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October 5, 1977

Mr. Mike Wright
Earth Science Laboratories
U.U.R.I.
580 Arapeen Dr.
Salt Lake City, Utah 84108

Dear Mr. Wright:

Enclosed is shallow test data by state and county for the area you are interested in.

Sincerely yours,

Karen Dean (ve)

Karen Dean, Geologist
Technical Services Dept.

KD:ve
encs.

State & County	total # wells	IP's ≤ 2000'	IP's ≤ 4000'	PDT's ≤ 2000'	PDT's ≤ 4000'	DST's ≤ 2000'	DST's ≤ 4000'
west of 103° TEXAS							
Brewster	87	–	–	15	19	3	4
Culberson	1859	13	190	71	229	84	198
Hudspeth	47	–	–	1	3	7	30
Jeff Davis	28	–	–	1	6	3	13
Loving	388	–	138	7	250	–	2
Pecos	10146	1891	2867	2466	4311	2466	4311
Presidio	40	–	–	2	6	7	10
Reeves	1974	6	542	25	624	29	279
Ward	7081	45	3617	28	3327	294	2830
Winkler	7501	–	3627	11	2176	66	1425
Texas subtotal	29175	1935	10981	2627	10951	2959	9102
NEW MEXICO							
Chaves	2521	230	1135	205	704	128	464
Eddy	8459	1077	4474	906	3507	935	3206
Lea	16866	3	4923	20	5708	189	3596
Lincoln	22	–	–	6	8	10	10
Roosevelt	1196	1	1	–	13	5	43
Otero	43	–	–	1	12	12	41
Bernadillo	5	–	–	2	2	–	1
Catron	9	–	–	–	–	1	2
Colfax	82	2	2	10	19	5	22
Curry	50	–	–	–	12	2	17
DeBaca	75	–	–	6	12	6	10
Dona Ana	9	–	–	2	2	–	2
Grant	3	–	–	–	–	–	2
Guadalupe	62	–	–	6	6	20	24
Harding	108	6	27	26	33	6	10
Hidalgo	12	–	2	2	3	1	2
McKinley	994	213	265	76	120	50	136
Mora	29	7	7	5	7	9	13
Quay	54	–	1	1	4	2	8
Rio Arriba	4461	14	2096	27	168	17	155
Sandoval	449	28	103	35	58	25	77
San Juan	9099	1365	3337	262	382	108	343

NEW MEXICO Cont'							
San Miguel	60	–	–	–	5	13	36
Santa Fe	18	–	–	2	8	3	6
Socorro	14	–	–	4	6	3	4
Torrance	49	–	–	6	7	1	5
Union	60	–	8	4	4	1	12
Valencia	47	–	–	3	5	1	16
New Mex. subtotal	23,109	2946	16,379	1617	10,815	1553	8263
NORTH DAKOTA							
Billings	190	1	1	–	–	3	3
Bottineau	1214	3	384	2	98	6	582
Bowman	180	3	3	3	4	8	8
Burke	758	6	7	6	6	2	3
Burleigh	26	–	–	–	–	–	5
Divide	149	–	–	–	–	4	4
Dunn	67	–	–	–	–	2	2
Emmons	23	–	–	–	–	–	12
Grant	20	–	–	–	–	–	1
McHenry	109	–	–	–	–	1	27
McKenzie	663	2	2	3	3	3	3
Mercer	18	–	–	–	–	–	1
Morton	24	–	–	–	–	2	5
Oliver	13	–	–	–	–	–	1
Renville	669	4	12	1	9	8	20
Sheridan	9	–	–	–	–	–	1
Slope	78	–	–	–	–	1	1
Stark	200	–	–	–	–	2	2
Ward	202	–	–	–	–	1	2
Williams	732	–	–	1	1	2	2
N. Dak. subtotal	5344	19	409	16	121	45	688
SOUTH DAKOTA	3						
Butte	59	–	–	–	–	2	14
Corson	24	–	–	–	–	5	11
Custer	64	5	5	18	18	4	7
Fall River	176	3	3	2	5	14	38

SOUTH DAKOTA cont'							
Haakon	30	–	–	2	2	4	12
Harding	179	1	1	3	3	4	21
Jackson	10	–	–	–	–	1	9
Jones	9	–	–	–	–	2	10
Lawrence	3	–	–	–	–	1	1
Meade	56	–	–	–	–	3	10
Mellette	2	–	–	–	4	–	1
Pennington	39	–	–	–	–	3	6
Perkins	16	–	–	–	–	–	4
Shannon	5	–	–	–	–	5	6
Stanley	19	–	–	–	–	4	15
Ziebach	16	–	–	–	–	–	6
SOUTH DAK	707	9	9	25	32	52	171
UTAH							
Box Elder	42	1	1	4	4	–	1
Cache	7	–	–	–	–	–	1
Carbon	127	3	14	3	13	6	77
Daggett	40	–	–	1	1	1	4
Duchesne	490	–	9	2	16	25	143
Emery	199	10	18	12	44	26	109
Garfield	117	–	–	–	10	2	34
Grand	800	103	143	82	113	38	123
Juab	3	–	–	–	–	–	1
Kane	29	–	–	–	4	1	9
Millard	27	–	–	–	–	3	6
Salt Lake	11	–	–	1	1	–	–
San Juan	1830	32	34	39	73	49	179
Sanpete	25	–	–	1	1	–	3
Sevier	24	–	–	–	–	10	21
Summit	61	1	1	–	2	23	45
Uintah	1073	15	71	66	114	56	393
Utah	20	–	–	–	–	–	4
Wasatch	16	–	–	–	1	17	23
Washington	213	36	37	26	27	–	4

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UTAH cont'							
Wayne	64	-	- 2	~~6~~2	6 ~~3~~	13	76
Utah subtotal	5218	201	328	239	430	270	1256
WYOMING							
Albany	279	14	44	5	10	30	92
Big Horn	1847	159	371	199	342	103	464
Campbell	5160	16	32	9	27	29	49
Carbon	1300	66	245	44	152	176	554
Converse	2497	41	100	150	226	38	103
Crook	1783	148	169	71	79	77	171
Fremont	2498	3441	3733	231	371	313	950
Goshen	196	–	–	3	3	3	22
Hot Springs	1803	156	724	172	290	73	375
Johnson	1439	52	258	24	49	53	233
Laramie	367	2	2	–	–	12	21
Lincoln	480	64	92	16	17	25	107
Natrona	5541	813	1373	1142	2230	184	515
Niobrara	1365	70	221	79	194	64	211
Park	2270	161	773	105	232	96	512
Platte	76	–	2	5	7	19	25
Sheridan	255	–	–	–	–	2	6
Sublette	1634	254 ~~193~~	637 ~~576~~	72 ~~265~~	125	265	947
Sweetwater	2114	74	279	21	115	134	910
Teton	27	–	–	–	5	7	25
Uinta	320	~~2~~4	5	17	21	7	30
Washakie	796	44	65	52	54	35	116
Weston	5008	426	844	329	417	20	134
Wyo. subtotals	28735	6005	9969	2746	4966	1765	6572
ARIZONA							
Apache	446	28	44	30	65	82	165
Cochise	57	–	–	9	13	6	7
Coconino	51	–	–	5	5	1	8
Graham	36	–	–	2	2	–	–
Maricopa	44	–	–	1	1	–	–
Mohave	22	–	–	3	3	1	2

ARIZONA cont'							
Navajo	111	–	–	23	28	24	43
Pinal	21	–	–	1	2	–	–
Yavapai	36	–	–	4	4	1	1
Yuma	26	–	–	–	–	1	4
Ariz. subtotals	850	28	44	78	123	116	230
COLORADO							
Adams	1707	2	2	6	7	7	8
Alamosa	6	–	–	–	1	–	–
Arapahoe	598	–	–	–	–	–	4
Archuleta	202	21	23	13	17	3	8
Baca	424	4	127	1	154	21	327
Bent	144	–	–	–	6	2	17
Boulder	163	8	19	4	15	2	11
Cheyenne	198	–	–	1	2	1	8
Conejos	3	–	–	–	–	1	1
Crowley	23	–	–	–	–	2	3
Delta	52	1	1	5	5	4	7
Dolores	45	–	–	–	–	2	6
Douglas	22	–	–	–	–	–	1
Elbert	289	–	–	12	15	6	15
El Paso	91	–	–	–	–	–	4
Fremont	350	9	27	64	106	–	4
Garfield	225	10	36	11	39	13	53
Grand	34	–	–	1	2	10	25
Gunnison	18	–	–	2	10	5	10
Huerfano	109	5	12	5	6	11	27
Jackson	281	31	59	4	6	41	99
Jefferson	17	–	–	–	–	1	1
Kiowa	300	1	9	1	14	4	89
Kit Carson	88	–	–	–	–	1	17
La Plata	821	14	154	18	57	32	132
Larimer	344	6	21	15	25	16	56
Las Animas	130	12	13	5	12	21	46
Lincoln	128	–	–	–	–	–	6

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COLORADO cont'							
Logan	3129	17	18	28	29	9	20
Mesa	280	12	60	24	49	29	95
Moffat	966	16	182	15	69	115	665
Montezuma	522	47	49	30	37	14	28
Montrose	69	—	1	6	6	8	12
Morgan	2138	3	4	4	4	11	18
Otero	39	—	—	1	1	—	1
Ouray	24	4	4	—	—	2	2
Park	19	—	—	—	—	—	1
Phillips	43	—	—	—	—	—	45
Pitkin	19	—	—	—	—	2	2
Prowers	152	—	—	1	14	2	54
Pueblo	91	—	—	1	1	1	3
Rio Blanco	2312	159	562	34	107	75	238
Rio Grande	1	1	1	—	—	—	—
Routt	234	2	38	5	22	20	78
Saguache	10	—	—	—	—	—	2
San Miguel	53	—	—	—	—	6	16
Sedgwick	78	—	12	—	—	—	22
Washington	3904	7	63	9	22	10	229
Weld	3127	7	7	22	23	15	15
Yuma	282	28	39	2	3	—	95
Colo. subtotal	24,304	427	1543	350	886	525	2626
IDAHO							
Bonner	5	—	—	1	1	2	2
Canyon	3	—	—	—	1	—	2
Caribou	4	—	—	—	—	—	1
Gem	1	—	—	—	—	3	3
Payette	8	1	1	2	2	3	3
Washington	2	—	—	—	—	—	1
	23	1	1	3	4	8	12
MONTANA							
Big Horn	403	67	73	12	19	27	66
Blaine	1029	205	312	20	24	227	318

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MONTANA
cont'

Carbon	450	11	35	22	40	42	129
Carter	367	7	8	9	9	15	74
Cascade	72	-	-	-	-	10	28
Chouteau	458	50	81	17	22	102	169
Custer	197	-	11	-	1	15	64
Daniels	70	-	-	-	1	4	4
Dawson	227	-	-	1	1	7	8
Fallon	801	104	105	9	9	26	34
Fergus	309	15	16	10	11	38	75
Gallatin	18	-	-	-	1	-	-
Garfield	184	34	34	4	4	8	19
Glacier	2530	50	1820	16	258	11	316
Golden Valley	79	3	5	-	3	30	83
~~Granite~~ Hill	958	188	204	23	44	280	527
Judith Basin	62	-	-	3	3	7	15
Lewis+Clark	17	-	-	-	-	1	4
Liberty	770	72	288	22	58	139	696
Lincoln	1	1	1	-	-	-	-
McCone	250	-	-	-	-	3	6
Meagher	7	-	-	1	1	7	7
Musselshell	906	5	158	15	40	19	276
Park	20	-	-	-	-	2	3
Petroleum	536	67	72	24	28	36	72
Phillips	697	363	364	72	72	153	214
Pondera	842	230	405	40	101	45	166
Powell	2	-	-	-	-	1	1
Powder River	1024	0	12	-	1	1	51
Richland	198	-	-	3	3	5	5
Roosevelt	454	1	1	10	10	19	24
Rosebud	803	2	3	2	8	22	84
Sheridan	429	-	-	-	-	3	4
Stillwater	224	40	62	21	30	40	131
Sweetgrass	49	2	3	3	7	11	31
Teton	526	38	194	25	92	57	157

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MONTANA cont'							
Toole	3406	1375	1759	229	287	261	767
Treasure	21	—	—	1	1	2	5
Valley	236	64	64	16	16	41	60
Wheatland	46	+	3	4	11	9	34
Wibaux	174	5	5	—	—	1	1
Yellowstone	268	17	17	16	19	22	44
Mont. subtotal	20,120	3016	6115	650	1235	1495	4772
NEVADA							
Churchill	26	1	1	1	1	—	—
Clark	31	—	—	12	13	1	1
Elko	22	—	—	0	1	1	3
Eureka	11	—	—	2	3	—	—
Lincoln	5	—	—	—	—	—	2
Nye	64	—	—	1	1	3	8
White Pine	42	—	—	2	3	—	10
	201	1	1	17	22	5	24
ALASKA - quad names							
Anchorage	30	—	—	—	1	7	16
Barrow	24	—	2	—	2	—	—
Beechey Point	220	23	23	—	4	1	12
Bering Glacier	10	—	—	—	—	3	6
Harrison Bay	7	—	—	—	1	—	—
Ikpikpuk R.	16	—	—	2	3	—	—
Iliamna	9	—	—	1	1	—	—
Kenai	464	2	3	4	8	1	26
Kotzebue	2	—	—	—	—	1	4
Sagavanirktok	14	—	—	—	—	2	9
Teshekpuk	3	—	—	3	3	—	—
Tyonek	86	—	2	—	3	—	12
Ugashik	10	—	—	—	—	1	1
Umiat	18	1	2	—	—	14	31
Alas. subtotal	913	26	32	10	26	30	117

CALIFORNIA							
Alameda	3	1	1	–	–	1	1
Colusa	43	–	2	–	–	–	–
Contra Costa	28	–	–	–	–	–	1
Fresno	293	9	11	3	5	–	1
Glenn	56	–	2	–	1	1	2
Imperial	30	–	–	3	3	1	1
Kern	6397	610	857	353	736	8	40
Kings	32	2	2	2	2	–	–
	6882	622	875	361	747	11	46
WASHINGTON							
Clallam	18	–	–	–	1	1	1
GraysHarbor	64	–	–	4	10	1	20
Jefferson	12	–	–	1	1	1	2
King	15	–	–	1	1	3	9
Lewis	90	–	–	–	–	10	19
Whatcom	43	–	–	2	2	2	2
Wash. subtotal	242	–	–	8	15	18	53
OREGON HAWAII	0						
Totals	145,823	20,253	45,811	8,747	30,373	8852	33952

April 5, 1976

AREA
USwest
Explor

MEMORANDUM

TO: All Geologists

FROM: R. Kehmeier and T. Vehrs

SUBJECT: ROCKY MOUNTAIN SECTION MEETINGS OF AAPG AND SEPM
"NEW CONCEPTS OF EXPLORATION IN THE ROCKIES"

The meetings were held in Billings, Montana, March 28th through the 31st, and were largely oriented towards oil and gas and geothermal energy exploration. Nine papers relating to uranium and uranium exploration were presented. Only the important aspects of the uranium-related papers will be summarized below. Information contained in the attached abstracts will not be duplicated.

URANIUM PAPERS

AN OVERVIEW OF AUSTRALIAN URANIUM DEPOSITS - Louis R. Reimer

1. Yeelirrie, Western Australia: Deposit contains approximately 100 million tons of uranium at an average grade of 3 lb/ton. The mineralized zone is four miles long by one half mile wide with a maximum depth of 30 feet. The deposit occupies an ancient river valley between granite highlands. The detrital material is cemented with calcrete and secondary uranium minerals are present as coatings on grains. Migrating ground waters carrying uranium evaporated, thereby depositing the uranium.

2. Lake Frome is a stratabound deposit occupying a fault controlled basin. Reserves are 18 million pounds at 3 lb/ton.

3. The Beverly deposit contains approximately 25 million tons of uranium at an average grade of about 5 lb/ton. The deposit is situated in a sandstone in a flood plain or lacustrine environment. Finely divided uraninite is closely associated with carbonaceous material.

4. The Mary Kathleen deposit contains between 15 and 21 million pounds of uranium at an average grade of 2 to 2½ lbs/ton. The deposit is localized in lower Proterozoic metasediments that are surrounded by granitic rocks. Uraninite ore is structurally controlled by shearing and brecciation. This deposit was probably derived by the metamorphism of an earlier stratabound deposit.

5. The Westmoreland area has approximately 35 million pounds of uranium reserves at an average grade of four to five lb/ton. The

vein deposit is localized in shear zones associated with andesite dikes.

6. Alligator District and Northern Territories: The deposits are all in the near proximity of the unconformity separating the lower Proterozoic from the upper Proterozoic rocks. The deposits are generally localized in shears and fractures. The Northern Territories contains approximately 700 million pounds of reserves at the present time. Nabarlek has reserves of 22 million pounds at 46 lb/ton. The ore at Koogarra has been dated at 870 million years and is localized in a quartz-chlorite schist. Ranger has 228 million pounds of uranium reserves in brecciated quartz-chlorite schists and gneisses. Jabiluka has approximately 450 million pounds of reserves at 8 lb/ton. The ore is associated with shears in quartz-chlorite schists. Gold mineralization is associated with the uranium and of considerable significance.

STRATIFORM URANIUM - COPPER DEPOSITS, RUM JUNGLE, NORTHERN TERRITORY, AUSTRALIA - John Sandy

Paper was not presented.

URANIUM EXPLORATION IN PRECAMBRIAN (?) CONGLOMERATES IN GUYANA, SOUTH AMERICA - Philip Donnerstag

In the Guyana shield of South America, biotite hornblende gneisses and metasedimentary rocks are overlain by Guyana system sandstones, shales and tuffs. The Roraima Formation was the exploration target and has a minimum age of 1700 m.y. It is up to 9000 feet thick and contains high energy conglomerates. An airborne radiometric survey was conducted above the rims of the Roraima Formation and 11 anomalies at or near the base of the Roraima Formation were discovered. The best radioactivity was associated with granite carrying 110 ppm U. Uranium exploration in this area was prompted by uranium occurrences in Precambrian conglomerates in Brazil.

URANIUM IN PLUTONIC ROCKS - Frank C. Armstrong

The talk was very much a rerun of earlier talks on the same subject. Uranium increases in igneous rocks as they become more acid. The bulk of uranium in volcanic rocks is localized in the groundmass. In New Hampshire, in the Highlandcroft series (metamorphosed), 51% of the uranium is in accessory minerals (epidote). In the New Hampshire series (unmetamorphosed), most of the uranium is in felsic minerals. In alkalic rocks, the uranium is generally located within the crystal structure of accessory minerals and therefore difficult to leach. In the Ilimaussaq intrusion of Greenland, with a sulfate roast at 700° C, there is a 70% recovery of the uranium present. Retention of uranium in late crystallizing rocks is indicated by abundant pegmatites and aplitic dikes according to Armstrong.

HELIUM DETECTION, AN EXPLORATION GUIDE TO URANIUM SOURCES - R. H. DeVoto and R. H. Mead

The majority of the facts are presented in the attached abstract. The findings of this study are significant but the interpretations may stretch the data a bit thin. The method certainly offers promise but must be used cautiously. DeVoto plans an extensive research program this summer to include reproducibility studies in the Powder River Basin, long traverses in the Powder River Basin over several known uranium deposits and traverses in the Ambrosia Lake District over deposits at varying depths.

THE OKLO PHENOMENON: GEOLOGICAL AND NUCLEAR ASPECTS - D. G. Brookins

All information contained in abstract.

THE SABKHA ENVIRONMENT: A NEW FRONTIER FOR URANIUM EXPLORATION - R. R. Rawson

R. R. Rawson applied a sabkha environment origin to the uranium deposits in the Jurassic Todilto Formation near Grants, New Mexico. He believes that the crinkly beds represent stromatolites and that some of the folded structures may be algal domes in the F-33 mine. The age of the uranium mineralization in the Todilto Formation is 150 to 155 m.y. (i.e. preMorrison). Rawson believes this model has considerable merit and suggested several places in the Utah, Nevada area where it could be applied:

1. the Permian Transition in Utah
2. the Bonneville Tertiary Lake System
3. Green River Basin

The sabkha environment in the Permian of Texas differs sufficiently from the Todilto that I (RJK) seriously question his interpretation of the environmental deposition. However, there is reason to believe that the sabkha environment could act as a uranium concentrator but I (RJK) have serious doubts about the ability of the sabkha environment to produce any deposits of economic size.

URANIUM IN TERTIARY CHANNELS SOUTHEAST OF LAKE FROME, SOUTH AUSTRALIA - D. Brunt and B. Ruben

The majority of the uranium deposits are near the edges of the Tertiary channels and are associated with interfingerings of clay and sandstone near the channel margins. Associated with these deposits is a redox front similar to Wyoming roll-front deposits but with well-developed limonitic alteration rather than hematitic alteration. Ore is associated with humic material coating the sand grains and filling voids. When clay interbeds are absent along channel margins, the redox front extends to the channel boundaries. The geometry, location and associations of the Lake Frome ore bodies are similar to those seen in Ambrosia Lake.

SYNOPSIS OF GEOTHERMAL PAPERS

Geothermal energy appears to be considered by not only the government but by industry as a viable source of energy and quite a bit of exploration effort is being put into geothermal sources.

Apparently two things are needed to make an economic geothermal resource:

1. a high temperature for the water, and
2. a large amount of water in the aquifer which is readily available for conversion into electrical power.

The temperature of the water can be highly variable and it depends on not only its use but its proximity to a user. The exploration for a known geothermal resource area or "KGRA" as it is referred to by the government, involves a combination of geology, geochemistry and geophysics. Probably the best paper given on geothermal energy was the one given for geothermal exploration of the Roosevelt KGRA area in Utah. This was given by people from the Phillips Petroleum Company. In this study they used a combination of hydrochemistry, chemical geothermometry, petrography, gravity, magnetics, resistivity, mapping, ground noise and thermogradient drilling to help them define and model the geothermal source. Several different kinds of resistivity are used and new ones are being developed which appear to have great promise.

PETROLEUM PAPERS

The only petroleum paper that had any information that could prove to be useful was given by W.H. Alderman of Amoco Production, entitled "Use of Interactive Computergraphics for Exploration." Mr. Alderman stated that the use of interactive computergraphics for exploration up to this point had been for only large companies that were able to maintain their own files based on scout ticket information. However, the Dept. of the Interior has now put together a data storing system called "Petroleum Data Base" which makes it possible for the small companies and independents to have access to a data base that can be used as an interactive data storage and retrieval system. This petroleum data base is managed by the GE Time Sharing Program. It apparently contains all of the petroleum tests drilled in the U. S. and stores some information on each hole. The information has been taken from scout tickets. We have contacted the local GE sales representative about this system and are currently awaiting more information from him.

Dick Kehmeier
Dick Kehmeier

Tom Vehrs (by RJK)
Tom Vehrs

RJK/TV:wh

ABSTRACTS
TECHNICAL PAPERS

BABCOCK THEATRE
Monday, March 29, Afternoon

1:20 (No. 45)

AN OVERVIEW OF AUSTRALIAN URANIUM DEPOSITS

LOUIS R. REIMER
Wyoming Mineral Corporation, Lakewood, Colorado

The geology, ore reserves, mineralogy, and other pertinent details of the following Australian uranium deposits are presented with emphasis on the larger deposits.

