3. NE¼ NW¼ NW¼ section 4. Elev. 769.0 feet above sea level
Permit No. 16168; W. C. Vandenberg Jr.—Crummer, Carnes & Stout No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand and gravel	85	85
Mud, gray	12	97
Sand (water)	48	145
Sand	51	196
Gravel and mud	22	218

MISSISSIPPIAN:
Coldwater:

Shale, red and gray (may include some drift)	18	236

4. NE¼ NW¼ SW¼ section 5. Elev. 716.7 feet above sea level
Permit No. 7128; A. E. Kopprasch, Tr.—Bockler No. 1
PLEISTOCENE:
Glacial Drift:

Clay	10	10
Sand	90	100
Clay	40	140
Gravel	40	180
Sand	30	210
Gravel	8	218

MISSISSIPPIAN:
Coldwater:

5. S½ SW¼ SE¼ section 6. Elev. 709.0 feet above sea level
Permit No. 12746; W. A. Elliot—G. F. Hutchinson No. 1
PLEISTOCENE:
Glacial Drift:

Sand	10	10
Clay and mud	10	20
Sand (water)	155	175
Clay and mud	25	200

MISSISSIPPIAN:
Coldwater:

6. SE¼ SW¼ SE¼ section 7. Elev. 703.3 feet above sea level
Permit No. 7806; Bloomingdale Development Co.—Decker No. 7
PLEISTOCENE:
Glacial Drift:

Sand, gravel, and some mud	160	160
Gravel	10	170
"Pump mud"	15	185
Sand, coarse and gravel	43	228
Sand, fine	6	234
Gravel, coarse	2	236

MISSISSIPPIAN:
Coldwater:

7. SE¼ NW¼ SE¼ section 8. Elev. 735.7 feet above sea level
Permit No. 5816; D. F. Jones—Charles Pease No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Mud	63	63
Sand	29	92
Gravel	3	95
Gravel and mud, red (Pre-Wisconsin?)	27	122
Sand and gravel	27	149
Gravel	18	167
Mud	12	179
Gravel	4	183
Mud, gray	28	211

MISSISSIPPIAN:
Coldwater:

8. SW¼ SW¼ NE¼ section 9. Elev. 766.4 feet above sea level
Permit No. 15126; L. W. Page—R. & E. Latchau No. 1
PLEISTOCENE:
Glacial Drift:

Clay	10	10
Gravel	4	14
Clay and gravel	47	61
Gravel (water)	44	105
Sand (water)	15	120
Gravel, sandy	27	147
Sand (water)	18	165
Gravel (water)	5	170
Gravel, muddy (water)	35	205
Clay, brown	9	214
Gravel, muddy	28	242

MISSISSIPPIAN:
Coldwater:

9. SW¼ SE¼ NW¼ section 10. Elev. 780.1 feet above sea level
Permit No. 15238; Harris Oil Co.—S. Hayes No. 2
PLEISTOCENE:
Glacial Drift:

Sand and mud	40	40
Mud, gray	45	85
Sand (some water at 120-47′)	62	147
Mud	7	154
Sand (much water)	16	170
Sand, heaving (140′ of water at 172′)	35	205
Sand (water)	15	220
Gravel, heaving (50′ of water)	14	234
Gravel	16	250
Gravel and sand	25	275
Gravel	55	330

MISSISSIPPIAN:
Coldwater:

10. NE¼ NE¼ NW¼ section 11. Elev. 773.8 feet above sea level
Permit No. 13340; E. W. Leeder—Elisha Ampey No. 2
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Mud	40	40
Mud and gravel	66	106
Sand and gravel	44	150
Gravel	10	160
Sand	22	182
Gravel	8	190
Sand	46	236
Sand and gravel	76	312
Shale (?), blue and gravel	13	325
Gravel	2	327
Gravel and mud	3	330

MISSISSIPPIAN:
Coldwater:

11. NW¼ NW¼ SW¼ section 12. Elev. 769.0 feet above sea level
Permit No. 8951; Vi-Hes Oil Co.—Frank Gelden No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand	85	85
Shale (?)	12	97
Sand, hard	3	100
Gravel	15	115
Sand and gravel	55	170
Sand	159	329
Mud	1	330
Sand	36	366
Gravel	8	374
Sand	4	378

MISSISSIPPIAN:
Coldwater:

12. NE¼ SE¼ SW¼ section 13. Elev. 722.5 feet above sea level
Permit No. 15078; J. H. Fitchett—Geo. Sage et al No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand and boulders	20	20
Gravel, sand, and mud	10	30
Sand, muddy	40	70
Sand and gravel, heaving	32	102
Sand	138	240
Sand and mud	8	248
Gravel	2	250

MISSISSIPPIAN:
Coldwater:

13. NW¼ SW¼ NW¼ section 15. Elev. 772.8 feet above sea level
Permit No. 5389; H. C. Nelson—A. L. Shock No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Mud	20	20
Sand and gravel	25	45
Mud	45	90
Sand and mud	35	125
Mud, sandy and gravel	36	161
Gravel and sand	31	192
Sand, heaving	16	208
Mud and gravel	15	223
Gravel and mud, blue	29	252

MISSISSIPPIAN:
Coldwater:

14. NE¼ SW¼ NE¼ section 16. Elev. 754.7 feet above sea level
Permit No. 5651; Rex Oil & Gas Co.—Van Pryon No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Drift	10	10
Sand	90	100
Gravel, gray	30	130
Mud, blue (Pre-Wisconsin?)	30	160
Sand, yellow	40	200
Gravel, gray	30	230
Sand, gray and mud	38	268

MISSISSIPPIAN:
Coldwater:

15. SE¼ NE¼ SE¼ section 17. Elev. 726.0 feet above sea level
Permit No. 5353; Wm. F. Malow—M. G. Dickerson No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand, yellow	9	9
Clay, blue	20	29
Sand and gravel (water)	4	33
Clay, blue	10	43
Sand and gravel (water)	12	55
Sand and gravel, hardpan	27	82
Sand and gravel (water)	30	112
Hardpan, clay	3	115
Sand, fine (water)	58	173
Clay, brown	54	227
Gravel	1	228
Clay, brown, sandy	26	254

MISSISSIPPIAN:
Coldwater:

16. NE¼ NE¼ NE¼ section 18. Elev. 732.4 feet above sea level
Permit No. 8412; J. H. Fitchett—R. E. West No. A-3
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand, red	60	60
Sand, red and white	40	100
Sand	50	150
Gravel	21	171
Sand	55	226
Gravel and sand	4	230
Sand and mud	25	255

MISSISSIPPIAN:
Coldwater:

17. SE¼ SE¼ SW¼ section 19. Elev. 734.0 feet above sea level
Permit No. 5962; H. G. White—H. Lackey No. 1
PLEISTOCENE:
Glacial Drift:

Drift	24	24
Sand	48	72
Drift	25	97
Sand	103	200
Mud, blue, gravel, and chert	18	218
Gravel	6	224
Shale (?), brown	11	235
Sand, gravel, and shale (?)	19	254
Gravel	1	255

MISSISSIPPIAN:
Coldwater:

18. NE¼ SE¼ NW¼ section 22. Elev. 764.2 feet above sea level
Permit No. 16832; W. B. Darke—Ola M. Camden et al No. 1
PLEISTOCENE:
Glacial Drift:

Drift	21	21
Mud	43	64
Mud, sand, and gravel	47	111
Sand and gravel	67	178
Gravel and mud	15	193
Sand and gravel	51	244

MISSISSIPPIAN:
Coldwater:

19. NE¼ SE¼ SE¼ section 24. Elev. 819.0 feet above sea level
Permit No. 6064; R. W. Cooper—School District No. 5
PLEISTOCENE:
Glacial Drift:

Sand and gravel (water at 65′ and 110′)	210	210
Shale (?) (Pre-Wisconsin?)	20	230
Gravel	25	255

MISSISSIPPIAN:
Coldwater:

20. SW¼ SW¼ NW¼ section 32. Elev. 777.0 feet above sea level
Permit No. 5489; Lima Oil Corp.—G. Rouse No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand and gravel	97	97
Mud, grayish-brown	47	144
Sand, white, heaving	2	146
Shale (?), gray, muddy (Pre-Wisconsin?)	4	150
Sand and gravel	60	210

MISSISSIPPIAN:
Coldwater:

21. NE¼ SE¼ SW¼ section 33. Elev. 821.5 feet above sea level
Permit No. 5685; Hogue, McQueen & Borg—J. W. & E. Hoffman No. 1
PLEISTOCENE:
Glacial Drift:

Clay	10	10
Gravel	5	15
Clay	22	37
Gravel and clay	18	55
Sand, heavy	165	220
Sand, gray	21	241
Gumbo	12	253
Sand	17	270
Gumbo	5	275
Sand	11	286
Gumbo	7	293
Sand	9	302
Gumbo	6	308
Sand	7	315
Gravel	5	320
Sand, coarse	11	331
Gravel	13	344

MISSISSIPPIAN:
Coldwater:

COLUMBIA TOWNSHIP (T 1 S, R 15 W)

1. SW¼ SE¼ SW¼ section 1. Elev. 689.6 feet above sea level
Permit No. 15594; Sewage Sanitation Co.—Arthur Teal No. 1
PLEISTOCENE:
Glacial Drift:

Drift	44	44
Sand and gravel (water)	63	107
Sand (water)	33	140
Gravel	32	172
Clay and gravel	21	193

MISSISSIPPIAN:
Coldwater:

2. S½ N½ SE¼ SE¼ section 3. Elev. 666.0 feet above sea level
Permit No. 6203; Louis Rose—J. Ruess No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Mud	60	60
Sand	190	250
Mud, blue (Pre-Wisconsin?)	10	260
Gravel	8	268

MISSISSIPPIAN:
Coldwater:

3. NE¼ NE¼ NW¼ section 4. Elev. 659.3 feet above sea level
Permit No. 14875; Ford Henry—Walker et al No. 1
PLEISTOCENE:
Glacial Drift:

Sand	133	133
Sand, heaving	39	172
Sand	28	200
Mud, pink (Pre-Wisconsin?)	10	210
Sand and gravel (water)	15	225
Mud, blue and gravel	13	238

MISSISSIPPIAN:
Coldwater:

4. SW¼ NW¼ NE¼ section 6. Elev. 679.5 feet above sea level
Permit No. 15365; Ford Oil Co.—Anna Thomas No. 1
PLEISTOCENE:
Glacial Drift:

Sand and gravel	91	91
Mud, sandy	69	160
Sand and gravel	34	194
Gravel	13	207
Mud and gravel	33	240
Gravel	54	294

MISSISSIPPIAN:
Coldwater:

5. SW¼ SW¼ NE¼ section 7. Elev. 679.9 feet above sea level
Permit No. 5715; F. J. White—M. N. Gruss No. 1
PLEISTOCENE:
Glacial Drift:

Sand, gray, soft	40	40
Gravel	20	60
Sand and mud	140	200
Gravel	12	212

MISSISSIPPIAN:
Coldwater:

6. NE¼ NW¼ NE¼ section 10. Elev. 678.4 feet above sea level
Permit No. 6165; Lang & Lewis—Landrus Bros. No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand	192	192
Shale (?) (Pre-Wisconsin?)	18	210
Sand	85	295
Sand and gravel	15	310

MISSISSIPPIAN:
Coldwater:

7. SW¼ NE¼ NW¼ section 12. Elev. 695.2 feet above sea level
Permit No. 6000; Daily Crude Oil Co.—Wm. Teal No. 1
PLEISTOCENE:
Glacial Drift:

