unconsolidated, contains rounded pebbles.
L-AW-104	Qb	Qb	Sandstone, white, fine-grained, well-consolidated, red recent caliche and soil over outcrop.
L-DE-001	To	To and Qs or Qcs	Caliche, sand and gravel. Caliche, white to light gray, covered by red-brown sand.
L-DE-002	To	To and Qs or Qcs	Sand and caliche. Sand, red-brown, fine-grained, 2 ft deep. Caliche, light gray, hard.
L-DE-003	To	To and Qs	Sand and silt, red-brown, fine-grained, in slightly-cemented gravel, contains caliche.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-DE-004	To	Qs or Qcs	Sand and silt, red-brown, fine-grained, contains caliche.
L-DE-005	To	To with Qs or Qcs	Sand, silt, caliche. Sand and silt, red-brown, fine-grained. Sand and gravel under sand and silt.
L-DE-006*	To	To	Cap rock caliche, light gray, mottled, very hard, abrasive surface.
L-DE-007	Qcs	Qcs	Plowed field. Sand and silt, red-brown, fine-grained.
L-DE-101*	To	Qt?	Sand and silt with gravel and pebble lenses, red-brown, moderately-consolidated. Pebbles are quartz, sandstone, chert. Gravel, poorly-sorted, subangular to well-rounded.
L-DE-102	To	To and Qt	Siltstone, light red-brown, thin-bedded, few caliche pebbles. Overlain by 2 ft of Qt with thin Qs at top.
L-DE-103	To	Qs	Sand, bright red-brown, fine-grained.
L-DE-104	To	Qt?	Sand, dark brown, fine-grained, few small pebbles, unconsolidated to slightly-consolidated.
L-DE-105	Qs	Qt	Sand, bright red-brown, fine-grained, gravel lens. Clay, tan, at base of outcrop.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

A-4

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-DE-106	Qs	Qs	Silt, brown, fine-grained, well-rounded, tightly packed, some clay. May be terrace under sand.
L-DE-107*	Qal	Qal and Qs	Sand and silt, red-brown, fine-grained, pebbles, surface has been disturbed.
L-DE-108	Qt	Qt	Gravel, poorly-sorted, red sand, angular to rounded pebbles and cobbles of quartzite, sandstone, igneous and metamorphic fragments, unconsolidated.
L-EE-101	Pq	Qs	Clayey soil, red brown.
L-FE-101	Pq	Qt	Sand, red, fine-grained, with unsorted rounded to subangular pebbles.
L-FE-102	Qs	Qs	Sand, brown, fine-grained.
L-FE-103	Qs	Qs and Qt	Clay and silt with gravel, red. Thin layer of sand, brown, fine-grained on top.
L-FE-104	Pq	Qt with Qs cover	Silt and clay with gravel, red. Thin brown sand layer on top.
L-FE-105	Qs	Qt	Sand, light brown, fine-grained, well-sorted, some caliche nodules, pebbles and gravel in sand.
L-FE-106A	Qs	Qs	Sand, light brown, fine-grained, well-sorted.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-FE-106B	Qs	Qt	Gravel, silt, and sand, brown, unconsolidated, grades from coarse cobbles at base to small pebbles at top. Sand, fine-grained, over gravel.
L-FW-101	Kcwa	Kcwa	Siltstone, shale (minor), limestone, minor conglomerate, interbedded, yellowish-tan, highly-weathered and fractured, marine fossils.
L-FW-102*	To	To	Conglomerate, basal unit, weakly-consolidated to unconsolidated, rounded pebbles, poorly-sorted to well-sorted, pebbles largely quartzite.
L-FW-103	To	To	Conglomerate and sand, weakly-consolidated to unconsolidated. Conglomerate, basal unit. Sand, yellow with black lens.
L-GE-101*	Pb	weathered Pb?	Road cut. Sand and silt, bright red, fine-grained. Few unrounded pebbles of light red caliche nodules.
L-GE-102*	Pb	Pb	Shale, dolomite, siltstone, interbedded. Shale, reddish-brown, greenish-gray, thin-bedded, highly-weathered. Dolomite, gray with manganese dendrites. Siltstone, thinly bedded.
L-GE-103*	Pwh	weathered Pwh?	Sand and silt, bright red, unconsolidated.
L-GE-104*	Pwh	Pwh	Sandy silty soil, red, with large-pink and cream gypsum float blocks.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-GE-105	Pwh	Pwh	Road cut. Gypsum and dolomite, interbedded. Gypsum, pink and cream, massive. Dolomite, green, thin-bedded. Silt, red, unconsolidated.
L-GE-106*	Pq	weathered Pq	Sand and silt, red and gray mottled, fractured.
L-GE-107	Pq	weathered Pq	Sand and silt, red and gray mottled, fractured.
L-GE-108	Pq	Qt possibly with Qs	Road cut. Silt and gravel. Silt, light brown and red. Gravel, dark red, poorly-sorted, well-rounded to angular pebbles, clay matrix.
L-GE-109	Pq	Pd	Sandstone, brown, coarse-grained, friable, thin-bedded, poorly-sorted, subangular, limonite-staining.
L-GE-110*	Pq	Pq	Road cut. Sandstone, red, fine-grained, thin-to thick-bedded, 0.5" thick gypsum bed interbedded with sandstone. Fault in section.
L-CW-001*	Qcs	Qcs	Plowed field. Sand and silt, red-brown.
L-CW-002	Qp	Qcs	Sand and silt with some clay, light brown, root-bound.
L-CW-003	Qcs	Qp	Sand and clay, dark brown, loose surface, consolidated under surface, mud cracks.
L-CW-004*	Qcs	Qp	Clay, gray-brown, hard, consolidated.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-HW-001	To	To?	Caliche in soil.
L-HW-002*	Qb	Qb	Sandstone with gravel and fractured limestone, white.
L-HW-003	Pq	Qs?	Plowed field. Soil, red-brown, sandy.
L-HW-004	Tk d	weathered Tk d or Qs?	Plowed field. Soil, red-brown, sandy or silty. Some caliche under soil cover.
L-HW-005	Tk d	Tk d	Mesa. Sands and gravels, red-brown to gray, cemented, well-rounded cobbles, thin-bedded sands.
L-HW-006	Tk d	Qs	Sand and silt, red-brown.
L-HW-007	To	To and Qcs	Road cut. Sand and silt, red-brown, with caliche nodules, over coarse-grained sand.
L-HW-008	To	Qcs?	Sand, red-brown, fine-grained, harder at depth.
L-HW-009	To	Qcs?	Sand and silt, light brown, fine-grained.
L-HW-010*	To	To	Cap rock caliche, white to light gray, calichified sand under cap rock.
L-HW-011	Qcs	Qcs	Sand and silt with minor clay, brown.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GECHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-HW-101	To	To	Sand, silt, gravel. Sand and silt on top, red, with thin pebble lenses, about 10 ft thick. Base of section: gravel, unsorted, larger cobbles are caliche nodules. Smaller pebbles are igneous and metamorphic rock fragments, quartz, and caliche; sand and silt, light red to tan, fine-grained.
L-HW-102	Qt	Qt	Silt with small pebbles, red-brown, caliche pebbles.
L-HW-103A	Red	basal Red	Sand and pebbles. Sand, brown, coarse-grained.
L-HW-103B	Red	Qt (weathered Red)	Sand with pebbles, brown.
L-JE-101*	Pb	weathered Pb?	Road cut. Sand, red, rounded grains, unconsolidated. Contains clay and silt.
L-JE-102*	Pb	Pb	Shale and gypsum, interbedded. Shale, gray and red, thin-bedded, with thin gypsum interbeds. Gypsum, white to light red, with green-gray muds. Red soil at surface.
L-JE-103	Pb	Pb	Road cut, highly-weathered. Shale and gypsum. Shale lens, gray. Gypsum, green to white, thin beds. High clay content in soil.
L-JE-104*	Pb	Pb	Road cut about 30 ft high, highly-weathered with deep gullies. Shale, red and gray-green banded, poorly consolidated, thin gypsum layers, hard green massive siltstone layer. Pebbles and cobbles in talus from top of road cut.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-JE-105	Qs	Qs	Sand, brown, fine-grained, well-sorted.
L-JW-001*	Pq	top of Pq	Soil and shale. Soil, red, decomposed shale. Shale, red.
L-JW-002*	Pq	T d	Sandstone, light gray, coarse-grained, well-sorted, micaceous, slight Fe alteration, minor red shale beds.
L-JW-003*	Pq	T d	Sandstone, bright gray with red (Fe) staining, coarse-grained, massive, some fracturing along bedding.
L-JW-004*	T d	T d	Sandstone, mostly yellow with yellow-red staining, coarse-grained, cross-bedded, weakly cemented, harder in some areas, red nodules.
L-JW-005	T d	weathered T d or Qcs?	Soil, red-brown, fine-grained, caliche.
L-JW-006*	Pq	Qt	Soil, sandy and silty, reddish-gray, not compacted.
L-LW-001*	To	weathered To	Soil, light reddish brown, sand and caliche.
L-LW-002*	To	To	Cap rock caliche, light tan to milky white, medium-to very-hard, massive, fine-grained.
L-LW-003*	To	To	Caliche, slightly reddish, hard, cemented.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-LW-004*	To	To	Sandstone and caliche. Sandstone, reddish-gray color, cemented, some Fe staining along minor fractures.
L-LW-005	To	To?	Ledge with some soil.
L-LW-006*	To	To	Sandstone, reddish, fine-grained, very hard, with caliche and chert.
L-LW-007	To	To	Caliche sand, reddish.
L-LW-008*	To	To	Sandstone, light reddish-brown, massive, pebbles coated with caliche, root casts, unconsolidated.
L-LW-101	To	To	Cap rock and sandstone, light tan, fine-grained, well-consolidated.
L-LW-102	To	To	Sandstone, red, medium-grained with pebbles, cross-bedded, friable.
L-ME-001*	Pq	Trd (and Qcs?)	Sandstone and soil. Sandstone, yellow with Fe staining, coarse-grained, arkosic.
L-ME-002	Qt	Qt	Gravel with sand, light brown to red, poorly-consolidated, calcite cement.
L-ME-003	Pq	Qt	Sand and silt, red-brown, fine-grained.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-ME-004	Pq	weathered Pq or Qt?	Sand and silt, red-brown, fine-grained, contains pebbles.
L-ME-005	Pq	Qt	Sand, red-brown, fine-grained.
L-MW-001	Qcs	Qcs	Plowed field. Soil, red-brown, sandy at surface, clay and sand at about 6 in depth.
L-MW-002	Qcs	Qcs	Plowed field. Soil, red-brown, sand and silt grading into silt and clay.
L-MW-003	Qp	Qp	Plowed field. Soil, brown, fine sand at surface; clay, hard, below surface.
L-MW-004	Qp	Qp	Plowed field. Sand, clay, organic material, dark brown, loose at surface, hard below surface.
L-MW-005	Qp	Qp	Plowed field. Sand and clay, brown.
L-MW-006	Qp	Qp	Sand and clay. Surface: sand, brown, fine-grained; below surface: clay and sand, red-brown, hard.
L-MW-007	Qcs	Qcs	Plowed field. Sand and silt, brown-gray on surface, red-brown below.
L-MW-008	Qcs	Qcs	Plowed field. Soil, brown, sandy, underlain by hard silt and sand.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-MW-013	Qp	Qp	Sand and calichified silt, brown.
L-MW-014	Qcs	Qcs	Plowed field. Sand and silt, red-brown.
L-NE-001	Pq	Pq	Siltstone and shale, red, moderately-consolidated, thin-bedded.
L-NE-002	Ed	Pq	Clay, pale gray, weakly-consolidated, thin-bedded.
L-NW-001*	Qta	Qta	Caliche and salt, light yellow to white.
L-NW-002*	Qta	Qta	Caliche and salt.
L-NW-003*	Qta	Qta	Caliche, light yellow.
L-NW-004	Qta	Qta	Upper terrace around lake. Soil, hard pan, some caliche.
L-NW-005*	Qta	Qta	Sand and caliche, light brown soil with white surface, fine-grained sand.
L-NW-006*	Qta	Qta	Sand and caliche, white surface, granular.
L-NW-007*	Qta	Qta	Sand, light brown, granular.
L-NW-008	Qal	Qal	Sand and caliche, light brown, fine-grained.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-NW-009	Qal	Qal, recent caliche	Sand with caliche skin, light brown, fine-grained, granular.
L-NW-010	Qal	Qal, recent caliche	Sand with caliche skin, light brown, fine-grained, granular.
L-NW-011*	Edk	Kdk, Qs, recent caliche?	Sand with caliche skin, brown, granular.
L-NW-012	To	To, Qs, recent caliche?	Sand, light brown, fine-grained, granular, caliche nodules, caliche skin.
L-NW-013	To	To, Qs, recent caliche?	Sand, light brown, granular, caliche nodules, caliche skin.
L-NW-014*	Qsd	Qsd	Soil, light brown, hard pan.
L-NW-015*	Qsd	Qsd and Qta	Sand, caliche, and clay, light brown, granular.
L-NW-016*	Qta	Qta	Sand, caliche, and clay, light brown, fine-grained.
L-NW-017*	Qta	Qta	Sand and clay with caliche skin, dirty white, fine-grained.
L-NW-018*	Qta	Qta	Sand and clay with caliche skin, dirty white, fine-grained, carbon spots in clay.
L-NW-019	Qta	Qta	Caliche, sand, and clay, off-white.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-NW-020*	Qta	Qta	Sand, caliche, dark soil, light brown.
L-NW-021*	To	Qcs	Sand, caliche, sandy soil, light brown, fine-grained.
L-NW-022*	Qsd	Qs	Sand with some clay, light brown, fine-grained, some hard pan.
L-NW-023	Qp	Qp	Sand, clay, caliche nodules, light gray, fine-grained, hard pan.
L-NW-024	Qp	Qp	Clay, sand and silt, light brown, hard pan, mud cracks.
L-NW-025	Qp	Qp	Clay, dark gray-brown, congealed, mud cracks.
L-NW-026	Qp	Qp	Clay, dark brown, mud cracks.
L-NW-027	Qsd	Qcs?	Clay and sand, brown, darker at depth, semi-hard at depth, some mud cracks.
L-NW-028	Qsd	Qcs?	Sand, silt, and clay, light brown-gray, fine-grained, caliche nodules, hard pan.
L-PW-001*	Qtu	Qtu or Qcs?	Sand, red-brown, unconsolidated, pebble sand with minor caliche.
L-PW-002*	Qtu	Qtu	Sandstone, light yellow to white, cemented, coarse-grained, moderately-sorted, caliche, ash(?).