District	Deposit Name	Reserves Lbs.x10^6	Type Host Rock	Form
Alligator	Nabarlek	22	Chlorite schist	Vein
Rivers	Jabiluka 1 & 2	242	Carb. & chloritic schist	Vein?
N.T.	Ranger 1	228	Qtz. & chloritic schist	Vein
	Koongarra	88	Qtz. chlorite schist	Vein
S. Alligator River Mines N.T.		Minor	S.S. & carb. shale	Vein
Rum Jungle Mines N.T.		1 +	Graphitic — chloritic sh.	Vein
Yeelirrie W.A.	Yeelirrie	101.2	Calcrete	Vug fillings
Mary Kathleen Qld.	Mary Kathleen	20	Garnet-diopside granulite	?
Westmoreland	Westmoreland, Qld.	32	Filled shear margin	Vein
Pandanus Creek	Cobar II, N.T.	Minor	Acid volcanics	Vein
Qld - N.T.	Eva, N.T.	Minor	Acid volcanics	Vein
Lake Frome	Beverly	35	S.S. & siltstone	Stratiform
S.A.	Others	N/A	S.S. & siltstone	Stratiform
Other South	Mt. Painter	18?	Granitic Breccia	?
Australian	Radium Hill	Minor?	Amphibolites & gneisses	Shear filling
Ngalia Basin N.T.		Expl. Cont.	Arkosic S.S.	Roll?
Northwest Aust.	Mundong Well	Minor	Schist	Shear filling

2:10 (No. 46)

THICK COAL BEDS IN THE WASATCH FORMATION, WESTERN POWDER RIVER BASIN, WYOMING

WILLIAM C. CULBERTSON
U.S. Geological Survey, Denver, Colorado

In an area of 325 square miles in east central Sheridan County, Wyoming (western Powder River basin), the Eocene Wasatch Formation is as much as 1,700 feet thick, and contains as many as 18 beds of subbituminous coal more than 2 feet thick. The resources of coal in beds more than 10 feet thick are estimated to be 2.3 billion tons, of which 2.1 billion tons are contained in two beds, the Ulm 1 and Ulm 2, whose maximum thicknesses are 44 and 30 feet, respectively. Most beds are not suitable for recovery by stripping because of high local relief, but the Ulm 1 and Ulm 2 locally underlie flat upland areas at shallow depths, principally in the Verona and Ulm quadrangles, in the vicinity of Tps. 54 and 55 N., R. 81 W. Analysis of samples of coal from the outcrop indicate that the Ulm beds contain 0.4 to 1.9 percent sulfur.

The thicker coal beds are extensively burned along the outcrop, so drilling is necessary for exploration. Power augering, combined with gamma-ray logging, was used as a rapid and inexpensive method of exploration to depths of about 100 feet. Because the coal has very low radioactivity, the gamma-ray log accurately delineates the coal bed and major partings, but may not record partings less than 1 foot thick.

2:35 (No. 47)

STRATIFORM URANIUM — COPPER DEPOSITS RUM JUNGLE, NORTHERN TERRITORY AUSTRALIA

Paper not given

JOHN SANDY
Wold Minerals Exploration Company; Casper, Wyoming

Uranium mineralization at Rum Jungle is found chiefly in graphitic black shales of Lower Proterozoic age. The beds dip away from a complex of metamorphic and granitic rocks forming a dome which is partly depositional and partly due to doming accompanying granite emplacement.

Genesis of the mineralization appears to be syngenetic with diagenetic effects and subsequent hydrothermal remobilization of metals resulting in small, high-grade lenses of uranium and copper with minor amounts of lead, cobalt and gold occurring along shears and fold-deformation fractures. Several other theories have been postulated based on a comparison with similar deposits in the United States, Germany, and Rhodesia.

3:00 (No. 48)

SEDIMENTATION AND MULTIPLE COAL SEAM CORRELATIONS IN AN UPPER CRETACEOUS SWAMP COMPLEX, JOHN HENRY MEMBER OF THE STRAIGHT CLIFFS FORMATION, SOUTHERN KAIPAROWITS REGION, UTAH

JERRY VANINETTI
Consulting Geologist, Salt Lake City, Utah

A maximum of eleven coal seams greater than four feet in thickness comprising six major coal zones has been delineated in a stratigraphic study of the John Henry Member of the Straight Cliffs Formation (Upper Cretaceous). The data base for this study is comprised of over 200 drill holes on one-half mile centers and numerous complete and partially measured sections within a 70 square mile area in the southern Kaiparowith Region, south-central Utah.

The depositional setting for the coal-bearing strata is interpreted as the backswamp or landward portion of a strandplain swamp complex. At least ten different times within the subject area, swamp conditions were interrupted by an influx of clastic river-borne sediments. Once floods terminated peat-forming conditions, short-lived, highly meandering, north and northeast flowing fluvial channel systems were established over the flood sediments. After short periods of time, geologically speaking, the fluvial channel systems either abandoned their courses to other sites in the backswamp or became inactive. At these times, swamp conditions were reestablished and coal-forming environments again prevailed. The sedimentary succession in the coal-bearing section is essentially a repeating record of the above processes.

The isopach maps of the strata between coal seams as compared with paleochannel sandstone trend maps illustrates the significant effect of differential compaction around paleochannel sandstone bodies. Areas marginal to paleochannel sandstone axes compact significantly whereas the axis areas show minimal compaction. In addition, coal seam isopach maps, in cases, show an influence of paleochannel sandstone position where coals are thinner over minimally compacted sandstone axes as compared to thicker coal in paleo-marsh areas. Variations in the thickness of coal seams as well as the strata between coal seams can be most easily understood and predicted with an awareness of depositional processes and trends.

3:25 (No. 49)

URANIUM EXPLORATION IN PRECAMBRIAN (?) CONGLOMERATES IN GUYANA, SOUTH AMERICA

PHILIP DONNERSTAG*
Denison Mines (U.S.) Incorporated, Denver, Colorado

The Roraima formation of Guyana, probably of Precambrian age, consists of nearly flat-lying sandstones, pebbly sandstones, and conglomerates. Gabbroic sills are intercalated in the sediments. The Roraima rests unconformably on a complex of shaley sediments, and volcanic and pyroclastic rocks.

Because of its gross similarity to other uranium producing conglomerates, such as the Witwatersrand of South Africa, and the lower Huronian of the Blind River area in Canada, the Roraima was believed to have potential for uranium deposits. In 1968, and exploration program for uranium was initiated over a large area of Roraima in western Guyana. The program consisted of airborne radioactivity surveys, ground recovery of anomalous areas, geologic mapping in the anomalous areas, and diamond drilling.

Core from the drill holes showed minor anomalous amounts of uranium, but concentrations were too low to permit mineral identification. Results of the program were not considered to be sufficiently encouraging, so the program was terminated at the end of 1970.

3:50 (No. 50)

NEW FRONTIERS IN COLORADO COAL RESEARCH

D. KEITH MURRAY
Colorado Geological Survey, Denver, Colorado

Despite the fact that coal-bearing sediments underlie nearly 30 percent of the State of Colorado — or nearly 30,000 square miles, an area exceeded by only 5 other states — very little data have been published on the stratigraphy, petrography, chemistry, or palynology of Colorado coals. Moreover, although coal has been mined for over 100 years in the state, chiefly in or near the outcrop areas around the peripheries of the 8 coal regions, estimates of total remaining coal resources at best are based on surprisingly incomplete data, covering only about 20 percent of the regions known to be coal-bearing. Statistics recently published by the U.S. Geological Survey show estimated total remaining in-place coal and lignite resources, as of January 1, 1974, to depths of 6,000 feet, to be over 434 billion tons (4th in the U.S.), of which some 290 billion tons occur above 3,000 feet. In the category of remaining identified coal resources, based on the heat value (Btu's per lb.), Colorado also ranks fourth in the United Sates, behind North Dakota, Montana, and Illinois. However, in terms of remaining identified bituminous coal resources, Colorado rates second, behind Illinois, but first in low-sulfur bituminous coal. The immense size of the coal resources of the state, together with steadily increasing demand for high-quality, low-sulfur steam and metallurgical coal, demand that the decision-makers in the public sector have at their fingertips an accurate, up-to-date data base for this important commodity in order that optimum resource planning, development, utilization and management might be achieved, consistent with environmental and human concerns. To this end, the Colorado Geological Survey, in cooperative grant arrangements with the U.S. Geological Survey and U.S. Bureau of Mines, has in progress the following applied research projects: (1) a compilation map showing key data on coal and other energy resources in the state, together with energy conversion facilities and distribution systems; (2) collection for chemical analysis of samples of Colorado coal being actively mined or expected to be mined in the next ± 10 years, and of samples that will improve our understanding of chemically and stratigraphically anomalous compositions of coal, partings, underclay, and associated strata; and (3) an evaluation of the methane potential of the coal beds of Colorado for the purposes of improving mine safety and increasing mine productivity in areas of high gas concentrations, and to develop significant new sources of pipeline-quality methane.

Additional new frontiers of coal research that the Colorado Geological Survey believes are worthy of serious consideration include the following: (1) evaluate the coking-coal deposits of Colorado, which constitute a vital component of the western U.S. steel industry, both to assist decision-makers in obtaining increased and more efficient production in the areas of known reserves, and to delineate new areas of potential resources; (2) establish a detailed framework of stratigraphic, petrographic, and palynologic analysis in order to accurately map, correlate, evaluate, and predict the quality of the coal deposits of the state; (3) determine and interrelate the petrographic composition, thermal behavior, and stage of coalification of Colorado coals in order to better understand and predict their affect on mining rate and equipment wear, their response to various preparation methods (e.g., pulverization, washing, drying), and their optimum utilization (e.g., coking, steam generation, liquid or gaseous conversion); and (4) determine the relationship between coal metamorphism, the thermal history of the state's sedimentary basins, and the generation and migration of hydrocarbons, particularly methane, in these basins. Certain aspects of each of the above-named projects are innovative in nature, requiring that we enter new frontiers of knowledge in order to better understand this remarkable, complex, versatile substance called coal.

4:15 (No. 51)

LIQUEFACTION OF NORTHERN GREAT PLAINS LIGNITES

DONALD E. SEVERSON
University of North Dakota, Grand Forks, North Dakota

The rationale is presented for coal liquefaction as a means of obtaining substitute sources for liquids presently derived from petroleum. The chemistry of coal liquefaction is briefly explained. Presently considered approaches to the commercialization of coal liquefaction technology are reviewed, and current status of various government - sponsored approaches reported. Adaption of this technology to Northern Great Plains lignites is discussed. The liquefaction research program of Project Lignite at the University of North Dakota is described, and projections of the work are discussed.

Tuesday, March 30, Morning

8:00 (No. 53)

ABNORMAL ELECTRICAL RESISTIVITY AND FLUID-PRESSURE IN THE BAKKEN FORMATION, WILLISTON BASIN AND ITS RELATION TO PETROLEUM GENERATION, MIGRATION AND ACCUMULATION

FRED F. MEISSNER
Filon Exploration Corporation, Denver, Colorado

Geochemical data show that organic shales in the Bakken formation (lower Mississippian) are excellent petroleum source-rocks where they have been buried sufficiently to have achieved thermal "maturity".

Anomalous variations in electrical resistivity found in the Bakken shales are believed to be caused by the indigenous generation of hydrocarbons. Changes from low and "normal" shale resistivities (2 to 15 ohm-meters) to nearly infinite resistivity occur abruptly at a subsurface temperature of approximately 165° F. This temperature appears compatible with that for the "critical temperature" of oil-generation, based on recently developed thermodynamic time-temperature relationships and indicates that generation is currently active. The dramatic change from low to high resistivity suggests that conductive pore-water in "immature" source-rock shales has been replaced by non-conductive hydrocarbons as oil is generated and the source-rock becomes "mature". The phenomenon further suggests that the hydrocarbons may be expelled as a continuous fluid-phase saturating an oil-wet solid matrix. Variations in geothermal gradient associated with the resistivity-derived "maturity" criterion show that depth to oil generation varies from approximately 8500 feet on the east side of the Williston basin to 7000 feet on the western side.

Drill-stem-tests within the "mature" area of the Bakken formation show that formation fluids are substantially over-pressured and that hydrocarbons are the only producible fluid species present. Collapse of the rock matrix as overburden - supporting solid organic material is partially converted to non-expelled fluid is believed to be the dominant process responsible for high fluid pressures. The amount and distribution of fluid over-pressure in the Bakken may be determined from sonic log transit times. DST-measured and log-determined fluid-pressure gradients range from .47 to .80 psi per foot, and all values greater than .47 (hydrostatic) are confined to the area of source-rock "maturity" and active hydrocarbon generation. Although the Bakken is sandwiched between seemingly impermeable rocks in the overlying Lodgepole and underlying Three Forks formations, the fact that maximum fluid overpressure is less than lithostatic (1.0) suggests that some fluid expulsion is taking place from the system.

The area of Bakken oil generation contains several oil fields which produce from fracture-type reservoirs developed within or adjacent to the source-rock unit. Fracturing is believed to be controlled by the combined presence of 1) high pore-fluid pressure and 2) high differential rock stress, as predicted by the Hubbert-Rubey effective stress concept and the Mohr-Coulomb-Griffith failure theory. Differential stress at Antelope field is caused by drape-fold "bending" over an uplifted basement fault block.

Fracturing related to oil generation and associated fluid over-pressure may be an important mechanism allowing migration of oil from Bakken source-rocks vertically upward through overlying dense rocks in the Lodgepole to reservoirs in the Mission Canyon or downward through dense rocks in the Three Forks to reservoirs in the Nisku.

8:25 (No. 54)

URANIUM IN PLUTONIC ROCKS

FRANK C. ARMSTRONG
U.S. Geological Survey, Reston, Virginia

Uranium is a strongly lithophile element and is concentrated in the granitic and in some alkalic rocks on the crust of the earth. In both types of rocks it is concentrated in the late-crystallizing constituents of the magma. In most granitic rocks, the bulk of the uranium is in the essential minerals of the rock, where it occurs as minute crystals or uraninite or as molecular or ionic disseminations in fractures, crystal defects, or along cleavage planes or grain boundaries. Uranium also enters tantalates, titanates, and niobates, and substitutes in the crystal structure of accessory minerals. In sodium- and potassium-rich alkalic rocks, uranium appears to be concentrated primarily in accessory minerals. Uraninite and molecular and ionic uranium are easily leachable, whereas uranium that substitutes in the crystal structure of minerals is not.

Large bodies of granitic rocks that contain 0.03 to 0.05 percent U_3O_8 can be ore deposits. Possible examples are Rossing, South West Africa; at Charlebois Lake, Canada; and at certain localities in central Idaho and northeastern Washington. Large bodies of alkalic rocks containing similar amounts of uranium may also be ore deposits but normally have more difficult metallurgical extraction problems. One possible example is the Ilimaussaq intrusion, southern Greenland, and another is the intrusive alkalic suite in the Bearpaw Mountains, Montana.

8:50 (No. 55)

HEAT-FLOW STUDIES IN THE STEAMBOAT MOUNTAIN-LEMEI ROCK AREA, SKAMANIA COUNTY, WASHINGTON

J. ERIC SCHUSTER
Department of Natural Resources, Olympia, Washington
DAVID D. BLACKWELL
Southern Methodist University, Dallas, Texas
PAUL E. HAMMOND
Portland State University, Portland, Oregon
MARSHALL T. HUNTTING
Consulting Geologist, Silver Creek, Washington

With the financial support of the National Science Foundation, the Washington State Department of Natural Resources drilled several 152 m.-deep heat-flow holes in the Steamboat Mountain-Lemei Rock area of Skamania County, Washington. The study area is located in the southern part of Washington's Cascade Mountains between 45°54' and 46°07' N., and 121°40' and 121°53' W. This area was selected for study because geologic mapping had identified a north-trending chain of late Quaternary basaltic volcancoes that had extruded a sequence of lava flows up to 600 meters thick, and because the chain of volcanoes is areally coincident with a well-defined gravity low with a minimum value of about -110 milligals.

The Quaternary lava flows all exhibit normal remanent magnetic polarity, so are probably less than 690,000 years old. Most of the flows and volcanoes appear to be younger than the Salmon Springs glaciation (35,000-50,000 years ago), and some are younger than Fraser glaciation (less than about 10,000 years old). One large lava flow (the Big Lava Bed) and its source cinder cone can be shown to be between 450 and 4,000 years old by their relationship to dated ash and cinder deposits erupted from nearby Mount St. Helens. The young basalts rest on deformed Tertiary sedimentary and volcanic rocks. Thermal springs with low discharge and temperatures of less than 50°C. occur about 20 km. south of the study area.

Thermal conductivities are 3.6 ± 1.5, 2.86-4.2, 3.14, and 3.0 ± 0.5 millical. / cm.sec. °C. for the Tertiary volcanics, Tertiary sediments, Tertiary basalts, and Quaternary basalts, respectively. Gradients of 47.3, 51.7, and 50.7°C./km. and heat flows of 1.58, 1.72, and 1.83 microcal./cm.^{2}sec., respectively, were measured in two drill holes near the east flank of the chain of volcanoes. Gradiants of 44 and 45.6°C./km. and heat flows of 1.24 and 1.31 microcal./cm.^{2}sec., respectively, were measured in two holes near the axis of the chain, and one gradient of 59.7°C./km. and heat flow of 1.56 microcal./cm.^{2}sec. were measured in a drill hole near the west flank of the chain. All gradients and heat flows are terrain corrected.

These heat-flow values are probably typical regional heat-flow values for the Cascade Mountains. The data show that there is no large-sized heat source body within the general area of the heat-flow study. However, there is only one location in Washington, also in the Cascade Mountains, where higher gradients have been measured.

9:15 (No. 56)

SYNTHETIC SEISMIC SECTIONS OF SELECTED STRATIGRAPHIC TRAPS AND AQUIFERS IN THE SOUTHEAST POWDER RIVER BASIN, WYOMING

ROBERT T. RYDER, ROBERT C. ANDERSON,
and ALFRED H. BALCH
U.S. Geological Survey, Denver, Colorado
WILLIAM J. HEAD
U.S. Geological Survey, Cheyenne, Wyoming
MYUNG W. LEE
Colorado School of Mines, Golden, Colorado

Detailed stratigraphic sections in the vicinity of the Old Woman anticline indicate that sandstone units in the Minnelusa Formation and Canyon Springs Sandstone Member of the Sundance Formation are potential exploration targets for stratigraphically trapped oil in the southeast Powder River Basin. In the Red Bird field on the north plunge of the Old Woman structure oil is trapped in the 80-foot (24-m)-thick Canyon Springs Sandstone Member where it wedges out updip against an erosional outlier of red siltstone and claystone units of the Spearfish Formation. Oil is also trapped in the porous 50-foot (15-m)-thick first Leo sandstone, an economic unit in the Minneslusa Formation, where it grades laterally into anhydrite, anhydrite-cemented sandstone, and dolomite. A similar type of trapping mechanism in the Minnelusa Formation is responsible for the Pine Lodge oil field 18 mi (29 km) to the southwest. Synthetic seismic sections based on numerous sonic and density logs from the Old Woman area suggest that the porous sandstone units of the Minnelusa Formation (φ = 2.60 g/cc, V=11,000 ft/sec) can be differentiated on seismic records from equivalent nonporous anhydrite-cemented sandstone units (φ = 2.75 g/cc, V=18,000 ft/sec). Likewise, the Canyon Springs Member (φ=2.25 g/cc, V=9,300 ft/sec) should be recognizable on seismic records where it pinches out against the nonporous Spearfish Formation (φ = 2.55 g/cc, V=12,500 ft/sec).

The seismic method may also be useful in predicting high water-yield wells in the Madison Limestone aquifer. Synthetic seismograms constructed from the sonic logs of several wells indicate that the Madison Limestone with good porosity development (velocity of porous zones = 17,000 to 17,500 ft/sec) may be distinguishable on seismic records from relatively impervious intervals of Madison Limestone (V=18,000 to 21,000 ft/sec).

9:40 (No. 57)

LEASE OF FEDERAL GEOTHERMAL ENERGY A ROCKY ROAD

DAN STARK
Bureau of Land Management, Billings, Montana

The path of an application to develop geothermal energy on Federal lands is often long and arduous. And, in this process, the merit of the proposal sometimes appears lost when we look at the final outcome. This short discussion is designed to inform you of and clarify those procedures covering geothermal applications between the time of filing and issuance of a lease decision. Emphasis will be placed on nonadjudicative procedures and actions which affect the ultimate lease decision.

10:05 (No. 58)

USE OF INTERACTIVE COMPUTER GRAPHICS FOR EXPLORATION

WILLIS H. ALDERMAN
Amoco Production Company, Denver, Colorado

The use of the interactive computer terminal for generation of graphic displays is becoming one of the most potential, powerful and interesting newer tools available to the explorationist.

Live, integrated, user-oriented digital data files are of utmost importance to the oil and gas explorationist. They must be organized, indexed, cross-referenced and identified more precisely than any other kind of file. The capabilities and usage of an on-line, large computer data base are explained in this paper. Slides show a geologist in a working environment generating his maps and cross sections on an interactive terminal Cathode Ray Tube System (CRT).

Computer graphic hardware and software development is progressing at a rapid pace. Many more scientific digital data bases are becoming available. The future looks bright for interactive computer graphics.

10:30 (No. 59)

HEAT-FLOW STUDY OF THE SNAKE RIVER PLAIN, IDAHO

CHARLES A. BROTT and DAVID D. BLACKWELL
Southern Methodist University, Dallas, Texas
JOHN C. MITCHELL
Idaho Department of Water Resources, Boise, Idaho

A heat flow study of the Snake River Plain is in progress with the objectives of evaluating the geothermal potential and providing constraints for regional geotectonic interpretation of the Plain. Heat flow data have been obtained from over 100 water wells, thirteen 100 foot (31.1m) holes drilled specifically for this study along two north-south profiles across the western part of the Plain, and two 500 foot (155.5m) bore holes in the Idaho Batholith at the northern end of the profiles. Observed geothermal gradients range from 40°C/km to over 150°C/km and observed heat flow values range from 2.3 to over 4.5 ucal/cm^{2}sec. Preliminary results show anomalous heat flow values (greater than 2.5 ucal/cm^{2}sec) over large areas of the Plain.

Thus the preliminary results indicate the regional heat flow of the Snake River Plain is above the average of regions of high heat flow of the western United States. Differentiation of the heat transfer due to regional aquifer systems and that due to crustal and mantal heat sources is still uncertain; however, the heat flow data does provide constraints for the evaluation of aquifer systems and on the mode of the formation of the Plain. Preliminary conclusions are that the crustal and/or mantle component of heat flow must be higher than the surrounding areas of the Northern Rocky Mountains and the Basin and Range Province and that large areas of the Plain have significant geothermal potential.