Sand	55	55
Sand, heaving	60	115
Sand and gravel, heaving	50	165
Sand and gravel	25	190
Mud and pea gravel	19	209
Shale (?) and mud (Pre-Wisconsin?)	26	235
Mud	20	255

MISSISSIPPIAN:
Coldwater:

8. NW¼ NW¼ SE¼ section 13. Elev. 713.1 feet above sea level
Permit No. 6359; A. E. Kopprasch, Tr.—Homer Cooley No. 2
PLEISTOCENE:
Glacial Drift:

Clay	20	20
Sand	40	60
Gravel	20	80
Sand	60	140
Gravel	15	155
Sand	40	195
Gravel	25	220
Clay	10	230
Sand	30	260
Gravel	22	282
Sand	13	295
Gravel	10	305

MISSISSIPPIAN:
Coldwater:

9. SW¼ SE¼ SW¼ section 18. Elev. 708.3 feet above sea level
Permit No. 5630; H. C. Nelson—Jung No. 1
PLEISTOCENE:
Glacial Drift:

Drift and sand	43	43
Sand	49	92

	Thickness	Depth
Sand and gravel	50	142
Sand, heaving	21	163
Sand	32	195

MISSISSIPPIAN:
Coldwater:

10. SW¼ SW¼ SW¼ section 19. Elev. 715.8 feet above sea level
Permit No. 5836; DeVries & Boeve—C. E. Taylor No. 1
PLEISTOCENE:
Glacial Drift:

Clay, yellow	60	60
Sand	210	270
Mud, gray	65	335
Gravel (water)	3	338

MISSISSIPPIAN:
Coldwater:

11. NE¼ NW¼ SE¼ section 20. Elev. 680.0 feet above sea level
Permit No. 15694; W. S. Cook, Inc. & C. E. Weller—Ulysses Roberts No. 1
PLEISTOCENE:
Glacial Drift:

Sand and mud	27	27
Sand and gravel (water)	57	84
Sand, heaving	41	125
Mud, gray, sandy	17	142
Sand, heaving	6	148
Sand	7	155
Mud, sandy	10	165
Gravel and mud	1	166
Gravel	7	173

MISSISSIPPIAN:
Coldwater:

12. SE¼ SE¼ NE¼ section 23. Elev. 680.5 feet above sea level
Permit No. 14977; Oil Producers, Inc.—C. & M. Peper No. 14
PLEISTOCENE:
Glacial Drift:

Mud and sand (water all through drift)	65	65
Sand	140	205
Gravel and mud	19	224
Sand and gravel	62	286
Gravel	21	307

MISSISSIPPIAN:
Coldwater:

13. NW¼ SE¼ NE¼ section 24. Elev. 688.2 feet above sea level
Permit No. 16872; Ford Oil Co.—Abel DeRocher No. 1
PLEISTOCENE:
Glacial Drift:

Mud and sand	110	110

	Thickness	Depth
Sand and gravel	40	150
Mud, blue (Pre-Wisconsin?)	5	155
Mud and gravel	40	195
Gravel (hole full of water)	25	220

MISSISSIPPIAN:
Coldwater:

14. SW¼ SE¼ SE¼ section 25. Elev. 790.9 feet above sea level
Permit No. 7791; D. A. Matteson—Lee Messer No. 1
PLEISTOCENE:
Glacial Drift:

Sand	65	65
Clay	25	90
Sand (water)	220	310
Gravel and shale (?), blue	23	333

MISSISSIPPIAN:
Coldwater:

15. NW¼ SW¼ NW¼ section 26. Elev. 670.2 feet above sea level
Permit No. 16070; Harris Oil Co.—Luce No. 1
PLEISTOCENE:
Glacial Drift:

Mud	50	50
Sand (hole full of water at 50′)	150	200
Sand, heaving	35	235
Gravel and some mud	15	250
Gravel	35	285
Mud, blue	5	290

MISSISSIPPIAN:
Coldwater:

16. SW¼ SE¼ NE¼ section 27. Elev. 683.1 feet above sea level
Permit No. 15963; Harris Oil Co.—Horton No. 1
PLEISTOCENE:
Glacial Drift:

Mud	60	60
Sand (some water)	81	141
Mud and sand	14	155
Gravel	10	165
Sand, heaving (hole full of water)	60	225
No record	42	267
Sand, heaving	33	300
Gravel	10	310
Gravel (lots of water)	25	335
Gravel (hole full of water)	30	365
Mud, pink	9	374

MISSISSIPPIAN:
Coldwater:

17. NE¼ NW¼ SE¼ section 28. Elev. 706.6 feet above sea level
Permit No. 7293; W. E. Frude—A. J. Allen No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Sand and shale (?), hard	40	40
Sand	80	120
Sand and shale (?), blue	15	135
Sand	40	175
Shale (?), blue	15	190
Shale (?), sandy	10	200
Sand, heaving	10	210
Sand	24	234
Drift, hard and shale (?)	6	240
Sand, hard and shale (?)	8	248
MISSISSIPPIAN:		
Coldwater:		

18. NE¼ NE¼ NE¼ section 34. Elev. 698.3 feet above sea level
Permit No. 10401; Harris Oil Co.—Graham No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Drift	425	425
MISSISSIPPIAN:		
Coldwater:		
Lime, "Coldwater" (hole full of fresh water)	10	435

19. NW¼ NW¼ SE¼ section 36. Elev. 695.0 feet above sea level
Permit No. 15101; Ronald G. Smith—Cecil Dobben No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Sand and mud (water)	61	61
Sand (water)	19	80
Sand, heaving (water at 210-50')	170	250
Shale (?) and sand	10	260
MISSISSIPPIAN:		
Coldwater		

COVERT TOWNSHIP (T 2 S, R 17 W)

1. SE¼ SW¼ SW¼ section 28. Elev. 672.6 feet above sea level
Permit No. 6092; Coloma Development Co.—John Sanders No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Drift (water at 250-51')	291	291
MISSISSIPPIAN:		
Coldwater:		

2. SW¼ SE¼ NE¼ section 34. Elev. 695.0 feet above sea level
Permit No. 583; Bi-County Fuel & Gas Co.—Emanuel Home No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Sand (water at 82')	193	193
Clay	48	241
Sand	122	363
Clay	40	403
Shale (?)	52	455
Clay	50	505
Clay, heavy	35	540
Sand	15	555
Shell (?) (water)	5	560
MISSISSIPPIAN:		
Ellsworth:		

DECATUR TOWNSHIP (T 4 S, R 14 W)

1. NE¼ SE¼ SW¼ section 2. Elev. 744.8 feet above sea level
Permit No. 16688; Fisher-McCall Oil & Gas, Inc.—J. Polomcak No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Sand, fine	85	85
Sand and gravel (heaving 15-20' in pipe, hole half full of water)	57	142
Drift, sand and gravel (hole half full of water)	18	160
Gravel, clean (water 80' below surface)	10	170
MISSISSIPPIAN:		
Coldwater:		

2. SE¼ SE¼ NE¼ section 9. Elev. 799.1 feet above sea level
Permit No. 7184; Fisher-McCall & R. B. Newcombe—Solomon No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Drift	181	181
Gravel	22	203
Sand and mud	59	262
Drift	142	404
MISSISSIPPIAN:		
Coldwater:		

3. NW¼ NE¼ SE¼ section 10. Elev. 784.5 feet above sea level
Permit No. 14388; Mercer Oil Co., Inc.—Lapekas No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Sand and gravel, yellow	90	90
Mud, gray	24	114
Gravel, gray (hole full of water, flowed through hole full of rotary mud while rig was shut down)	83	197
Clay, blue	61	258
MISSISSIPPIAN:		
Coldwater:		

4. SE¼ SW¼ NE¼ section 13. Elev. 828.7 feet above sea level
Permit No. 7383; Michi-Cal Oil Co.—Jessie Watson No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Drift	20	20
Gravel and sand, brown	51	71
Gravel and sand, dark	19	90
Gravel, gray, muddy	60	150
Sand, gray	32	182
Sand, brown	10	192
Sand and mud, gray	8	200
Gravel, gray	65	265
MISSISSIPPIAN:		
Coldwater:		

5. NE¼ NW¼ NW¼ section 14. Elev. 752.0 feet above sea level
Permit No. 10675; Alton C. Murray—H. R. Elliott No. 1

PLEISTOCENE:		
Glacial Drift:		
Drift	150	150
MISSISSIPPIAN:		
Coldwater:		
Shale, gray (flow fresh water at 216′—estimated 500 GPM)	72	222
Lime, "Coldwater"	12	234

6. SW¼ SW¼ NE¼ section 29. Elev. 754.0 feet above sea level
Permit No. 985; Dayton Oil & Gas Co.—Warner No. 1

PLEISTOCENE:		
Glacial Drift:		
Muck	4	4
Sand and gravel	16	20
Sand	60	80
Sand and gravel	152	232
MISSISSIPPIAN:		
Coldwater:		

7. SW¼ NE¼ SW¼ section 31. Elev. 760.0 feet above sea level (approx.)
Permit No. 50; Vermont Petroleum Development Co., Inc.—Anton Fier No. 1

PLEISTOCENE:		
Glacial Drift:		
Soil	10	10
Gravel	95	105
Mud, pink, calcareous (Pre-Wisconsin?)	80	185
Gravel	20	205
Mud, blue	80	285
Gravel	20	305
MISSISSIPPIAN:		
Coldwater:		

8. SE¼ NE¼ section 32. Elev. 775.0 feet above sea level (approx.)
Permit No. —; Wert Oil & Gas Co.—A. D. Vought No. 1

	Thickness	Depth
PLEISTOCENE:		
Glacial Drift:		
Muck	9	9
Gravel (water)	18	27
Clay, gray, very sticky	113	140
Clay, red (Pre-Wisconsin?)	20	160
Gravel, fine (water flowed 6½′ high over 10″ pipe, estimated 1,000 GPM)	40	200
Quicksand, brown	75	275
Gravel, coarse, muddy	7	282
Shale (?), blue-gray	18	300
Gravel (water)	1½	301½
MISSISSIPPIAN:		
Coldwater:		

GENEVA TOWNSHIP (T 1 S, R 16 W)

1. NW¼ SE¼ NW¼ section 1. Elev. 673.0 feet above sea level
Permit No. 16314; Cook Drilling Co. & A. J. Gilmore—Hammond No. 2

PLEISTOCENE:		
Glacial Drift:		
Sand and gravel	23	23
Sand	111	134
Sand, muddy	46	180
Sand	20	200
Sand, muddy	8	208
Gravel	12	220
MISSISSIPPIAN:		
Coldwater:		

2. NW¼ SE¼ SE¼ section 9. Elev. 636.1 feet above sea level
Permit No. 15631; Basin Oil Co. & Swan-King—Steve Kraus No. 4

PLEISTOCENE:		
Glacial Drift:		
Mud, sandy	65	65
Gravel (water—couldn't bail dry)	10	75
Mud, sandy	265	340
Gravel (hole full of water at 340-45′)	25	365
MISSISSIPPIAN:		
Coldwater:		

3. NW¼ SE¼ NE¼ section 10. Elev. 669.0 feet above sea level
Permit No. 14842; Lund & Weinberg—Tolles et al No. 1

PLEISTOCENE:		
Glacial Drift:		
Clay	80	80

	Thickness	Depth
"Lime sand" ("crag"?) (water)	6	86
Clay and "lime sand"	34	120
Clay	48	168
Clay and gravel	19	187
Lime shell (??) (a little water)	4	191

MISSISSIPPIAN:
Coldwater:

4. NW¼ NW¼ NW¼ section 15. Elev. 653.2 feet above sea level
Permit No. 15397; Cook Drilling Co.—Schabbel No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Drift	64	64
Sand and mud	59	123
Sand, mud, and gravel	125	248
Sand and mud	36	284
Sand, mud, and gravel	32	316
Sand and gravel	16	332
Gravel	18	350
Mud	7	357

MISSISSIPPIAN:
Coldwater:

5. SW¼ NW¼ SE¼ section 16. Elev. 640.8 feet above sea level
Permit No. 16531; Ford Oil Co.—Ben Seleski No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Mud and sand	95	95
Sand and mud (hole full of water at 125-30′)	65	160
Mud and gravel (water)	40	200

MISSISSIPPIAN:
Coldwater:

6. SW¼ SE¼ SW¼ section 20. Elev. 627.4 feet above sea level
Permit No. 14834; N. L. Stevens—Sollitt No. 8.
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand	65	65
Sand and gravel	138	203
Gravel (hole full of water at 210′)	9	212

MISSISSIPPIAN:
Coldwater:

7. NE¼ SW¼ SE¼ section 26. Elev. 661.8 feet above sea level
Permit No. 17292; N. L. Stevens—John & Mary Kochis No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand and clay	18	18
Sand and gravel	18	36

	Thickness	Depth
Clay, sand, and gravel	100	136
Mud, pink (Pre-Wisconsin?)	39	175
Gravel	31	206

MISSISSIPPIAN:
Coldwater:

8. N½ SE¼ SW¼ section 27. Elev. 660.0 feet above sea level
Permit No. 16811; N. L. Stevens—Funk No. 3.
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Mud, sandy	90	90
Sand (water)	30	120
Gravel (water)	25	145
Gravel	14	159

MISSISSIPPIAN:
Coldwater:

9. NE¼ SW¼ SE¼ section 28. Elev. 650.4 feet above sea level
Permit No. 14839; N. L. Stevens—Wm. E. Frude No. 2
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand	30	30
Sand and mud (water at 107′)	96	126
Sand and mud (increase water)	24	150
Gravel (water)	35	185
Mud	12	197
Mud, blue	33	230

MISSISSIPPIAN:
Coldwater:

10. NW¼ SW¼ NE¼ section 29. Elev. 631.7 feet above sea level
Permit No. 14621; Harris Oil Co.—Gus Heinze No. 3
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Drift	45	45
Mud, gravel and sand	69	114
Mud	44	158
Sand and mud	42	200
Sand, mud, and gravel	22	222

MISSISSIPPIAN:
Coldwater:

11. NW¼ NW¼ SE¼ section 31. Elev. 655.7 feet above sea level
Permit No. 14681; Gortsema & Meyer—Anna B. Carlson No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Mud, sandy	100	100
Sand and gravel (water)	20	120

	Thickness	Depth
Mud, sandy	80	200
Sand and gravel (water)	124	324

MISSISSIPPIAN:
Coldwater:

12. SE¼ NW¼ SW¼ section 32. Elev. 635.5 feet above sea level
Permit No. 14540; V. & S. Oil Co.—Perlman No. 1
PLEISTOCENE:
Glacial Drift:

Mud and sand	132	132
Mud and gravel (water at 190-210′)	78	210
Gravel, mud, and sand	30	240
Mud and gravel	53	293
Sand	40	333

MISSISSIPPIAN:
Coldwater:

13. SW¼ SW¼ SE¼ section 33. Elev. 656.4 feet above sea level
Permit No. 14660; Del Fortney & Harris Oil Co.—Hildebrandt Keating-Carpenter No. 1
PLEISTOCENE:
Glacial Drift:

Mud, sandy (no water)	170	170
Gravel, fine (water)	10	180
Mud and sand	40	220
Gravel (75′ of water)	5	225

MISSISSIPPIAN:
Coldwater:

14. NW¼ SW¼ NE¼ section 34. Elev. 671.5 feet above sea level
Permit No. 14383; Rush & Rathburn—Popp No. 1
PLEISTOCENE:
Glacial Drift:

No record (water sand at 50′)	50	50
No record (pea gravel at 150′)	100	150
No record	66	216
Gravel	44	260
No record	4	264

MISSISSIPPIAN:
Coldwater:

HAMILTON TOWNSHIP (T 4 S, R 15 W)

1. NW¼ SW¼ NW¼ section 16. Elev. 774.4 feet above sea level
Permit No. 5866; R. A. T. Wright et al—Will Young No. 1
PLEISTOCENE:
Glacial Drift:

Drift (some bad gravel beds at bottom)	186	186

MISSISSIPPIAN:
Coldwater:

2. SE¼ SE¼ SW¼ section 23. Elev. 756.4 feet above sea level
Permit No. 5452; Gulf Refining Co.—Wayslenko No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Gravel	150	150
Sand, white	26	176
Sand and gravel	29	205
Sand	9	214
Gravel and mud	36	250
Mud, gray	15	265
Gravel and mud	25	290
Sand, gravel, and mud	15	305

MISSISSIPPIAN:
Coldwater:

3. SW¼ SE¼ SE¼ section 25. Elev. 747.0 feet above sea level
Permit No. 5256; Gulf Refining Co.—Iodent No. 1
PLEISTOCENE:
Glacial Drift:

Sand and gravel	82	82
Gravel	44	126
Mud, red (Pre-Wisconsin?)	28	154
Sand and gravel	60	214
Gravel	4	218
Sand	46	264

MISSISSIPPIAN:
Coldwater:

4. SE¼ NE¼ SE¼ section 27. Elev. 751.0 feet above sea level
Permit No. 5582; Gulf Refining Co.—D. Vereeke No. 1
PLEISTOCENE:
Glacial Drift:

Sand and gravel	132	132
Sand, gray	5	137
Gravel	9	146
Shale (?), blue	3	149
Shale (?) and gravel	1	150

MISSISSIPPIAN:
Coldwater:

5. SE¼ SE¼ NW¼ section 35. Elev. 747.0 feet above sea level
Permit No. 5647; Gulf Refining Co.—Paul No. 1
PLEISTOCENE:
Glacial Drift:

Sand and gravel	62	62
Mud, white	7	69
Mud, brown	4	73
Gravel	15	88
Rock, pink (Marshall boulder?)	17	105
Mud, pink	10	115

	Thickness	Depth
Sand and gravel	15	130
Gravel (water)	6	136
Sand	17	153

MISSISSIPPIAN:
Coldwater:

KEELER TOWNSHIP (T 4 S, R 16 W)

1. N½ SW¼ SW¼ section 18. Elev. 756.4 feet above sea level
Permit No. 12804; Nothdurft & Kibler—Shaul No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Mud	20	20
Quicksand	280	300
Mud	50	350

Note: This well did not penetrate the drift.

2. NW¼ NW¼ SE¼ section 33. Elev. 799.0 feet above sea level
Permit No. 14438; Ohio Oil Co.—Pauline Klett No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand	210	210
Sand and gravel	35	245
Gravel	110	355
Shale (?), gray	12	367
Gravel, coarse	8	375

MISSISSIPPIAN:
Ellsworth:

LAWRENCE TOWNSHIP (T 3 S, R 15 W)

1. NW¼ NW¼ SW¼ section 7. Elev. 714.4 feet above sea level
Permit No. 8268; Smith Petroleum Co.—F. Northrup No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Mud	64	64
Clay	21	85
Sand	20	105
Clay	35	140
Sand	113	253

MISSISSIPPIAN:
Coldwater:

2. NE¼ NE¼ NW¼ section 13. Elev. 790.4 feet above sea level
Permit No. 6533; Fisher-McCall Oil & Gas, Inc.—H. A. Witter No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Drift	240	240

	Thickness	Depth
Shale (?), blue	30	270
Mud and gravel	31	301

MISSISSIPPIAN:
Coldwater:

3. SE¼ SW¼ NW¼ section 27. Elev. 761.0 feet above sea level
Permit No. 14822; Gannett & Sleep—V. Ampey No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Clay, sand, and gravel	139	139
Sand, gray and pea gravel (water at 165′)	61	200
Gravel	39	239
Gravel and sand	28	267
Sand	33	300
Sand and gravel	10	310
Sand	39	349

MISSISSIPPIAN:
Coldwater:

PAW PAW TOWNSHIP (T 3 S, R 14 W)

1. SE¼ SE¼ SE¼ section 5. Elev. 743.4 feet above sea level
Permit No. 9141; Sun Oil Co.—Otis T. Buys No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand (water at 43-93′)	110	110
Gravel	11	121
Sand and gravel	35	156
Sand	36	192
Sand and gravel	44	236

MISSISSIPPIAN:
Coldwater:

PINE GROVE TOWNSHIP (T 1 S, R 13 W)

1. SW¼ NW¼ SW¼ section 3. Elev. 740.9 feet above sea level
Permit No. 16312; Ford Henry—Geo. Hrabacka No. 2
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Drift (water 0-90′)	182	182
Pea gravel (water)	20	202
Drift	13	215

MISSISSIPPIAN:
Coldwater:

2. SW¼ SE¼ NW¼ section 4. Elev. 816.5 feet above sea level
Permit No. 16661; Harris Oil Co.—Felix Frankowski No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Gravel	3	3

	Thickness	Depth
Boulders	17	20
Gravel	60	80
Gravel and mud	20	100
Gravel (some water)	15	115
Sand, heaving (water)	125	240
Gravel	10	250
Boulder (ruined drive shoe)	at	250
Mud and gravel	18	268
MISSISSIPPIAN:		
Coldwater:		
Shale, gray	152	420
Lime shell (some water)	6	426

3. NE¼ NE¼ NE¼ section 9. Elev. 783.7 feet above sea level
Permit No. 16408; Smith Petroleum Co.—Sudeikis, Jr. No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand	45	45
Sand and gravel (water)	80	125
Sand and gravel (dry)	27	152
Gravel (water)	8	160
Gravel (dry)	32	192
MISSISSIPPIAN:		
Coldwater:		

4. SE¼ SW¼ NE¼ section 10. Elev. 840.6 feet above sea level
Permit No. 14869; S. L. Godfrey—Harbolt No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand and gravel	47	47
Clay	88	135
Sand, muddy	55	190
Sand (some water)	30	220
Sand	5	225
Gravel (water)	23	248
Gravel	26	274
Gravel, muddy (no water)	58	332
MISSISSIPPIAN:		
Coldwater:		

5. SE¼ NE¼ SW¼ section 19. Elev. 809.0 feet above sea level
Permit No. 15642; E. W. Leeder—Irwin-Dadrich Comm. No. 1

PLEISTOCENE:		
Glacial Drift:		
Mud, sandy (water at 55′)	78	78
Sand (water at 98′)	52	130
Clay	10	140
Sand, gravel, and clay	20	160
Mud, gray	40	200
Gravel	10	210

	Thickness	Depth
MISSISSIPPIAN:		
Coldwater:		
Shale, blue	145	355
Shale, gray	71	426
Lime "Coldwater" (3 bailers water overnight at 473-83′)	109	535

6. NE¼ NE¼ SE¼ section 22. Elev. 816.0 feet above sea level
Permit No. 17309; Otto Ottersky—Raymond Brown No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand	40	40
Sand and gravel	65	105
Mud, sand, and gravel	135	240
Gravel	15	255
MISSISSIPPIAN:		
Coldwater:		

7. SW¼ SW¼ SE¼ section 23. Elev. 780.5 feet above sea level
Permit No. 6239; E. W. Collins—H. Willis Estate No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand and gravel	150	150
Slate (?), blue (Pre-Wisconsin?)	10	160
Sand	15	175
MISSISSIPPIAN:		
Coldwater:		