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-PW-003*	Qtu	Qtu	Sand and gravel, white, massive-bedded, contains caliche.
L-PW-004*	Qtu	Qtu	Sandstone, red-brown, coarse-grained, slightly-consolidated, massive.
L-PW-005*	To	To	Cap rock, white massive caliche with chert nodules and pebbles.
L-PW-006*	To	To	Gravel, yellow-red (Fe stain), unsorted, cemented, massive.
L-PW-007*	R d	R d	Shale, red-brown, thin-bedded, friable, gypsum developed.
L-PW-008*	R d	R d	Sandstone, yellow-gray, fine-grained, thin-bedded, cross-bedded, with mica, gypsum, minor clay.
L-PW-009*	R d	R d	Sandstone, yellow-gray, fine-grained, thin-bedded, cross-bedded, with mica, gypsum, minor clay.
L-PW-011	Qcs	Qcs	Sandy soil, light brown, fine-grained, well-sorted,
L-PW-014	Qcs	Qcs	Plowed field. Sand, red-brown, fine-grained.
L-PW-015	Qp	Qp	Sand with clay below, brown, good humic layer, top 6 in loose, harder below.
L-QE-101*	Pb	weathered Pb?	Soil, red-brown, clayey, siltstone pebbles, no outcrop.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-QE-102*	Pwh	weathered Pwh?	Sand, red and gray mottled, fine-grained, well-sorted.
L-QE-103	Pwh	Pwh	Dolomite, gray.
L-QE-104	Pwh	weathered Pwh or Pb?	Sand and silt, red, fine-grained, gypsum fragments.
L-QE-105	Pwh	weathered Pwh?	Clayey, silty soil.
L-QE-106	Pwh	Pwh	Sandstone, red and gray mottled, fine-grained, highly-weathered.
L-QE-107	Pb	Pb	Sand and silt. Sand, red-brown, very fine-grained, thin calcareous layer, overlies silt. Silt, gray. Poorly consolidated, weathered surface.
L-QE-108	Pwh	weathered Pwh?	Red clayey soil.
L-QE-109*	Pwh	Pwh	Road cut, 1 ft thick weathered zone at surface. Gypsum, sandstone, siltstone. Gypsum, gray, fractured. Sandstone, black and white, friable, medium-grained. Siltstone, dark gray and white, thin-bedded. Sand, red and gray mottled, very fine-grained, highly-weathered at bottom of cut.
L-RE-101	Psa	Psa	Road cut. Conglomerate, poorly sorted, siliceous pebbles, matrix of fine light red sand.

*Geochemical analysis performed on sample.

APPENDIX A. SITE DESCRIPTIONS FOR HAND-HELD SPECTROMETER READINGS AND GEOCHEMICAL ANALYSIS SAMPLES

Station Number	Mapped as (Barnes, 1967)	Interpreted to be	Sample Description
L-RE-102	Psa	Psa	Silt and clay, red, carbonaceous, highly-weathered.
L-RE-103	Pb	Pb	Road cut about 15 ft high. Shale, light tan-gray, indistinctly bedded, well-consolidated, hard on fresh and weathered surface. Red caliche layer on top of outcrop.
L-RE-104	Pb	Pb	Dolomite, gray, very fine-grained, few marine fossils. Red soil cover with caliche and shale fragments.
L-RW-001	Tr d	Qs	Soil, red-brown, fine-grained.
L-RW-002	Tr d	Qs	Sand and silt, red-brown, fine-grained, hard pan.
L-RW-003*	Tr d	Qt	Sand and silt, red-brown, unsorted.
L-RW-004*	Tr d	Tr d	Sand and gravel, tan-gray, cemented, cross-bedded.

*Geochemical analysis performed on sample.

Appendix B

Hand-Held Spectrometer Assays and Station Locations

Note: Station numbers ending in the 100s were surveyed in January 1979. The remaining stations were surveyed in July, August, and September 1978.

APPENDIX B. HAND-HELD SPECTROMETER ASSAYS AND STATION LOCATIONS

Station Number	Latitude (North)	Longitude (West)	Thorium (eTh) (ppm)	Uranium (eU) (ppm)	Potassium (K) (%)	$\frac{eU}{eTh}$	$\frac{eU}{K}$
L-AW-001*	33°47.2'	101°6.9'	11.4±.7	2.1±.3	1.3±.1	.2	1.6
L-AW-002	33°47.2'	101°6.7'	10.8±.7	2.0±.3	1.3±.1	.2	1.6
L-AW-003	33°47.2'	101°6.5'	11.4±.7	1.8±.3	1.4±.1	.2	1.3
L-AW-004	33°46.8'	101°9.9'	10.6±.6	2.0±.3	1.3±.1	.2	1.6
L-AW-005	33°46.9'	101°10.2'	12.5±.7	1.8±.3	1.7±.1	.1	1.1
L-AW-101	33°47.8'	101°12.8'	3.6±.3	1.5±.2	.7±.04	.4	2.2
L-AW-102	33°48.0'	101°12.3'	3.5±.3	3.0±.2	.4±.04	.9	7.5
L-AW-103	33°47.6'	101°13.8'	4.1±.3	1.3±.2	.9±.04	.3	1.5
L-AW-104	33°47.5'	101°15.1'	2.8±.3	3.0±.2	.4±.03	1.1	7.5
L-DE-001	33°54.4'	100°55.9'	4.4±.4	1.6±.2	1.0±.1	.4	1.6
L-DE-002	33°54.4'	100°56.8'	6.5±.5	2.3±.3	1.0±.1	.4	2.4
L-DE-003	33°54.2'	100°57.7'	7.0±.5	1.6±.3	1.0±.1	.2	1.7
L-DE-004	33°54.4'	100°58.7'	6.9±.5	1.7±.3	1.1±.1	.2	1.6
L-DE-005	33°54.4'	100°59.7'	5.2±.5	1.8±.3	.9±.1	.4	2.0
L-DE-006*	33°54.2'	100° 0.4'	3.3±.4	1.5±.2	.4±.04	.5	3.8
L-DE-007	33°54.4'	100° 1.0'	10.0±.6	2.6±.3	1.4±.1	.3	1.9
L-DE-101*	33°46.8'	100°54.4'	7.6±.5	2.6±.3	1.1±.1	.3	2.4
L-DE-102	33°46.8'	100°54.2'	5.9±.6	1.1±.3	.9±.1	.2	1.3
L-DE-103	33°46.8'	100°53.7'	6.6±.5	1.9±.3	1.0±.1	.3	1.9
L-DE-104	33°46.8'	100°52.9'	5.5±.5	2.1±.3	1.0±.1	.4	2.2

* Geochemical analysis of sample from station (tabulated in Appendix C).