10:55 (No. 60)

PROPOSED GEOTHERMAL CIRCULATION PATTERN, CORWIN SPRINGS-GARDINER AREA, MONTANA

ERIC M. STRUHSACKER
Montana State University, Bozeman, Montana

Hot spring activity has persisted in the Corwin Springs-Gardiner area since the Pleistocene. The only active hot springs, LaDuke and Bear Creek, emerge at opposite ends of a 2-square-mile Pleistocene travertine deposit. The hot springs and travertine lie along the northwest trending Gardiner Fault, a Laramide high angle reverse imbricate fault zone, which bounds the Beartooth crystalline rock uplift on the southwest. The post-Laramide Reese Creek and Mammoth Faults are graben-forming normal faults that extend from the park upland, northward into the hanging wall of the Gardiner Fault. The local thermal features lie on or between the intersections of these faults with the Gardiner Fault zone. More than 10,000 ft. of Paleozoic and Mesozoic sedimentary rock is preserved within the graben in the footwall of the Gardiner Fault. From a structural high within Yellowstone Park, the sedimentary units dip gently into the Gardiner Fault zone, where they are dragged up and locally overturned to form an asymmetrical syncline striking northwest. These structural relationships suggest that ground waters flow down permeable sedimentary units within the graben from the Yellowstone upland to great depth under the Gardiner Fault zone. Waters are heated at this depth and ascend through fractures to the surface. The cavernous Mississippian Madison Limestone, lying near a depth of 10,000 ft. under the Gardiner Fault zone, may be the principal aquifer and produce the high Ca content of the active hot springs. A normal thermal gradient could cause significant heating at this depth.

11:20 (No. 61)

SEISMIC DATA ANALYSIS WITH TIME SEISCROP* MAP TECHNIQUES

MARION R. BONES, BEN F. GILES and EDWARD R. TEGLAND
Geophysical Service, Inc., Dallas, Texas

A simple procedure can be utilized to allow the geophysicist to view his seismic data in an amplitude, X-Y horizontal space context as well as a vertical section presentation.

Several simple models are used to introduce the concept of the time Seiscrop* map. The method is a logical approach to viewing 3-Dimensional data. However, any reasonably spaced seismic grid may be viewed for both quality control of the processing and development of the structural interpretation.

Data examples over various structural features illustrate interesting interpretative uses of the process. "Bright Spot" and "Flat Spots" can be seen and easily identified and interpreted, particularly when shown as a color movie. Currently, commonly used data collection methods can be redily modified to utilize this interpretative display technique.

*Trademark of Geophysical Service Inc.

Tuesday, March 30, Afternoon

1:20 (No. 62)

AN OVERVIEW OF EXPLORATION GEOPHYSICS — RECENT BREAKTHROUGHS IN GEOPHYSICS AND RECOGNITION OF CHALLENGING NEW PROBLEMS

BILLY S. FLOWERS
Shell Oil Company, New Orleans, Louisiana

Recent spectacular advances in geophysical technology are improving the explorationist's efficiency in his search for new hydrocarbon reserves. Each new development, however, usually points out some previously unrecognized shortcoming in geophysical techniques or the need for more precise geological information in the interpretation of geophysical data.

For instance, it is remarkable that hydrocarbons can be detected directly with "bright spot" amplitude anomalies but the correct interpretation of these anomalies requires a more detailed knowledge of the stratigraphy than the geophysicist normally has; even the percentage of gas saturation is an important variable because low gas saturations lead to good amplitude anomalies.

Automatic migration has clarified structural configurations where the seismic ray paths are simple, but many interesting areas have complex ray paths that are either focused or scattered by a series of "sonic lenses" of unknown geometry, velocity, and position. Correct interpretation of structures in this setting requires three-dimensional models of these parameters with some technique of model verification.

Surface arrays and common depth point stacking, now routine techniques, opened new areas to successful exploration by eliminating noise and multiples. Now, however, we find as our techniques improve there are interesting areas still obscured by more severe noises and by multiples beyond the reach of stacking.

While the advances have been specacular, they have exposed new problems, and possibly new opportunities, which are indeed challenging.

1:45 (No. 63)

CORWIN SPRINGS KNOWN GEOTHERMAL RESOURCES AREA PARK COUNTY, MONTANA

H. C. JIM TAYLOR
U.S. Geological Survey, Billings, Montana

The Corwin Springs Known Geothermal Resources Area is contiguous to Yellowstone National Park along a part of the northern boundary of the park near Gardiner, Park County, Mont. The area contains two known sites of hot springs activity — LaDuke Spring, located 2.8 km southeast of the small resort community of Corwin Springs, and Bear Creek Spring, located 2.6 km east of Gardiner. LaDuke Spring issues from brecciated quartzite and has a flow rate of 380 l/min, a surface water temperature of 65°C, a silica-geothermometer temperature of 66.9°C, and a Na-K-Ca geothermometer temperature of 77°C. Bear Creek Spring issues from limestone and has a flow rate of 4 l/min, a surface water temperature of 32°C, a silica temperature of 44.8°C, and a Na-K-Ca temperature of 87.3°C. The springs, which are actively depositing travertine, are situated on or near the trace of the Gardiner fault — a high-angle reverse fault which forms the southwestern boundary of the Beartooth uplift.

Interesting features of this potentially significant geothermal area include: (1) the proximity of the Corwin Springs area to the intense geothermal activity and significant Pliocene and Pleistocene volcanism in Yellowstone National Park; (2) the Sepulcher graben, a potential geothermal reservoir and major geologic structure extending from the Corwin Springs area into Yellowstone National Park; (3) the Gardiner fault and its role in localizing thermal activity in the Corwin Springs area; (4) the negative gravity anomaly centered over the northern terminus of the Sepulcher graben; (5) the negative magnetic anomaly in the area; (6) the location of the area within the Intermountain seismic belt; (7) the existence of recent tectonism within the area, as demonstrated by Pleistocene and Holocene faulting; and (8) the observed surface and estimated geochemical temperatures of the two known hot springs — features which do not indicate high subsurface temperatures.

2:10 (No. 64)

ANALYTICAL SOLUTIONS APPLIED TO FAULTING IN THE LARAMIDE ROCKY MOUNTAIN FORELANDS

GARY COUPLES
Rice University, Houston, Texas
DAVID W. STEARNS
Texas A&M University, College Station, Texas

The ability to predict and understand fault attitudes in the Rocky Mountain Forelands is complicated by the fact that nearly all known fault types occur at some place within the province. However, this ability can be improved considerably by the study and application of solutions to certain analytical problems which may reflect the geologic conditions of the region. The few analytical solutions that exist in the literature, such as those of Hafner (1951) and Sanford (1959), have proven very useful in predicting certain fault relationships in the Forelands, but these solutions do not represent the complete range of possibilities. Geologic facts from the area indicate that there are boundary conditions other than those previously presented that could add to our understanding. Therefore, several "new" solutions have been generated in order to add to the "old", thus increasing our total ability to predict such things as fault attitude, fault spacing, and relative age of occurrence. These new solutions create a wider spectrum of conditions to choose from in trying to unravel fault geometries from limited data such as scattered drilling information and widely-spaced or "uninterpretable" seismic records.

2:35 (No. 65)

GEOELECTRICAL INVESTIGATIONS OF THE BOISE, IDAHO GEOTHERMAL SYSTEM

PAUL R. DONALDSON and JAMES K. APPLEGATE
Boise State University, Boise, Idaho

Electrical conductivity in rocks is enhanced profoundly by elevated pore fluid temperatures. Of the potentially useful geophysical tools, this makes the electrical techniques most directly useful in delineating geothermal systems. The bipole-dipole mapping method has gained popularity in geothermal exploration because of the inherent sensitivity of the method to lateral changes in resistivity. This characteristic makes the method useful in defining certain structural controls as well as locating the boundaries of anomalously conductive regions associated with geothermal systems. The addition of a rotating source field enhances the methods sensitivity to lateral boundaries, making interpretations more straightforward.

These techniques have been helpful in the initial investigations of the Boise, Idaho geothermal system, particularly in defining fault and fracture systems which appear to control access to the resource.

These studies were made possible by an ERDA grant.

3:00 (No. 66)

GEOTHERMAL EXPLORATION OF ROOSEVELT KGRA, UTAH

CHARLES W. BERGE, GARY W. CROSBY, and R. C. LENZER
Phillips Petroleum Company, Del Mar, California

The Phillips Petroleum Company exploration program combining geological, geochemical and geophysical methods has resulted in discovery of a high temperature, low salinity, liquid dominated geothermal system. Testing to determine commercial production of the system is now in progress.

The Roosevelt prospect is situated at the boundary between the Mineral Range and Milford graben in eastern Beaver County, Utah. Valley fill sediments in the graben are approximately 1,500 meters thick in the center of the valley. Bedrock is stepped up along several normal faults to the west flank of the range, where the westernmost exposures consist of Precambrian (?) gneissic rocks. These are invaded in a zone of injection by Late Cenozoic granite and related silicic differentiates. Paleozoic sedimentary rocks, exposed on the west side of the valley, terminate by being removed by erosion somewhere in the graben.

The westernmost exposures of Precambrian crystallines appear to be in a horst block which is bounded on the east by the Dome fault. Rhyolitic flows, from seven or more eruptive centers, cap much of the granite east of the prospect. Magma additions to the chamber, feeding these eruptive centers, is thought to be supplying the heat beneath Roosevelt prospect.

Recent faulting in the vicinity of the prospect is indicated by fresh scarps in alluvium and the cutting and displacement of hot spring deposits. Faults appear to be major controlling structures in the subsurface hydrologic regime.

The investigations undertaken prior to the July 30, 1974, lease sale included hydrochemistry, chemical geothermometry, petrography, gravity, magnetics, resistivity (dipole mapping and MT), groundnoise and thermal gradient drilling. A model assimilating the data was formulated. Additional resistivity, thermal gradient drilling and deep drilling has resulted in modifications of the existing model.

Of all tools used, shallow temperature gradients appear to best outline the potential reservoir area as we now know it or perceive it to be.

The thermal anomaly, as mapped by Phillips Petroleum Company, covers approximately 8,000 acres. All of this, however, should not be thought of as potentially productive, inasmuch as production is controlled not only by heat and fluid availability, but by the presence of fracture zones.

The thermal anomaly is underlain by intermediate and silicic crystalline rocks, at the surface or at shallow depths. The fracture system is the reservoir. The depth to its top is less than 900 meters over a significant portion of the anomaly. The fracture zones have extraordinarily high effective permeability locally, yielding up to 113,000 kg/hr flashed steam from a reservoir in excess of 200°C, pressures near hydrostatic, and fluids with less than 10,000 ppm total dissolved solids. Predicted reservoir temperatures from analysis of surface waters are remarkably similar to reservoir temperatures encountered in deep drilling operations.

3:25 (No. 67)

THE RAFT RIVER, IDAHO, GEOTHERMAL WELLS: SITING, DRILLING, AND TESTING

ROGER C. STOKER, JAY F. KUNZE, and LOWELL G. MILLER
Idaho National Engineering Lab, Idaho Falls, Idaho

The area of Southern and Eastern Idaho is one of the most promising regions in the United States for near surface, economically recoverable geothermal energy. This portion of the state is divided between two physiographic regions. The Snake River Plain is typical of the volcanic rift regions of the U.S. where approximately 8% of the hot wells, geothermal springs and geysers in the Western U.S. are located. South of this region is the Basin and Range Province which covers Nevada, the Western half of Utah, the Southwestern half of Arizona, as well as parts of California, New Mexico, Colorado, and Montana, in addition to parts of Southern Idaho. In this province are located more than a third of the known hot wells, geothermal springs, and geysers in the Western U.S.

In 1973, the Idaho National Engineering Laboratory (INEL) was funded by the Energy Research and Development Administration (ERDA) to pursue a program of research and development into the geothermal potential of the Raft River Valley, Cassia County, Idaho. A cooperative effort was then undertaken involving Aerojet Nuclear Company, U.S. Geological Survey, State of Idaho, and Raft River Rural Electric Cooperative. The objective of this effort is directed toward evaluating the possibility of establishing a geothermal plant in the area for the production of electricity.

The first step toward this objective — the drilling of two wells and their evaluation — has been partially completed during this last year. A review of the problems and experiences during the siting, drilling, and testing of these wells is very appropriate at this time.

The siting phase was completed with an evaluation of all geological and geophysical data gathered, primarily by the USGS, during a 1½ year field study. The drilling phase was conducted by INEL with a drilling rig from Reynolds Electric and Engineering Company, another ERDA contractor of Las Vegas, Nevada. The testing phase involved both INEL and the University of California, Lawrence Berkeley Laboratory personnel. All phases of the project are reviewed and the current plans are discussed.

3:50 (No. 68)

GEOLOGIC CONTROLS OVER HOT WATER MIGRATION AT SELECTED HOT SPRINGS, SOUTHWESTERN MONTANA

ROBERT A. CHADWICK, MICHAEL J. GALLOWAY
and JOHN D. GOERING
Montana State University, Bozeman, Montana

Development of models for thermal water circulation in areas away from active volcanism is needed. In southwestern Montana, 27 hot springs (discharges above 35°C) are under geologic investigation for geothermal potential. Many springs are located on or near faults or major fractured zones. Preliminary investigation suggests several models for thermal water circulation; permeable joint-shear zone intersection, graben block, and synclinal controls are exemplified by Potosi, Wolf Creek, and New Biltmore hot springs, respectively.

Potosi hot springs waters issue as numerous seeps from N 85° W permeable joints where intersected by a N 5° E shattered zone in quartz monzonite of the Tobacco Root batholith. Water evidently percolates to depth along the permeable joints and rises where they intersect the relatively impermeable shattered zone. This model, with modifications, may apply to Boulder and other hot springs in fractured crystalline rock.

Wolf Creek hot springs issues from a N 5° W recently active fault which displaces bench gravels in the Upper Madison Valley and may form the west edge of a deep sediment-filled graben in Precambrian metamorphic rocks. The Madison Range frontal fault bounds the graben on the east. Water may circulate to depth beneath the graben or within the valley fill sediments and may rise along the bounding fault. Chico and Bozeman hot springs may also illustrate graben or hinged fault block control.

New Biltmore, Renova, and LaDuke hot springs waters may have risen along Paleozoic carbonate aquifers from depths of synclines located beneath the Big Hole, Jefferson, and Upper Yellowstone valleys respectively.

4:15 (No. 69)

GEOLOGIC AND SEISMIC STUDIES OF THE BOISE FRONT, IDAHO, FOR GEOTHERMAL RESOURCE EVALUATION

JAMES K. APPLEGATE, PAUL R. DONALDSON
and LELAND L. MINK
Boise State University, Boise, Idaho

Hot water has been used for space heating since 1890. Consequently, a project to investigate the possibilities of expanding the resource utilization was begun in January 1975.

It is postulated that the best productive zones would be in the areas of increased fracture porosity at the intersection of two or more faults. Thus, an integrated study utilizing remote sensing, field geology, resistivity, ground magnetics, microseismic and active seismic techniques was undertaken. Numerous fault trends have been defined by the investigation. The faults do not appear to be currently active, based on approximately nine months of microseismic monitoring.

Currently, exploratory holes are being drilled to perhaps better understand the geologic relationships. However, further investigations need to be undertaken to investigate a larger area and to also detail the relationship between various fault systems. Dipole-bipole resistivity mapping, electromagnetic soundings and active seismic studies would be particularly beneficial.

The studies have been funded by ERDA.

4:40 (No. 70)

GEOTHERMAL POTENTIAL OF THE CRAZY MOUNTAINS BASIN

JOHN R. FANSHAWE
Consulting Geologist, Billings, Montana

The "normal" late Cretaceous sedimentary cycles in the Crazy Mountains area held until Eagle time when volcanism from the Livingston centers began adding pyroclastic material. The structural downwarp along the south and west edges of the basin began in the Tertiary near the close of the Laramide compressional phase and continued on into the Eocene, receiving great thicknesses of andesitic ejecta, some agglomerate beds, and interlayered arenaceous sediments. The final Eocene episode was the intrusion of the Crazy Mountains stocks and associated radial dikes. There are no extrusive rocks involved. The entire region was then uplifted as a stable block.

Geothermal seeps are few, and are limited to the basin margins. Wells drilled for oil and gas do not show a significant thermal gradient change — except for the one at McLeod which now flows water at 120°F and the Ringling well which flows at 110°F.

The heating mechanism may be either depth where the normal earth temperature affects the water before it rises to the surface, or proximity to magma or cooling igneous material fairly close to the surface. Many of the hot or warm springs in western Montana have been relegated to the former category. Recent geological and geophysical studies in the Yellowstone Park region indicate a continuing northward or northeastward migration of the hot spot in the mantle which has now reached the north part of the Park. This, plus Holocene faulting, makes the southwest portion of the basin, as well as the upper Yellowstone valley, an area of great geothermal potential.

Wednesday, March 31, Morning

8:00 (No. 71)

HELIUM DETECTION, AN EXPLORATION GUIDE TO URANIUM SOURCES

RICHARD H. DeVOTO and RICHARD H. MEAD
Colorado School of Mines, Golden, Colorado

Alpha particles are constantly generated during the radioactive decay of uranium-238, uranium-235 and their many daughter products. The alpha particles readily pick up electrons and become gaseous, inert helium-4 molecules. The inert, light nature and extremely high diffusive mobility of helium makes it likely that helium will not combine with other elements in crustal rocks and that it will tend to escape upwards into the atmosphere.

Most of the significant helium accumulations in the United States occur in Paleozoic reservoir rocks, some of which are spatially associated with slightly uraniferous black shales. Helium accumulations are almost conspicously absent or sparsely known in association with the major uranium deposits in Mezozoic and Cenozoic host rocks in the western United States. These circumstances suggest that Paleozoic shales, having been buried more deeply, are generally less permeable to helium than are Mezozoic and Cenozoic shales and mudstones. Thus, helium generated continuously from uranium deposits in Mesozoic and Cenozoic rocks is not being trapped (and accumulated) in Mesozoic and Cenozoic reservoirs as it is by Paleozoic shales.

This paper describes the results of research to determine if helium generated from a typical, shallow, Wyoming, roll-front uranium deposit could be detected in anomalous concentrations in the atmosphere, in soil gas, or in shallow (2-6 feet) or deep (20 to 100 feet) bore holes in proximity to the uranium deposit. A reconnaissance helium-sampling program has been conducted over the Iragaray uranium deposit (Wyoming Minerals Co.), northwest of Pumpkin Buttes, Powder River Basin, Wyoming. This roll-front, uranium deposit occurs in Wind River strata at 300- to 350- foot depths. Field measurements of helium concentrations of the atmosphere, soil gas at 6 feet deep, and in bore holes at 20, 40, 60, and 100 feet deep over the known uranium deposits were made by means of a portable helium-leak detector mass spectrometer, which measures the total (helium-4 plus helium-3) helium concentration.

This field research has revealed several significant facts:

a. Helium concentrations in the atmosphere fluctuate markedly over short periods of time. In the test work during a 24-hour test at a single site, the atmospheric helium concentrations varied from 4.7 to 6.3 ppm.
b. Helium concentrations in the atmosphere at ground level vary markedly along a profile perpendicular to the length of the uranium deposit. *Detectable helium anomalies, up to* 6.6 ppm, 18% above the average background helium concentration of 5.6 ppm, have been found above the uranium deposit.
c. The helium concentration in soil gas at 6-feet deep is not consistently higher than that in the atmosphere above the uranium deposit.
d. The helium concentration does not increase in deeper boreholes as the sample point gets nearer to the uranium deposit.
e. Instrument noise, drift, voltage variations, and atmospheric temperature, pressure, and wind effects significantly influence the helium readings and must be minimized to yield interpretable results.

The tentative conclusions that can be drawn from this preliminary helium-detection research above one Wyoming roll-front uranium deposit are that:

a. large (3 to 10 times background concentrations) helium anomalies should not be expected above buried Cenozoic sandstone uranium deposits,
b. it is possible to detect low-level (10-30% above average background) anomalous helium concentrations in the atmosphere above buried Cenozoic sandstone uranium deposits,
c. in this case, the helium generated by the radioactive decay of the uranium is apparently diffusing instantaneously, as the helium concentration does not increase with depth above the uranium deposit,
d. helium field sampling programs should definitely include measuring helium concentrations in atmosphere, and it may well be that subsequent, additional test work will show the sampling of the atmosphere to be the most effective helium-detection field technique, and
e. instrument and atmospheric variations during the field survey should be minimized by the use of a gas of constant helium concentration as a reference.

8:25 (No. 72)

LANDSAT IMAGERY: AN EVOLVING EXPLORATION TOOL FOR GEOLOGISTS

RICHARD M. ZOERB
Petty-Ray Geophysical, Houston, Texas

Since becoming available about four years ago, LANDSAT imagery has gained wide acceptance as a tool for resources problem solving on a regional scale. Users include specialists in agriculture, forestry, wildlife management and public health. Successful applications range from water quality and other environmental monitoring programs to geologic mapping for mineral deposits. The data serve the needs of government agencies as well as academic institutions and industry.

Typical end-use displays of LANDSAT images bear a strong resemblance to very high altitude airphotos. However, this format obscures the fact that basic LANDSAT data are in a digital mode, and that they therefore have much in common with source material used in applied geophysics. LANDSAT images represent variations in the intensity of visible and nonvisible light reflected from the surface of the earth, just as seismically derived data represent acoustic energy reflected from the earth's interior. In both cases great volumes of data are digitally recorded and stored on magnetic tape. Although sources of energy differ in terms of their velocity, frequency range, and wave length, data from both can be operated upon by standard seismic analysis and filtering techniques. Statistical methods used in seismic processing have proved helpful in enhancing LANDSAT results, particularly in tailoring output to the needs of the exploration geologist.

A review of satellite-related systems acquaints the earth scientist with existing methods of data acquisition and with types of hard copy which currently are available to him. Examples of LANDSAT imagery include areas in North America, Central America, Europe and Africa. Comparisons are made of the content of the four available spectral bands, and of the effects of filtering for purposes of image enhancement. Potential use to the exploration geologist is further illustrated with false color and density slice/contrast stretch displays based on refinement of data obtained directly from magnetic tapes.

8:50 (No. 73)

CHARACTERISTICS OF UPPER CRETACEOUS LANCE CHANNELS, NIOBRARA COUNTY, WYOMING

HARRY W. DODGE, JR.
U.S. Geological Survey, Denver, Colorado

The Lance Formation resulted from a southeasterly transgression causing deposition on a relatively stable coastal plain. These rocks partly consist of lenticular, multistoried, channel sandstone bodies deposited in point-bar sequences by meandering rivers and streams. The sandstone bodies are separated by interfluvial organic-rich mudstone and siltstone deposited in lakes, ponds, and marshes. Overbank siltstones are found in interfluvial areas. Measurements of 398 Lance channel trough (festoon) axes plotted on rose diagrams indicate a general southeastern paleoflow direction. However, some paleoflow directions in all quadrants suggest meandering. This scatter of paleocurrent direction is supported by multistoried channel complexes that show diverse axes.

Sedimentary structures are best exposed in a multistoried channel complex on the Peterson Ranch in central Niobrara County. Three upward-intersecting channel sequences totaling 23 m thick, each with a scoured surface at the base, are found in this complex. Clay clasts and, at some localities, dinosaur bones are found above this scour surface. The lower channel deposits consist sequentially upwards of a current-rippled bed, horizontal or near-horizontal beds, low-angle tabular crossbeds, and large-scale trough crossbeds. The upper part of the channel sequences contain alternating ripples, small trough crossbeds, clay drapes, and very thin horizontal beds. These sequences of structure suggest lateral-accretion point-bar type of channel deposits.