8. NW¼ NW¼ NE¼ section 29. Elev. 798.4 feet above sea level
Permit No. 16604; Merrill Drilling Co.—Bert Buis No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand	35	35
Sand and shale (?) breaks (approximately 2′ streaks of sand)	52	87
Sand and gravel	73	160
Mud, gray and gravel (Pre-Wisconsin?)	65	225
Sand, white and gravel	45	270
Shale (?) and sand	15	285
MISSISSIPPIAN:		
Coldwater:		

9. SW¼ NE¼ NW¼ section 35. Elev. 750.5 feet above sea level
Permit No. 7832; W. Spencer Cook—M. D. Ray No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand and gravel	253	253
Gravel	55	308
Sand and gravel	3	311
MISSISSIPPIAN:		
Coldwater:		

PORTER TOWNSHIP (T 4 S, R 13 W)

1. SE¼ SE¼ SE¼ section 5. Elev. 955.7 feet above sea level
Permit No. 15192; Fisher-McCall Oil & Gas, Inc.—L. Erwin No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Sand, yellow	29	29
Gravel	41	70
Sand, gray	96	166
Sand and gravel	59	225
Sand, red (Pre-Wisconsin?)	5	230
Sand, gray	160	390
Gravel	34	424
Mud and gravel	17	441
Pea gravel	6	447

MISSISSIPPIAN:
Coldwater:

2. SW¼ SE¼ NW¼ section 9. Elev. 961.5 feet above sea level
Permit No. 16770; Fisher-McCall Oil & Gas, Inc.—Chas. Lamme No. 1
PLEISTOCENE:
Glacial Drift:

Sand and gravel (water at 144'—good)	273	273
Sand (hole half full of water)	190	463
Gravel	5	468

MISSISSIPPIAN:
Coldwater:

3. SE¼ SW¼ SE¼ section 14. Elev. 912.2 feet above sea level
Permit No. 7309; L. P. Petersen—Petersen Point Farm No. 2
PLEISTOCENE:
Glacial Drift:

Gravel, white	42	42
Gravel, brown	49	91
Gravel, gray	32	123
Mud, gray, sandy	77	200
Shale (?), blue	25	225
Mud, gray, sandy	65	290
Sand, brown	24	314
Gravel, gray	1	315

MISSISSIPPIAN:
Coldwater:

4. NW¼ NW¼ NE¼ section 16. Elev. 919.3 feet above sea level
Permit No. 6507; W. Spencer Cook—H. Mahoney No. 1
PLEISTOCENE:
Glacial Drift:

Sand and gravel	90	90
Sand, fine	55	145
Sand	85	230

	Thickness	Depth
Mud	15	245
Sand, fine	25	270
Mud	29	299
Mud, sandy	13	312
Sand, fine	130	442
Mud and boulders	7	449
Gravel	17	466
Gravel and shale (?), sandy	9	475

MISSISSIPPIAN:
Coldwater:

5. NW¼ SE¼ NE¼ section 17. Elev. 924.8 feet above sea level
Permit No. 16280; W. D. Gannett—Alva Gibson No. 1
PLEISTOCENE:
Glacial Drift:

Gravel	95	95
Sand and gravel	392	487
Mud (may be Coldwater in part?)	50	537

MISSISSIPPIAN:
Coldwater:

6. NE¼ NE¼ SW¼ section 18. Elev. 880.0 feet above sea level
Permit No. 6931; R. T. & E. Corp.—J. J. Theisen No. 2
PLEISTOCENE:
Glacial Drift:

Drift	100	100
Sand, brown	65	165
Mud and gravel	46	211
Gravel	34	245
Shale (?), blue	11	256
Sand	54	310
Gravel	12	322
Shale (?), blue	27	349
Sand	35	384
Shale (?), gray	26	410
Shale (?), blue	15	425
Sand, brown	5	430

MISSISSIPPIAN:
Coldwater:

7. S½ N½ SE¼ section 19. Elev. 958.0 feet above sea level
Permit No. 7499; R. T. & E. Corp.—Stanley Bray No. 2
PLEISTOCENE:
Glacial Drift:

Sand, brown and gravel	141	141
Quicksand	26	167
Sand, brown and gravel	54	221
Drift, blue	21	242

	Thickness	Depth
Sand, brown	18	260
Drift, mixed	13	273
Sand, brown and gravel	68	341
Sand, brown and shale (?)	29	370
Sand, brown	30	400
Shale (?), blue	20	420
Sand, brown	5	425
Sand, gray and shale	24	449

MISSISSIPPIAN:
Coldwater:

8. NE¼ NE¼ SE¼ section 25. Elev. 908.6 feet above sea level
Permit No. 8122; Turner Petroleum Corp.—A. Adams No. 1
PLEISTOCENE:
Glacial Drift:

Sand and gravel	70	70
Sand	15	85
Mud, gray	60	145
Sand	25	170
Mud and sand	153	323
Mud and gravel	26	349

MISSISSIPPIAN:
Coldwater:

9. NW¼ NE¼ NE¼ section 28. Elev. 924.4 feet above sea level
Permit No. 6362; R. B. Tamblyn & McLeese—Leo Cornish No. 1
PLEISTOCENE:
Glacial Drift:

Gravel	335	335
Quicksand (water)	73	408
Sand (hole full of water)	72	480

MISSISSIPPIAN:
Coldwater:

10. NE¼ NE¼ NW¼ section 35. Elev. 901.0 feet above sea level
Permit No. 6171; Turner Petroleum Corp.—S. Stern & Co. No. 1
PLEISTOCENE:
Glacial Drift:

Sand and gravel	30	30
Sand	30	60
Mud	205	265
Sand and gravel	122	387
Gravel	3	390

MISSISSIPPIAN:
Coldwater:

SOUTH HAVEN TOWNSHIP (T 1 S, R 17 W)

1. SW¼ SW¼ NE¼ section 1. Elev. 618.9 feet above sea level
Permit No. 15185; Louis Zellman—John Brown No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Drift	354	354
Sand and mud	88	442
Gravel	4	446

MISSISSIPPIAN:
Coldwater:

2. SW¼ NW¼ NE¼ section 10. Elev. 621.0 feet above sea level (approx.)
Mineral Well; Janis Hotel
PLEISTOCENE:
Glacial Drift:

Sand, fine with large pebbles	20	20
Clay, gray, pebbly	20	40
Sand, yellow-gray, fine	10	50
Clay, light gray, fine grained	20	70
Clay, gray, pebbly	10	80
Gravel	20	100
Clay, gray, pebbly	20	120

MISSISSIPPIAN:
Coldwater:

3. Section 10. Elev. 635.0 feet above sea level (approx.)
Water Well; Max Stieve Tourist Cabins
PLEISTOCENE:
Glacial Drift:

Sand	8	8
Clay, yellow	7	15
Clay, blue	30	45
Sand, very fine with clay streaks (varves?)	7	52
Sand and clay	3	55
Sand, hard; clay and gravel, stony	25	80
Sand (upper 4′ fine to average, bottom 3′ coarser, gravel at bottom; water level stands at 60′ below surface)	7	87

Finished with 7′ of No. 60 screen; delivers 66 GPM

4. SW¼ NW¼ NE¼ section 22. Elev. 634.0 feet above sea level
Permit No. 15601; Ford Henry—H. W. Lang No. 1
PLEISTOCENE:
Glacial Drift:

Mud, pink mixed with gravel (no water)	145	145

MISSISSIPPIAN:
Coldwater:

Note: There may be more drift in this well than is indicated.

5. NW¼ SW¼ NE¼ section 23. Elev. 657.4 feet above sea level
Permit No. 14912; Wing Brothers—R. B. Monroe No. 1
PLEISTOCENE:
Glacial Drift:

	Thickness	Depth
Clay, mud and sand	37	37
Mud, sandy	23	60
Sand, muddy	20	80
Sand, muddy and gravel	21	101
Sand, muddy	14	115
Pea gravel (small amount of water)	8	123
Sand, muddy and pea gravel	21	144
Gravel, muddy	21	165
Mud, gravel, and sand	37	202

MISSISSIPPIAN:
Coldwater:

6. NW¼ NW¼ NE¼ section 24. Elev. 660.7 feet above sea level
Permit No. 14098; Rush & Rathburn—Richards No. 1
PLEISTOCENE:
Glacial Drift:

No record	70	70
Water sand	at	70
No record	80	150
Water sand	at	150
No record	345	495
Clay, blue	at	495
Gravel, coarse (to ½") (400' of water fast)	5	500

MISSISSIPPIAN:
Ellsworth:

7. SE¼ NW¼ NE¼ section 36. Elev. 675.5 feet above sea level
Permit No. 6060; Rowmor Corp.—W. A. Kuhn No. 1
PLEISTOCENE:
Glacial Drift:

Mud	104	104
Mud and gravel	68	172
Mud, gray	12	184
Lime shell (?)	12	196
Gravel	28	224
Mud	36	260
Sand and gravel	50	310
Gravel	17	327
Sand and gravel	14	341
Gravel	8	349
Sand and gravel	4	353
Shale (?), blue	11	364
Mud, dark	23	387
Sand, fine	15	402
Sand	18	420
Shale (?)	12	432

	Thickness	Depth
Gravel	5	437
Mud and sand	35	472
Mud, gray	43	515
Sand	65	580

MISSISSIPPIAN:
Ellsworth:

WAVERLY TOWNSHIP (T 2 S, R 14 W)

1. NW¼ NW¼ NE¼ section 3. Elev. 750.0 feet above sea level
Permit No. 6358; Hagan & Hagan—A. Voss No. 1
PLEISTOCENE:
Glacial Drift:

Shale (?), reddish, soft, sandy	110	110
Gravel	11	121
Gravel and mud	40	161
No record	21	182

MISSISSIPPIAN:
Coldwater:

2. NW¼ SW¼ SE¼ section 8. Elev. 771.3 feet above sea level
Permit No. 5634; Truss, Biggs & Rose—Guy Wilcox No. 1
PLEISTOCENE:
Glacial Drift:

Clay	12	12
Sand	5	17
Mud and sand	30	47
Gravel and sand	6	53
Mud	5	58
Gumbo	16	74
Gravel and clay	18	92
Sand and mud	8	100
Sand	11	111
Sand and clay	9	120
Sand, gray	67	187
Gumbo and mud	13	200
Sand, heavy	27	227
Sand	23	250
Sand and mud	7	257
Sand	3	260
Gumbo	5	265
Gravel	15	280

MISSISSIPPIAN:
Coldwater:

3. SW¼ SW¼ SE¼ section 12. Elev. 751.4 feet above sea level
Permit No. 15774; Collins Oil Co.—Ringel No. 1
PLEISTOCENE:
Glacial Drift:

Sand	43	43

	Thickness	Depth
Sand, muddy	7	50
Sand and gravel, heaving (water)	78	128
Pea gravel (dry)	27	155
Sand, muddy	13	168
Sand and gravel	27	195
MISSISSIPPIAN:		
Coldwater:		

4. NW¼ SW¼ NW¼ section 13. Elev. 732.0 feet above sea level
Permit No. 16194; Collins Oil Co.—Otto Rademacher No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand and gravel (water at 30-170′)	170	170
MISSISSIPPIAN:		
Coldwater:		

5. SW¼ SW¼ SW¼ section 19. Elev. 698.9 feet above sea level
Permit No. 15501; Fisher-McCall Oil & Gas, Inc.—M. S. Mills No. 1

PLEISTOCENE:		
Glacial Drift:		
Sand and mud	120	120
Pea gravel (flow of water)	40	160
Gravel and sand	300	480
MISSISSIPPIAN:		
Coldwater:		

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INDEX

PART II

A SURVEY OF GROUNDWATER RESOURCES
IN
OAKLAND COUNTY, MICHIGAN

ANDREW J. MOZOLA

A SURVEY OF GROUNDWATER RESOURCES IN OAKLAND COUNTY, MICHIGAN

by

ANDREW J. MOZOLA

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Geology in the Graduate School of Syracuse University, December, 1953.