APPENDIX B. HAND-HELD SPECTROMETER ASSAYS AND STATION LOCATIONS

Station Number	Latitude (North)	Longitude (West)	Thorium (eTh) (ppm)	Uranium (eU) (ppm)	Potassium (K) (%)	$\frac{eU}{eTh}$	$\frac{eU}{K}$
L-DE-105	33°46.8'	100°51.8'	8.2 $\pm$.6	2.4 $\pm$.3	1.4 $\pm$.1	.3	1.6
L-DE-106	33°46.8'	100°50.2'	4.2 $\pm$.4	2.4 $\pm$.2	1.2 $\pm$.1	.6	1.9
L-DE-107*	33°53.5'	100°49.3'	6.5 $\pm$.5	1.9 $\pm$.3	1.0 $\pm$.1	.3	1.8
L-DE-108	33°55.2'	100°45.6'	4.9 $\pm$.5	1.9 $\pm$.2	.7 $\pm$.1	.4	2.9
L-EE-101	33°32.7'	100°55.2'	5.8 $\pm$.4	1.5 $\pm$.2	.9 $\pm$.04	.3	1.7
L-FE-101	33°40.6'	100°42.4'	6.8 $\pm$.5	3.7 $\pm$.3	1.3 $\pm$.1	.5	2.9
L-FE-102	33°40.6'	100°40.6'	4.7 $\pm$.4	2.7 $\pm$.3	1.0 $\pm$.1	.6	2.6
L-FE-103	33°40.6'	100°39.7'	6.8 $\pm$.5	2.6 $\pm$.3	1.2 $\pm$.1	.4	2.1
L-FE-104	33°40.6'	100°38.2'	7.4 $\pm$.5	3.3 $\pm$.3	2.3 $\pm$.1	.4	1.4
L-FE-105	33°41.1'	100°37.9'	4.9 $\pm$.5	2.9 $\pm$.3	1.4 $\pm$.1	.6	2.1
L-FE-106A	33°41.7'	100°37.5'	5.9 $\pm$.5	2.2 $\pm$.3	1.0 $\pm$.1	.4	2.2
L-FE-106B	33°41.7'	100°37.5'	4.3 $\pm$.5	2.2 $\pm$.3	.7 $\pm$.1	.5	3.1
L-FW-101	33°31.3'	101°40.8'	2.9 $\pm$.3	3.3 $\pm$.2	.2 $\pm$.03	1.1	19.4
L-FW-102*	33°31.5'	101°40.8'	2.9 $\pm$.3	4.4 $\pm$.2	.2 $\pm$.03	1.5	18.9
L-FW-103	33°31.4'	101°40.9'	2.6 $\pm$.3	2.4 $\pm$.2	.3 $\pm$.03	.9	8.5
L-GE-101*	33°36.6'	100°21.1'	5.4 $\pm$.5	2.8 $\pm$.3	1.7 $\pm$.1	.5	1.7
L-GE-102*	33°36.5'	100°21.1'	8.1 $\pm$.6	3.2 $\pm$.3	1.6 $\pm$.1	.4	1.9
L-GE-103*	33°33.9'	100°24.7'	4.1 $\pm$.4	4.0 $\pm$.3	3.1 $\pm$.1	1.0	1.3
L-GE-104*	33°32.9'	100°25.7'	5.0 $\pm$.4	5.2 $\pm$.3	1.0 $\pm$.1	1.0	5.0
L-GE-105	33°36.2'	100°29.7'	6.3 $\pm$.6	4.9 $\pm$.4	1.4 $\pm$.1	.8	3.4

* Geochemical analysis of sample from station (tabulated in Appendix C).

APPENDIX B. HAND-HELD SPECTROMETER ASSAYS AND STATION LOCATIONS

B-4

Station Number	Latitude (North)	Longitude (West)	Thorium (eTh) (ppm)	Uranium (eU) (ppm)	Potassium (K) (%)	$\frac{eU}{eTh}$	$\frac{eU}{K}$
L-GE-106*	33°36.9'	100°38.6'	8.3 $\pm$.6	4.0 $\pm$.4	1.8 $\pm$.1	.5	2.2
L-GE-107	33°37.1'	100°41.7'	8.0 $\pm$.6	3.8 $\pm$.4	2.1 $\pm$.1	.5	1.8
L-GE-108A	33°37.0'	100°42.7'	4.6 $\pm$.5	3.5 $\pm$.3	1.0 $\pm$.1	.8	3.6
L-GE-108B	33°37.0'	100°42.7'	5.4 $\pm$.5	3.8 $\pm$.3	1.2 $\pm$.1	.7	3.2
L-GE-109A	33°37.5'	100°47.2'	5.7 $\pm$.5	4.9 $\pm$.4	.7 $\pm$.1	.9	7.5
L-GE-109B	33°37.5'	100°47.2'	3.7 $\pm$.4	5.7 $\pm$.4	.5 $\pm$.1	1.5	11.0
L-GE-110*	33°37.5'	100°48.0'	5.7 $\pm$.5	4.2 $\pm$.3	2.6 $\pm$.1	.7	1.6
L-CW-001*	33°42.5'	101°16.6'	10.8 $\pm$.7	1.8 $\pm$.3	1.0 $\pm$.1	.2	1.7
L-CW-002	33°42.5'	101°16.7'	10.7 $\pm$.7	2.5 $\pm$.3	1.1 $\pm$.1	.2	2.2
L-CW-003	33°42.5'	101°16.9'	11.1 $\pm$.7	3.1 $\pm$.3	1.6 $\pm$.1	.3	2.0
L-CW-004*	33°42.5'	101°17.0'	9.5 $\pm$.6	2.2 $\pm$.3	1.4 $\pm$.1	.2	1.6
L-HW-001	33°42.0'	101° 8.7'	5.8 $\pm$.5	2.1 $\pm$.3	.9 $\pm$.1	.4	2.2
L-HW-002A*	33°42.0'	101° 8.8'	3.4 $\pm$.4	2.4 $\pm$.2	.4 $\pm$.04	.7	6.0
L-HW-002B	33°42.0'	101° 8.8'	4.3 $\pm$.4	2.1 $\pm$.2	.5 $\pm$.04	.5	4.2
L-HW-003	33°34.0'	101° .4'	7.0 $\pm$.5	2.2 $\pm$.3	.7 $\pm$.1	.3	3.0
L-HW-004	33°34.6'	101° .4'	6.6 $\pm$.5	1.9 $\pm$.3	.7 $\pm$.1	.3	2.5
L-HW-005	33°35.2'	101° .5'	8.6 $\pm$.6	2.2 $\pm$.3	.7 $\pm$.1	.3	3.0
L-HW-006	33°35.6'	101° .7'	8.7 $\pm$.6	1.6 $\pm$.3	1.1 $\pm$.1	.2	1.5
L-HW-007	33°36.1'	101° .9'	6.4 $\pm$.5	2.1 $\pm$.3	1.2 $\pm$.1	.3	1.8
L-HW-008	33°36.5'	101° 1.0'	5.2 $\pm$.5	1.1 $\pm$.2	1.1 $\pm$.1	.2	1.0

* Geochemical analysis of sample from station (tabulated in Appendix C).

APPENDIX B. HAND-HELD SPECTROMETER ASSAYS AND STATION LOCATIONS

Station Number	Latitude (North)	Longitude (West)	Thorium (eTh) (ppm)	Uranium (eU) (ppm)	Potassium (K) (%)	eU/eTh	eU/K
L-HW-009	33°36.9'	101° 1.3'	7.8±.6	1.9±.3	1.1±.1	.2	1.7
L-HW-010*	33°37.0'	101° 1.5'	3.6±.4	1.8±.2	.6±.04	.5	3.2
L-HW-011	33°38.5'	101° 3.1'	11.6±.7	2.1±.3	1.4±.1	.2	1.5
L-HW-101A	33°40.1'	101° 8.9'	3.8±.4	2.4±.3	.6±.1	.6	3.9
L-HW-101B	33°40.1'	101° 8.9'	3.2±.4	2.4±.3	.4±.1	.8	5.5
L-HW-102A	33°38.1'	100°53.9'	5.4±.5	2.3±.3	1.0±.1	.4	2.3
L-HW-102B	33°38.1'	100°53.9'	5.4±.5	3.0±.3	1.0±.1	.6	3.2
L-HW-103A	33°37.9'	100°54.3'	5.7±.5	4.6±.3	.2±.04	.8	18.9
L-HW-103B	33°37.9'	100°54.3'	6.9±.5	4.4±.3	.4±.1	.6	11.2
L-JE-101*	33°16.8'	100°14.9'	4.5±.4	2.0±.2	.9±.04	.5	2.3
L-JE-102*	33°17.2'	100°14.8'	6.6±.4	2.2±.2	1.1±.1	.3	2.0
L-JE-103	33°17.4'	100°14.8'	10.6±.5	2.6±.3	2.1±.1	.2	1.3
L-JE-104A*	33°18.0'	100°14.8'	13.0±.6	3.1±.3	2.8±.1	.2	1.1
L-JE-104B*	33°18.0'	100°14.8'	5.8±.4	2.6±.2	.9±.04	.4	3.0
L-JE-105	33°18.5'	100°14.6'	3.1±.3	1.3±.2	.7±.04	.4	1.9
L-JW-001*	33°21.3'	101° 3.9'	8.7±.6	3.6±.3	1.5±.1	.4	2.5
L-JW-002*	33°21.3'	101° 4.0'	7.0±.5	7.1±.4	1.1±.1	1.0	6.8
L-JW-003*	33°21.4'	101° 4.1'	?	?	?	?	?
L-JW-004*	33°21.4'	101° 4.3'	?	?	?	?	?
L-JW-005	33°21.4'	101° 4.6'	9.8±.6	2.1±.3	.9±.1	.2	2.3
L-JW-006*	33°21.4'	101° 3.5'	8.1±.6	4.2±.3	1.2±.1	.5	3.5
L-LW-001A	33°27.5'	101°34.6'	6.2±.5	2.8±.3	.8±.1	.4	3.5
L-LW-001B*	33°27.5'	101°34.6'	4.9±.4	2.9±.3	.7±.1	.6	4.0
L-LW-002*	33°27.5'	101°34.6'	4.4±.4	3.7±.3	.4±.1	.8	8.7
L-LW-003*	33°27.5'	101°34.6'	4.6±.4	1.9±.2	.7±.1	.4	2.6

*Geochemical analysis of sample from station (tabulated in Appendix C).

APPENDIX B. HAND-HELD SPECTROMETER ASSAYS AND STATION LOCATIONS

Station Number	Latitude (North)	Longitude (West)	Thorium (eTh) (ppm)	Uranium (eU) (ppm)	Potassium (K) (%)	$\frac{eU}{eTh}$	$\frac{eU}{K}$
L-LW-004A*	33°27.4'	101°34.6'	3.2 $\pm$.4	2.4 $\pm$.3	.4 $\pm$.04	.7	5.3
L-LW-004B*	33°27.4'	101°34.6'	3.4 $\pm$.4	2.0 $\pm$.2	.6 $\pm$.04	.6	3.3
L-LW-005A	33°27.4'	101°34.6'	4.5 $\pm$.4	1.9 $\pm$.2	.8 $\pm$.1	.4	2.5
L-LW-005B	33°27.4'	101°34.6'	4.4 $\pm$.4	2.0 $\pm$.2	.8 $\pm$.1	.5	2.7
L-LW-006*	33°27.4'	101°34.6'	4.8 $\pm$.4	1.9 $\pm$.2	.8 $\pm$.1	.4	2.5
L-LW-007	33°27.4'	101°34.6'	4.8 $\pm$.4	2.5 $\pm$.3	.9 $\pm$.1	.5	2.7
L-LW-008*	33°27.4'	101°34.6'	6.7 $\pm$.5	2.5 $\pm$.3	1.2 $\pm$.1	.4	2.1
L-LW-101	33°29.0'	101°37.2'	1.8 $\pm$.3	1.9 $\pm$.2	.3 $\pm$.03	1.0	6.4
L-LW-102	33°30.0'	101°37.2'	2.2 $\pm$.3	1.7 $\pm$.2	.3 $\pm$.03	.8	5.1
L-ME-001*	33°26.4'	100°49.1'	5.2 $\pm$.5	11.3 $\pm$.4	.6 $\pm$.1	2.1	19.7
L-ME-002	33°26.3'	100°48.7'	4.7 $\pm$.4	5.2 $\pm$.3	.6 $\pm$.1	1.1	8.5
L-ME-003	33°28.9'	100°58.3'	7.4 $\pm$.6	2.9 $\pm$.3	1.5 $\pm$.1	.4	1.9
L-ME-004	33°28.8'	100°58.7'	7.0 $\pm$.5	2.1 $\pm$.3	.9 $\pm$.1	.3	2.4
L-ME-005	33°28.8'	100°59.2'	8.9 $\pm$.6	1.5 $\pm$.3	1.7 $\pm$.1	.2	.9
L-MW-001	33°25.9'	101°51.9'	7.1 $\pm$.5	1.6 $\pm$.3	1.0 $\pm$.1	.2	1.6
L-MW-002	33°25.9'	101°52.0'	7.0 $\pm$.5	2.1 $\pm$.3	1.1 $\pm$.1	.3	1.9
L-MW-003	33°26.9'	101°52.2'	10.6 $\pm$.7	2.0 $\pm$.3	1.7 $\pm$.1	.2	1.2
L-MW-004	33°25.9'	101°52.3'	11.4 $\pm$.7	2.3 $\pm$.3	1.6 $\pm$.1	.2	1.4
L-MW-005	33°26.0'	101°53.0'	12.0 $\pm$.7	1.8 $\pm$.3	1.6 $\pm$.1	.1	1.1
L-MW-006	33°26.0'	101°53.2'	7.5 $\pm$.5	1.3 $\pm$.3	1.0 $\pm$.1	.2	1.3
L-MW-007	33°26.0'	101°53.4'	7.2 $\pm$.5	2.0 $\pm$.3	1.1 $\pm$.1	.3	1.7
L-MW-008	33°26.1'	101°48.4'	5.4 $\pm$.5	1.7 $\pm$.2	.9 $\pm$.1	.3	2.0

* Geochemical analysis of sample from station (tabulated in Appendix C).