The Lance Formation contains uranium, but, to date, no known mining operations are in progress. Exploration in the Lance and equivalent formations has increased sharply in the past few years.

9:15 (No. 74)

THE OKLO PHENOMENON: GEOLOGICAL AND NUCLEAR ASPECTS

DOUGLAS G. BROOKINS
University of New Mexico, Albuquerque, New Mexico

The Oklo Uranium Mine, near Franceville, Republic of Gabon, has attracted worldwide interest because part of the deposit can properly be described as a 'fossil nuclear reactor'. The bulk of the ore at Oklo is relatively low grade (0.2 - 0.5 % U) and sporadically distributed in carbonaceous sandy and conglomeratic parts of the 1.8 b.y. old Francevillian Series. In places sandstone layers have been fractured during tilting; the fractures, infilled by shale, contain redistributed, very high grade ore (to 75 % U). This high grade ore, formed close to 1.8 b.y. ago, is depleted in 235-U (i.e. 0.3 - 0.6 % versus 0.7 % for 'normal' U). This discovery was made by the French A.E.C. in 1970 and the world advised of 'The Oklo Phenomenon' in 1972. From the time of discovery, the French A.E.C. investigators suspected that a fission reaction might have occurred as the conditions for criticality; viz. high U content, absence of initial poisons, favorable water: U ratio, etc. were probably met as the ore formed. Confirmation of fission reactions at Oklo was documented by discovery of anomalous enrichments in many of the isotopes produced by fission in a conventional light-water reactor, although at Oklo some elements have migrated and other have remained in situ. Even those isotopes which have migrated at Oklo are thought to be locally redistributed and their presence masked by large amounts of normal elements introduced later. This unique deposit thus lends support to those advocating geologic sites for radioactive waste disposal, and is especially valuable for providing data for theoretical modeling in conjunction with hydrodynamic and other criteria for site selection.

The geologic setting of Oklo is in many ways similar to deposits of the Colorado Plateau. Fortunately, the sedimentary rocks in the 1.8 b.y. old Francevillian Basin have not been disturbed significantly since their formation and thus the uranium deposits are also essentially undisturbed. As several other uranium deposits of a similar nature (except for the 'reactor ore') are aligned along the same tectonic element(s) within the basin and echelon elements are present in unexplored basins close by, then prospecting for sedimentary, sandstone-type uranium deposits (as opposed to the usual search for Precambrian quartz-pebble conglomerate deposits) in not only the Precambrian basins in Gabon (or nearby) but also worldwide should result in new uranium deposits being found.

9:40 (No. 75)

DISTRIBUTION OF URANIUM RESOURCES IN THE NON-COMMUNIST WORLD

ROBERT J. MEEHAN
United States Energy Reserch and Development Administration
Grand Junction, Colorado

A review of the currently reported distribution of uranium resources in the non-communist countries of the world indicates the United States, South Africa, Australia, and Canada control about 80 percent of the reasonably assured resources (reserves) exploitable at a cost of $15 or less per pound U_3O_8. About 80 percent of the estimated additional resources (potential) at the $15 or less per pound cost are in the United States and Canada. About 60 percent of the reasonably assured resources and about 70 percent of the estimated additional resources are in sandstones principally in the United States and in conglomerates in Canada and South Africa. Other important environments for these resources are vein and related deposits in metamorphic rocks primarily in Canada and Australia, disseminations in granitic rocks in South West Africa and disseminations in black shale in Sweden.

10:05 (No. 76)

STATISTICS AS A TOOL IN OIL AND GAS EXPLORATION

JOHN D. PRUIT
Petroleum Inc., Denver, Colorado

Oil and gas fields are found because they have areal extent. The probability P_s of finding a field of areal extent A in a basin (search area) of areal extent B with n randomly-placed wildcats is expressed by $P_s = \frac{nA}{B}$. For selectively-placed wildcats the equation is $P_s = \frac{cnA}{B}$ where c is a constant describing the efficiency of the selection process. Unfortunately, c is frequently not predictable in advance of drilling.

Changes in geologic setting greatly affect exploratory success ratios (P_s). Several high-success geologic settings have long been recognized as attractive exploration targets by industry. Other potentially high-success settings are less well recognized.

Statistics may be used as an aid in evaluating the potential of some high-success areas in early stages of exploratory history. Conversely, knowledge of the geologic setting may allow extrapolation of potential P_s after only a few widely-spaced wells have been drilled in some frontier areas.

Emphasis is placed on the necessity of incorporating geologic data in intelligent statistical analysis of exploratory success. Statistical implications of various general approaches to exploratory drilling are discussed.

10:30

(No. 77)

THE SABKHA ENVIRONMENT: A NEW FRONTIER FOR URANIUM EXPLORATION

RICHARD R. RAWSON
Northern Arizona University, Flagstaff, Arizona

It has been proposed by Renfro (1974) that some stratiform copper deposits may have been formed by a sabkha process. Sabkhas are formed in arid supratidal environments where they receive aperiodic flooding of the surface and also ground water is drawn upward through the sediments by evaporative pumping. Algal mats and mounds are associated with this environment and become buried by prograding sediments of carbonate or gypsum of the sabkha. Copper ions carried in the oxygenated continental ground waters are reduced when moving up through the decaying algal mats and precipiated as sulfides forming stratiform copper deposits.

The same conditions could also cause the deposition of uranium minerals in the carbonates of the sabkha environment. The uranium (+ 6 state) bearing ground water moves through the sediment until reaching the zone beneath the sabkha where it is drawn upward by evaporation and reduced (+ 4 state) by the decaying algal matter and deposited as uraninite.

An example of this type of deposit may be found in the Jurassic Todilto Formation near Grants, New Mexico. Anderson & Kirland (1960) reported that organic layers in the limestone have been replaced by uraninite. Uranium has been reported to be concentrated in the "crinkly" beds and the "folded" structures in the Todilto. The "crinkly" beds appear to be stromatolites and some of the folded structures may be algal domes. The Todilto overlies the Entrada Sandstone which is an excellent aquifer. Radio isotope dates reported on the uraninite in the Todilto indicate that it was emplaced shortly after deposition.

10:55 (No. 78)

SEISMIC EXPERIMENTS CLINKERS AREA, WYOMING

PIERRE BENICHOU
Compagnie Generale de Geophysique, Denver, Colorado

Recent exploration in the Powder River Basin has shown an area of poor seismic data due to "Clinker beds" or oxydized coal beds. The purpose of the experiments run in the area is to compare different sources: dynamite, primacord, vibroseis, and optimize the seismic parameters.

Two sets of experiments were run:

E1 on regular coal beds, west of Sheridan, Wyo.
E2 on clinker beds, east of Sheridan, Wyo.

The conclusion is that coal beds do not act as a screen to the seismic energy, however, the clinker beds act as filters, screening high frequency signals. Examples of the experimental work procedure as well as seismic sections comparing the different sources are given.

11:20 (No. 79)

URANIUM IN TERTIARY CHANNELS SOUTHEAST OF LAKE FROME, SOUTH AUSTRALIA

DAVID BRUNT
Mines Administration Proprietary Ltd., Brisbane, Australia
BRUCE RUBIN
Teton Exploration Drilling Company, Inc.
Albuquerque, New Mexico

Lower Tertiary fluvial paleochannels incised in older rocks occur over a wide area of the southern Frome Embayment, South Australia. The buried channels contain similar stratigraphic sequences of interbedded sands, silts, and clays, probably derived from an adjacent uranium rich precambrian province. Uranium mineralization is pervasive within two paleochannels. Four small uranium deposits have been found in the basal sand of these channel sequences at the margin of extensive tongues of limonitic stained sand. A geochemical zonation reflected by variation in limonite, pyrite, carbon, and humic material is defined across one of these deposits. A genetic model is proposed suggesting formation by a uraniferous geochemical cell which migrated down the paleo-stream channel gradient and concentrated uranium along its lateral margin adjacent to the channel bank.

Wednesday, March 31, Afternoon

1:20 (No. 80)

ALVORD VALLEY, OREGON GEOTHERMAL INVESTIGATION

JOHN G. CLEARY
University of Montana, Missoula, Montana

The Alvord Valley located in southeastern Oregon may have geothermal power potential. Underground temperatures in the five hot springs in the valley have been estimated to be in excess of 140°C through the use of various chemical geothermometers (Mariner, et al., 1974). The valley is bounded on both sides by north trending basin and range type normal faults exposing as much as 5500 feet of Miocene and younger volcanic rocks (Fuller, 1931).

The sulfates of the five Alvord area hot springs and associated local evaporites were sampled and analyzed for their sulfur isotopic values. Preliminary results indicate that the sulfate in the hot springs is leached from the playa evaporite deposits through which the water is circulating and that there is apparently no component of magmatic sulfur in the water. This agrees with both deuterium - hydrogen and 180/160 isotope data for the same springs which indicate that the water is meteoric in origin (R. H. Mariner, USGS, unpublished data). Four of the five springs contain anomalous amounts of boron thought by some workers to be characteristic of waters of volcanic origin. However, analysis of volcanic and older metavolcanic rocks exposed on the valley sides show that the boron probably originates from leaching of volcanic rocks present at the base of the section. Thus anomalous amounts of boron also do not necessarily indicate the presence of magmatic water.

Gravity profiles were run across four of the five areas containing springs to help delineate the structural configuration of the valley and faults through which hot spring waters are circulating. These structure profiles together with sulfur isotope and other geochemical information indicate that the water in the Alvord Valley geothermal system originates as runoff from the mountains on each side of the valley. The water then circulates down through faults and fractures in the mountains and reappears at the surface along faults at the margins or in the middle of the valley. The origin of the heat for this system is either: 1) rapid circualtion of water in an area with a high geothermal gradient; 2) an active deep-seated heat source such as a magma chamber or solid igneous rocks in the process of cooling; or 3) frictional heating due to rapid circulation. The fact that no component of magmatic water was found in the hot springs suggests that the first possibility is the most likely.

1:45 (No. 81)

SOURCE BEDS OF PETROLEUM IN THE DENVER BASIN

PAUL J. SWETLAND, and JERRY L. CLAYTON
U.S. Geological Survey, Denver, Colorado

Crude oil and shale samples from the Denver Basin were analyzed by organic geochemical techniques to determine oil-source bed relationships. Infrared spectrophotometry, gas chromatography of the $C_{15}+$ saturates, mass spectrometry, and carbon- and sulfur-isotopic ratios were used to characterize both the crude oils and the extractable organic matter in shales. The oils were further characterized by gas chromatography of the C_4-C_7 fraction and optical-rotation measurements.

In general, oils in Cretaceous rocks are compositionally similar, and they can be distinguished from oils in the Permian Lyons Sandstone. The Cretaceous oils were compared with extractable organic matter in Cretaceous shales to determine the regional and stratigraphic occurrence of petroleum source beds. The results show that most Cretaceous shales are thermally immature over a large part of the basin. In areas where the Cretaceous section has had a thermal history sufficient to cause generation of petroleumlike hydrocarbons within the shales, many potential source beds exist. The geographically limited occurrence of source beds and the occurrence of oil in thermally immature areas suggest that extensive vertical and lateral migration has occurred.

2:10 (No. 82)

THE DANGER OF FEDERAL WITHDRAWALS TO NATURAL RESOURCES DEVELOPMENT

WAYNE N. ASPINALL
Lawyer - Consultant Natural Resources Values,
Palisade, Colorado

The finding, exploration and development of resources values in the exterior-interior of the earth, its rocks and fossils, is necessary to modern man's existence. Over one-third of our nation's natural resources values belong to the Federal Government which is directly responsible for what happens to the natural resources values in its one-third of our nation. Currently there is wide-spread thought in our nation either to not develop our natural resources values or to make the development of such natural resources values so difficult and complicated that in all too many instances the obstacles and delays to development are working against our national welfare. A point at issue is a current practice of our national administrative agencies of government to withdraw (either with or without statutory authority) greater and greater amounts of our Federal lands from development. The statutorily authorized as well as the expressed national policy of multiple use of our natural resources values is being disregarded and voided to the extent of endangering our free enterprise system and the stability of our government.

2:35 (No. 83)

RECONNAISSANCE FOR URANIUM IN THE APPALACHIAN BASIN — SOME INITIAL RESULTS

ARTHUR F. JACOB
U.S. Geological Survey, Denver, Colorado

Anomalous radioactivity occurs in several Paleozoic sedimentary rock units in the Appalachian Basin.

Cambrian sandstone beds show radioactivity 20 times background in places. Detrital monazite is 10-50 percent of some samples, so most of the radioactive deposits probably are fossil placers. However, some thin sections and radiographs show radioactive secondary hematite and unidentified radioactive clay-size minerals; these radioactive minerals suggest that local post-depositional mobilization and concentration of uranium or thorium have occurred. Limited exposures make depositional environments difficult to interpret.

Uranium deposits (maximum 0.3 percent U) near Jim Thorpe, Pennsylvania, are below and in the Spechty Kofp Member of the Catskill Formation (Devonian-Mississippian). They are in fine- to coarse-grained sandstone deposited by meandering and braided rivers on the landward part of a deltaic plain. Here, uranium-bearing, oxodizing ground water that was moving basinward locally may have encountered reductants and precipitated the deposits that occur in this area. Small, lower grade uranium deposits in north-central Pennsylvania and south-central New York are in darker colored rocks deposited in distributary channels on the seaward part of a deltaic plain. Here, reducing solutions may have been responsible for precipitating the uranium.

Small deposits of uranium (maximum 1.8 percent U) are in beds of braided-stream(?) conglomerate interbedded with red beds in the upper part of the Mauch Chunk Formation (Mississippian and Pennsylvanian) near Jim Thorpe, Pennsylvania. A sandstone sample of the Mauch Chunk from Webster Springs, West Virginia, showed 0.04 percent U.

Radioactive anomalies (maximum 45 times background) in the Pocono Formation (Mississippian) near Marlinton, West Virginia, are in rocks formed in distributary channels on the seaward part of a deltaic plain in a belt at least 47 km long. One sample has 0.016 percent U and 0.11 percent Th; semi-quantitative spectrographic analysis of three samples show 1.5-2 percent Ti, 2->2 percent Zr, and 0.3-0.6 percent rare earths. These data and abundant zircon and ilmenite observed in thin sections indicate that the deposits are fossil placers.

The Dunkard Group (Upper Pennsylvanian and Lower Permian) in Ohio, Pennsylvania, and West Virginia consists of a southern, red, sandy facies, an intermediate transitional facies, and a northern, gray, shaly facies. Part of the sand grains in the Dunkard are first-cycle grains derived from radioactive crystalline rocks further south and east in the Blue Ridge and Piedmont Provinces. Oxidizing ground water moving north and west down the depositional dip could have caused the red color of the red facies and transported diagenetically released uranium to depositional sites in the red or tansitional facies. Sandstone beds in the red facies show radioactivity about 2 times background. A fluvial-channel sandstone bed near the southern edge of the transitional facies has radioactivity about 12 times background and maximum 0.009 percent U. The Monongahela Formation (Upper Pennsylvanian), which underlies the Dunkard, shows similar relationships.

3:00 (No. 84)

DEPOSITIONAL ENVIRONMENTS OF OIL SHALE

RONALD C. SURDAM, and LESLIE L. LUNDELL
University of Wyoming, Laramie, Wyoming

Oil shale in the Green River Formation of Wyoming and Colorado is associated with domal stromatolities, cross-bedded ooliths and pisoliths, ostracodal lag deposits, flat pebble conglomerates, bedded saline minerals and barren marlstones with flute casts. In addition, some oil shale units contain mudcracks, breccias and saline mineral nodules. Obviously neither the depth of water, nor the presence of bottom currents in the depositional environment are limiting factors relative to oil shale deposition.

On the other hand, the influx of detrital sediments is a serious constraint on oil shale deposition. Kerogen content of oil shale drops drastically near clastic deltas and prograding clastic shorelines. Much of the oil shale in the Green River Formation was deposited in an environment characterized by shallow water, periodic desiccation, high organic productivity, and a very low sediment influx. These conditions are well satisfied by a playa-lake complex, or in other words, a shallow-water lake surrounded and protected by a broad playa fringe.

Kerogen-rich laminae of the oil shale are the result of a relatively continuous deposition of algal mats and oozes, whereas the carbonate-rich laminae are derived from at least two sources: 1) clastic transport and 2) chemical precipitation. Seasonal flooding of the playa-lake with fresher water contributes not only detrital carbonates washed into the lacustrine environment from the playa fringer, but also contributes carbonate as a chemical precipitate.

3:25 (No. 85)

ECONOMIC VALUES USING DISTRIBUTED RANGES OF VALUES OF RESERVES AND IN-SITU MARKET VALUES

DR. JOHN A. PEDERSON, and DR. JOHN LOHRENZ
U.S. Geological Survey, Denver, Colorado

The policy of the Department of the Interior is to issue mineral leases at fair market value (FMV). Comparable sales and income approaches to FMV are acceptable from a legal viewpoint, with comparable sales preferred, if possible to use. The usual way of implementing the comparable sales approach is to consider the in-situ market value on a unit basis of the mineral being considered.

FMV can be a range with a specific "best" value. A comparable sales approach model has been developed that uses separate probabilistic oil and gas reserves and unit values of each of these two products. Probabilistic input data with various different distributions are tested. The results, which are estimates of FMV, are essentially lognormally distributed regardless of the input distribution. The results also show the necessity of taking care in defining the type and range of distribution in input data values for probabilistic calculation as well as the "best" or modal values. Even apparently subtle changes to the distributions for some input data values can drastically affect the expected market value.

3:50 (No. 86)

STRETCHING THE SEISMIC DOLLAR

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North American Exploration Company, Inc., Denver, Colorado

The primary purpose in presenting this paper is to emphasize that in seismic prospecting one must be able to arrive at a logical answer using the least expensive, reliable method for defining seismic prospects. A discussion of the history of seismic prospecting, use of previously recorded seismic data, with a summary of advanced seismic techniques will be given.

Many of the basins in the Rocky Mountains will be reviewed with an outline of the recommended seismic methods suited to each of these basins. I shall attempt to illustrate how the seimologist and geologist can use the seismic portion of their exploration budget most effectively in each of these basins and in each new prospect or area of interest they encounter.

4:15 (No. 87)

RECENT DEVELOPMENTS IN COAL EXPLORATION IN SOUTHEASTERN MONTANA AND NORTHEASTERN WYOMING

ROBERT E. MATSON, and JOHN PINCHOCK
Montana Bureau of Mines and Geology, Butte, Montana

Recent coal exploration in the Tongue River Member of the Fort Union Formation and the Wasatch Formation is discussed. Coal sections in the Decker, Hanging Woman Creek, and Moorhead, Montana, areas and the Spotted Horse, Gillette, and Rochelle Hills, Wyoming, areas are reviewed and compared.

The Tongue River Member coal in the Decker area has the highest rank of any coal in the Powder River Basin.

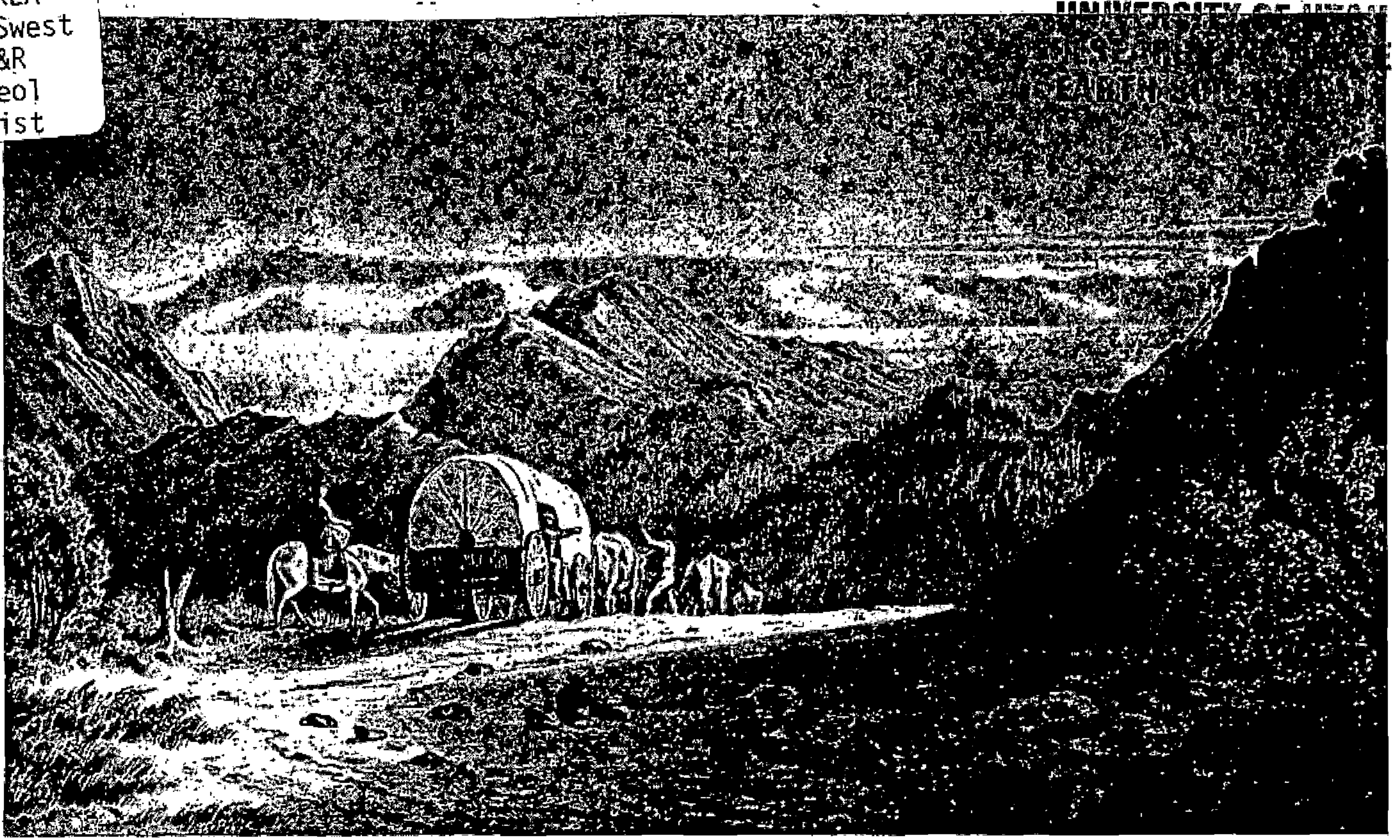
Proper evaluation of coal resources requires utilization of shallow drilling with geophysical logging of drill holes. This information supplements available subsurface data such as oil well logs. Many oil well logs are useful in coal evaluation, particularly if gamma ray logs have been run to the surface.

Coal sections in the Powder River Basin of southeastern Montana and northeastern Wyoming are correlatable, and the coal bed names have been standardized, although some problems still exist.