CONTENTS

ILLUSTRATIONS

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A Survey of Groundwater Resources in Oakland County, Michigan

INTRODUCTION

PURPOSE AND SCOPE OF THE REPORT

This report summarizes the occurrence of groundwater in the consolidated sediments and in the unconsolidated glacial deposits of Oakland County, Michigan. It may be used as a guide for the future development of municipal, industrial, and private water supplies of the region.

Field investigations of the groundwater resources for this region were started in June 1949, and were continued through the spring of 1952. In the course of the field work, records were collected regarding the availability and the quality of the groundwater, the trend in groundwater levels, the occurrence of gas and salt water in the drift deposits, and information relating to the geologic and groundwater conditions of the county. The results contained in this report are based on the qualitative evaluation and analysis of these records.

ACKNOWLEDGMENTS

The writer is greatly indebted to the Michigan Geological Survey for providing the grant which made this investigation possible. Mr. Norman Billings, formerly hydrogeologist of the State Geological Survey, now hydrologist with the Michigan Water Resources Commission, was most helpful with suggestions as the occasions demanded, and in making available the initial well records and other facilities that were needed from time to time.

Special acknowledgments are due to Ivan Fosheim, Superintendent of the Water Department for the City of Pontiac; George Schmid, Water Supply Engineer, City of Royal Oak; and L. R. Gare, City Engineer, City of Birmingham, for providing a wealth of well records and related data of their respective municipalities. The writer is also indebted to many officials of industries, cities, and villages who furnished additional information about their wells and water supplies. The writer expresses his appreciation to the well drillers, especially Harvey Tracy, James Price, Elmer Russell,

Leon Berg, R. C. Hessler, C. W. Kinsey, The Dunbar Drilling Company, and the Layne-Northern Drilling Company, for furnishing logs and/or other related well data. Mr. Leary L. Oberlin contributed data on wells which reach or penetrate bedrock.

The majority of chemical analyses of groundwater samples included in this report were made available to the writer by the Michigan Department of Health. Additional analyses were collected during the course of the investigation directly from the various municipalities, industries, and private sources within the county. The writer is deeply grateful to Mr. Russell Grinnell, Superintendent of the Sewage Disposal Plant, City of Birmingham, for the continuing monthly chemical analyses of water samples taken from each of the municipal wells.

Acknowledgment is given to Dr. Earl T. Apfel, of Syracuse University, in appreciation of his guidance and critical review of this study, and to L. E. Dickinson, of Wayne University, and to Miss Helen M. Martin, Research Geologist of the Michigan Geological Survey, for editing the manuscript.

PREVIOUS WORK AND SOURCES OF INFORMATION

The surface geology of Oakland County has been adequately mapped and described by Leverett and Taylor (1915), and a more detailed contribution to the Pleistocene geology of the Cranbrook area, in the southeastern part of the county, has been made by G. M. Stanley (1936). A study of the glacial history of streams of the southern part of Oakland County is included in a bulletin by J. W. Bay (1938). The geology of a small part of the southernmost townships is reported in Folio 205 by W. H. Sherzer (1916).

The earliest discussion on the groundwater resources of the county was prepared by Frank Leverett and others (1906) as a U.S. Geological Survey Water Supply Paper. This report describes the public water-supply systems of cities, villages and other civil districts, delineates areas of known artesian flows and includes a summary of wells by municipalities and townships.

In 1930, the Department of Water Supply, City of Pontiac, Michigan, issued a report prepared by F. C. Taylor (1930) on the groundwater sources in the Pontiac area. This report included a hydrologic study of the Clinton River watershed and a detailed examination of the "Pontiac stratum" from which the city obtains its water supply. In addition, a summary of well logs and a map of Oakland

County showing the general water table and artesian head as of 1930 are included in the report.

In 1947, the Michigan Geological Survey in cooperation with the public schools of Oakland County conducted a well-water survey for the purpose of obtaining much needed data on groundwater conditions within the area. Forms were issued to the school children to be taken home and completed by their parents, or by owners of the individual wells. Of the returned forms, many were incomplete and/or inaccurate. However, some information was made available on flowing wells and on the presence of salt water in wells completed in drift deposits.

A report[1] prepared by an engineering firm (Pate and Hirn, 1949) for the city of Berkley, Michigan, contains information on water consumption and local groundwater levels. This study was made for the purpose of predicting future demands upon the groundwater supply. Additional municipal reports, which contained data on water losses, static water levels and quality of water, were made available to the writer by several communities.

METHODS OF INVESTIGATION

The results of this investigation are based on records collected in the period June 1949 through June 1952. The initial well logs and related data were obtained from the files of the State Geological Survey and from published sources, but much additional information was needed because of the size of Oakland County. In view of the fact that the major part of the population is centered in the southeastern part of the county, where temporary water shortages have been experienced by several of the communities and subdivisions, special effort was made to secure as many data as possible for the critical area. Throughout the course of the investigation, contacts were made and interviews were held with nearly all the well drillers operating in Oakland County. For several reasons the information desired from well drillers was not always readily available. Those drillers who maintained detailed records of each well were reluctant to open their files for study either for personal reasons or fear of having such information eventually made available to competitors. A number of the well drillers flatly refused to cooperate or were too preoccupied to unearth old records. Many drillers who offered to cooperate in this project kept no records or at best were able to furnish only partial data.

[1]Unpublished.

Municipalities and other civil divisions of local government were the best sources of information, particularly in southeastern Oakland County. Many data were collected in the way of well logs, monthly and annual reports of groundwater pumpage, water-level changes, and estimates on water losses as determined by a comparison of pumpage against metered water consumption. Most industries were very cooperative with this project, but only the larger and older establishments had well-information on file. The newer and smaller plants generally maintained no records and were satisfied in merely having a well or wells that furnished an adequate water supply. In the process of securing well records, many logs furnished by several of the drillers failed to indicate the approximate location of wells, and much time was spent in the field locating the wells in question so that they could be properly spotted on topographic maps of the area. In all nearly 1,138 complete or partial well records form the basis of this report. Their locations are shown on a map filed in the open file of the Geological Survey Division of the Department of Conservation. Since the initial logs for this study were obtained from the Michigan Geological Survey or from previously published sources, only the additional records acquired have been tabulated at the end of the report (Table 1). For purposes of easy reference and general location, all well records are designated by township and then numbered consecutively; the numbering generally begins with wells situated in section one and continues throughout. Each record shown in Table 1 has its location more precisely identified by township and range. Township names have been abbreviated whenever any reference is made to a specific log, and such abbreviations are appropriately indicated in Table 1.

Of the total wells drilled in Oakland County, a surprisingly small number reach or penetrate into the underlying bedrock. As a result, the configuration of the bedrock surface and the pre-glacial drainage system could not be mapped to the degree of finality that the writer had anticipated. Most of the wells that reach or penetrate bedrock are in the more critical area of Oakland County, and thus only a generalized bedrock-surface map for the southeastern part of the county can be shown in this report. A few rock depths were obtained by seismic methods when a seismograph was made available to the writer. The number of determinations was limited inasmuch as a six-trace seismograph required a number of setups

where bedrock was in excess of 150 feet. In addition to bedrock depths, data relating to the groundwater levels were collected wherever such information was available. All water-level measurements were calculated from the elevation of the ground surface at the well. The elevations thus obtained were used in the preparation of a map showing the general configuration of the water table and artesian head.

Information was also obtained during the course of this investigation on the quality of water. Analyses dating back to 1923 were obtained from the Michigan Department of Health and were used whenever possible for making a comparison of the quality of water with analyses of more recent samples. In addition, the writer was furnished with monthly analyses of water samples drawn from each of the seven municipal wells in the city of Birmingham. These analyses were plotted graphically to note the changes in the quality of the water resulting from excessive withdrawal or variations with the season of the year. More than 400 records of complete or partial chemical analyses were obtained from these various sources and form the main basis for the conclusions reached on the quality of water in Oakland County.

Throughout the course of this investigation attention was given to evidences relating to glacial deposits of pre-Wisconsin age and to the occurrence of salt water and gas in the drift. These facets of the investigation are discussed in the appropriate sections of this report.

Chapter I

GEOGRAPHY OF THE AREA

LOCATION AND SIZE

Oakland County is located in southeastern Michigan and includes within its limits an area of 877 square miles as measured from maps just prior to the 1940 Decennial Census (fig. 1). It is square in shape and comprised of five tiers of townships both north and south. The southern limit of the county is marked by the linear survey base line (Eight Mile Road) and its western limit is 42 miles or six tiers of townships east of the principal meridian of Michigan. It is bordered on the north by Genesee and Lapeer counties, on the west by Genesee and Livingston counties, on the east by Macomb County, and on the south by Washtenaw and Wayne counties. Wayne County includes within its civil boundaries the city of Detroit, the county seat, and the largest municipality of the state. The civil divisions within Oakland County include fourteen cities, ten villages and twenty-five townships. The principal cities lie along the Woodward Super-Highway (U.S. 10) which traverses the county in a southeast-northwest direction. Southeastward, the superhighway joins Woodward Avenue, the main thoroughfare of

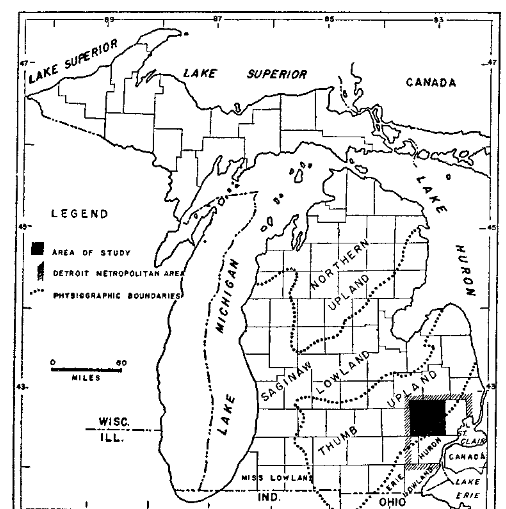


FIGURE I — INDEX MAP OF MICHIGAN

the city of Detroit. The largest city, Pontiac, is the county seat and occupies the approximate geographical center of the county, but 28 miles from Detroit. No part of Oakland County borders any part of the Great Lakes system and hence it is considered inland.

TOPOGRAPHY

According to Fenneman (1930), Oakland County is a part of the Eastern Lake Section of the Central Lowland province east of the Mississippi River. The topography of the county is typical of an area that has been glaciated in the past by the great ice advances of Pleistocene time. Features characterizing the landscape of the area are two hilly belts that cross the county in a northeast-southwest trend, an intervening but extensive and in many places pitted gravel plain and a gently sloping lake plain that lies to the southeast of the more southerly belt of hills. The more northerly of the two hilly belts cuts across the northwest corner of the county, passing through Rose Center, Davisburg and the village of Ortonville in the north. This hilly belt comprises some of the most elevated tracts in the county with elevations generally between 1,000 and 1,100 feet above sea level and many hills and knobs exceed 1,100 feet. The more conspicuous hills in this range are Bald Knob (1,198 feet), Pine Knob (1,221 feet) and Mt. Judah (1,180 feet). The southerly belt of hills, with elevations between 800 and 1,000 feet, is likewise strong and hilly and cuts nearly diagonally across the county, passing through the village of Novi, the city of Pontiac and just north of the village of Rochester at the northeast end. Both the northerly and southerly belts merge in an area northeast of the village of Rochester.