APPENDIX B. HAND-HELD SPECTROMETER ASSAYS AND STATION LOCATIONS

Station Number	Latitude (North)	Longitude (West)	Thorium (eTh) (ppm)	Uranium (eU) (ppm)	Potassium (K) (%)	$\frac{eU}{eTh}$	$\frac{eU}{K}$
L-MW-013	33°23.9'	101°46.7'	11.2 $\pm$.7	1.4 $\pm$.3	1.1 $\pm$.1	.1	1.2
L-MW-014	33°23.9'	101°46.8'	6.9 $\pm$.5	1.7 $\pm$.3	1.0 $\pm$.1	.2	1.6
L-NE-001	33° 3.3'	100°57.4'	14.0 $\pm$.7	3.9 $\pm$.4	4.1 $\pm$.1	.3	1.0
L-NE-002	33° 3.3'	100°56.9'	11.0 $\pm$.7	4.1 $\pm$.4	2.9 $\pm$.1	.4	1.4
L-NW-001*	33°13.4'	101°55.2'	7.3 $\pm$.5	11.5 $\pm$.5	.9 $\pm$.1	1.6	13.4
L-NW-002*	33°13.4'	101°55.0'	8.2 $\pm$.6	12.3 $\pm$.5	1.0 $\pm$.1	1.5	12.4
L-NW-003*	33°13.3'	101°55.0'	5.2 $\pm$.5	7.3 $\pm$.4	1.1 $\pm$.1	1.4	6.7
L-NW-004	33°14.2'	101°53.2'	6.8 $\pm$.5	2.7 $\pm$.3	1.3 $\pm$.1	.4	2.1
L-NW-005*	33°14.2'	101°53.2'	6.6 $\pm$.5	3.2 $\pm$.3	1.1 $\pm$.1	.5	2.8
L-NW-006*	33°14.3'	101°53.3'	5.6 $\pm$.5	4.8 $\pm$.3	1.1 $\pm$.1	.9	4.2
L-NW-007*	33°14.3'	101°53.3'	5.1 $\pm$.5	2.4 $\pm$.3	1.1 $\pm$.1	.5	2.1
L-NW-008	33°14.4'	101°53.4'	3.1 $\pm$.4	1.7 $\pm$.2	.7 $\pm$.04	.6	2.5
L-NW-009	33°14.4'	101°53.4'	4.1 $\pm$.4	2.8 $\pm$.3	1.0 $\pm$.1	.7	2.7
L-NW-010	33°14.5'	101°53.4'	6.4 $\pm$.5	3.0 $\pm$.3	1.3 $\pm$.1	.5	2.3
L-NW-011*	33°14.5'	101°53.5'	6.2 $\pm$.5	11.4 $\pm$.5	.7 $\pm$.1	1.8	16.8
L-NW-012	33°14.6'	101°53.5'	6.4 $\pm$.5	2.5 $\pm$.3	1.3 $\pm$.1	.4	1.9
L-NW-013	33°14.6'	101°53.5'	7.1 $\pm$.5	3.2 $\pm$.3	1.2 $\pm$.1	.5	2.6
L-NW-014*	33°13.2'	101°53.6'	7.8 $\pm$.6	3.4 $\pm$.3	1.2 $\pm$.1	.4	2.8
L-NW-015*	33°13.2'	101°53.9'	7.1 $\pm$.5	4.3 $\pm$.3	1.3 $\pm$.1	.6	3.4
L-NW-016*	33°13.2'	101°54.1'	7.6 $\pm$.6	5.7 $\pm$.4	1.3 $\pm$.1	.7	4.2

* Geochemical analysis of sample from station (tabulated in Appendix C).

APPENDIX B. HAND-HELD SPECTROMETER ASSAYS AND STATION LOCATIONS

Station Number	Latitude (North)	Longitude (West)	Thorium (eTh) (ppm)	Uranium (eU) (ppm)	Potassium (K) (%)	$\frac{eU}{eTh}$	$\frac{eU}{K}$
L-NW-017*	33°13.3'	101°54.4'	5.4 $\pm$.5	7.1 $\pm$.4	1.4 $\pm$.1	1.3	5.2
L-NW-018*	33°13.3'	101°54.6'	7.1 $\pm$.5	7.3 $\pm$.4	1.4 $\pm$.1	1.0	5.1
L-NW-019	33°13.3'	101°54.8'	7.6 $\pm$.6	8.3 $\pm$.4	1.4 $\pm$.1	1.1	6.1
L-NW-020*	33°13.3'	101°55.1'	6.9 $\pm$.5	4.3 $\pm$.3	.9 $\pm$.1	.6	4.5
L-NW-021*	33°13.3'	101°55.3'	7.0 $\pm$.5	3.0 $\pm$.3	1.0 $\pm$.1	.4	2.9
L-NW-022*	33°10.2'	101°53.9'	7.1 $\pm$.5	3.2 $\pm$.3	1.0 $\pm$.1	.5	3.1
L-NW-023	33°10.2'	101°53.6'	7.5 $\pm$.5	2.8 $\pm$.3	.9 $\pm$.1	.4	3.2
L-NW-024	33°10.2'	101°53.5'	9.0 $\pm$.6	2.8 $\pm$.3	1.3 $\pm$.1	.3	2.3
L-NW-025	33°10.2'	101°53.3'	11.8 $\pm$.7	2.5 $\pm$.3	1.6 $\pm$.1	.2	1.5
L-NW-026	33°10.2'	101°52.5'	11.6 $\pm$.7	2.4 $\pm$.3	1.4 $\pm$.1	.2	1.8
L-NW-027	33°10.2'	101°52.3'	8.8 $\pm$.6	1.3 $\pm$.3	1.1 $\pm$.1	.1	1.1
L-NW-028	33°10.2'	101°52.2'	8.2 $\pm$.6	1.6 $\pm$.3	1.3 $\pm$.1	.2	1.3
L-PW-001*	33° 4.9'	101°30.9'	5.7 $\pm$.5	3.1 $\pm$.3	.8 $\pm$.1	.5	3.6
L-PW-002*	33° 4.9'	101°30.9'	5.4 $\pm$.5	24.8 $\pm$.6	.7 $\pm$.1	3.9	34.9
L-PW-003*	33° 4.8'	101°30.9'	5.5 $\pm$.5	15.1 $\pm$.5	.8 $\pm$.1	2.8	19.2
L-PW-004*	33° 4.8'	101°30.8'	5.6 $\pm$.6	7.2 $\pm$.5	.9 $\pm$.1	1.3	7.7
L-PW-005*	33° 4.7'	101°30.8'	4.9 $\pm$.5	4.3 $\pm$.3	1.0 $\pm$.1	.9	4.3
L-PW-006*	33° 4.7'	101°30.8'	3.9 $\pm$.4	2.8 $\pm$.3	.4 $\pm$.1	.7	7.4
L-PW-007*	33° 4.6'	101°30.8'	9.1 $\pm$.6	3.3 $\pm$.3	1.3 $\pm$.1	.4	2.7
L-PW-008*	33° 4.6'	101°30.7'	9.6 $\pm$.6	2.5 $\pm$.3	1.7 $\pm$.1	.3	1.4

* Geochemical analysis of sample from station (tabulated in Appendix C).

APPENDIX B. HAND-HELD SPECTROMETER ASSAYS AND STATION LOCATIONS

Station Number	Latitude (North)	Longitude (West)	Thorium (eTh) (ppm)	Uranium (eU) (ppm)	Potassium (K) (%)	$\frac{eU}{eTh}$	$\frac{eU}{K}$
L-PW-009*	33° 4.5'	101°30.7'	5.5 $\pm$.5	3.2 $\pm$.3	.7 $\pm$.1	.6	4.5
L-PW-011	33° 5.1'	101°42.1'	7.7 $\pm$.6	2.8 $\pm$.3	1.0 $\pm$.1	.4	2.9
L-PW-014	33° 5.3'	101°40.1'	5.6 $\pm$.5	2.0 $\pm$.3	.8 $\pm$.1	.4	2.5
L-PW-015	33° 5.3'	101°39.8'	10.8 $\pm$.7	2.2 $\pm$.3	1.6 $\pm$.1	.2	1.4
L-QE-101*	33° 8.1'	100°15.3'	9.3 $\pm$.5	2.1 $\pm$.2	1.7 $\pm$.1	.2	1.3
L-QE-102*	33° 8.0'	100°15.9'	6.9 $\pm$.5	1.5 $\pm$.3	1.4 $\pm$.1	.2	1.1
L-QE-103	33° 8.1'	100°15.9'	3.9 $\pm$.4	1.8 $\pm$.2	1.2 $\pm$.1	.5	1.5
L-QE-104	33° 8.1'	100°15.7'	6.2 $\pm$.6	1.5 $\pm$.3	1.4 $\pm$.1	.2	1.0
L-QE-105	33° 8.1'	100°16.3'	7.3 $\pm$.6	2.4 $\pm$.3	1.3 $\pm$.1	.3	1.8
L-QE-106	33° 8.1'	100°17.1'	8.4 $\pm$.7	2.5 $\pm$.3	1.4 $\pm$.1	.3	1.8
L-QE-107	33° 8.1'	100°18.6'	5.7 $\pm$.5	1.1 $\pm$.3	1.5 $\pm$.1	.2	.7
L-QE-108	33° 8.1'	100°21.4'	7.0 $\pm$.5	2.1 $\pm$.3	1.4 $\pm$.1	.3	1.5
L-QE-109*	33° 8.1'	100°22.9'	3.8 $\pm$.5	.9 $\pm$.2	1.1 $\pm$.1	.2	.9
L-RE-101A	33° 9.1'	100° 1.5'	8.1 $\pm$.5	2.2 $\pm$.2	6.9 $\pm$.1	.3	.3
L-RE-101B	33° 9.1'	100° 1.5'	5.6 $\pm$.4	1.4 $\pm$.2	.8 $\pm$.04	.3	1.8
L-RE-102	33° 8.8'	100° 3.3'	10.1 $\pm$.5	4.3 $\pm$.3	1.2 $\pm$.1	.4	3.7
L-RE-103A	33° 7.5'	100° 6.5'	7.3 $\pm$.4	4.1 $\pm$.3	3.0 $\pm$.1	.6	1.4
L-RE-103B	33° 7.5'	100° 6.5'	4.8 $\pm$.4	1.5 $\pm$.2	.2 $\pm$.03	.3	7.3
L-RE-104	33° 8.0'	100° 9.8'	4.6 $\pm$.3	2.2 $\pm$.2	.6 $\pm$.04	.5	3.8
L-RW-001	33° 7.9'	101° 8.0'	9.4 $\pm$.6	2.6 $\pm$.3	.9 $\pm$.1	.3	2.8
L-RW-002	33° 7.6'	101° 7.5'	10.0 $\pm$.6	2.8 $\pm$.3	1.2 $\pm$.1	.3	2.4

* Geochemical analysis of sample from station (tabulated in Appendix C).