—NOTES—

ANNALS OF THE FORMER WORLD

BASIN AND RANGE-I



First View of Great Salt Lake Valley (lithograph)

THE poles of the earth have wandered. The equator has apparently moved. The continents, perched on their plates, are thought to have been carried so very far and to be going in so many directions that it seems an act of almost pure hubris to assert that some landmark of our world is fixed at 73 degrees 57 minutes and 53 seconds west longitude and 40 degrees 51 minutes and 14 seconds north latitude—a temporary description, at any rate, as if for a boat on the sea. Nevertheless, these coördinates will, for what is generally described as the foreseeable future, bring you with absolute precision to the west apron of the George Washington Bridge. Nine A.M. A weekday morning. The traffic is some gross demonstration in particle physics. It bursts from its confining source, aimed at Chicago, Cheyenne, Sacramento, through the high dark roadcuts of the Palisades Sill. A young woman, on foot, is being pressed up against the rockwall by the wind booms of the big semis—Con Weimar Bulk Transportation, Fruehauf Long Ranger. Her face is Nordic, her eyes dark brown and Latin—the bequests of grandparents from the extremes of Europe. She wears mountain boots, bluejeans. She carries a single-jack sledgehammer. What the truckers seem to notice, though, is her youth, her long bright Norwegian hair; and they flirt by air horn, driving needles into her ears. Her name is Karen Kleinspehn. She is a geologist, a graduate student nearing her Ph.D., and there is little doubt in her mind that she and the road and the rock before her, and the big bridge and its awesome city—in fact, nearly the whole of the continental United States and Canada and Mexico to boot—are in stately manner moving in the direction of the trucks. She has not come here, however, to ponder global tectonics, although goodness knows she could, the sill being, in theory, a signature of the events that created the Atlantic. In the Triassic, when New Jersey and Mauretania were of a piece, the region is said to have begun literally to pull itself apart, straining to spread out, to break into great crustal blocks. Valleys in effect competed. One of them would open deep enough to admit ocean water, and so for some years would resemble the present Red Sea. The mantle below the crust—exciting and excited by these events—would send up fillings of fluid rock, and with such pressure behind them that they could intrude between horizontal layers of, say, shale and sandstone and lift the country a thousand feet. The intrusion could spread laterally through hundreds of square miles, becoming a broad new layer—a sill—within the country rock.

This particular sill came into the earth about two miles below the surface, Kleinspehn remarks, and she smacks it with the sledge. An air horn blasts. The passing tires, in their numbers, sound like heavy surf. She has to shout to be heard. She pounds again. The rock is competent. The wall of the cut is sheer. She hits it again and again—until a chunk of some poundage falls free. Its fresh surface is asparkle with crystals—freeform, asymmetrical, improvisational plagioclase crystals, bestrewn against a field of dark hornblende. The rock as a whole is called diabase. It is salt-and-peppery charcoal-tweed savings-bank rock. It came to be that way by cooling slowly, at depth, and forming these beautiful crystals.

"It pays to put your nose on the outcrop," she says, turning the sample in her hand. With a smaller hammer, she tidies it up, like a butcher trimming a roast. With a felt-tip pen, she marks it "1." Moving along the cut, she points out xenoliths—blobs of the country rock that fell into the magma and became encased there like raisins in bread. She points to flow patterns, to swirls in the diabase where solidifying segments were rolled over, to layers of coarse-grained crystals that settled, like sediments, in beds. The Palisades Sill—in its chemistry and its texture—is a standard example of homogeneous magma resulting in multiple expressions of rock. It tilts westward. The sill came into a crustal block whose western extremity—known in New Jersey as the Border Fault—is thirty miles away. As the block's western end went down, it formed the Newark Basin. The high eastern end gradually eroded, shedding sediments into the basin, and the sill was ultimately revealed—a process assisted by the creation and development of the Hudson, which eventually cut out the cliffside panorama of New Jersey as seen across the river from Manhattan: the broad sill, which had cracked, while cooling, into slender columns so upright and uniform that inevitably they would be likened to palisades.

In the many fractures of these big roadcuts, there is some suggestion of columns, but actually the cracks running through the cuts are too various to be explained by columnar jointing, let alone by the impudence of dynamite. The sill may have been stressed pretty severely by the tilting of the fault block, Kleinspehn says, or it may have cracked in response to the release of weight as the load above it was eroded away. Solid-earth tides could break it up, too. The sea is not all that responds to the moon. Twice a day the solid earth bobs up and down, as much as a foot. That kind of force and that kind of distance are more than enough to break hard rock. Wells will flow faster during lunar high tides.

For that matter, geologists have done their share to bust up these roadcuts. "They've really been *through* here!" They have fungoed so much rock off the walls they may have set them back a foot. And everywhere, in profusion along this half mile of diabase, there are small, neatly cored holes, in no way resembling the shot holes and guide holes of the roadblasters, which are larger and vertical, but small horizontal borings that would be snug to a roll of coins. They were made by geologists taking paleomagnetic samples. As the magma crystallized and turned solid, certain iron minerals within it lined themselves up like compasses, pointing toward the magnetic pole. As it happened, the direction in those years was northerly. The earth's magnetic field has reversed itself a number of hundreds of times, switching from north to south, south to north, at intervals that have varied in length. Geologists have figured out just when the reversals occurred, and have thus developed a distinct arrhythmic yardstick through time. There are many other chronological frames, of course, and if from other indicators, such as fossils, one knows the age of a rock unit within several million years, a look at the mineral compasses inside it can narrow the age toward precision. Paleomagnetic insights have contributed greatly to the study of the travels of the continents, helping to show where they may have been with respect to one another. In the argot of geology, paleomagnetic specialists are sometimes called paleomagicians. Enough paleomagicians have been up and down the big roadcuts of the Pali-

"There are a lot of books not earning their keep around here."

"Lately, it seems every problem Bill and I have turns up either on the Phil Donahue show or in the Sunday 'Times Magazine.'"

• •

sades Sill to prepare what appears to be a Hilton for wrens and purple martins. Birds have shown no interest.

Near the end of the highway's groove in the sill, there opens a broad, forgettable view of the valley of the Hackensack. The road is descending toward the river. At an even greater angle, the sill—tilting westward—dives into the earth. Accordingly, as Karen Kleinspehn continues to move downhill she is going "upsection" through the diabase toward the top of the tilting sill. The texture of the rock becomes smoother, the crystals smaller, and soon she finds the contact where the magma—at 2000 degrees Fahrenheit—touched the country rock. The country rock was a shale, which had earlier been the deep muck of some Triassic lake, where the labyrinthodont amphibians lived, and paleoniscid fish. The diabase below the contact now is a smooth and uniform hard dark rock, no tweed—its crystals too small to be discernible, having had so little time to grow in the chill zone. The contact is a straight, clear line. She rests her hand across it. The heat of the magma penetrated about a hundred feet into the shale, enough to cook it, to metamorphose it, to turn it into spotted slate. Sampling the slate with her sledgehammer, she has to pound with even more persistence than before. "Some weird, wild minerals turn up in this stuff," she comments between swings. "The metamorphic aureole of this formation is about the hardest rock in New Jersey."

She moves a few hundred feet farther on, near the end of the series of cuts. Pin oaks, sycamores, aspens, cottonwoods have come in on the wind with milkweed and wisteria to seize living space between the rock and the road, although the environment appears to be less welcoming than the center of Carson Sink. There are fossil burrows in the slate—long stringers where Triassic animals travelled through the quiet mud, not far below the surface of the shallow lake. There is a huge rubber sandal by the road, a crate of broken eggs, three golf balls. Two are very cheap but one is an Acushnet Titleist. A soda can comes clinking down the interstate, moving ten miles an hour before the easterly winds of the traffic. The screen of trees damps the truck noise. Karen sits down to rest, to talk, with her back against a cottonwood. "Roadcuts can be a godsend. There's a series of roadcuts near Pikeville, Kentucky—very big ones—where you can see distributary channels in a river-delta system, with natural levees, and with splay deposits going out from the levees into overbank deposits of shales and coal. It's a face-on view of the fingers of a delta, coming at you—the Pocahontas delta system, shed off the Appalachians in Mississippian-Pennsylvanian time. You see river channels that migrated back and forth across a valley and were superposed vertically on one another through time. You see it all there in one series of exposures, instead of having to fit together many smaller pieces of the puzzle."

Geologists on the whole are inconsistent drivers. When a roadcut presents itself, they tend to lurch and weave. To them, the roadcut is a portal, a fragment of a regional story, a proscenium arch that leads their imaginations into the earth and through the surrounding terrain. In the rock itself are the essential clues to the scenes in which the rock began to form—a lake in Wyoming, about as large as Huron; a shallow ocean reaching westward from Washington Crossing; big rivers that rose in Nevada and fell through California to the sea. Unfortunately, highway departments tend to obscure such scenes. They scatter seed wherever they think it will grow. They "hair everything over"—as geologists around the country will typically complain.

"We think rocks are beautiful. Highway departments think rocks are obscene."

"In the north it's vetch."

"In the south it's the god-damned kudzu. You need a howitzer to blast through it. It covers the mountainsides, too."

"Almost all our stops on field trips are at roadcuts. In areas where structure is not well exposed, roadcuts are essential to do geology."

"Without some roadcuts, all you could do is drill a hole, or find natural streamcuts, which are few and far between."

"We as geologists are fortunate to live in a period of great road building."

"It's a way of sampling fresh rock. The road builders slice through indiscriminately, and no little rocks, no softer units are allowed to hide."

"A roadcut is to a geologist as a stethoscope is to a doctor."

"An X-ray to a dentist."

"The Rosetta Stone to an Egyptologist."

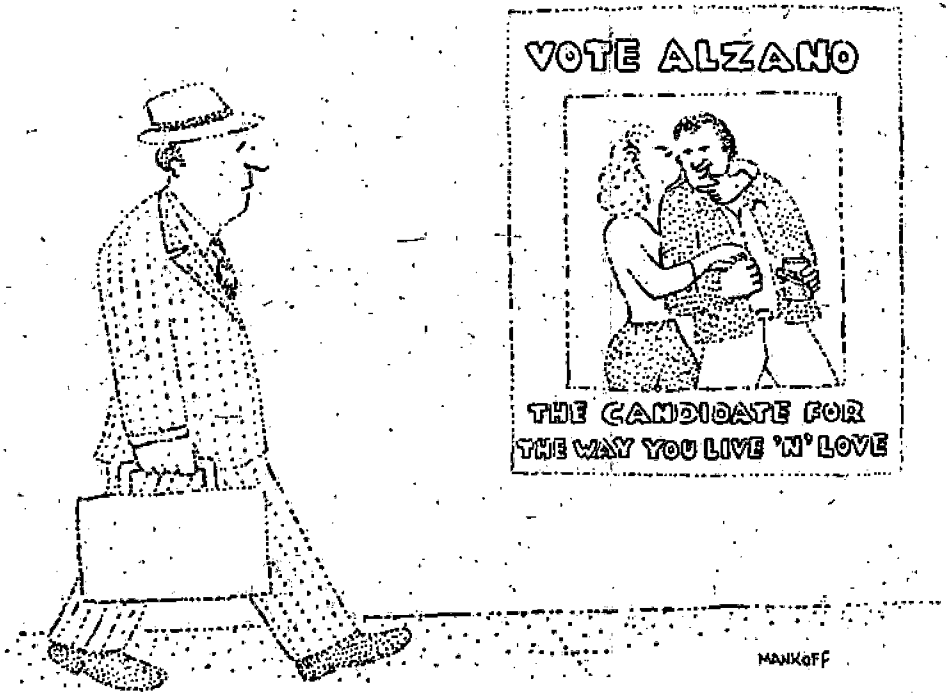
"A twenty-dollar bill to a hungry man."

"If I'm going to drive safely, I can't do geology."

In moist climates, where vegetation veils the earth, streamcuts are about the only natural places where geologists can see exposures of rock, and geologists have walked hundreds of thousands of miles in and beside streams. If roadcuts in the moist world are a kind of gift, they are equally so in other places. Rocks are not easy to read where natural outcrops are so deeply weathered that a hammer will virtually sink out of sight—for example, in piedmont Georgia. Make a fresh roadcut almost anywhere at all and geologists will close in swiftly, like missionaries racing anthropologists to a tribe just discovered up the Xingu.

"I studied roadcuts and outcrops as a kid, on long trips with my family," Karen says. "I was probably doomed to be a geologist from the beginning." She grew up in the Genesee Valley, and most of the long trips were down through Pennsylvania and the Virginias to see her father's parents, in North Carolina. On such a journey, it would have been difficult not to notice all the sheets of rock that had been bent, tortured, folded, faulted, crumpled—and to wonder how that happened, since the sheets of rock would have started out as flat as a pad of paper. "I am mainly interested in sedimentology, in sedimentary structures. It allows me to do a lot of field work. I'm not too interested in theories of what happens *x* kilometres down in the earth at certain temperatures and pressures. You seldom do field work if you're interested in the mantle. There's a little bit of the humanities that creeps into geology, and that's why I am in it. You can't prove things as rigorously as physicists or chemists do. There are no white coats in a geology lab, although geology is going that way. Under the Newark Basin are worn-down remains of the Appalachians—below us here, and under that valley, and so on over to the Border Fault. In the West, for my thesis, I am working on a basin that also formed on top of a preëxisting deformed belt. I can't say that the basin formed just like this one, but what absorbs me are the mechanics of these successor basins, superposed on mountain belts. The Great Valley in California is probably an example of a late-stage compressional basin—formed as plates came together. We think the Newark Basin is an extensional basin—formed as plates moved apart. In the geologic record, how do we recognize the differences between the two? I am trying to get the picture of the basin as a whole, and what is the history that you can read in these cuts. I can't synthesize all this in one morning on a field trip, but I can look at the rock here and then evaluate someone else's interpretation." She pauses. She looks back along the rockwall. "This interstate is like a knife wound all across the country," she remarks. "Sure—you could do this sort of thing from here to California. Anyone who wants to, though, had better hurry. Before long, to go all the way across by yourself will be a fossil experience. A person or two. One car. Coast to coast. People do it now without thinking much about it. Yet it's a most unusual kind of personal freedom—particular to this time span, the one we happen to be in. It's an amazing, temporary phenomenon that will end. We have the best highway system in the world. It lets us do what people in no other country can do. And it is also an ecological disaster."

In June, every year, students and professors from Eastern colleges—with their hydrochloric-acid phials and their hammers and their Brunton compasses—head West. To be sure, there is plenty of absorbing geology under the shag of Eastern America, galvanic conundrums in Appalachian structure and intricate puzzles in history and stratigraphy. In no manner would one wish to mitigate the importance of the Eastern scene. Undeniably, though, the West is where the rocks are—"where it all hangs out," as someone in the United States Geological Survey has put it—and of Eastern geologists who do any kind of summer field work about seventy-five per cent go West. They carry state geological maps and the regional geological highway maps that have been published by the American Association of Petroleum Geologists—maps as prodigally colored as drip paintings and equally formless in their worm-trail-and-paramecium depictions of



the country's uppermost rock. The maps give two dimensions but more than suggest the third. They tell the general age and story of the banks of the asphalt stream. Kleinspehn has been doing this for some years, getting into her Minibago, old and overloaded, a two-door Ford, heavy-duty springs, with odd pieces of the Rockies under the front seat and a mountain tent in the gear behind, to cross the Triassic lowlands and the Border Fault and to rise into the Ridge and Valley Province, the folded-and-faulted, deformed Appalachians—the beginnings of a journey that above all else is physiographic, a journey that tends to mock the idea of a nation, of a political state, as an unnatural subdivision of the globe, as a metaphor of the human ego sketched on paper and framed in straight lines and in riparian boundaries between unalterable coasts. The United States: really a quartering of a continent, a drawer in North America. Pull it out and prairie dogs would spill off one side, alligators off the other—a terrain crisscrossed with geological boundaries, mammalian boundaries, amphibian boundaries: the limits of the world of the river frog, the extent of the Nugget Formation, the range of the mountain cougar. The range of the cougar is the cougar's natural state, overlying segments of tens of thousands of other states, a few of them proclaimed a nation. The United States of America. President Jimmy Carter presiding, on the Atlantic Coastal Plain. The change is generally dramatic as one province gives way to another; and halfway across Pennsylvania, as you leave the quartzite ridges and carbonate valleys of the folded-and-faulted mountains, you drop for a moment into Cambrian rock near the base of a long climb, a ten-mile gradient upsection in time from the Cambrian into the Ordovician into the Silurian into the Devonian into the Mississippian (generally through the same chapters of the earth represented in the walls of the Grand Canyon) and finally out onto the Pennsylvanian itself, the upper deck, the capstone rock, of the Allegheny Plateau. Now even the Exxon map shows a new geology, roads running every which way like shatter lines in glass, following the crazed geometries of this deeply dissected country, whereas, before, the roads had no choice but to run northeast-southwest among the long ropy trends of the deformed mountains, following the endless ridges. On these transcontinental trips, Karen has driven as much as a thousand miles in a day at speeds that she has come to regard as dangerous and no less emphatically immoral. She has almost never slept under a roof, nor can she imagine why anyone on such a journey would want or need to; she "scopes out" her campsites in the late-failing light with strong affection for national forests and less for the three-dollar campgrounds where you roll out your Ensolite between two trailers, where gregarious trains honk like Buicks, and Yamahas on instruments climb escarpments in the night. The physiographic boundary is indistinct where you shade off the Allegheny Plateau and onto the stable craton, the continent's enduring core, its heartland, immemorially unstrained, the steady, predictable hedreocraton—the Stable Interior Craton. There are old mountains to the east, maturing mountains to the west, adolescent mountains beyond. The craton has participated on its edges in the violent creation of the mountains. But it remains intact within, and half a nation wide—the lasting, stolid craton, slowly, slowly downwasting. It has lost five centimetres since the birth of Christ. In much of Canada and parts of Minnesota and Wisconsin, the surface of the craton is Precambrian—earth-basement rock, the continental shield. Ohio, Indiana, Illinois, and so forth, the whole of what used to be called the Middle West, is shield rock covered with a sedimentary veneer that has never been metamorphosed, never been ground into tectonic hash—sandstones, siltstones, limestones, dolomites; flatter than the ground above them, the silent floors of departed oceans, of epicratonic seas. Iowa. Nebraska. Now with each westward township the country thickens, rises—a thousand, two thousand, five thousand feet—on crumbs shed off the Rockies and generously served to the craton. At last the Front Range comes to view—the chevroned mural of the mountains, sparkling white on gray, and on its outfanning sediments you are lifted into the Rockies and you plunge through a canyon to the Laramie Plains. "You go from one major geologic province to another and—whoa!—you really know you're doing it." There are mountains now behind you, mountains before you, mountains that are set on top of mountains, a complex score of underthrust, upthrust, overthrust mountains, at the conclusion of which, through another canyon, you come into the Basin and Range. Brigham Young, when he came through a neighboring canyon and saw rivers flowing out on alluvial fans from the wall of the Wasatch to the flats beyond, made a quick decision and said, "This is the place." The scene suggested settling for it. The alternative was to press on beside a saline sea and then across salt barrens so vast and flat that when microwave relays would be set there they would not require towers. There are mountains, to be sure—off to one side and the other: the Oquirrhs, the Stansburys, the Promontories, the Silver Island Mountains. And with Nevada these high, discrete, austere new ranges begin to come in waves, range after range after north-south range, consistently in rhythm with wide flat valleys: basin, range; basin, range; a mile of height between basin and range. Beside the Humboldt you wind around the noses of the mountains, the Humboldt, framed in cottonwood—a sound, substantial, year-round-flowing river, among the largest in the world that fail to reach the sea. It sinks, it disappears, in an evaporite plain, near the bottom of a series of fault blocks that have broken out to form a kind of stairway that you climb to go out of the Basin and Range. On one step is Reno, and at the top is Donner Summit of the uplifting Sierra Nevada, which has gone above fourteen thousand feet but seems by no means to have finished its invasion of the sky. The Sierra is rising on its east side and is hinged on the west, so the slope is long to the Sacramento Valley—the physiographic province of the Great Valley—flat and sea-level and utterly incongruous within its flanking mountains. It was not eroded out in the normal way of valleys. Mountains came up around it. Across the fertile flatland, beyond the avocados, stand the Coast Ranges, the ultimate province of the present, the berm of the ocean—the Coast Ranges, with their dry and straw-brown Spanish demeanor, their shadows of the live oaks on the ground.

If you were to make that trip in the Triassic—New York to San Francisco, Interstate 80, say roughly at the end of Triassic time—you would move west from the nonexistent Hudson River with the Palisades Sill ten thousand feet down. The motions that will open the Atlantic are well under way (as things appear in present theory), but the brine has not yet come in. Behind you, in fact, where the ocean will be, are several thousand miles of land—a contiguous landmass, fragments of which will be Africa, Antarctica, India, Australia. You cross the Newark Basin. It is for the most part filled with red mud. In the mud are tracks that seem to have been made by a two-ton newt. You come to a long, low, north-south-trending, black, steaming hill. It is a flow of lava that has come out over the mud and has cooled quickly in the air to form the dense smooth textures of basalt. Someday, towns and landmarks of this extruded hill will in one way or another take from it their names: Montclair, Mountainside, Great Notch, Glen Ridge. You top the rise, and now you can see across the rest of the basin to the Border Fault, and—where Whippany and Parsippany will be, some thirty miles west of New York—there is a mountain front perhaps seven thousand feet high. You climb this range and see more and more mountains beyond, and they are the folded-and-faulted Appalachians, but middle-aged and a little rough still at the edges, not caterpillar furry and worn-down smooth. Numbers do not seem to work well with regard to deep time. Any number above a couple of thousand years—fifty thousand, fifty million—will with nearly equal effect awe the imagination to the point of paralysis. This Triassic journey, anyway, is happening close to two hundred million years ago, or five per cent back into the existence of the earth. From the subalpine peaks of New Jersey, the descent is long and gradual to the lowlands of western Pennsylvania, where flat-lying sedimentary rocks begin to reach out across the craton—coals and sandstones, shales and limestones, slowly downwasting, Ohio, Indiana, Illinois, Iowa, erosionally losing an inch every thousand years. Where the Missouri will flow, past Council Bluffs, you come into a world of ruddy hills, Permian red, that continue to the far end of Nebraska, where you descend to the Wyoming flats. Sandy in places, silty, muddy, they run on and on, near sea level, all the way across Wyoming and into Utah. They are as red as brick. They will become the red cliffs and red canyons of Wyoming, the walls of Flaming Gorge. Triassic rock is not exclusively red, but much of it is red all over the world—red in the shales of New Jersey, red in the sandstones of Yunan, red in the banks of the Volga, red by the Solway Firth. Triassic redbeds, as they are called, are in the dry valleys of Antarctica, the red marls of Worcestershire, the hills of Alsace-Lorraine. The Petrified Forest. The Painted Desert. The South African redbeds of the Great Karroo. Triassic red rock is red through and through, and not merely weathered red on the surface, like the great Redwall Limestone of the Grand Canyon, which is actually gray. There may have been a superabundance of oxygen in the atmosphere from late Pennsylvanian through Permian and Triassic time. As sea level changed and changed again all through the Pennsylvanian, tremendous quantities of vegetation grew and then were drowned and buried, grew and then were drowned and buried—to become, eventually, seam upon seam of coal, interlayered with sandstones and shales. Living plants take in carbon dioxide, keep the carbon in their carbohydrates, and give up the oxygen to the atmosphere. Animals, from bacteria upward, then eat the plants and reoxidize the carbon. This cycle would go awry if a great many plants were buried. Their carbon would be buried with them—isolated in rock—and so the amount of oxygen in the atmosphere would build up. All over the world, so much carbon was buried in Pennsylvanian time that the oxygen pressure in the atmosphere quite possibly doubled. There is more speculation than hypothesis in this, but what could the oxygen do? Where could it go? After carbon, the one other thing it could oxidize in great quantity was iron—abundant, pale-green ferrous iron, which exists everywhere, in fully five per cent of crustal rock; and when ferrous iron takes on oxygen, it turns a ferric red. That may have been what happened—in time that followed the Pennsylvanian. Permian rock is generally red. Redbeds on an epic scale are the signs of the Triassic, when the earth in its rutilance may have outdone Mars.