Lying between the two belts is a broad pitted flat plain composed of outwash sands and gravels. In places the gravel plain is up to ten miles in width, its flatness being interrupted by a broken group of hills having a general trend similar to the two belts previously mentioned. In a few places a hill or a group of hills rises conspicuously above the level floor of the plain. Scattered throughout the hilly belts and the outwash plains are hundreds of depressions, many of them occupied by inland lakes which range in size from small ponds less than an acre in area to lakes covering one and one-half square miles. Largest of these inland lakes are Cass Lake and Orchard Lake just southwest of Pontiac.

In the extreme southeastern part of the county is the glacial

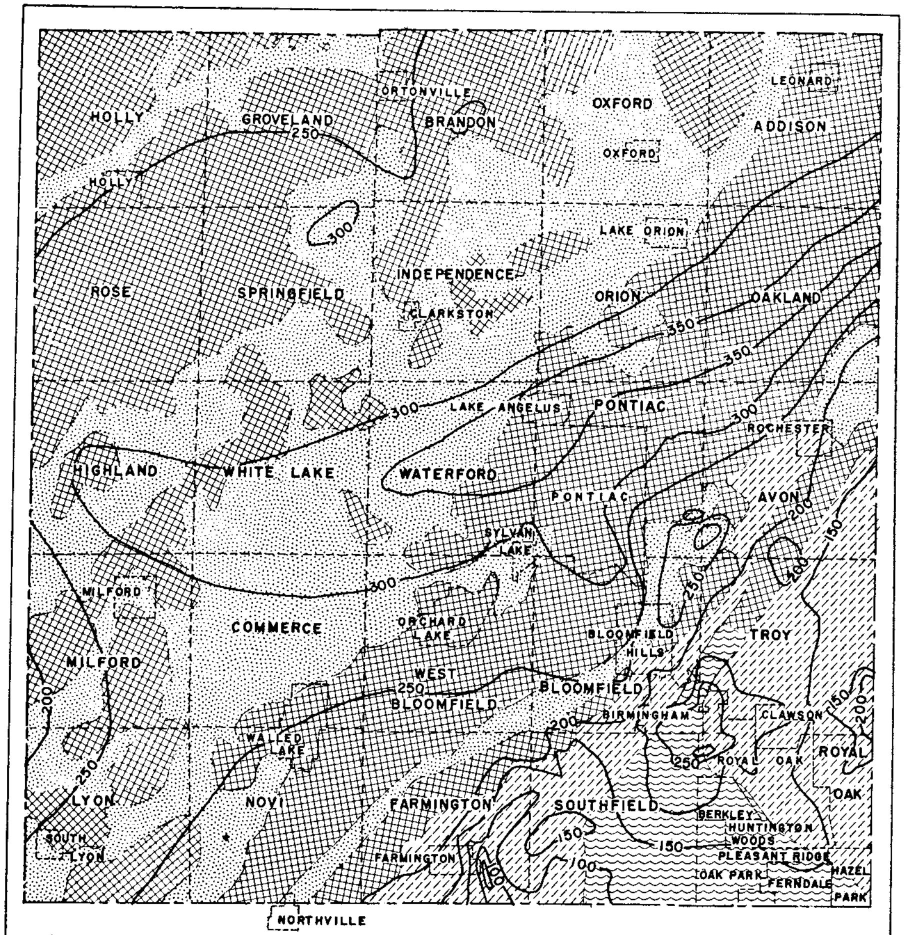
lake plain which slopes gently southeastward. The flatness of the lake plain is conspicuously interrupted by the stream courses and slightly by a series of former glacial lake beaches which often escape the notice of the casual observer. The elevation of this plain decreases from approximately 800 feet in the northwest to 630 feet near the southeast corner of the county.

Examination of the topographic maps of the county reveals a range in elevation from 630 feet to 1,221 feet, or a total relief of 591 feet. The average elevation of the county for the most part is 950 to 1,000 feet. Excepting a small area in the northwest part, which slopes to the north and northwest, the regional slope of the county is to the southeast. The topographic features of the region are reflected in the glacial geology map shown in Figure 2.

DRAINAGE

The drainage development in Oakland County is poor and hence youthful, as is usual in an area covered by glacial and glaciofluvial deposits. Many stream courses are poorly defined and connect a series or chain of lakes, and the only place where the streams incise (or cut their channels deeply below the general level) is to be observed in the lake plain area. Approximately 425 lakes covering nearly 100,000 acres are within the boundaries of the county. Many of these lakes do not form any part of the river systems but exist as isolated bodies of water with neither surface inlets nor outlets and thus can be considered as exposed parts of the groundwater surface. This fact is an important phenomenon in the study and evaluation of the groundwater hydrology.

The major topographic divide follows along the northern hilly belt and along a portion of the elevated outwash plains area which occupies a position along the "Thumb Upland," a predominant and elevated tract extending southwestwardly from the tip of the Thumb (Huron County) to the southern boundary of Michigan at the junction of the Ohio-Indiana State line (fig. 1). From this upland divide secondary divides can be traced between river basins that drain into Lake Michigan and Saginaw Bay from those that are contributory to lakes Huron, Erie and St. Clair. In Oakland County, five river systems have their origin in the hilly belts (moraines) and outwash plains. That part of the county northwest of the upland divide is drained by the Flint and Shiawassee river systems, both tributary to the Saginaw River system which emp-



SURFICIAL GEOLOGY AND DRIFT-THICKNESS MAP OF OAKLAND COUNTY, MICH.

OUTWASH DEPOSITS	LARGE WATER SUPPLIES POSSIBLE.
MORAINES AND TILL PLAINS	MODERATE SUPPLIES FOR MOST DOMESTIC AND COMMERCIAL PURPOSES, LARGE SUPPLIES FOR MUNICIPAL AND INDUSTRIAL USES POSSIBLE FROM INTERBEDDED SAND AND GRAVEL DEPOSITS
WATER-LAID MORAINES	SMALL TO MODERATE SUPPLIES.
LAKE-PLAIN CLAYS	SMALL SUPPLIES FROM INTERBEDDED SAND AND GRAVEL, SOME MODERATE TO LARGE SUPPLIES FOR MUNICIPAL USES POSSIBLE THROUGH EXPLORATION AND DEVELOPMENT.

CONTOUR INTERVAL 50 FT.

N

1 0 1 2 3 4 5 6
MILES

FIGURE 2

SURFICIAL GEOLOGY AFTER LEVERETT, RUSSELL, SHERZER, AND MARTIN

BASE SOURCE:- DETROIT METROPOLITAN REGIONAL PLANNING COMM.

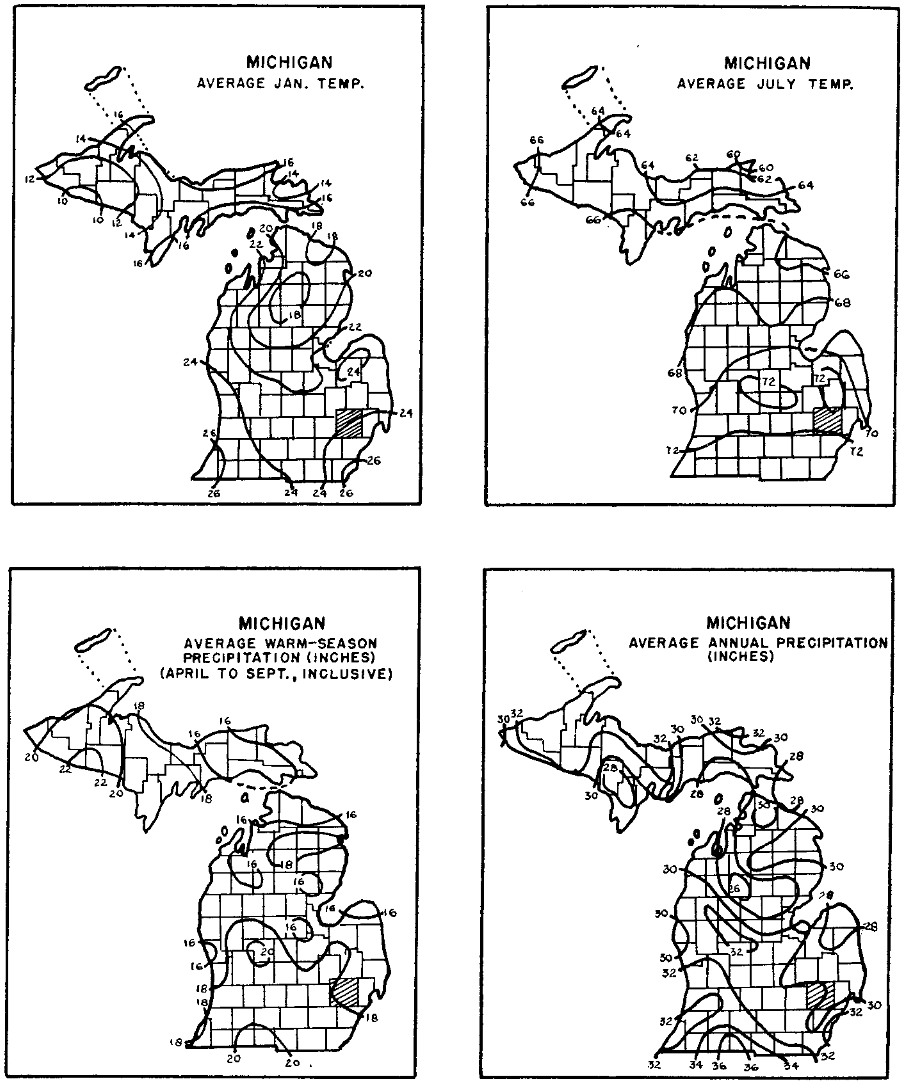
A.J.M.

ties into Saginaw Bay. Kearsley Creek and the south branch of the Flint River, in the north-central part of the county, flow northward to join the main branch of the Flint River. The northwest area of the county is drained by the headwaters of the main Shiawassee River and its tributaries, Thread and Swartz creeks. The area southeast of the upland divide is drained by the Clinton, Huron, and Rouge river systems. Both the Huron and Clinton rivers have their origin in the gravel plains and drain the overflow from many of the inland lakes. The Huron River flows southwestward out of the county and eventually swings south, then southeast into Lake Erie at a point several miles south of Grosse Isle. The Clinton River, originating on the eastern side of the Huron-Clinton divide, drains the eastern part of the county and discharges into Anchor Bay of Lake St. Clair. The River Rouge and its upper and middle branches, which have their origin in the southerly range of hills, flow over the glacial lake plain and into the Detroit River just south of Detroit.

Artificial drainage of lakes and marshes has been attempted with varying degrees of success in the hilly ranges and outwash plains. However, artificial drainage has been more successfully accomplished at greater cost in the glacial lake plain area where the rapidly growing communities, and the relatively less pervious nature of the mantle, made artificial drainage practice a necessity in the interest of sanitation and health.