APPENDIX B. HAND-HELD SPECTROMETER ASSAYS AND STATION LOCATIONS

Station Number	Latitude (North)	Longitude (West)	Thorium (eTh) (ppm)	Uranium (eU) (ppm)	Potassium (K) (%)	$\frac{eU}{eTh}$	$\frac{eU}{K}$
L-RW-003*	33° 7.5'	101° 7.2'	9.8 $\pm$.6	4.3 $\pm$.4	1.0 $\pm$.1	.4	4.4
L-RW-004*	33° 7.6'	101° 6.9'	10.6 $\pm$.6	6.2 $\pm$.4	1.0 $\pm$.1	.6	6.4

* Geochemical analysis of sample from station (tabulated in Appendix C).

Appendix C

Soil and Rock Chemical and Radiochemical Analyses

Note: The chemical analyses were made by fluorescence. The radiochemical (disequilibrium) analyses were made by high-resolution gamma spectrometry.

The data presented for the disequilibrium analyses can be interpreted in the following manner. At equilibrium, the ratios of U-234/U-238, Ra-226/U-238, and Pb-210/Ra-226 should be 1.0. In situations where the uranium is being leached from its host mineral, the U-234/U-238 ratio would be expected to be less than 1.0. Further, the Ra-226/U-238 ratio should be less than 1.0. However, because uranium and radium are both mobile elements, complete dependence upon the Ra-226/U-238 ratio for estimating uranium leaching-radium enrichment or uranium enrichment-radium leaching cannot be made. Uranium enrichment would be indicated by a U-234/U-238 ratio greater than 1.0.

The following table of estimates was provided by William E. Wilson (personal communication). These estimates should be used as guidelines for gauging the reliability of the equilibrium determinations.

<u>Sample</u>	<u>Accuracy (%)</u>	<u>U concentration (ppm)</u>
L-QE-109	<u>+200</u>	0.4
L-GE-104	<u>+200</u>	0.7
L-QE-109A	<u>+50</u>	1.5
L-GE-110	<u>+40</u>	2.3
L-FW-102	<u>+20</u>	4.4

For best interpretations of the state of disequilibrium, only those samples in which the uranium concentration is greater than 5 ppm should be used. In the present study, because of the lack of statistically complete sampling and the low uranium concentrations, all of the information (eU from hand-held spectrometer, U-234/U-238, Ra-226/U-238, and Pb-210/Ra-226) was used to estimate the state of disequilibrium.

APPENDIX C. SOIL AND ROCK CHEMICAL AND RADIOCHEMICAL ANALYSES

Station Number*	Thorium (ppm)	Uranium (ppm)	Radiochemical			Chemical U_3O_8 (ppm)
			$\frac{U-234}{U-238}$	$\frac{Ra-226}{U-238}$	$\frac{Pb-210}{Ra-226}$	
L-AW-001	7.3	2.9	0	1.6	1.0	
L-DE-006	.9	1.1	1.3	2.7	.3	
L-DE-101						1
L-DE-107						1
L-FW-102	1.0	4.4	3.2	1.3	.9	
L-GE-101						1
L-GE-102						3
L-GE-103						2
L-GE-104	0	.7	.1	.1	0	
L-GE-106						2
L-GE-110	3.9	2.3	17.0	.3	3.4	
L-GW-001	6.2	2.8	5.9	.7	1.9	
L-GW-004	8.1	2.6	1.2	1.6	1.0	
L-HW-002	1.2	2.5	1.1	2.1	.6	
L-HW-010	1.7	1.4	0	2.2	.6	
L-JE-101						13
L-JE-102						11
L-JE-104						3
L-JW-001	6.9	4.8	.9	1.4	.7	
L-JW-002	6.5	10.9	1.3	1.7	.9	
L-JW-003	6.6	9.9	.2	1.1	.9	
L-JW-004	12.2	7.7	2.5	1.3	.8	
L-JW-006	6.1	6.7	0	.8	.2	
L-LW-001	4.7	1.7	2.4	2.7	.5	
L-LW-002	3.6	2.9	.9	1.5	.7	
L-LW-003	2.5	1.4	.5	3.1	.3	
L-LW-004	1.9	1.1	0	.8	2.2	
L-LW-006	1.0	1.5	0	.9	1.1	
L-LW-008	3.1	1.5	1.6	2.8	.6	
L-ME-001	5.3	23.7	1.1	1.2	1.1	
L-NW-001	3.9	95.1	1.5	.2	.9	
L-NW-002	2.9	22.9	1.2	.5	.9	
L-NW-003	3.6	14.9	.8	.4	1.0	
L-NW-005	3.8	3.1	0	2.0	.7	
L-NW-006	3.2	14.4	.5	.4	.9	

* Station locations tabulated in Appendix B and posted on Plate 5.

APPENDIX C. SOIL AND ROCK CHEMICAL AND RADIOCHEMICAL ANALYSES

Station Number*	Thorium (ppm)	Uranium (ppm)	Radiochemical			Chemical U_3O_8 (ppm)
			$\frac{U-234}{U-238}$	$\frac{Ra-226}{U-238}$	$\frac{Pb-210}{Ra-226}$	
L-NW-007	5.3	2.0	1.6	1.9	.9	
L-NW-011	8.1	4.7	1.3	.7	1.2	
L-NW-014	6.3	4.3	0	2.0	.7	
L-NW-015	5.8	5.5	3.6	1.5	1.1	
L-NW-016	4.3	10.6	.5	1.1	.7	
L NW 017	4.5	13.6	1.1	.6	1.2	
L-NW-018	4.5	12.8	.7	.8	1.0	
L-NW-020	4.9	12.4	.4	.5	1.0	
L-NW-021	4.7	3.6	1.4	1.7	.9	
L-NW-022	7.2	2.8	0	1.9	.5	
L-PW-001	5.6	4.5	1.2	1.2	1.0	
L-PW-002	3.7	34.2	.9	1.4	.9	
L-PW-003	3.5	7.8	.6	1.4	.6	
L-PW-004	4.5	13.0	1.0	.5	.6	
L-PW-005	3.2	8.7	2.5	.4	.9	
L-PW-006	2.5	2.9	3.8	1.1	.9	
L-PW-007	8.6	2.5	1.8	1.3	.8	
L-PW-008	4.9	4.0	0	2.9	.2	
L-PW-009	4.0	2.4	1.7	.8	1.0	
L-QE-101						1
L-QE-102						1
L-QE-109	too low to count					
L-QE-109A	2.1	1.5	6.7	1.6	.7	
L-RW-003	9.9	4.3	0	2.2	.5	
L-RW-004	8.2	5.1	0	1.1	.7	

* Station locations tabulated in Appendix B and posted on Plate 5.

Appendix D

Thin-Section Analyses

APPENDIX D. THIN-SECTION ANALYSES

Sample L-FW-101. Cretaceous limestone		
Mineral	%	Description
calcite	75	orthochemical and allochemical varieties; as fossils, limestone fragments, $\frac{1}{4}$ - 1 mm sparry grains in a 1 cm long area, all surrounded by micrite
quartz	25	monocrystalline detrital grains .04-.4 mm across, angular to subrounded with most grains angular and subangular; many grains appear corroded by the calcite matrix
feldspar		a few grains of plagioclase and untwinned feldspar
chert		a number of detrital grains
rock fragments		a few quartz sandstone to siltstone grain size fragments; these fragments may be a coarse-grained variety of chert
limonite		a couple small spots that may be secondary after pyrite

Rock Textures: fair sorting, grain fabric is one of detrital grains floating in micrite cement, angular to subrounded.

Notes: Low porosity.

APPENDIX D. THIN-SECTION ANALYSIS

Sample L-FW-102. Ogallala (Pliocene) basal conglomerate (Grain Mount)		
Mineral	%	Description
quartz		mostly rounded and strained monocrystalline grains although several polycrystalline grains present; one ½ mm grain has 30 apatite inclusions
microcline		
plagioclase		mostly fresh, some grains with clay alteration
rock fragments		fragments of extremely fine-grained carbonate mud with and without quartz and feldspar detrital grains, chert, jasper, siltstone
zircon		rounded and broken angular grains

Rock Textures: most grains are rounded to subrounded, poor sorting.

APPENDIX D. THIN-SECTION ANALYSIS

Sample L-GE-110. Quartermaster Formation (Permian) sandstone		
Mineral	%	Description
quartz	54*	monocrystalline detrital grains
plagioclase		several fresh grains
muscovite		
biotite		dark brown to light brown
glauconite		as very fine-grained polycrystalline green pellets
apatite		as inclusions in quartz and as single detrital grains
opaque Fe-Ti oxides	2	some grains altered to orange-brown limonite
limonite	2	cement; there are a number of 1 mm circular areas in thin-section that have no limonite
gypsum	40	as cement and as layers of selenite
carbonate	2	as monocrystalline sparry grains and as fine-grained polycrystalline aggregates; dolomite(?)
microcline		several fresh grains
rock fragments		very fine-grained altered volcanic(?) fragments; due to the nature of these fragments they could be nothing more than highly altered feldspar grains
zircon		single detrital grain
tourmaline		single detrital grain

Special Notes: *percentage estimate includes all silicate grains but quartz is dominant.

Rock Textures: good sorting, most grains .03 - .1 mm, angular detrital grains floating in gypsum cement.

APPENDIX D. THIN-SECTION ANALYSIS

Sample L-HW-010. Ogallala (Pliocene) cap rock		
Mineral	%	Description
calcite	90	extremely fine grained dark turbid brown with most grains less than 1 micron; grains that line pore spaces are clear and about 3 microns in size; turbidity probably due to clay; comprises the bulk of the rock; several 40 micron size grains that are clear
detrital fragments	3	
quartz		monocrystalline detrital grains; a few polycrystalline grains (sandstone?); the dominant silicate mineral
microcline		one very fresh grain
plagioclase		
chert		as detrital grains
tourmaline		single grain with yellow to deep golden brown pleochroism
silica		very fine-grained material in and around some pore spaces
zircon		a single rounded grain
untwinned feldspar		
rock fragments		quartz sandstone
pore spaces	7	
<u>Rock Textures:</u> silicate grains floating in carbonate; the silicates are not uniformly distributed but occur as groups of many grains in areas about 2 - 3 mm across in addition to being generally scattered throughout section; angular to rounded; most grains 0.5-.1 mm with the largest grain being .3 mm; fair sorting.		