As you come off the red flats to cross western Utah, nearly two hundred million years before the present, you travel in the dark, there being not one grain of evidence to suggest its Triassic appearance, no paleoenvironmental clue. Ahead, though, in eastern Nevada, is a line of mountains that are much of an age with the peaks of New Jersey—a little rounded, beginning to show age—and after you climb them and go down off their western slopes you discern before you the white summits of alpine fresh terrain, of new rough mountains rammed into thin air, with snow banners flying off the matterhorns, ridges, crests, and spurs. You are in central Nevada, about four hundred miles east of San Francisco, and after you have climbed these mountains you look out upon (as it appears in present theory) open sea. You drop swiftly to the coast, and then move on across moderately profound water full of pelagic squid, water that is quietly accumulating the sediments which—ages in the future—will become the roof rock of the rising Sierra. Tall volcanoes are standing in the sea. Then, at roughly the point where the Sierran foothills will end and the Great Valley will begin—at Auburn, California—you move beyond the shelf and over deep ocean. There are probably some islands out there somewhere, but fundamentally you are crossing above ocean crustal floor that reaches to the China Sea. Below you there is no hint of North America, no hint of the valley or the hills where Sacramento and San Francisco will be.

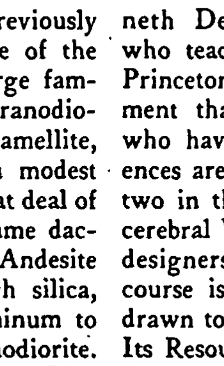
I USED to sit in class and listen to the terms come floating down the room like paper airplanes. Geology was called a descriptive science, and with its pitted outwash plains and drowned rivers, its hanging tributaries and starved coastlines, it was nothing if not descriptive. It was a fountain of metaphor—of isostatic adjustments and degraded channels, of angular unconformities and shifting divides, of rootless mountains and bitter lakes. Streams eroded headward, digging from two sides into mountain or hill, avidly struggling toward each other until the divide between them broke down, and the two rivers that did the breaking now became confluent (one yielding to the other, giving up its direction of flow and going the opposite way) to become a single stream. Stream capture. In the Sierra Nevada, the Yuba had captured the Bear. The Macho member of a formation in New Mexico was derived in large part from the solution and collapse of another formation. There was fatigued rock and incompetent rock and inequigranular fabric in rock. If you bent or folded rock, the inside of the curve was in a state of compression, the outside of the curve was under great tension, and somewhere in the middle was the surface of no strain. Thrust fault, reverse fault, normal fault—the two sides were active in every fault. The inclination of a slope on which boulders would stay put was the angle of repose. There seemed, indeed, to be more than a little of the humanities in this subject. Geologists communicated in English; and they could name things in a manner that sent shivers through the bones. They had roof pendants in their discordant batholiths, mosaic conglomerates in desert pavement. There was ultrabasic, deep-ocean, mottled green-and-black rock—or serpentine. There was the slip face of the barchan dune. In 1841, a paleontologist had decided that the big creatures of the Mesozoic were "fearfully great lizards," and had therefore named them dinosaurs. There were festooned crossbeds and limestone sinks, pillow lavas and petrified trees, incised meanders and defeated streams. There were dike swarms and slickensides, explosion pits, volcanic bombs. Pulsating glaciers. Hogbacks. Radiolarian ooze. There was almost enough resonance in some terms to stir the adolescent groin. The swelling up of mountains was described as an orogeny. Ontogeny, phylogeny, orogeny—accent syllable two. The Antler Orogeny, the Avalonian Orogeny, the Taconic, Acadian, Alleghenian Orogenies. The Laramide Orogeny. The center of the United States had had a dull geologic history—nothing much being accumulated, nothing much being eroded away. It was just sitting there conservatively. The East had once been radical—had been unstable, reformist, revolutionary, in the Paleozoic pulses of three or four orogenies. Now, for the last hundred and fifty million years, the East had been stable and conservative. The far-out stuff was in the Far West of the country—wild, weirdsma, a leather-jacket geology in mirrored shades, with its welded tuffs and Franciscan mélange (internally deformed, complex beyond analysis), its strike-slip faults and falling buildings, its boiling springs and fresh volcanics, its extensional disassembling of the earth.

There was, to be sure, another side of the page—full of geological language of the sort that would have attracted Gilbert and Sullivan. Rock that stayed put was called autochthonous, and if it had moved it was allochthonous. "Normal" meant "at right angles." "Normal" also meant a fault with a depressed hanging wall. There was a Green River Basin in Wyoming that was not to be confused with the Green River Basin in Wyoming. One was topographical and was *on* Wyoming. The other was structural and was *under* Wyoming. The Great Basin, which is centered in Utah and Nevada, was not to be confused with the Basin and Range, which is centered in Utah and Nevada. The Great Basin was topographical, and extraordinary in the world as a vastness of land that had no drainage to the sea. The Basin and Range was a realm of related mountains that all but coincided with the

Great Basin, spilling over slightly to the north and south. To anyone with a smoothly functioning bifocal mind, there was no lack of clarity about Iowa in the Pennsylvanian, Missouri in the Mississippian, Nevada in Nebraskan, Indiana in Illinoian, Vermont in Kansan, Texas in Wisconsinan time. Meteoric water, with study, turned out to be rain. It ran downhill in consequent, subsequent, obsequent, resequent, and not a few insequent streams.

As years went by, such verbal deposits would thicken. Someone developed enough effrontery to call a piece of our earth an epieugeosyncline. There were those who said interfluve when they meant between two streams, and a perfectly good word like mesopotamian would do. A cactolith, according to the American Geological Institute's "Glossary of Geology and Related Sciences," was "a quasi-horizontal chonolith composed of anastomosing ductoliths, whose distal ends curl like a harpolith, thin like a sphenolith, or bulge discordantly like an akmolith or ethmolith." The same class of people who called one rock serpentine called another jacupirangite. Clinoptilolite, eclogite, migmatite, tincalconite, szaibelyite, pumpellyite. Meyerhofferite. The same class of people who called one rock paracelsian called another despujolsite. Metakirchheimerite, katzenbuckelite, mboziite, noselite, neighborite, pigeonite, muskoxite, pabstite, samsonite, aenigmatite. Joesmithite. With the X-ray diffractometer and the X-ray fluorescence spectrometer, which came into general use in geology laboratories in the late nineteen-fifties, and then with the electron probe (around 1970), geologists obtained ever closer examinations of the components of rock. What they had long seen through magnifying lenses as specimens held in the hand—or in thin slices under microscopes—did not always register identically in the eyes of these machines. Andesite, for example, had been given its name for being the predominant rock of the high mountains of South America. According to the machines, there is surprisingly little andesite in the Andes. The Sierra Nevada is renowned throughout the world for its relatively young and absolutely beautiful granite. There is precious little granite in the Sierra. Yosemite Falls, Half Dome, El Capitan—for the most part the "granite" of the Sierra is granodiorite. It has always been difficult enough to hold in the mind that a magma which hardens in the earth as granite will—if it should flow out upon the earth—harden as rhyolite, that what hardens within the earth as diorite will harden upon the earth as andesite, that what hardens within the earth as gabbro will harden upon the earth as basalt, the difference from pair to pair being a matter of chemical composition and the differences within each pair being a matter of texture and of crystalline form, with the darker rock at the gabbro end and the lighter rock the granite. All of that—not to mention such wee appendixes as the fact that diabase is a special texture of gabbro—was difficult enough for the layman to remember before the diffractometers and the spectrometers and the electron probes came along to present their multiplex cavils. What had previously been described as the granite of the world turned out to be a large family of rock that included granodiorite, monzonite, syenite, adamellite, trondhjemite, alaskite, and a modest amount of true granite. A great deal of rhyolite, under scrutiny, became dacite, rhyodacite, quartz latite. Andesite was found to contain enough silica, potassium, sodium, and aluminum to be the fraternal twin of granodiorite. These points are pretty fine. The home terms still apply. The enthusiasm geologists show for adding new words to their conversation is, if anything, exceeded by their affection for the old. They are not about to drop granite. They say granodiorite when they are in church and granite the rest of the week.

When I was seventeen and staring up the skirts of Eastern valleys, I was taught the rudiments of what is now referred to as the Old Geology. The New Geology is the package phrase for the effects of the revolution that occurred in earth science in the nineteen-sixties, when geologists clambered onto seafloor spreading, when people began to discuss continents in terms of their velocities, and when the interactions of some twenty parts of the globe became known as plate tectonics. There were few hints of all that when I was seventeen, and now, a shake later, middle-aged and fading, I wanted to learn some geology again, to feel the difference between the Old and the New, to sense if possible how the science had settled down a decade after its great upheaval, but less in megapictures than in day-to-day contact with country rock, seeing what had not changed as well as what had changed. The thought occurred to me that if you were to walk a series of roadcuts with a geologist something illuminating would in all likelihood occur. This was long before I met Karen Kleinspehn, or, for that matter, David Love, of the United States Geological Survey, or Anita Harris, also of the Survey, or Eldridge Moores, of the University of California at Davis, all of whom would eventually take me with them through various stretches of the continent. What I did first off was what anyone would do. I called my local geologist. I live in Princeton, New Jersey, and the man I got in touch with was Kenneth Deffeyes, a senior professor who teaches introductory geology at Princeton University. It is an assignment that is angled wide. Students who have little aptitude for the sciences are required to take a course or two in the sciences en route to some cerebral Valhalla dangled high by the designers of curriculum. Deffeyes' course is one that such students are drawn to select. He calls it Earth and Its Resources. They call it Rocks for Jocks.



Deffeyes is a big man with a tenured waistline. His hair flies behind him like Ludwig van Beethoven's. He lectures in sneakers. His voice is syllabic, elocutionary, operatic. He has been described by a colleague as "an intellectual roving shortstop, with more ideas per square metre than anyone else in the department—they just tumble out." His surname rhymes with "the maze." He has been a geological engineer, a chemical oceanographer, a sedimentary petrologist. As he lectures, his eyes search the hall. He is careful to be clear but also to bring forth the full promise of his topic, for he knows that while the odd jock and the pale poet are the white of his target the bull's-eye is the future geologist. Undergraduates do not come to Princeton intending to study geology. When freshmen fill out cards stating their three principal interests, no one includes rocks. Those who will make the subject their field of major study become interested after they arrive. It is up to Deffeyes to interest them—and not a few of them—or his department goes into a subduction zone. So his eyes search the hall. People out of his course have been drafted by the Kansas City Kings and have set records in distance running. They have also become professors of geological geophysics at Caltech and of petrology at Harvard.

Deffeyes' own research has gone from Basin and Range sediments to the floor of the deep sea to unimaginable events in the mantle, but his enthusiasms are catholic and he appears to be less attached to any one part of the story than to the entire narrative of geology in its four-dimensional recapitulations of space and time. His goals as a teacher are ambitious to the point of irrationality: At the very least, he seems to expect a hundred mint geologists to emerge from his course—expects perhaps to turn on his television and see a certified igneous petrographer up front with the starting Kings. I came to know Deffeyes when I wondered how gold gets into mountains. I knew that most old-time hard-rock prospectors had little to go on but an association of gold with quartz. And I knew the erosional details of how gold comes out of mountains and into the rubble of streams. What I wanted to learn was what put the gold in the mountains in the first place. I asked a historical geologist and a geomorphologist. They both recommended Deffeyes. He explained that gold is not merely rare. It can be said to love itself. It is, with platinum, the noblest of the noble metals—those which resist combination with other elements. Gold wants to be free. In cool crust rock, it generally is free. At very high temperatures, however, it will go into compounds; and the gold that is among the magmatic fluids in certain pockets of interior earth may be combined, for example, with chlorine. Gold chloride is "modestly" soluble, and will dissolve in water that comes down and circulates in the magma. The water picks up many other elements, too: potassium, sodium, silicon. Heated, the solution rises into fissures in hard crust rock, where the cooling gold breaks away from the chlorine and—in specks, in flakes, in nuggets even larger than the eggs of geese—falls out of the water as metal. Silicon precipitates, too, filling up the fissures and enveloping the gold with veins of silicon dioxide, which is quartz.

When I asked Deffeyes what one might expect from a close inspection of roadcuts, he said they were windows into the world as it was in other times. We made plans to take samples of highway rock. I suggested going north up some new interstate to see what the blasting had disclosed. He said if you go north, in most places on this continent, the geology does not greatly vary. You should proceed in the direction of the continent itself. Go west. I had been thinking of a weekend trip to Whiteface Mountain, or something like it, but now, suddenly, a vaulting alternative came to mind. What about Interstate 80, I asked him. It goes the distance. How would it be? "Absorbing," he said. And he mused aloud: After 80 crosses the Border Fault, it pussyfoots along on morainal till that levelled up the fingers of the foldbelt hills. It does a similar dance with glacial debris in parts of Pennsylvania. It needs no assistance on the craton. It climbs a ramp to the Rockies and a fault-block staircase up the front of the Sierra. It is geologically shrewd. It was the route of animal migrations, and of human history that followed. It avoids melodrama, avoids the Grand Canyons, the Jackson Holes, the geologic operas of the country, but it would surely be a sound experience of the big picture, of the history, the construction, the components of the continent. And in all likelihood it would display in its roadcuts rock from every epoch and era.

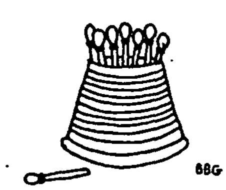
In the year that followed, I would go back and forth across the interstate like some sort of shuttle working out on a loom, accompanying geologists on purposes of their own or being accompanied by them from cut to cut and coast to coast. At any location on earth, as the rock record goes down into time and out into earlier geographies it touches upon tens of hundreds of stories, wherein the face of the earth often changed, changed utterly, and changed again, like the face of a crackling fire. The rock beside the road exposes one or two levels of the column of time and generally implies what went on immediately below and what occurred (or never occurred) above. To tell all the stories would be to tell pretty much the whole of geology in many volumes across a fifty-foot shelf, a task for which I am in every conceivable way unqualified. I am a layman who has travelled for a couple of years with a small core sampling of academic and government geologists ranging in experience from a graduate student to an authentic *éminence grise*, and what I intend to do now is to distill the trips of those years. I wish to make no attempt to speak for all geology or even to sweep in a great many facts that came along. I want to choose some things that interested me and through them to suggest the general history of the continent by describing events and landscapes that geologists see written in rocks.

To poke around in a preliminary way, Deffeyes and I went up to the Palisades Sill, where I was to return with Karen Kleinspehn, borrowed some diabase with a ten-pound sledge, and then began to travel westward, traversing the Hackensack Valley. It was morning. Small airplanes engorged with businessmen were settling into Teterboro. Deffeyes pointed out that if this were near the end of Wisconsinan time, when the ice was in retreat, those airplanes would have been settling down through several hundred feet of water, with the runway at the bottom of a lake. Glacial Lake Hackensack was the size of Lake Geneva and was host to many islands. It had the Palisades Sill for an eastern shoreline, and on the west the lava hill that is now known as the First Watchung Mountain. The glacier had stopped at Perth Amboy, leaving its moraine there to block the foot of the lake, which the glacier fed with meltwater as it retreated to the north. Nearly two hundred million years earlier, the runway would have been laid out on a baking red flat beside the first, cooling Watchung—glowing from cracks, from lava fountains, but generally black as carbon. Basalt flows don't light up the sky. Three hundred million years before that, the airplanes would have been settling down toward the same site through water—in this instance, salt water—on the eastern shelf of a broad low continent, where an almost pure limestone was forming, because virtually nothing from the worn-away continent was eroding into the shallow sea. Three random moments from the upper ninth of time.

In Paterson, I-80 chops the Watchung lava. Walking the cut from end to end, Deffeyes picked up some peripheral shale—Triassic red shale. He put it in his mouth and chewed it. "If it's gritty it's a silt bed, and if it's creamy it's a shale," he said. "This is creamy. Try it." I would not have thought to put it in coffee. In the blocky basaltic wall of the road, there were many small pockets, caves the size of peas, caves the size of lemons. "As magma approaches the surface of the earth, it is so perfused with gases that it fizzes water. A zeolite called clinoptilolite is the strongest adsorber of strontium and cesium from radioactive wastes. The clinoptilolite will adsorb a great deal of lethal material, which you can then store in a small space. When William Wyler made 'The Big Country,' there was a climactic chase scene in which the bad guy was shot and came clattering down a canyon wall in what appeared to be a shower of clinoptilolite. Geologists were on the phone to Wyler at once. 'Loved your movie. Where was that canyon?' There are a lot of zeolites in the Alps, in Nova Scotia, and in North Table Mountain in Colorado. When I was at the School of Mines, I used to go up to North Table Mountain just to wham around. Some of the best zeolites in the world are in this part of New Jersey."

There were oaks and maples on top of Hook Mountain, and, in the wall of the roadcut, basal rosettes of woolly mullein, growing in the rock. The Romans drenched stalks of mullein with suet and used them for funeral torches. American Indians taught the early pioneers to use the long flannel leaves of this plant as innersoles. Only three miles west of us was the Border Fault, where the basin had touched the range, where the stubby remnants of the fault scarp are now under glacial debris. Deffeyes said that the displacement along the fault—the eventual difference between two points that had been adjacent when the faulting began—exceeded fifteen thousand feet. Of course, this happened over several millions of years, and the mountains fronting the basin were all the while eroding, so they were never anything like fifteen thousand feet high. Generally, though, in the late Triassic, there would have been about a mile of difference, a mile of relief, between basin and range. In flash floods, boulders came raining off the mountains and piled in fans at the edge of the basin, ultimately to be filled in with sands and muds and to form conglomerate, New Jersey's so-called Hammer Creek Conglomerate—multicircled, polka-dotted headcheese rock, sometimes known as puddingstone. Here where the basin met the range, the sediments piled up so much that after all of the erosion of two hundred million years what remains is three miles thick. "I was in a bar once in Austin, Nevada," Deffeyes said, "and there was a sudden torrential downpour. The bartender began nailing plywood over the door. I wondered why he was doing that, until boulders came tumbling down the main street of the town. When you start pulling a continent apart, you have a lot of consequences of the same event. Faulting produced this basin. Sediments filled it in. Pull things apart and you produce a surface vacancy, which is faulting, and a subsurface vacancy, which causes upwelling of hot mantle that intrudes as sills or comes out as lava flows. In the Old Geology, you might have seen a sill within the country rock and said, 'Ah, the sill came much later.' With the New Geology, you see that all this was happening more or less at one time. The continent was splitting apart and the ultimate event was the opening of the Atlantic. If you look at the foldbelt in northwest Africa, you see the other side of the New Jersey story. The folding there is of the same age as the Appalachians, and the subsequent faulting is Triassic. Put the two continents together on a map and you will see what I mean. Fault blocks like this one are still in evidence, but discontinuously, from the Connecticut Valley to South Carolina. They are all parts of the suite that opened the Atlantic seaway. The story is very similar in the Great Basin—in the West, in the Basin and Range. The earth is splitting apart there, quite possibly opening a seaway. It is not something that happened a couple of hundred million years ago. It only began in the Miocene, and it is going on today. What we are looking at here in New Jersey is not just some little geologic feature, like a zeolite crystal. This is the opening of the Atlantic. If you want to see happening right now what happened here two hundred million years ago, you can see it all in Nevada."

BASIN. Fault. Range. Basin. Fault. Range. A mile of relief between basin and range. Stillwater Range. Pleasant Valley. Tobin Range. Jersey Valley. Sonoma Range. Pumpernickel Valley. Shoshone Range. Reese River Valley. Pequop Mountains. Steptoe Valley. Ondographic rhythms of the Basin and Range. We are maybe forty miles off the interstate, in the Pleasant Valley basin, looking up at the Tobin Range. At the nine-thousand-foot level, there is a stratum of cloud against the shoulders of the mountains, hanging like a ring of Saturn. The summit of Mt. Tobin stands clear, above the cloud. When we crossed the range, we came through a ranch on the ridgeline where sheep were fenced around a running brook and bales of hay were bright green. Junipers in the mountains were thickly hung with berries, and the air was unadulterated gin. This country from afar is synopsized and dismissed as "desert"—the home of the coyote and the pocket mouse, the side-blotched lizard and the vagrant shrew, the MX rocket and the pallid bat. There are minks and river otters in the Basin and Range. There are deer and antelope, porcupines and cougars, pelicans, cormorants, and common loons. There are Bonaparte's gulls and marbled godwits, American coots and Virginia rails. Pheasants. Grouse. Sandhill cranes. Ferruginous hawks and flammulated owls. Snow geese. This Nevada terrain is not corrugated, like the folded Appalachians, like a tubal air mattress, like a rippled potato chip. This is not—in that compressive manner—a ridge-and-valley situation. Each range here is like a warship standing on its own, and the Great Basin is an ocean of loose sediment with these mountain ranges standing in it as if they were members of a fleet without precedent, assembled at Guam to assault Japan. Some of the ranges are forty miles long, others a hundred, a hundred and fifty. They point generally north. The basins that separate them—ten and fifteen miles wide—will run on for fifty, a hundred, two hundred and fifty miles with lone, daisy-petalled windmills standing over sage and wild rye. Animals tend to be content with their home ranges and not to venture out across the big dry valleys. "Imagine a chipmunk hiking across one of these basins," Deffeyes remarks. "The fauna in the high ranges here are quite *distinct from one to another*. Animals are isolated like Darwin's finches in the Galápagos. These ranges are truly islands."



Supreme over all is silence. Discounting the cry of the occasional bird, the wailing of a pack of coyotes, silence—a great spatial silence—is pure in the Basin and Range. It is a soundless immensity with mountains in it. You stand, as we do now, and look up at a high mountain front, and turn your head and look fifty miles down the valley, and there is utter silence. It is the silence of the winter forests of the Yukon, here carried high to the ridgelines of the ranges. As the physicist Freeman Dyson has written in "Disturbing the Universe," "It is a soul-shattering silence. You hold your breath and hear absolutely nothing. No rustling of leaves in the wind, no rumbling of distant traffic, no chatter of birds or insects or children. You are alone with God in that silence. There in the white flat silence I began for the first time to feel a slight sense of shame for what we were proposing to do. Did we really intend to invade this silence with our trucks and bulldozers and after a few years leave it a radioactive junkyard?"