CLIMATE

The position of Michigan in the heart of the Great Lakes Region has given the state the longest lake shore line in the Union. Because of this feature, Michigan is naturally under the climatic influence of these large bodies of water, and thus two distinct types of climate (fig. 3) are observed in the state (Yearbook of Agriculture, 1941). Interior counties of both peninsulas have a climate that alternates between continental and semi-marine depending upon the meteorological conditions. The marine type of climate is brought about by the influence of the lakes and by the direction and force of the prevailing winds. With little or no wind, the weather of the interior counties becomes continental in character—hot in summer and cold in winter. However, quick climate changes may be brought by strong winds blowing from the lakes. Counties which extend in part along the shore of Lake Michigan, Lake Superior and Lake



SOURCE: YEARBOOK OF AGRICULTURE, 1941—CLIMATE OF MICHIGAN

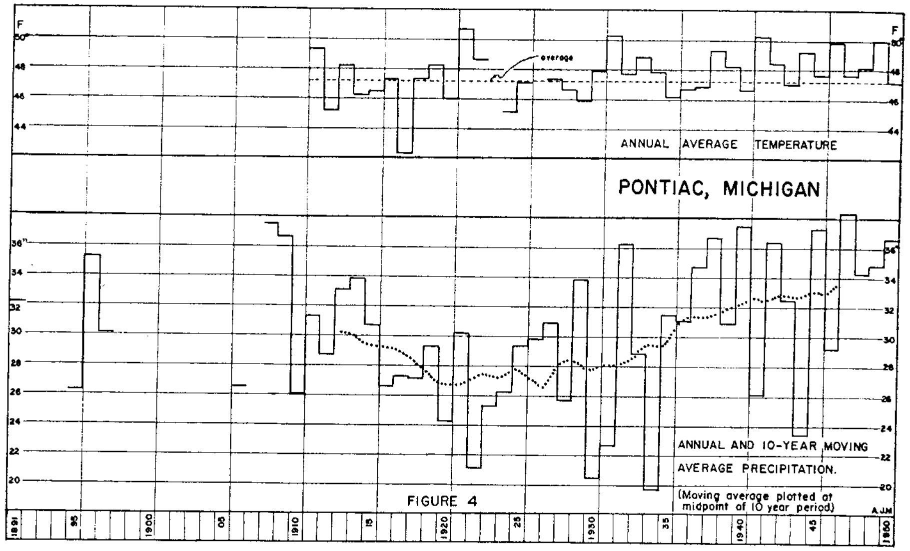
FIGURE 3

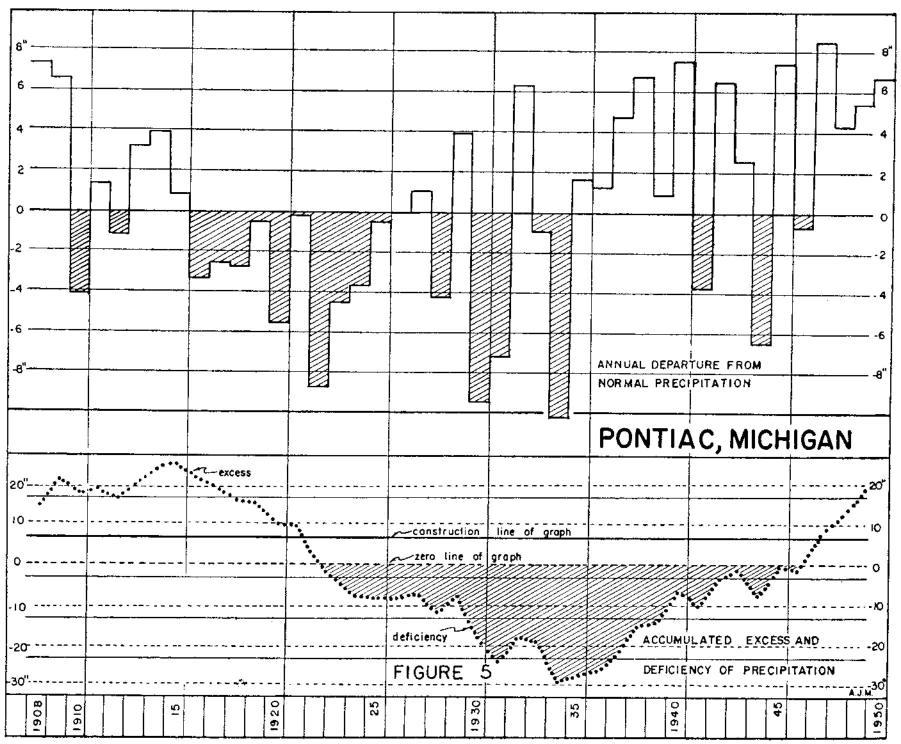
Huron have a modified marine climate for the larger part of the year since the lakes seldom freeze over entirely. Inasmuch as large bodies of water are more uniform in temperature and also less responsive to weather changes, the effect of the lakes is to hold over the winter cold longer in the spring and the summer heat longer in the fall in comparison to the areas surrounded by land.

Oakland County in eastern lower Michigan, according to the U. S. Weather Bureau, lies in the pathway of storms that move across the Great Lakes Region, and hence its climate is characterized by frequent and rapid changes in weather which such storms produce in their passage. Although the county nowhere touches any of the Great Lakes, the precipitation to a certain extent is modified by the nearness of the water bodies. Temperatures below zero occur in January and February but the winters are not generally severe. Hot and humid weather is frequent during the summer months of July and August. As may be noted from Table 2, the average annual temperature at Pontiac is 47.2°F. The average temperature in July is 71.4° F. and the average temperature for the month of January is 23.1° F. (fig. 3). Highest and lowest temperatures recorded at Pontiac are 104° F. and -22° F. respectively. As a general rule, no extremely hot or cold spells are experienced, and extremes in temperature are the exception rather than the rule. The annual mean temperatures for the past 40 years are shown plotted in Figure 4. It is to be noted that in the past two decades the annual mean temperature has generally exceeded the average annual temperature.

Monthly and annual precipitation records for Pontiac go back as far as 1888 but have not been continuous. However, in the period for which complete and detailed records are available, the records show that 25 years had precipitation above normal, two years had normal or nearly normal, and 23 years had below normal precipitation. From the charts shown in Figure 5 it appears that precipitation in the Pontiac region occurs in cycles—periods of excessive precipitation alternating with periods of deficiency. These cycles are not of uniform length or behavior and may at times be erratic to a considerable degree, as indicated on the chart for the period 1926-1934. This cyclic occurrence has its effects upon the groundwater level of the region.

The average annual precipitation for Pontiac is 29.94 inches computed in 1950 on the basis of the records available. The month of May has the highest average monthly precipitation (3.42 inches)





and January the lowest (1.81 inches). Seasonal precipitation does not vary since rainy or dry months can occur any time during the year, as shown on the monthly precipitation chart (fig. 27). Precipitation in the spring and fall months is usually caused by cyclonic disturbances and in the summer by local showers or thunderstorms. The number of days having 0.01 inch or more of precipitation averages 94 per year. Precipitation is recorded for 7 to 10 days each month. Snowfall averages 38.7 inches annually. The first snowfall is late in October or early November and the last snowfall usually in April and occasionally in May. The growing season averages 152 days. The average date of the last killing frost is May 10 and the first killing frost occurs around October 9. Excepting during the months of January and February, the prevailing winds are from the southwest and hence are land breezes. (Table 2).

POPULATION AND GROWTH

The settlement of the area which is now Oakland County was delayed from 10 to 20 years by a false report that the region was an impenetrable morass. The report was submitted shortly after the Revolutionary War (Official Directory, 1949-50) by surveyors who had been bogged down in swamps in the vicinity of the present Oakland-Wayne County line. This report diverted settlement from Michigan toward Ohio, Indiana, and Illinois, until a new survey, ordered by Territorial Governor Cass, rectified the error and the area was declared fit for human habitation. After the first permanent settlement at Rochester in 1817, and at Pontiac in the following year, the region has steadily continued to grow. The opening of the Erie Canal, from the Hudson River to Lake Erie in 1828 provided the greatest impetus to the early growth of Oakland County. The canal offered an all-water route from the Atlantic seaboard to within eight miles of the county's south border. The manufacture of vehicles, wagons, buggies and sleighs during the early decades, and automotive products in more recent decades, at Pontiac and elsewhere in the county, has been the stimulus for continued growth of the region up to the present.

The population of Oakland County (Table 3) as determined by the Federal Census of 1950 was 393,467 inhabitants (425.9 per sq. mi.), a gain of nearly 55 per cent over 1940 (289.7 per sq. mi.). Of this number, 241,719 (61.4%) were classified as urban and

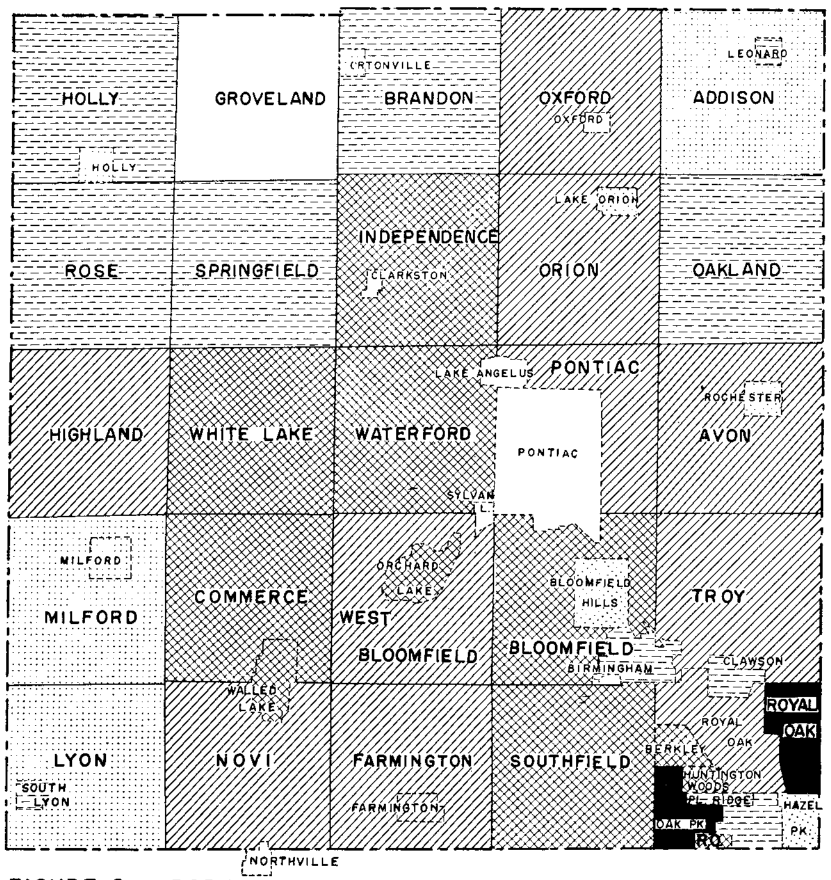
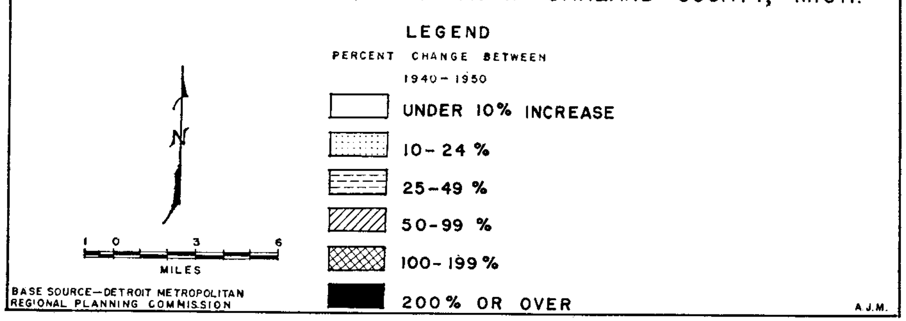


FIGURE 6 — POPULATION GROWTH IN OAKLAND COUNTY, MICH.