Notes: Detrital grains occur in clusters.

APPENDIX D. THIN-SECTION ANALYSIS

Sample L-JW-002. Dockum (Triassic) sandstone		
Mineral	%	Description
quartz	49*	monocrystalline detrital grains; partially replaced by calcite resulting in extremely irregular corroded rims
plagioclase		
microcline		
muscovite		¼ mm long detrital flakes
biotite		dark brown to brown detrital grains
untwinned feldspar		
chert		
opaque Fe-Ti oxides	1	
hematite		authigenic tabular crystal overgrowths on opaque Fe-Ti oxide detrital grains
apatite		as inclusions in quartz grains
zircon		as inclusions in quartz
chert		
rock fragments		muscovite and quartz rich metamorphic fragments; fine-grained altered fragments that could be volcanic
calcite	50	as 1.5 mm sparry grains forming the cement of this rock
tourmaline		single .15 mm grain, gray-green to very pale gray-green color, also a golden brown to pale brown grain
<u>Special Notes:</u> *this 49 percent includes all silicate grains and rock fragments with quartz clearly comprising the bulk of this percentage.		

APPENDIX D. THIN-SECTION ANALYSIS

Sample L-JW-002. (Continued)

Rock Textures: most grains are angular with a grain size of .1-.2 mm, good sorting, grain fabric is one of silicate grains floating in carbonate cement although there are a few point contacts.

APPENDIX D. THIN-SECTION ANALYSIS

Sample L-JW-003. Dockum (Triassic) sandstone

Mineral	%	Description
quartz	65	angular to subrounded monocrystalline grains
plagioclase		fresh and extremely altered (to clay) grains
microcline		a number of fresh grains
chert	2	detrital grains some of which are rounded
zircon		as inclusions in some grains
muscovite		in rock fragments
rock fragments	5	a number of fine-grained altered fragments that could be volcanic; some granitic fragments both igneous and metamorphic
pore space	25	
total feldspar	2	
limonite	1	the weak cementing agent that binds this friable sandstone together

Special Notes: estimated percentages.

Rock Textures: good sorting with virtually all grains .1-.3 mm; angular to subrounded with most grains subangular and angular; grain fabric consists of point contacts, long contacts, and concave-convex contacts with point contacts being the most common.

APPENDIX D. THIN-SECTION ANALYSIS

Sample L-LW-002. Ogallala (Pliocene) cap rock

Mineral	%	Description
calcite	90	forms the bulk of the sample; very fine-grained clear material with a typical grain size of 5 microns; there are a few 1/5 mm pockets of 40 micron size grains
detrital grains	5	
quartz		the dominant detrital mineral occurring as monocrystalline grains
plagioclase		several grains, one of which is poikilitic with muscovite and apatite
untwinned feldspar		probably orthoclase, a few grains
tourmaline		a single very pale green to gray-green grain
rock fragments		a few chert and siltstone fragments
pore spaces	5	typically .1-.3 mm

Rock Textures: silicate grains range in size from .02 - .55 mm with most grains about .1 mm; angular to rounded; grain fabric is one of silicate grains floating in carbonate; silicate grains are uniformly distributed throughout the calcite; fair sorting.

APPENDIX D. THIN-SECTION ANALYSIS

Sample L-NE-001. Quartermaster Formation (Permian) siltstone		
Mineral	%	Description
<hr/>		
quartz	22*	the dominant silicate mineral, monocrystalline detrital grains
muscovite		a number of grains
plagioclase		several grains
biotite		one grain observed
tourmaline		several grains in shades of light green
zircon		single detrital grains
apatite		single grains
opaque Fe-Ti oxides	1	scattered throughout rock, possibly the source of the limonite
limonite	2	acts as cement
carbonate	75	anhedral to euhedral (rhombs), acid response suggests this mineral is dolomite

Special Notes: *percentage estimate includes the other silicates but quartz is by far the dominant silicate mineral. The dolomite appears detrital although some of the mineral acts as cement.

Rock Textures: typical grain size about .02 mm, good sorting, most grains are angular.

Appendix E

Symbols and Abbreviations

APPENDIX E. SYMBOLS AND ABBREVIATIONS

Abbreviations

asl	above sea level
BFEC	Bendix Field Engineering Corporation
214Bi	Bismuth-214
B.P.	before present
C	Celsius
cm	centimeter
cps	counts per second
eTh	equivalent Thorium
eU	equivalent Uranium
F	Fahrenheit
Fe	iron
ft	feet
hr	hour
in	inches
K	Potassium
40K	Potassium-40
km	kilometers
l	liters
m	meters
mi	miles
mm	millimeter
m.y.	million years
NTMS	National Topographic Map Series
NURE	National Uranium Resource Evaluation
ORNL	Oak Ridge National Laboratory
Pb-210	Lead-210
ppb	parts per billion
ppm	parts per million
Ra-226	Radium-226
sl	sea level
Th	Thorium-232 from radiochemical analysis
208Tl	Thallium-208
U	Uranium-238 from radiochemical analysis
U-234	Uranium-234
U-238	Uranium-238

Symbols

°	degrees
>	greater than
'	minutes
%	per cent
σ	standard deviation
Σ	sum

APPENDIX F

SUMMARIZATION OF THE DETAILED INTERPRETATION

Note: Radiometric responses not reported unless
recognizably characteristic over the entire
unit.
Mean reported is the mean calculated for
the entire quadrangle.

Appendix F. Summarization of the Detailed Interpretation

Stratigraphic Unit	Aerial Radiometric Data						Truck-Mounted Spectrometer Data			
	^{214}Bi	^{208}Tl	^{40}K	$\frac{^{214}\text{Bi}}{^{208}\text{Tl}}$	$\frac{^{214}\text{Bi}}{^{40}\text{K}}$	$\frac{^{208}\text{Tl}}{^{40}\text{K}}$	eU	eTh	K	eU/eTh
Choza Formation (Pch)	Less than +2G except along flight ML-3.	Largely at or above the mean.	Generally above the mean. Maximum of +3G.	Generally between +1G and -1G.			3.1 to 4.4 ppm			0.5 to 0.3
San Angelo Formation (Psa)	Less than +2G.	Generally above the mean.	Generally above the mean.	Between +1G and -1G.		Above the mean.	3.5 to 6.5 ppm	4.5 to 8 ppm	1 to 1.8%	0.5 to 0.9
Blaine Formation (Pb)	Values between +1G and +2G common in "middle" Pb. Generally less than +1G in the "lower" and "upper" Pb.	Relatively high (generally above the mean).	High, although K lower in "middle" Pb than in "lower" and "upper" Pb. Range over entire Pb: +3.5G to -2G.	Values commonly between +1G and +2G in "middle" Pb. Maximum values: +4G. Generally between +1G and -1G in the "lower" and "upper" Pb.			Summer 1978 survey: generally between 2.5 and 3.5 ppm. Winter survey: between 4 and 5.5 ppm.	4 to 7.5 ppm	1 to 2%; highest values in "upper" Pb.	
Whitehorse Sandstone and Cloud Chief Gypsum (Pwh)	Between +2G and -2G, except along ML-23 (maximum of +3G).	Less than +1G (tends to be near the mean).	Between +2G and -1G (generally above the mean) but not as high as over Pb.	Generally between +2G and -1G. Higher Bi/Tl values a function of low Tl.	Generally low -- no apparent pattern.	Consistently at or below the mean.	Summer 1978 survey: between 2.5 and 3.5 ppm. Winter survey: 4 to 4.5 ppm.	4.5 to 7 ppm	1 to 1.8%	
Quarter-master Formation (Pq)	"Lower" Pq: generally below the mean in southern part of quadrangle; 0 to +2G in northern part. "Upper" Pq: commonly high (maximum of +8G in southern part of the quadrangle; 0 to +2G in northern part.	Between +1.5G and -2G (generally above the mean). Lower values often associated with unmapped sand cover.	Above the mean (maximum of +4.5G in southern third of quadrangle).	Areas of high ratio in the southern part of quadrangle.	Less than +1G (generally below the mean) in the "lower" Pq. Areas of high ratio in southern part of quadrangle; less than +1G in northern part.		"Lower" Pq: 5 to 10 ppm in 4 to 6 ppm. "Upper" Pq: 3.5 to 5.5 ppm in summer 1978 survey; 4 to 6 ppm in winter survey.	Slight decrease to north.	High	
Dockum Group (Td)	Less than +1.5G north of flight line ML-16. Less than +3G north of ML-13. South of ML-13 high ^{214}Bi (large areas greater than +3G). As high as +8G basal Td. (Lower in upper Td than over basal Td in south -- still above the mean.)	Higher in south than in north. Less than +0.5G north of ML-13. -1G to +3G values common south of ML-13. (Lower in basal Td in south than in upper Td.)	Generally low. Seldom above +1.5G.	High in southern part of the quadrangle over basal Td.	High in southern part of the quadrangle.		Summer 1978 survey: areas of average ^{214}Bi in aerial data in 3 to 4 ppm range. Anomalous areas of basal Td: 5 to 10 ppm. Northern half of quadrangle: no anomalies.	7 to 10 ppm common.	1 to 1.6% common.	Generally about .5 in upper part of Td. Ratios as high as 1.6 in basal Td in southern part of the quadrangle.
Cretaceous System (Kwa, Kdk, Kl, Ke)	Between +1G and -1G	Between +1G and -1G	Between +1G and -1G				No eU anomalies observed over mapped Cretaceous outcrops.			