What Deffeyes finds pleasant here in Pleasant Valley is the aromatic sage. Deffeyes grew up all over the West, his father a petroleum engineer, and he says without apparent irony that the smell of sagebrush is one of two odors that will unfailingly bring upon him an attack of nostalgia, the other being the scent of an oil refinery. Flash floods have caused boulders the size of human heads to come tumbling off the range. With alluvial materials of finer size, they have piled up in fans at the edge of the basin. ("The cloudburst is the dominant sculptor here.") The fans are unconsolidated. In time to come, they will pile up to such enormous thicknesses that they will sink deep and be heated and compressed to form conglomerate. Erosion, which provides the material to build the fans, is tearing down the mountains even as they rise. Mountains are not somehow created whole and subsequently worn away. They wear down as they come up, and these mountains have been rising and eroding in fairly even ratio for millions of years—rising and shedding sediment steadily through time, always the same, never the same, like row upon row of fountains. In the southern part of the province, in the Mojave, the ranges have stopped rising and are gradually wearing away. The Shadow Mountains. The Dead Mountains, Old Dad Mountains, Cowhole Mountains, Bullion, Mule, and Chocolate Mountains. They are inselberge now, buried ever deeper in their own waste. For the most part, though, the ranges are rising, and there can be no doubt of it here, hundreds of miles north of the Mojave, for we are looking at a new seismic scar that runs as far as we can see. It runs along the foot of the mountains, along the fault where the basin meets the range. From out in the valley, it looks like a long, buff-painted, essentially horizontal stripe. Up close, it is a gap in the vegetation, where plants growing side by side were suddenly separated by several metres, where, one October evening, the basin and the range—Pleasant Valley, Tobin Range—moved, all in an instant, apart. They jumped sixteen feet. The erosion rate at which the mountains were coming down was an inch a century. So in the mountains' contest with erosion they gained in one moment about twenty thousand years. These mountains do not rise like bread. They sit still for a long time and build up tension, and then suddenly jump. Passively, they are eroded for millennia, and then they jump again. They have been doing this for about eight million years. This fault, which jumped in 1915, opened like a zipper far up the valley, and, exploding into the silence, tore along the mountain base for upward of twenty miles with a sound that suggested a runaway locomotive.

"This is the sort of place where you really do not put a nuclear plant," says Deffeyes. "There was other action in the neighborhood at the same time—in the Stillwater Range, the Sonoma Range, Pumpernickel Valley. Actually, this is not a particularly spectacular scarp. The lesson is that the whole thing—the whole Basin and Range, or most of it—is alive. The earth is moving. The faults are moving. There are hot springs all over the province. There are young volcanic rocks. Fault scars everywhere. The world is splitting open and coming apart. You see a sudden break in the sage like this and it says to you that a fault is there and a fault block is coming up. This is a gorgeous, fresh, young, active fault scarp. It's growing. The range is lifting up. This Nevada topography is what you see *during* mountain building. There are no foothills. It is all too young. It is live country. This is the tectonic, active, spreading, mountain-building world. To a nongeologist, it's just ranges, ranges, ranges."

Most mountain ranges around the world are the result of compression, of segments of the earth's crust being brought together, bent, mashed, thrust and folded, squeezed up into the sky—the Himalaya, the Appalachians, the Alps, the Urals, the Andes. The ranges of the Basin and Range came up another way. The crust—in this region between the Rockies and the Sierra—is spreading out, being stretched, being thinned, being literally pulled to pieces. The sites of Reno and Salt Lake City, on opposite sides of the province, have moved apart fifty miles. The crust of the Great Basin has broken into blocks. The blocks are

not, except for simplicity's sake, analogous to dominoes. They are irregular in shape. They more truly suggest stretch marks. Which they are. They trend north-south because the direction of the stretching is east-west. The breaks, or faults, between them are not vertical but dive into the earth at roughly sixty-degree angles, and this, from the outset, affected the centers of gravity of the great blocks in a way that caused them to tilt. Classically, the high edge of one touched the low edge of another and formed a kind of trough, or basin. The high edge—sculpted, eroded, serrated by weather—turned into mountains. The detritus of the mountains rolled into the basin. The basin filled with water—at first, it was fresh blue water—and accepted layer upon layer of sediment from the mountains, accumulating weight, and thus unbalancing the block even further. Its tilt became more pronounced. In the manner of a seesaw, the high, mountain side of the block went higher and the low, basin side went lower until the block as a whole reached a state of precarious and temporary truce with God, physics, and mechanical and chemical erosion, not to mention, far below, the agitated mantle, which was running a temperature hotter than normal, and was, almost surely, controlling the action. Basin and range. Integral fault blocks: low side the basin, high side the range. For five hundred miles they nudged one another across the province of the Basin and Range. With extra faulting, and whatnot, they took care of their own irregularities. Some had their high sides on the west, some on the east. The escarpment of the Wasatch Mountains—easternmost expression of this immense suite of mountains—faced west. The Sierra—the westernmost, the highest, the predominant range, with Donner Pass only halfway up it—presented its escarpment to the east. As the developing Sierra made its skyward climb—as it went on up past ten and twelve and fourteen thousand feet—it became so predominant that it cut off the incoming Pacific rain, cast a rain shadow (as the phenomenon is called) over lush, warm, Floridian and verdant Nevada. Cut it off and kept it dry.

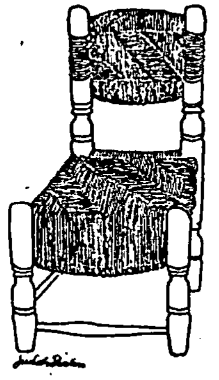
We move on (we're in a pickup) into dusk—north up Pleasant Valley, with its single telephone line on sticks too skinny to qualify as poles. The big flanking ranges are in alpenglow. Into the cold clear sky come the ranking stars. Jackrabbits appear, and crisscross the road. We pass the darkening shapes of cattle. An eerie trail of vapor traverses the basin, sent up by a clear, hot stream. It is only a couple of feet wide, but it is running swiftly and has multiple sets of hot white rapids. In the source springs, there is a thumping sound of boiling and rage. Beside the springs are lucid green pools, rimmed with accumulated travertine, like the travertine walls of Lincoln Center, the travertine pools of Havasu Canyon, but these pools are too hot to touch. Fall in there and you are Brunswick stew. "This is a direct result of the crustal spreading," Deffeyes says. "It brings hot mantle up near the surface. There is probably a fracture here, through which the water is coming up to this row of springs. The water is rich in dissolved minerals. Hot springs like these are the source of vein-type ore deposits. It's the same story that I told you about the hydrothermal transport of gold. When rainwater gets down into hot rock, it brings up what it happens to find there—silver, tungsten, copper, gold. An ore-deposit map and a hot-springs map will look much the same. Seismic waves move slowly through hot rock. The hotter the rock, the slower the waves. Nowhere in the continental United States do seismic waves move more slowly than they do beneath the Basin and Range. So we're not woofing when we say there's hot mantle down there. We've measured the heat."

The basin-range fault blocks in a sense are floating on the mantle. In fact, the earth's crust everywhere in a sense is floating on the mantle. Add weight to the crust and it rides deeper, remove cargo and it rides higher, exactly like a vessel at a pier. Slowly disassemble the Rocky Mountains and carry the material in small fragments to the Mississippi Delta. The delta builds down. It presses ever deeper on the mantle. Its depth at the moment exceeds twenty-five thousand feet. The heat and the pressure are so great down there that the silt is turning into siltstone, the sand into sandstone, the mud into shale. For another example, the last Pleistocene ice sheet loaded two miles of ice onto Scotland, and that dunked Scotland in the mantle. After the ice melted, Scotland came up again, lifting its beaches high into the air. Isostatic adjustment. Let go a block of wood that you hold underwater and it adjusts itself to the surface isostatically. A frog sits on the wood. It goes down. He vomits. It goes up a little. He jumps. It adjusts. Wherever landscape is eroded away, what remains will rise in adjustment. Older rock is lifted to view. When, for whatever reason, crust becomes thicker, it adjusts downward. All of this—with the central image of the basin-range fault blocks floating in the mantle—may suggest that the mantle is molten, which it is not. The mantle is solid. Only in certain pockets near the surface does it turn into magma and squirt upward. The temperature of the mantle varies widely, as would the temperature of anything that is two thousand miles thick. Under the craton, it is described as chilled. By surface standards, though, it is generally white hot, everywhere around the world—white hot and solid but magisterially viscous, permitting the crust above it to "float." Deffeyes was in his bathtub one Saturday afternoon thinking about the viscosity of the mantle. Suddenly he stood up and reached for a towel. "Piano wire!" he said to himself, and he dressed quickly and went to the library to look up a book on piano tuning and to calculate the viscosity of the wire. Just what he guessed—10^{22} poises. Piano wire. Look under the hood of a well-tuned Steinway and you are looking at strings that could float a small continent. They are rigid, but ever so slowly they will sag, will slacken, will deform and give way, with the exact viscosity of the earth's mantle. "And that," says Deffeyes, "is what keeps the piano tuner in business." More miles, and there appears ahead of us something like a Christmas tree alone in the night. It is Winnemucca, there being no other possibility. Neon looks good in Nevada. The tawdriness is refined out of it in so much wide black space. We drive on and on toward the glow of colors. It is still far away and it has not increased in size. We pass nothing. Deffeyes says, "On these roads, it's ten to the minus five that anyone will come along." The better part of an hour later, we come to the beginnings of the casino-flashing town. The news this year is that dollar slot machines are outdrawing nickel slot machines for the first time, ever.

DEFFEYES' purposes in coming to Nevada are pure and noble. His considerable energies appear to be about equally divided between the pursuit of pure science and the pursuit of noble metal. In order to enloft mankind's understanding of the basins, he has been taking paleomagnetic samples of basin sediments. He seeks insight into the way in which the rifting earth comes apart. He wants to perceive the subtle differences in the histories of one fault block and another. His ideas about silver, on the other hand, may send his children to college. This is, after all, Nevada, whose geology bought the tickets for the Spanish-American War. George Hearst found his fortune in the ground here. There were silver ores of such concentration that certain miners did nothing more to the heavy gray rocks than pack them up and ship them to Europe. To be sure, those days and those rocks—those supergene enrichments—are gone, but it has crossed the mind of Deffeyes that there may be something left for Deffeyes. Banqueting Sybarites surely did not lick their plates.

We rented the pickup in Salt Lake City—a white Ford. "If we had a bale of hay in here we'd be Nevada authentic," Deffeyes remarked, and he swept snow off the truck with a broom. November. Three inches on the ground and more falling, slanting in to us from the west. We squinted, and rubbed the insides of the windows, and passed low commercial buildings that drifted in and out of sight. "WILD DUCKS & PHEASANTS PROCESSED. DEER CUT & WRAPPED. DRIVE-IN WINDOW. 7:00 TILL MIDNIGHT." Behind us we could not see, of course, the wall of the Wasatch, its triangles and pinnacles white, but westward of the city visibility improved, and soon other mountains—the Oquirrh Mountains—came looming out of the blankness, their strata steeply dipping and as distinct as the stripes of an awning. "Those are Pennsylvanian and Permian sandstones and limestones," Deffeyes said. "There was glaciation in the Southern Hemisphere at the time. The ice came and went. Sea level kept flapping up and down. So the deposition has a striped look."

When a mountain range comes up into the air, a whole lot comes up with it. The event that had lifted the Oquirrhs—the stretching of the crust until it broke into blocks—was only among the latest of many episodes that have adjusted dramatically the appearance of central Utah. As we could plainly see from the interstate, the rock now residing in that striped mountainside had once been brutally shoved around—shoved, not pulled, and with such force that a large part of it had been tipped up more than ninety degrees, to and well beyond the vertical. Overturned. Such violence can happen on an epic scale. There is an entire nation in Europe that is upside down. It is not a superpower, but it is a whole country nonetheless—San Marino, overturned. Basin and Range faulting, on its own, has never overturned anything. The great fault blocks have a maximum tilt of thirty degrees. The event that so deformed the rock in the Oquirrhs took place roughly sixty million years ago—fifty-two million years before the Oquirrhs came into existence—and it was an event that made alpine fresh compressional mountains, which had their time here under the sun and were disassembled by erosion, taken down and washed away; and now those crazily upended stripes within the Oquirrhs are the evidence and fragmental remains of those ancestral mountains, brought up out of the earth and put on view as a component of new mountains. The new mountains—the mountains of the Basin and Range—are packages variously containing rock that formed at one time or another during some five hundred and fifty million years, or an eighth of the earth's total time. It was thought until recently that older rock was in certain of the ranges, but improved techniques of dating have shown that not to be true. Seven-eighths of the earth's time is lost here, gone without evidence—rock that disintegrated and went off to be recycled. One-eighth, for all that, is no small amount of earth history, and as the great crustal blocks of the Basin and Range have tipped their mountains into the air, with individual faults offset as much as twenty thousand feet, they have brought to the surface and have randomly exposed former seafloors and basaltic dikes, entombed rivers and veins of gold, volcanic spewings and dunal sands—chaotic, concatenated shards of time. In the Basin and Range are the well-washed limestones of clear and sparkling shallow Devonian seas. There are dark, hard, cherty siltstones from some deep ocean trench full of rapidly accumulating Pennsylvanian guck. There are Triassic sediments rich in fossils, scattered pods of Cretaceous granite, Oligocene welded tuffs. There is not much layer-cake geology. The layers have too often been tortured by successive convulsive events.



The welded tuffs were the regional surface when basin-range faulting began. And for more than twenty million previous years they had been the surface, the uppermost rock, with scant relief in the topography of these vast volcanic plains, whose great size and barren aspect are commensurate with the magnitude of the holocaust that brought the rock onto the land. Up through perhaps a hundred fissures, dikes, chimneys, vents, fractures came a violently expanding, exploding mixture of steam and rhyolite glass, and, in enormous incandescent clouds, heavier than air, it scudded across the landscape like a dust storm. The volcanic ash that would someday settle down on Herculaneum and Pompeii was a light powder compared with this stuff, and as the great ground-covering clouds oozed into the contours of the existing landscape they sent streams hissing to extinction, and covered the streambeds and then the valleys, and—with wave after wave of additional cloud—obliterated entire drainages like plaster filling a mold. They filled in every gully and gulch, cave, swale, and draw until almost nothing stuck above a blazing level plain, and then more clouds came exploding from below and in unimpeded waves spread out across the plain. Needless to say, every living creature in the region died. Single outpourings settled upon areas the size of Massachusetts, and before the heavy ash stopped flowing it had covered twenty times that. Moreover, it was hot enough to weld. As the great clouds collapsed and condensed, they formed a compact rock in large part consisting of volcanic glass. It was so thick—as much as three hundred metres thick—that quartz crystals and feldspars formed slowly in the cooling glass. "When you bury a countryside in that much rock so hot it welds, that is the ultimate environmental catastrophe," Deffeyes remarked. "I'm glad there hasn't been one recently."

The province, stung like that, sat still here for twenty-two million years, with volcanism continuing only on its periphery, while erosion worked on the tuff, making draws and gulches, modest valleys and unspectacular hills, but not extensively altering the essentially level plain. There was no repetition of the foaming, frothing outpourings that had completely changed many tens of thousands of square miles of the face of the earth, but so much disturbance arising from and within the underlying earth was obviously precursive of disturbances to follow, when the plains of welded tuff and some thousands of feet below them began to rift into crustal blocks and become the Basin and Range.

The basins filled immediately with water, and life came into the lakes. "Late-Miocene fossils are the earliest we have wherever we have found fossils in those lakebeds," Deffeyes said. "So Basin and Range faulting can be dated to the late Miocene—about eight million years ago." Gradually, as the rain shadow lengthened, the lakes "turned chemical"—became saline or alkaline (bitter)—and eventually they dried up. There are basalt flows in the Basin and Range that are also post-Miocene—lavas that poured out on the surface well after the block faulting had begun, like the Watchungs of New Jersey. There are ruins of cinder cones—evidence of fairly recent local violence—and, in the basins and on the ranges, widespread falls of light ash from volcanoes beyond the province. You see, too, the stream deltas, shoreline terraces, and wave-cut cliffs of big lakes that came into the Great Basin after Pleistocene glaciation began. The change in world climate that made ice in the north temporarily preëmpted the rain shadow and dropped into the Great Basin torrents from the sky. In a region where evaporation had greatly exceeded precipitation, the reverse was now the case, and the big lakes in time connected the basins and made islands of the ranges—Lake Manlius (its bed is now, in part, Death Valley); Lake Lahontan, near Reno (its bed is now, in part, the Humboldt and Carson sinks); and Lake Bonneville. Lake Bonneville grew until it was the size of Lake Erie. Then it grew some more. At Red Rock Pass, in Idaho, it spilled over the brim of the Great Basin and into the Snake River plain. By now it was as large as Lake Michigan. It was not a glacial lake, just a sort of side effect of the distant glaciation, and it sat there for thousands of years with limestone terraces forming and waves cutting benches at the shoreline. Eventually, it began to drop, in stages, pausing wherever evaporation and precipitation were in temporary equilibrium, and more benches were cut and more terraces were made, and then, as the rain shadow took over again, the water shrank back past Erie size and kept on shrinking and turning more and more chemical and getting smaller and shallower and shallower and smaller and near the end of its days became the Great Salt Lake.

The Great Salt Lake reached out to our right and disappeared in snow. In a sense, there was no beach. The basin flatness just ran to the lake and kept on going, wet. The angle formed at the shoreline appeared to be about 179.9 degrees. There were dark shapes of islands, firmaments in the swirling snow—elongate, north-south-trending islands, the engulfed summits of buried ranges. "Chemically, this is one of the toughest environments in the world," Deffeyes said. "You swing from the saltiest to the most dilute waters on the planet in a matter of hours. Some of the most primitive things living are all that can take that. The brine is nearly saturated with sodium chloride. For a short period each year, so much water comes down out of the Wasatch that large parts of the lake surface are relatively fresh. Any creature living there gets an osmotic shock that amounts to hundreds of pounds per square inch. No higher plants can take that, no higher animals—no multicelled organisms. Few bacteria. Few algae. Brine shrimp, which do live there, die by the millions from the shock."

I have seen the salt lake incredibly beautiful in winter dusk under snow-streamer curtains of cloud moving fast through the sky, with the wall of the Wasatch a deep rose and the lake islands rising from what seemed to be rippled slate. All of that was now implied by the mysterious shapes in the foreshortening snow. I didn't mind the snow. One June day, moreover, with Karen Kleinspehn—on her way west for summer field work—I stopped in the Wasatch for a picnic of fruit and cheese beside a clear Pyrenean stream rushing white over cobbles of quartzite and sandstone through a green upland meadow—cattle in the meadow, cottonwoods along the banks of this clear, fresh, suggestively confident, vitally ignorant river, talking so profusely on its way to its fate, which was to move among paradisal mountain landscapes until, through a terminal canyon, the Great Basin drew it in. No outlet. Three such rivers feed the Great Salt Lake. It does indeed consume them. Descending, we ourselves went through a canyon so narrow that the Union Pacific Railroad was in the median of the interstate and on into an even steeper canyon laid out as if for skiing in a hypnotizing rhythm of christiania turns under high walls of rose-brick Nugget sandstone and brittle shattered marine limestone covered with scrub oaks. "Good God, we are dropping out of the sky," said Kleinspehn, hands on the wheel, plunging through the big sheer roadcuts, one of which suddenly opened to distance, presented the Basin and Range.

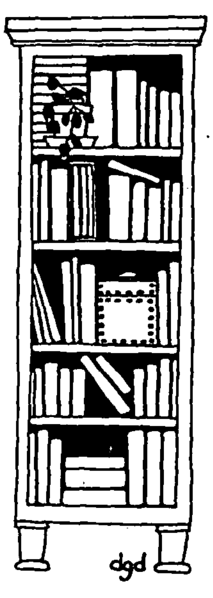
" 'This is the place.' "

"You can imagine how he felt."

In the foreground was the alabaster city, with its expensive neighborhoods strung out along the Wasatch Fault, getting ready to jump fifteen feet. In the distance were the Oquirrhs, the Stansburys, the lake. Sunday afternoon and the Mormons were out on the flats by the water in folding chairs at collapsible tables, end to end like refectory tables, twenty people down to dinner, with acres of beachflat all to themselves and seagulls around them like sacred cows. To go swimming, we had to walk first—several hundred yards straight out, until the water was ankle-deep. Then we lay down on our backs and floated. I have never been able to float. When I took the Red Cross tests, age nine to fifteen, my feet went down and I hung in the water with my chin wrenched up like something off Owl Creek Bridge. I kicked, slyly kicked to push my mouth above the surface and breathe. I could not truly float. Now I tried a backstroke and, like some sort of hydrofoil, went a couple of thousand feet on out over the lake. Only my heels, rump, and shoulder blades seemed to be wet. I rolled over and crawled. I could all but crawl on my hands and knees. And this was June, at the south end—the least salty season, the least salty place in the whole of the Great Salt Lake.

Rolling up on one side, and propped on an elbow, I could see the Promontory Mountains across the water to the north, an apparent island but actually a peninsula, reaching southward into the lake. In 1869, a golden spike was carried into the Promontories and driven into a tie there to symbolize the completion of the first railroad to cross the North American continent—exactly one century before the first footprint on the moon, a span of time during which Salt Lake City and Reno would move apart by one human stride. In that time, also, the railroad twice became dissatisfied with the local arrangements of its roadbed—losing affection for the way of the golden spike (over the mountains) and building a causeway and wooden trestle across the lake itself, barely touching the Promontory peninsula at its southern tip. In the late nineteen-fifties, the trestle section was replaced by rock. The causeway traverses the lake like a solid breakwater, dividing it into halves. The principal rivers that flow into the Great Salt Lake all feed the southern half. The water on the north side of the causeway is generally a foot or two lower and considerably saltier than the water on the other side. Evaporate one cupful of Great Salt Lake North and you have upward of a third of a cup of salt. Evaporate a cupful of Great Salt Lake South and you have about a quarter of a cup of salt, or—nonetheless—eight times as much as from a cup of the ocean. As the lake drew at our bodies, trying to pull fresh water through our skins, it closed our pores tight and our lips swelled and became slightly numb. The water stung savagely at the slightest scratch and felt bitter, as strep in the back of the throat.

We filled a bag with eggstones from the bottom, with oölites, the Salt Lake sand. It was by no means ordinary sand—not the small, smoothed-off ruins of mountains, carried down and dumped by rivers. It was sand that had formed in the lake. Just as raindrops are created around motes of dust, oölites form around bits of rock so tiny that in wave-tossed water they will stir up and move. They move, and settle, move, and settle. And while they are up in the water calcium carbonate forms around them in layer after layer, building something like a pearl. Slice one in half with a diamond saw and you reveal a perfect bull's-eye, or, as its namer obviously imagined it, a stone egg, white and yolk—an oölite. Underwater on the Bahama Banks are sweeping oölitic dunes. When a geologist finds oölites embedded in rock—in, say, some Cambrian outcrop in the Lehigh Valley—the Bahamas come to mind, and the Great Salt Lake, and, by inference, a shallow, lime-rich Cambrian sea. Our sample bag was like a ten-pound sack of sugar. I rolled over on my back, set it on my stomach, and, floating a little lower, kicked in to shore.