Hand-Held Spectrometer Data				Chemical Analyses	Radiochemical Analyses	Comments
eU	eTh	K	eU/eTh			
						^{214}Bi , $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies along flight line M-8. No hand-held spectrometer data collected over Pb outcrops.
1.5 to 4 ppm	5.5 to 10 ppm	.3 to 1.2%	0.3 to 0.4			No ^{214}Bi , $^{214}\text{Bi}/^{208}\text{Tl}$ anomalies over Psa exposures.
2 to 3 ppm over "middle" Pb sediments. 1 to 3 ppm over "upper" Pb sediments.	4.5 to 13 ppm over "middle" Pb sediments. 5.5 to 9 ppm over "upper" Pb sediments.	.6 to 2.8% over "middle" Pb sediments. 1.5 to 1.7% over "upper" Pb.	0.2 to 0.5	3 to 13 ppm U_3O_8 over "middle" Pb sediments. 1 to 1 ppm U_3O_8 Pb sediments.		Some low ^{214}Bi , ^{208}Tl , and ^{40}K values over sediments mapped as Pb (Barnes, 1967) are interpreted to be a reflection of sand (Recent) cover. No ^{214}Bi values above +2% over Pb outcrops sampled.
West of Aspermont: less than 2.5 ppm. West of Guthrie: 4 to 5 ppm.	Lower over gypsum and dolomite than over shale. Ranges from 4 to 8 ppm.	Lower over gypsum and dolomite than over shale. Ranges from 1 to 3.1%.	0.2 to 1.0	West of Guthrie: 2 ppm U_3O_8 .	West of Aspermont: 1.5 ppm U, 2.1 ppm Th.	Lower ^{208}Tl values over this unit stand out in contrast to higher ^{208}Tl values recorded over sediments (Pb and Pq) in contact with this unit. HSSR well and spring data suggest anomalous amounts of uranium in areas mapped as Pwh.
1.5 to 4.2 ppm over sediments mapped as Pq but interpreted to be Qs or Qt. 4 to 5 ppm in northern half of quadrangle. 3.5 to 4 ppm in southern half of quadrangle.	6 to 8 ppm in northern half of quadrangle. 9 to 14 ppm in southern half of quadrangle.	.7 to 2.6% in northern half of quadrangle. 1.5 to 4.1% in southern half of quadrangle.	0.3 to 0.7 0.3 to 0.4		6.7 ppm U (site mapped as Pq but interpreted to be Qt). 2.3 to 5.1 ppm U, 3.9 to 8.2 ppm Th.	Some ^{214}Bi , $^{214}\text{Bi}/^{208}\text{Tl}$, $^{214}\text{Bi}/^{40}\text{K}$ anomalies over "upper" Quartermaster sediments may be associated with overlying Dockum sediments. HSSR stream samples showed high uranium concentration in areas mapped as Quartermaster.
Maximum of 2.5 ppm over covered Rd. Basal Rd in southern part of quadrangle: 4 to 11 ppm. Upper Rd in southern part of quadrangle: 1 to 3 ppm. Rd in northern part of quadrangle: 1 to 5 (high values from winter survey).	Basal Rd in southern part of quadrangle: 5 to 10.5 ppm. Upper Rd in northern part of quadrangle: 3.5 to 9.5 ppm. Rd in northern part of quadrangle: 4 to 3.5 ppm.	Basal Rd in southern part of quadrangle: .6 to 1.1%. Upper Rd in northern part of quadrangle: .7 to 1.7%. Rd in northern part of quadrangle: .2 to 1.5%.	Basal Rd in southern part of quadrangle: .4 to 2.1%. Upper Rd in northern part of quadrangle: .3 to .6. Rd in northern part of quadrangle: .3 to 1.5.		2.4 to 23.7 ppm U, 4.0 to 12.2 ppm Th.	Low ^{40}K in basal Dockum and high ^{40}K in "upper" Quartermaster can often be used to map contact. eU/eTh of 1 to 2 in truck data over basal Dockum near White River Reservoir is in same area as high ^{214}Bi , $^{214}\text{Bi}/^{208}\text{Tl}$ in aerial data. Favorable areas indicated by HSSR data.
3.3 ppm	1.9 ppm	0.2%	1.1			Limited exposures of Cretaceous sediments in the Lubbock 1" x 2" Quadrangle.

Appendix F. Summarization of the Detailed Interpretation

Stratigraphic Unit	Aerial Radiometric Data						Truck-Mounted Spectrometer Data			
	^{214}Bi	^{208}Tl	^{40}K	$\frac{^{214}\text{Bi}}{^{208}\text{Tl}}$	$\frac{^{214}\text{Bi}}{^{40}\text{K}}$	$\frac{^{208}\text{Tl}}{^{40}\text{K}}$	eU	eTh	K	eU/eTh
Ogallala (To)	Generally between +1.50 and -1.50. In places as high as +120. Anomalies observed in Wood Ranch (Slaton), Benson Lake, Blanco Canyon, Double Mountain Fork of Brazos River Canyon, and Double Lakes and Tahoka Lakes basins areas.	Consistently at or below the mean.	Consistently at or below the mean.	Generally between +1.50 and -1.50 with considerably higher ratios in localized areas.	Generally between +1.50 and -1.50 with considerably higher ratios in localized areas.		Summer 1978 survey: 2.5 to 4 ppm with some higher areas (Blanco Canyon, Double Lakes Basin, and Guthrie Lake Basin). Winter survey: 3.5 to 4.5 ppm.			
Blanco Formation (Qb)	Maximum value: +2.50. Highest at base of Qb.	Below the mean.	At or below the mean.	Above the mean. Highest at base of Qb.	Above the mean. Highest at base of Qb.		3.5 to 6 ppm	Low -- 4 to 4.5 ppm	Low -- .7 to 1.0%	Generally higher than surrounding material.
Tule Formation (Qcu)	Ranges from +1.50 to +8.250.	Near the mean.	Low -- maximum value +.250.				Generally between 3 and 4 ppm. Two sites greater than 4 ppm.	6 to 9 ppm	1 to 1.6%	Generally 0.4 to 0.6. Three sites between 0.7 and 1.0.
Windblown Cover Sands (Qcs)	Generally less than +10. Slight increase to the north.	Increases from south to north end of quadrangle.	Generally less than +10.	Moderate			Summer 1978 survey: 2 to 3.5 ppm in south. As high as 11 ppm in the quad (in part of the 3.5 to 6.5 ppm range in a few areas). 3.5 to 4.5 ppm in north. Winter survey: 4 to 5 ppm in north.	Less than 7 ppm in south. As high as 11 ppm in the north end of the quadrangle.		Generally in 0.4 to 0.6 range. As high as 1.2 in a few areas.
Tahoka Formation (Qta)	Generally greater than -10. As high as +5.50.	Generally at or below the mean. Range: +10 to -20	Generally near the mean. Range: +1.50 to -20.	Generally high. Maximum value: +130.			Less than 5 ppm; commonly in the 3 to 4 ppm range.			Less than 1.2
Playas (Qp)	Less than +10.						No eU anomalies.			
Terrace Deposits (Qtr)	Less than +20.						No eU anomalies.			
Windblown Sand (Qs)	Consistently below the mean -- (low).	Consistently below the mean -- (low).	Consistently below the mean -- (low).	Fluctuated	Fluctuated	Smooth and generally below the mean.	Summer 1978 survey: generally 2 to 3 ppm.	Generally 2.5 to 5.5 ppm.	Generally .5 to .7%.	
Quaternary Alluvium (Qal)	Generally low.	Generally low.	Generally low.				Generally low.	Generally low.	Generally low.	

Hand-Held Spectrometer Data				Chemical Analyses	Radiochemical Analyses	Comments
eU	eTh	K	eU/eTh			
Cap rock: 1.5 to 4 ppm. Below cap rock: between 1.5 and 3 ppm (summer 1978 survey); 4.5 ppm (winter survey). Less than 2.5 ppm over sediments mapped as T ₂ but interpreted to be Q ₃ or Q ₄ .	Cap rock: less than 5 ppm. Below cap rock: between 3 and 7 ppm.	Cap rock: less than .3% Below cap rock: between .4 and 1.2%.	0.4 to 1.0		Cap rock: 1.4 to 3.7 ppm U. Below cap rock: less than 3 ppm U except one basal to sample (4.5 ppm U). Less than 5 ppm Th	²⁰⁸ Tl and ⁴⁰ K over Ogallala outcrops consistently at or below the mean calculated for entire quadrangle—characteristic radiometric signature.
Less than 3 ppm	Less than 4.5 ppm	Less than .7%	0.4 to 1.1		2.5 ppm U, 1.2 ppm Th.	Low thorium in Blanco
3 to 25 ppm	5.5 to 7 ppm	.7 to .9%	0.5 to 3.9		4.5 to 34.2 ppm U, 3.5 to 5.6 ppm Th.	
Less than 3 ppm	Increases to the north. Ranges from 5.5 to 11 ppm.	.8 to 1.6%	0.2 to 0.4		Less than 3 ppm U. Between 7.3 and 11.4 ppm Th.	Increase in ²⁰⁸ Tl from south to north end of the Lubbock 1° x 2° Quadrangle is an obvious radiometric feature.
2.5 to 12 ppm	5 to 3 ppm	.9 to 1.4%	.4 to 1.6		2.0 to 95.1 ppm U; 2.9 to 5.3 ppm Th	Caliche skin on surface of lake basins interpreted to be source of some ²¹⁴ Pb anomalies observed in radiometric data.
1 to 3 ppm	7 to 12 ppm	.9 to 1.7%	0.1 to 0.4		2.6 ppm U, 3.1 ppm Th	Higher ²¹⁴ Pb, ²⁰⁸ Tl values in north end of Lubbock 1° x 2° Quadrangle than in south end.
Generally less than 3 ppm.	Generally 4 to 9 ppm	Generally .6 to 1.5%	Generally 0.3 to 1.1	1 ppm U ₃ O ₈		Limited exposure. No apparent pattern to radiometric signature.
Generally less than 2.5 ppm.	Generally less than 6 ppm	Generally less than 1%	Generally .3 to .6			Low ²¹⁴ Pb, ²⁰⁸ Tl, ⁴⁰ K -- obvious radiometric signature.
						Limited exposure.

Appendix G

Items Delivered to BFEC
But Not Included in the Present Report

APPENDIX G. ITEMS DELIVERED TO BFEC

191 1:62,500 single parameter profile maps
64 1:62,500 geologic profile maps
32 1:62,500 topographic maps
6 1:62,500 altimetry profile maps
2 1:250,000 aeromagnetic profile maps
1 computer print-out of truck-mounted spectrometer assays

PLATES

Note: In this section are reproduced all 114 plates of the report. The plates are reduced and printed on 8½" x 11" sheets for easy reference and general inspection. The plates are not intended to be seriously used in this format. The microfilm copies of the plates which are located in the pocket inside the back cover can be enlarged to the original presentation scale. This enlargement is recommended for the user wishing to gain an appreciation of the manual techniques described in the report.

Legend

Mean value	84.9 cps*
Standard deviation	16.1 cps
Adjusted mean value	84.9 cps
Adjusted standard deviation	30.1 cps
Length of one adjusted standard deviation (scale)	0.2 inches

Displacement (A_n) from mean value (flight line path) calculated by:

$$A_n = \frac{\left(\frac{P_n}{10} - \frac{A_n}{11} - \text{Adj. mean} \right)}{\frac{A_n}{11} - \text{Adj. mean}} \times \text{scale}$$

where n is the n th point along flight path

*cps = counts per second

G-Cubed, Inc.
Spokane, Washington

Evaluation of
Aerial Radiometric Survey Data
Lubbock, TX NTMS Quadrangle

**AIRBORNE RADIOMETRIC
PROFILES
BISMUTH**

Flight Lines ML-1 through ML-23

Revised: 1968 Engineering Corporation Subcontract # 14-176-5
10/1/68

Legend	
Mean value	54.5 cps*
Standard deviation	13.7 cps
Adjusted mean value	54.5 cps
Adjusted standard deviation	13.7 cps
Length of one adjusted standard deviation (scale)	0.2 inches

Displacement (Δp) from mean value (right hand path) calculated by:

$$\Delta p = \frac{(1.77 \cdot \sigma / \sqrt{n}) \cdot \Delta x \cdot \text{mean}}{\Delta x \cdot \text{st. dev.}}$$

where n is the nth point along flight path.