On the firm flat beach of the Great Salt Lake were many hundreds of thousands of brine flies—broad dark patches of them hopping and buzzing a steady collective electrical hum. A sacred gull made short bursts through the brine flies, its bill clapping. Three years before gulls ate crickets and saved the Mormons, Kit Carson shot gulls to feed the starving emigrants. Gulls, though, and brine flies are natural survivors. Now, at the end of spring runoff, dead creatures were everywhere. Osmotic shock had killed shrimp outnumbering the flies. Corpses, a couple of centimetres each, lay in hydrogen-sulphide decaying stink. Interlayered with the oölites on the bottom of the lake was a kind of galantine of brine shrimp, the greasy black muck of quintillions dead.

Salt crystals clung like snow to our hair, and were spread on our faces like powder. In man-made ponds near the shore, the sun was making Morton's salt. Spaced along the beach were water towers, courtesy of the State of Utah. You pulled a rope and took a shower.

And now in the autumn snow, Deffeyes and I could see shoreline terraces of Lake Bonneville a thousand feet above us on mountain slopes. That a lake so deep had been brought down to a present average depth of thirteen feet was food for melancholia. Still shrinking, it had long since become the world's second-deadest body of water. In a couple of hundred years, it could match the Dead Sea.

"Mother of God, that's nice," said Deffeyes suddenly, braking down the pickup on the shoulder of the road. The tip of the nose of the Stansbury Mountains had been sliced off by the interstate to reveal a sheer and massive section of handsome blue rock, thinly bedded, evenly bedded, forty metres high. Its parallel planes were tilting, dipping, gently to the east, with the exception of some confused and crumpled material that suggested a snowball splatted against glass, or a broken-down doorway in an otherwise undamaged wall. Deffeyes said, "Let's Richter the situation," and he got out and crossed the road. With his hammer, he chipped at the rock, puzzled the cut. He scraped the rock and dropped acid on the scrapings. Tilted by the western breeze, the snow was dipping sixty degrees east. The bedding planes were dipping twenty degrees east; and the stripes of Deffeyes' knitted cap were dipping fifty degrees north. The cap had a big tassel, and with his gray-wisped hair coming out from under in a curly mélange he looked like an exaggerated elf. He said he thought he knew what had caused "that big goober" in the rock, and it was almost certainly not a manifestation of some major tectonic event—merely local violence, a cashier shot in a grab raid, an item for an inside page. The cut was mainly limestone, which had collected as lime mud in an Ordovician sea. The goober was dolomite.

Limestone is calcium carbonate. Dolomite is calcium carbonate with magnesium added. Together they are known as the carbonate rocks. Deffeyes was taught in college that while it seemed obvious to infer that magnesium precipitating out of water changes limestone into dolomite there was no way to check this out empirically because dolomite was forming nowhere in the world. Deffeyes found that impossible to believe. Deffeyes was already a uniformitarian—a geologist who believes that the present is the key to the past, that if you want to understand how a rock is formed you go watch it forming now. Watch basalt flows at Mauna Loa. Watch the festooned crossbeddings of future sandstones being sketched by the currents of Hatteras. Watch a flooding river blanket the tracks of a bear. Surely, somewhere, he thought, limestone must be changing into dolomite now. Not long after graduate school, he and two others went to Bonaire, in the Netherlands Antilles, where they found a lagoon that was concentrating under the sun and "making a juice very rich in magnesium." The juice was flowing through the limestone below and changing it into dolomite. They presented the news in *Science*. When the rock of this big Utah roadcut had been the limy bottom of the Ordovician sea, the water had been so shallow that the lime mud had occasionally been above the surface and had dried out and cracked into chips, and then the water rose and the chips became embedded in more lime mud, and the process happened again and again so that the limestone now is a self-containing breccia studded with imprisoned chips—an accident so lovely to the eye you want to slice the rock and frame it.

In age, the blue stone approached five hundred million years. Captain Howard Stansbury, USA, whose name would rest upon the mountains of which the rock was a component, was approaching fifty when he came into the Great Basin in 1849. He had been making lighthouses in Florida. The government preferred that he survey the salt lake. With sixteen mules, a water keg, and some India-rubber bags, he circumambulated the lake, and then some. People told him not to try it. He ran out of water but not of luck. And he came back with a story of having seen—far out on the westward flats—scattered books, clothing, trunks, tools, chains, yokes, dead oxen, and abandoned wagons. The Donner Party went around the nose of the Stansburys in late August, 1846, rock on their left, lake marshes on their right. This huge blue roadcut, in its supranatural way, would have frightened them to death. They must have filed along just about where Deffeyes had parked the pickup, on the outside shoulder of the interstate. Deffeyes and I went back across the road, waiting first for a three-unit seven-axle tractor-trailer to pass. Deffeyes described it as "a freaking train."

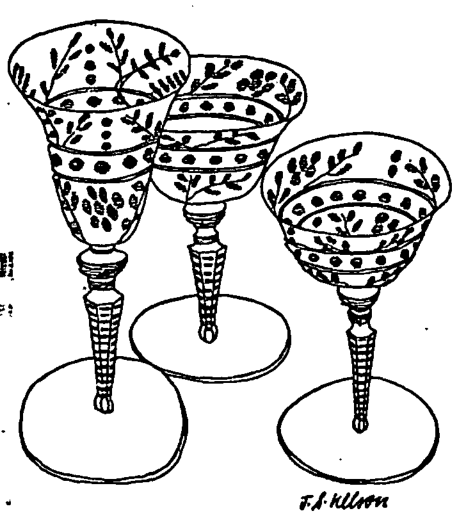
Stansbury Mountains, Skull Valley . . . The Donner Party found good grass in Skull Valley, and good water, and a note by a post at a spring. It had been torn to shreds by birds. The emigrants pieced it together. "Two days—two nights—hard driving—cross desert—reach water." They went out of Skull Valley over the Cedar Mountains into Ripple Valley and over Grayback Mountain to the Great Salt Lake Desert. Grayback Mountain was basalt, like the Watchungs of New Jersey. The New Jersey basalt flowed about two hundred million years ago. The Grayback Mountain basalt flowed thirty-eight million years ago. Well into this century, it was possible to find among the dark-gray outcrops of Grayback Mountain pieces of wagons and of oxhorn, discarded earthenware jugs. The snow suddenly gone now, and in cold sunshine, Deffeyes and I passed Grayback Mountain and then had the Great Salt Lake Desert before us—the dry bed of Bonneville—broader than the periphery of vision. The interstate runs close to but not parallel to the wagon trail, which trends a little more northwesterly. The wagon trail aims directly at Pilot Peak of the Pilot Range, which we could see clearly, upward of fifty miles away—a pyramidal summit with cloud coming off it in the wind like a banner unfurling. Across the dry lakebed, the emigrants homed on Pilot Peak, standing in what is now Nevada, above ten thousand feet. Along the fault scarp, at the base of Pilot Peak, are cold springs. When the emigrants arrived at the springs, their tongues were bloody and black.

"Imagine those poor sons of bitches out here with their animals, getting thirsty," Deffeyes said. "It's a wonder they didn't string the guy that invented this route up by his thumbs."

The flats for the most part were alkaline, a leather-colored mud superficially dry. Dig down two inches and it was damp and greasy. Come a little rain and an ox could go in to its knees. The emigrants made no intended stops on the Great Salt Lake Desert. They drove day and night for the Pilot Range. In the day, they saw mirages—towers and towns and shimmering lakes. Sometimes the lakes were real—playa lakes, temporary waters after a storm. Under a wind, playa lakes move like puddles of mercury in motion on a floor—two or three hundred square miles of water on the move, here today, there tomorrow, gone before long like a mirage, leaving wagons mired in unimagined mud. Very few emigrants chose to cross the Bonneville flats, although the route was promoted as a shortcut—"a nigher route"—rejoining the main migration four basins into Nevada. It was the invention of Lansford Hastings and was known as the Hastings Cutoff. Hastings wrote the helpful note in Skull Valley. His route was geologically unfavorable, but this escaped his knowledge and notice. His preoccupations were with politics. He wished to become President of California. He saw California—for the moment undefendably Mexican—as a new nation, under God, conceived at liberty and dedicated to the proposition that anything can be accomplished through promotion: President Lansford Hastings, in residence in a Western White House. His strategy for achieving high office was to create a new shortcut on the way west, to promote both the route and the destination through recruiting and pamphleteering, to attract emigrants by the thousands year after year, and as their counsellor and deliverer to use them as constituent soldiers in the promised heaven. He camped beside the trail farther east. He attracted the Donners. He attracted Reeds, Kesebergs, Murphys, McCutchens, drew them southward away from the main trek and into the detentive scrub oak made fertile by the limestones of the Wasatch. The Donners were straight off the craton—solid and trusting, from Springfield, Illinois. Weeks were used hacking a path through the scrub oaks, which were living barbed wire. Equipment was abandoned on the Bonneville flats to lighten up loads in the race against thirst. Even in miles, the nigher route proved longer than the one it was shortcutting, on the way to a sierra that was named for snow.

Deffeyes and I passed graffiti on the Bonneville flats. There being nothing to carve in and no medium substantial enough for sprayed paint, the graffitists had lugged cobbles out onto the hard mud—stones as big as grapefruit, ballast from the interstate—and in large dotted letters had written their names: ROSS, DAWN, DON, JUDY, MARK, MOON, ERIC, fifty or sixty miles of names. YARD SALE. Eric's lithography was in basalt and dolomite, pieces of Grayback Mountain, apparently, pieces of the Stansburys. His name, if it sits there a century or so, will eventually explode. Salt will work into the stones along the grain boundaries. When this happens, water evaporates out of the salt, and salt crystals keep collecting and expanding until they explode the rock. In Death Valley are thousands of little heaps of crumbs that were once granite boulders. Salt exploded them. Salt gets into fence posts and explodes them at the base.

Near the far side of Utah, the flats turned blinding white, corn-snow white, and revolving winds were making devils out of salt. Over the whiteness you could see the salt go off the curve of the earth. When the drivers of jet cars move at Mach .8 over the Bonneville Salt Flats, they feel that they are always about to crest a hill. Dig into the salt and it turns out to be a crusty white veneer, like cake icing, more than an inch thick—an almost pure sodium chloride. Below it are a few inches of sand-size salt particles, and below them a sort of creamy yo-



urt mud that is the color of blond offee. In much the manner in which hese salts were left behind by the hrinking outline of the saline lake, here were times around the edges of North America when the shrinking cean stranded bays that gradually ried up and left plains of salt. When he ocean came back, came up again, it pread inland over the salt, which was not so much dissolved as buried, under ayers of sediment washing in from the ontinent. With the weight of more nd more sediment, the layers of salt went deep. Salt has a low specific gravity and is very plastic. Pile eight housand feet of sediment on it and it tarts to move. Slowly, blobularly, it collects itself and moves. It shoves apart layers of rock. It mounds upon tself, and, breaking its way upward, ises in mushroom shape—a salt dome. Still rising into more shales and sandtones, it bends them into graceful arches and then bursts through them ike a bullet shooting upward through a splintering floor. The shape becomes a reverse teardrop. Generally, after the breakthrough, there will be some big ayers of sandstone leaning on the salt dome like boards leaning up against a wall. The sandstone is porous and probably has a layer of shale above it, which is not porous. Any fluid in the sandstone will not only be trapped under the shale but will also be trapped by the impermeable salt. Enter the strange companionship of oil and salt. Oil also moves after it forms. You never find it where God put it. It moves great distances through porous rock. Unless something traps it, it will move on upward until it reaches daylight and turns into tar. You don't run a limousine on tar, let alone a military-industrial complex. If, however, the oil moves upward through nclined sandstone and then hits a wall of salt, it stops, and stays—trapped. Run a little drill down the side of a salt dome and when you hit "sand" it may be full of oil. In the Gulf of Mexico were many of the bays that dried up covered with salt. Where the domes are now, there are towers in he Gulf. A number of salt domes are embedded in the Mississippi Dela, and have been mined. There are rooms inside them with ceilings a hundred feet high—room after room after room, like convention halls, with walls, floors, and ceilings of salt, above ninety-nine per cent pure.

Deffeyes was saying, "It's likely hat in under this salt flat are mounain structures just as complicated as any of the ranges. They're just buried."

We picked up some shattered limestones and welded tuffs close by the Nevada state line. The tuff was hard, heavy, crystalline rock, freckled with feldspars and quartz. You would never dig a city out of that. The ranges now were anything but buried, and Pilot Peak reached above the shadowed basin and high into sunlight, a mile above its valleys. Soon we were climbing the Toano Range. "Here comes another roadcut," said Deffeyes near the summit. "You can feel them coming on. The Taconic Parkway would drive you nuts. I-80 gives you one when you're ready for it." What it gave in the Toanos was granite—not some sibling, son, or cousin but granite himself: sparkling black hornblendes evenly spaced through a snowy field of feldspars and quartz. It was of much the same age as the celebrated rock of the Sierra. Its presence here suggested that the great crustal meltings in the tectonic drama farther west put out enough heat even in eastern Nevada to cook up this batch of fresh granite.

In this manner we moved along from roadcut to roadcut, range to range, like barnyard poultry pecking up rock, seeing what the fault blocks had lifted from below. We crossed the Goshute Valley and went up into the Pequops into red Devonian shales, Devonian siltstones, Devonian limestones—a great many millions of years older than the granite, and from another world. These were marine rocks (by and large), full of crinoids and other marine fossils. Nothing about their appearance differed from sediment that might have collected over Illinois or Iowa in midcontinental, epicratonic seas. They provided not so much as a hint that they were actually from the continental shelf, that Pequop Summit is more or less where North America ended in Devonian time. The first attempt to move covered wagons directly across the continent to California ended at the Pequops, too. The wagons were abandoned at a spring by the eastern base of the mountains, a short hike off the interstate. Later emigrants made cooking fires with the wood of the wagons. Deffeyes was spitting out the siltstones but chewing happily on the shales.

The oölites of the Great Salt Lake were forming in the present. The dolomite of the Stansbury Mountains was five hundred million years old. The tuff had been welded for thirty million years. The age of the granite was a hundred million years. The rock of Pequop Summit was four times as old as that. On a scale of zero to five hundred, those samplings were bunched toward the extremes, with nothing representing the middle three hundred million years. That was just chance, though—just what the faults had happened to throw up—and farther down the road, at Golconda, would come a full-dress two-hundred-million-year-old Triassic show.

Geologists mention at times something they call the Picture. In an absolutely unidiomatic way, they have often said to me, "You don't get the Picture." The oölites and dolomite—tuff and granite, the Pequop siltstones and shales—are pieces of the Picture. The stories that go with them—the creatures and the chemistry, the motions of the crust, the paleoenvironmental scenes—may well, as stories, stand on their own, but all are fragments of the Picture.

The foremost problem with the Picture is that ninety-nine per cent of it is missing—melted or dissolved, torn down, washed away, broken to bits, to become something else in the Picture. The geologist discovers lingering remains, and connects them with dotted lines. The Picture is enhanced by filling in the lines—in many instances with stratigraphy: the rock types and ages of strata, the scenes at the times of deposition. The lines themselves to geologists represent structure—folds, faults, flat-lying planes. Ultimately, they will infer why, how, and when a structure came to be—for example, why, how, and when certain strata were folded—and that they call tectonics. Stratigraphy, structure, tectonics. "First you read ze Kafka," I overheard someone say once in a library elevator. "Ond zen you read ze Turgenev. Ond zen ond only zen are—you—ready—for—ze Tolstoy."

And when you have memorized Tolstoy, you may be ready to take on the Picture. Multidimensional, worldwide in scope and in motion through time, it is sometimes called the Big Picture. The Megapicture. You are cautioned not to worry if at first you do not wholly see it. Geologists don't see it, either. Not all of it. The modest ones will sometimes scuff a boot and describe themselves and their colleagues as scientific versions of the characters in John Godfrey Saxe's version of the Hindu fable of the blind men and the elephant. "We are blind men feeling the elephant," David

Love, of the Geological Survey, has said to me at least fifty times. It is not unknown for a geological textbook to include snatches of the poem.

It was six men of Indostan
To learning much inclined,
Who went to see the Elephant
(Though all of them were blind),
That each by observation
Might satisfy his mind.

The first man of Indostan touches the animal's side and thinks it must be some sort of living wall. The second touches a tusk and thinks an elephant is like a spear. The others, in turn, touch the trunk, an ear, the tail, a knee —"snake," "fan," "rope," "tree."

And so these men of Indostan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right,
And all were in the wrong!

The blind men and the elephant are kept close at hand mainly to slow down what some graduate students refer to as "arm-waving"—the delivery, with pumping elbows, of hypotheses so breathtakingly original that the science seems for the moment more imaginative than descriptive. Where it is solid, it is imaginative enough. Geologists are famous for picking up two or three bones and sketching an entire and previously unheard-of creature into a landscape long established in the Picture. They look at mud and see mountains, in mountains oceans, in oceans mountains to be. They go up to some rock and figure out a story, another rock, another story, and as the stories compile through time they connect—and long case histories are contructed and written from interpreted patterns of clues. This is detective work on a scale unimaginable to most detectives, with the notable exception of Sherlock Holmes, who was, with his discoveries and interpretations of little bits of grit from Blackheath or Hampstead, the first forensic geologist, cknowledged as such by geologists to his day. Holmes was a fiction, but he tarted a branch of a science; and the science, with careful inference, carries act beyond the competence of invenon. Geologists, in their all but closed conversation, inhabit scenes that no ne ever saw, scenes of global sweep, one and gone again, including seas, mountains, rivers, forests, and archipelagoes of aching beauty rising in olcanic violence to settle down quiet and then forever disappear—*almost* sappear. If some fragment has remained in the crust somewhere and something has lifted the fragment to view, the geologist in his tweed cap goes out with his hammer and his sandwich, his magnifying glass and his imagination, and rebuilds the archipelago.

I once dreamed about a great fire that broke out at night at Nasser Aftab's House of Carpets. In Aftab's showroom under the queen-post trusses were layer upon layer and pile after pile of shags and broadlooms, hooks and throws, para-Persians and polyesters. The intense and shrivelling heat consumed or melted most of what was there. The roof gave way. It was a night of cyclonic winds, stabs of unseasonal lightning. Flaming debris fell on the carpets. Layers of ash descended, alighted, swirled in the wind, and drifted. Molten polyester hardened on the cellar stairs. Almost simultaneously there occurred a major accident in the ice-cream factory next door. As yet no people had arrived. Dead of night. Distant city. And before long the west wall of the House of Carpets fell in under the pressure and weight of a broad, braided ooze of six admixing flavors, which slowly entered Nasser Aftab's showroom and folded and double-folded and covered what was left of his carpets, moving them, as well, some distance across the room. Snow began to fall. It turned to sleet, and soon to freezing rain. In heavy winds under clearing skies, the temperature fell to six below zero. Celsius. Representatives of two warring insurance companies showed up just in front of the fire engines. The insurance companies needed to know precisely what had happened, and in what order, and to what extent it was Aftab's fault. If not a hundred per cent, then to what extent was it the ice-cream factory's fault? And how much fault must be—regrettably—assigned to God? The problem was obviously too tough for the Chicken Valley Police Department, or, for that matter, for any ordinary detective. It was a problem, naturally, for a field geologist. One shuffled in eventually. Scratched-up boots. A puzzled look. He picked up bits of wall and ceiling, looked under the carpets, tasted the ice cream. He felt the risers of the cellar stairs. Looking up, he told Hartford everything it wanted to know. For him this was so simple it was a five-minute job.

From the high ridges right down to the level of the road, there was snow all over the Ruby Mountains. "Ugh,"

said Deffeyes—his comment on t snow.

"Spoken like a skier," I said.

He said, "I'm a retired skier."

He skied for the School of Mine In other Rocky Mountain colleges an universities at the time, the best skie in the United States were duly enrolle and trying to look scholarly and maquerading as amateurs to polish the credentials for the 1952 Olymp Games. Deffeyes was outclassed eve on his own team, but there came a da when a great whiteout sent the supe stars sprawling on the mountain. De feyes' turn for the slalom came late the afternoon, and just as he was moving toward the gate the whiteou turned to alpenglow, suddenly bringing into focus the well-compacte snow. He shoved off, and was soo bombing. He was not hurting fo weight even then. He went down th mountain like an object dropped fro a tower. In the end, his time place him high among the ranking stars.

Now, in the early evening, crossin Independence Valley, Deffeyes seeme scarcely to notice that the white summits of the Ruby Range—above eleve thousand feet, and the highest mountains in this part of the Great Basin— were themselves being reddened wit alpenglow. He was musing aloud, fo reasons unapparent to me, about th melting points of tin and lead. He wa saying that as a general rule materia will flow rather than fracture if it hotter than half of its melting poin measured from absolute zero. At roor temperature, you can bend tin an lead. They are solid but they flow Room temperature is more than halfway between absolute zero and th melting points of tin and lead. A room temperature, you cannot ben glass or cast iron. Room temperature i less than halfway from absolute zero t the melting points of iron and glass "If you go down into the earth here t a depth that about equals the width o one of these fault blocks, the temperature is halfway between absolute zer and the melting point of the rock. Th crust is brittle above that point an plastic below it. Where the brittlenes ends is the bottom of the tilting faul block, which rests—floats, if you like —in the hot and plastic, slowly flowing lower crust and upper mantle. I think this is why the ranges are so rhythmic. The spacing between them seems to be governed by their depth— the depth of the cold brittle part of the crust. As you cross these valleys from one range to the next, you can sense

ow deep the blocks are. If they were a
ot deeper than their width—if the
emperature gradient were different
nd the cold brittle zone went down,
ay, five times the surface width—the
locks would not have mechanical
reedom. They could not tilt enough
o make these mountains. So I suspect
he blocks are shallow—about as deep
s they are wide. Earthquake history
upports this. Only shallow earth-
uakes have been recorded in the Basin
nd Range. At the western edge of
eath Valley, there are great convex
mountain faces that are called turtle-
acks. To me they are more suggestive
f whales. You look at them and you
ee that they were once plastically de-
ormed. I think the mountains have
ilted up enough there to be giving us
peek at the original bottom of a
lock. Death Valley is below sea level.
would bet that if we could scrape
way six thousand feet of gravel from
hese mile-high basins up here what
e would see at the base of these
ountains would look like the edge of
eath Valley. I haven't published this
ypothesis. I think it sounds right. I
aven't done any field work in Death
alley. I was just lucky enough to be
ere in 1961 with the guy who first
apped the geology. I have been lucky
l through the years to work in the
asin and Range. The Basin and
ange impresses me in terms of geol-
y as does no other place in North
merica. It's not at all easy, anywhere
the province, to say just what hap-
ned and when. Range after range—
s mysterious to me. A lot of geology
nysterious to me."

—John McPhee

(This is the first part of a two-part article.)

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abor Day, 1980—a time to reflect on
t workers have meant to this city:
s skyline a parade of high-rise mon-
nts glistening with labor's sweat. Its
hborhoods a patchwork of bungalows,
lats and shopping strips built on
ers' toil.
hanges, thousands of them, have mold-
hicago's face into new looks, its heart
new moods; but it still can turn back
ance at a roistering youth.—*Chicago Times.*

etter send that roistering youth to
howers.

●

SHINGTON (AP)—A third world war
vitable," says Chinese Vice Premier
Xiaoping.—*Huntsville (Ala.) Times.*

what language?