*cps = counts per second

Scale 1:250,000

G-Cubed, Inc.
Spokane, Washington

Evaluation of
Aerial Radiometric Survey Data
Lubbock, TX NTMS Quadrangle

AIRBORNE RADIOMETRIC
PROFILES
THALLIUM
Flight Lines ML-1 through ML-23

Revised Engineering Contract No. 10-175-3
May 1972

Legend	
Mean value	195.0 cps*
Standard deviation	50.1 cps
Adjusted mean value	185.0 cps
Adjusted standard deviation	50.1 cps
Length of one adjusted standard deviation (scale)	0.2 inches

Displacement (A_n) from mean value (light line point) calculated by:

$$A_n = \frac{(1 - \frac{1}{n}) \sum_{i=1}^n (x_i - \bar{x})^2}{n-1} \text{ scale}$$

where n is the nth point along flight path

*cps = counts per second

Scale = 250,000

G-Cubed, Inc.
Spokane, Washington

Evaluation of
Aerial Radiometric Survey Data
Lubbock, TX NTMS Quadrangle

**AIRBORNE RADIOMETRIC
PROFILES
POTASSIUM**

Flight Lines ML-1 through ML-23

Source: Tech Engineering Corporation, Lubbock, TX 79401
Date: 1978

Legend

Mean value	1.62
Standard deviation	0.78
Adjusted mean value	1.62
Adjusted standard deviation	0.78
Length of one adaptive standard deviation (std)	0.2 inches

Displacement (A_n) from mean value (right line path) calculated by:

$$A_n = \frac{(1.62 \cdot A_n / (1.62 - \text{mean}))}{0.78} \text{ scale}$$

where n is the nth point along flight path

Scale 1:250,000

G-Cubed, Inc.
Spokane, Washington

Evaluation of
Aerial Radiometric Survey Data
Lubbock, TX NTMS Quadrangle

**AIRBORNE RADIOMETRIC
PROFILES**
BI/TI
Flight Lines ML-1 through ML-23

Made: Field Engineering Corporation Subcontract 10-176-1
10/1/78

Legend

Mean value	0.28
Standard deviation	0.07
Adjusted mean value	0.28
Adjusted standard deviation	0.07
Length of one adjusted standard deviation (scale)	0.2 inches

Displacement (A_n) from mean value (flight line path) calculated by:

$$A_n = \frac{\left(\frac{1}{n} \sum_{i=1}^n A_i^2 - A_n^2 \right)^{1/2}}{A_n} \text{ scale}$$

where n is the nth point along flight path.

G-Cubed, Inc.
Spokane, Washington

Evaluation of
Aerial Radiometric Survey Data
Lubbock, TX NTMS Quadrangle

**AIRBORNE RADIOMETRIC
PROFILES**
T/K

Flight Lines ML-1 through ML-22

Scale: 1 inch = 250,000 feet
Date: 10/1/78

Page 11

Legend	
Mean value	84.9 cps*
Standard deviation	36.1 cps
Adjusted mean value	84.9 cps
Adjusted standard deviation	36.1 cps
Length of one adjusted standard deviation (scale)	0.2 inches

Displacement (A_0) from mean value (flight line path) calculated by:

$$A_0 = \frac{(1/n) \sum_{i=1}^n R_i - R_0}{\text{scale}}$$

where n = the nth point along flight path

*cps = counts per second

Scale: 1:750,000

G-Cube, Inc.
Spokane, Washington

Evaluation of
Aerial Radiometric Survey Data
Lubbock, TX NTMS Quadrangle

AIRBORNE RADIOMETRIC
PROFILES
BISMUTH

Flight Lines TL-1 through TL-10

Sheet 1 of 2 (Sheet 2 of 2)

Legend	
Mean value	1.62
Standard deviation	0.76
Adjusted mean value	1.62
Adjusted standard deviation	0.76
Length of one adjusted standard deviation (sigma)	0.2 inches
Displacement (A_n) from mean value (flight line path) calculated by:	
$A_n = \frac{\left(\sum_{i=1}^n \frac{D_i}{n} - \bar{D} \right) \times \text{scale}}{n}$	
where n is the nth point along flight path	
G-Cubed, Inc. Spokane, Washington	
Evaluation of Aerial Radiometric Survey Data Lubbock, TX NTMS Quadrangle	
AIRBORNE RADIOMETRIC PROFILES BI/TI Flight Lines TL-1 through TL-10	
<small>Model: 1 and Engineering 1-1000000 Subcontract 1-78-121-1 May, 1979</small>

Legend	
Mean value	0.43
Standard deviation	0.24
Adjusted mean value	0.43
Adjusted standard deviation	0.24
Length of one adjusted standard deviation (scale)	0.2 inches
Displacement (A_n) from mean value (flight line point) calculated by:	
$A_n = \left(\frac{\sum_{i=1}^n B_i^2}{n} - \frac{(\sum_{i=1}^n B_i)^2}{n^2} \right)^{1/2} \times \text{scale}$	
where n = the nth point along flight path

G-Cubed, Inc.
Spokane, Washington

Evaluation of
Aerial Radiometric Survey Data
Lubbock, TX NTMS Quadrangle

AIRBORNE RADIOMETRIC
PROFILES
BI/K
Flight Lines TL-1 through TL-10

Revised: Field Engineering Location Submittal # FES-74-5
May 1975

Legend	
Mean value	0.28
Standard deviation	0.07
Adjusted mean value	0.28
Adjusted standard deviation	0.07
Length of one adjusted standard deviation (feet)	0.2 inches
Displacement (A_n) from mean value (flight line path) calculated by:	
$A_n = \frac{1}{n} \sum_{i=1}^n (B_i / (71 - 44) \text{ mean}) \times \text{scale}$	
where n is the nth point along flight path

G-Cubed, Inc.
Spokane, Washington

Evaluation of
Aerial Radiometric Survey Data
Lubbock, TX NTMS Quadrangle

AIRBORNE RADIOMETRIC
PROFILES
TI/K

Flight Lines TL-1 through TL-10

Source: First Engineering Corporation, Spokane, WA 99201-1111
Date: 1/1/75

<p>Legend</p> <p>Geochronological Analysis (ppm) Hand-held spectrometer values (ppm)</p> <p>Station location (A indicates total U₂O₇ determined by geochron U₂O₇ analysis; (B) indicates U₂O₇ determined by geochronological analysis)</p>	
<p>Scale 1:250,000</p> <p>0 1 2 3 4 5 Miles</p> <p>0 1 2 3 4 5 Kilometers</p>	
<p>G-Cubed Inc. Spokane, Washington</p>	
<p>Evaluation of Aerial Radiometric Survey Data Lubbock, TX NTMS Quadrangle</p>	
<p>HAND-HELD SPECTROMETER AND GEOCHEMICAL ANALYSIS: URANIUM VALUES</p>	
<p>Source: Farris Engineering Corporation, Lubbock, TX 1975, 1976</p>

Legend	
Mean value	52,581 gamma
Standard deviation	429 gamma
Adjusted mean value	52,581 gamma
Adjusted standard deviation	429 gamma
Vertical Scale	1 in = 2000 gamma

Scale 1:250,000

0 1 2 3 4 5 Miles
0 1 2 3 4 5 Kilometers

G-Cubed, Inc.
Spokane, Washington

Evaluation of
Aerial Radiometric Survey Data
Lubbock, TX NTMS Quadrangle

**AEROMAGNETIC
PROFILES
AND INTERPRETATION**

Source: Data Engineering Corporation, Subcontract # FR-76-5
May, 1979

<p>Legend</p> <p>County Boundary</p> <p>Escarpment</p> <p>River</p> <p>High Ti - Low Ti contact</p> <p>High Bi and Bi/Ti</p> <p>Low Bi, Ti, and K</p> <p>High Ti and K</p>	
<p>Scale 1:250,000</p> <p>North Arrow</p>	
<p>G-Cubed Inc. Spokane, Washington</p>	
<p>Evolution of Aerial Radiometric Survey Data Lubbock, TX NTMS Quadrangle</p>	
<p>OBSOLETE RADIOMETRIC FEATURES</p>	
<p>Revised Field Engineering Inspection Subcommittee May 1979</p>

<p>Legend</p> <p>County Boundary</p> <p>Escapement River</p> <p>Obvious high Bi and Bi/Ti anomalies</p> <p>Approximate boundary of Cretaceous rocks</p>	
<p>Scale</p> <p>1:250,000</p> <p>0 1 2 3 4 5 6 7 8 9 10 Miles</p>	
<p>G-Cubed Inc. Spokane, Washington</p>	
<p>Evaluation of Aerial Radiometric Survey Data Lubbock, TX NTMS Quadrangle</p>	
<p>Obvious Bi and Bi/Ti Anomalies and the Extent of Cretaceous Rocks</p>	
<p><small>Spokane, Washington May 1979</small></p>

- Qol** Quaternary alluvium
 - Qcs** Quaternary windblown sand sheets (Qol and dunes (Qol))
 - Ql** Quaternary fluvial terrace deposits
 - Op** Quaternary playa deposits
 - Qla** Quaternary Tule Formation
 - Qca** Quaternary windblown cover sand
 - Qlu** Quaternary Tule Formation
 - Qb** Quaternary Blanca Formation
 - To** Tertiary Ogallala Formation
 - Kls** Cretaceous Duck Creek Shale and Niangua Shale
 - Ke** Cretaceous Edwards Limestone, Comanche Peak Limestone, Walnut Formation, and Antler Sand
 - Kd** Triassic Dockum Group
 - Pq** Permian Quartermaster Formation
 - Pwh** Permian Whitehorse Sandstone and Cloud Creek Gypsum
 - Pb** Permian Blaine Formation
 - Psa** Permian San Angelo Formation
 - Pch** Permian Chisos Formation
- Flight line positions not at true north-south locations.
 Survey from 1967 Geologic Atlas of Texas, Lubbock Sheet (Barrett) and Cross 89981

Vertical Scale 1" = 100'
 Horizontal Scale 1" = 62,500'

G-Cube, Inc.
 Spokane, Washington

Evaluation of
 Aerial Radiometric Survey Data
 Lubbock, TX NTMS Quadrangle

Geologic Profiles Along
 Flight Lines ML-13 through ML-18
 Lubbock 15' Quadrangle

Geologic Profile Map, Lubbock 15' Quadrangle, NTMS
 10/1/78

Page 45

Page 46

Page 49

Page 50

Page 52a

Page 52b

Page 52c

Page 53

Page 64

Page 65

Page 72

Page 73

Page 79

Page 80

Plate B1

Plate B2

Page 83

Page 84

LEGEND

REFERENCE LINES
 TH 6.0 PPM
 U 3.5 PPM
 K 1.0 %
 U/TH 0.5

ELEMENTAL RATIO PROFILES
 U/TH RATIO
 U/K RATIO

RADIOELEMENT PROFILES
 DATA LINE

ERROR BAR +/- 1 S.D.

BENDIX TRUCK SPECTROMETER SURVEY
 LINE NUMBER 171
 DATE RECORDED 8 15 78
 LUBBOCK, TEXAS PROJECT
 G-CUBED INCORPORATED
 SPOKANE, WASHINGTON

LEGEND

REFERENCE LINES
 TH 6.0 PPM
 U 3.5 PPM
 K 1.0 %
 U/TH 0.5

ELEMENTAL RATIO PROFILES
 U/TH RATIO
 U/K RATIO

RADIOELEMENT PROFILES
 DATA LINE

ERROR BAR +/- 1 S.D.

BENDIX TRUCK SPECTROMETER SURVEY
 LINE NUMBER 171
 DATE RECORDED 8 15 78
 LUBBOCK, TEXAS PROJECT
 G-CUBED INCORPORATED
 SPOKANE, WASHINGTON

Plate 92a

Plate 92b

CUMULATIVE