151,748 (38.6%) as rural. The breakdown of the rural group into rural farm and rural non-farm classification has not yet been made available by the census bureau. However, the rural population in 1940 was 43 per cent of the total, of which 36 per cent was classified as rural non-farm and only 7 per cent as rural farm. An interesting note is the shift of population from urban to rural areas. In 1930 the urban population of Oakland County was reported as 75 per cent of the total (Taylor, 1930). The percentage declined to 43 per cent by 1940. In the following decade, the urban population increased to 61 per cent, though it still remains below the 1930 figure.

Eighty-four per cent of the total population resides within the area of the nine townships of southeastern Oakland County and principally in the cities located along the superhighway (U.S. 10) which traverses the county diagonally. The populations of the several principal cities of this section are: Pontiac, 73,112; Royal Oak, 46,817; Ferndale, 29,670; Berkley 17,913; Hazel Park, 17,791; Birmingham, 15,370; Oak Park 5,243; Clawson, 5,176. Of these cities Oak Park, Berkley, and Royal Oak have shown the greatest gain and Pontiac the least gain in the number of inhabitants for the past decade. It is in the southeastern area of the county that reports of a water shortage have appeared in the public press. Of the twenty-five townships, two had population gains exceeding 150 per cent, five from 100 to 149 per cent, nine from 50 to 99 per cent, five from 25 to 49 per cent, and four townships had reported gains of less than 25 per cent. Largest gains were reported for Royal Oak and Commerce townships, and the least gain was reported for Groveland Township. As indicated on the population growth map (fig. 6), the townships along the principal highway routes figured most prominently in the gains. Since the end of the last war much land bordering the inland lake areas has been purchased by builders for the development of new subdivisions consisting of year-round homes and non-farm estates. The Detroit Area Regional Planning Commission[1] has estimated that Oakland County will have a population numbering 536,000 to 612,000 by the year 1960, and from 709,300 to 846,700 people by 1970. Greatest growth is expected to be in Commerce, Farmington, Lyon, and Novi townships. It appears to the writer that these townships are favored for growth because of their proximity to Detroit, their nearness to a

[1]Detroit News, December 31, 1950.

principal thoroughfare (U.S. 16) and the availability of land for future building developments. With this postulated increase in population and the expansion of industry which is also predicted, problems involving water supplies will undoubtedly be of much concern to the communities of these areas.

ECONOMIC DEVELOPMENT

Wayne, Oakland, Macomb counties and the easternmost townships of Washtenaw County are included within the limits of the Detroit Metropolitan Area[1] of southeastern Michigan (fig. 1). As a part of this metropolitan area, Oakland County is second only to Wayne County in population and in equalized tax valuation. The 1950 equalized valuation[2] is $966,300,000 and, as confirmed by the State Tax Commission, now exceeds the valuation of Kent County, previously acclaimed the second richest county in Michigan. Wayne and Macomb counties' equalized valuations are approximately $6,067,200,000 and $327,350,000 respectively. The rise in equalized valuations, particularly in the past several years, has been mainly the result of new construction. Oakland County is a part of the wealthiest, most populated and most industrialized part of the state, and it is predicted that the equalized valuation should exceed one billion dollars within a relatively short period of time.

Data relating to the total labor force and its breakdown into special categories are not yet available for 1950. However, the total labor force in Oakland County as indicated by the census of 1940 was 86,482, of which 46 per cent was engaged in manufacturing; 16 per cent in business and personal services; 15 per cent in retail and wholesale trade establishments; 10 per cent in transportation, communications, utilities, construction, and mining; 4.6 per cent in agriculture; and 8 per cent in unclassified occupations.

Manufacturing Industries

Heavy industry principally centered in the Pontiac region, consists mainly of plants manufacturing automobiles, coaches, automotive parts, rubber and steel products. The larger manufacturing

[1]A "metropolitan area" is based on a concept that includes entire counties. However, a county is included in a metropolitan area only when 50 per cent or more of its inhabitants fall within the limits of a metropolitan district, as defined in 1940 for the Census of Population. A "metropolitan district" consists of a central city or cities having a population of 50,000 or more and certain adjacent minor civil divisions or incorporated places. Ordinarily, the adjacent places include those having a population of 150 or more per square mile. Thus, a "metropolitan county" is applied to any county that is included within a metropolitan area. Source: County Data Book, U. S. Department of Commerce, Bureau of the Census.

[2]Office of the State Board of Equalization, State of Michigan, Lansing, Michigan, June 2, 1952

firms established in the area are the General Motors Corporation, Wilson Steel Foundry, and the Baldwin Rubber Company. Elsewhere in the county, and particularly in the southeastern part, the industrial plants are classified as light manufacturing, such as machinery, machine tools, fabricated metals and gears, and stone, clay, wood, chemical, and allied products. The types of industrial establishments are shown in Table 4 of this report. During the war years 1940 through 1945, the major war supply contracts reached nearly 2.5 billion dollars.

The industrial growth of the county for the past decade is indicated by the increase in the number of manufacturing establishments from 183 to 873. Further growth is expected because of the trend toward decentralization of industry away from the highly populated localities of the metropolitan area. The principal factor in movement of industry beyond the perimeters of the densely populated areas is the availability of low cost land. Although initially the factor of lower tax rates may be appealing, it is not the major stimulus toward decentralization, since tax rates increase with time and eventually become comparable to taxes of the more populated areas. Decentralization also leads to a dispersal of industries over a wider area, a desirable condition from the military point of view.

In 1940 the total number of manufacturing plants in Oakland County was 183 of which 79 were classified as heavy and 104 as light. By 1950 the heavy industry plants increased to 263 and the light industry to 610 plants. In the same period total employment for industries of all classifications more than doubled—increasing from 22,145 to 50,874 wage earners. The primary industrial areas of Oakland County today are located in the Pontiac region and in the southeastern part of the county. In the Pontiac industrial development area, the total number of plants increased from 68 to 166 with an employment gain of 14,775 wage earners; the present employment figure is 33,823. Both heavy and light industries more than doubled during the decade, heavy industry having a slightly greater gain. The industrial growth in this older manufacturing area was based on the already established motor vehicle industry. Transportation equipment, rubber, lumber and wood products, primary metals and chemicals are manufactured in this area. The southeastern industrial development area increased its employment from 1,947 to 12,886 wage earners, and its manufacturing plants by nearly ten times. Heavy industry increased from 23 to 132 plants and light industry from 35 to 396 plants. Industrial growth in this area was characterized by the development of fairly small plants of a diversified nature, many of which are suppliers for heavy manufacturing. Manufactured products are mainly instruments, machinery, fabricated metals and paper items.

Water-using industries, principally chemical, steel processing, machine tool and food products, increased from 107 to 465 in the same period. The increase in use of groundwater supplies is of paramount importance in both the Pontiac region and in southeastern Oakland County for continued industrial expansion. According to the Regional Planning Commission (Reid, 1950), manufacturing employment is estimated to reach 89,750 wage earners by 1970. It is predicted that employment in the Pontiac area will nearly double and more than double in the southeastern Oakland County area. The 1970 projections for employment gains are based on past growth trends and on the general pattern of industrial development in the region. Since the present industrial production pattern has already been established by such factors as market, proximity of raw and semi-finished materials, it is not expected that in the next 20 years any significant development will take place in the form of plants of a new industrial classification. However, the St. Lawrence Seaway may introduce new industrial classifications and thus change the manufacturing pattern of southeastern Michigan. The seaway will provide cheap transportation and access to foreign markets and raw materials.

Mineral Resources

The extractive industries have not been included in Table 4, and some mention should be made of the county's natural sand and gravel resources which have importance as building materials. The principal source of these materials is the outwash plains of the county. The largest commercial pits are located near Oxford where the most prolific sand and gravel deposits within the state are found. Small pits are numerous and scattered throughout the county. In 1939, the extractive industries employed 200 wage earners and the products were valued at $648,000. On the basis of 1951-52 large-scale operations of the large commercial pits, the value and tonnage of the products today must certainly exceed the 1939 figures by several times.

Trade

In 1948 three and one-half times as many persons were employed in manufacturing as in retail trade in Oakland County. This relationship is usually typical of highly industrialized areas. Net sales in 1948 exceeded 313 million dollars in comparison to the 1939 sales of 83 million dollars. In the same period employment in retail trades nearly doubled and the number of establishments increased from 2,832 to 8,419.

Agriculture

Early farming in Oakland County was devoted principally to wheat as a cash or barter crop and to corn and potatoes as staples. With the gradual increase of industrial activity, the type of farming changed from production of essential crops to specialized production to meet the demands of urban markets in Pontiac and Detroit. It also resulted in an increase in livestock population and the production of dairy products. Today the primary farm income is from livestock farming, especially production of dairy products. Income from fruit cultivation is secondary.

Approximately 60 per cent of the county is devoted to agriculture. In 1945, the county had 4,054 farms, averaging 88 acres per farm. Of these farms 2,606 were classified as commercial and 1,448 as non-commercial. According to the 1950 census, approximately 3,200 farms are now considered as commercial. The following table shows the number and size of farms in 1940 (Alchin, 1940):

TABLE 5

Size of Farm	Number of Farms
3- 20 acres	1,255
20- 70 acres	821
100-180 acres	869
180-260 acres	276
260-500 acres	151
500-700 acres	20
700- acres	17

Since 1940, the trend in agriculture has been toward less tenant farming and to an increase in the number of small farms between 3 and 20 acres. The purchase of smaller plots (usually less than 20 acres) has been commonplace in order to provide elbow room or land to supplement family income by gardening. The increase in small farms has taken place in Royal Oak, Southfield and Waterford townships which are rather heavily populated since these areas have taken the overflow from Pontiac, Royal Oak and Detroit. It may be well to note that this trend toward smaller farms, small residential plots and estates has placed an added demand upon the groundwater resources of the county. Watering of vegetable and flower gardens of such small-acre plots has not been an uncommon observation made by the writer in the course of the field investigation. The larger farms today are mostly in the northern townships where population increases have not been as great in the past decade.

Soils of the county are varied and the types widely scattered because of drainage characteristics and development on morainic, glacial outwash and lacustrine deposits. Muck acreage is small, and the soils developed thereon are devoted to canary grass, barley and truck crops. Loams and silt loams constitute 45 per cent of the total soil acreage and where well drained they are especially adapted to apple trees, small grain and hay. Where drainage is needed beets, beans, corn, alfalfa and small grain are grown. Fruit, such as peaches, apples and pears, is most suitably grown on sandy loams, which make up twenty per cent of the soils of the county. Loamy sands and sands make up twenty-five per cent of the soil cover, and special crops, as melons, cucumbers and potatoes, are grown on them. The value of farm products in 1945 was more than 4.5 million dollars, of which 56 per cent was derived from livestock and livestock products and 30 per cent from crops. Nearly 44 per cent of the total number of farms produced farm goods valued at less than $400. Intensive fruit areas are in Novi, Farmington, Bloomfield, West Bloomfield and Lyon townships. Production of small fruit is not popular on a large commercial scale because of the high labor requirements and hence such fruits are grown on the small farms for home use or sale on highway fruit and vegetable stands. Troy and Avon townships have the greatest concentration of vegetable growers, and milk production is carried on mainly in Novi, Brandon, Springfield, and Groveland townships. Livestock in the county consists of approximately 18,000 dairy cattle, 1,200 beef cattle, and 10,000 sheep.[1] Poultry farming is restricted primarily to chickens and turkeys—the major production divided among ten townships.

[1]Personal communication, County Agricultural Agent.

Recreation

The 425 inland lakes within the county have led to the development of some of the finest estates, palatial residences, public resorts and state parks. The public resorts and state parks are considered summer playgrounds and hence income is derived from nearby motels, tourist cabins, lake cottages and retail stores. This picture is changing somewhat since much of the land is now being purchased for the construction of permanent year-round residences.

Transportation and Public Utilities

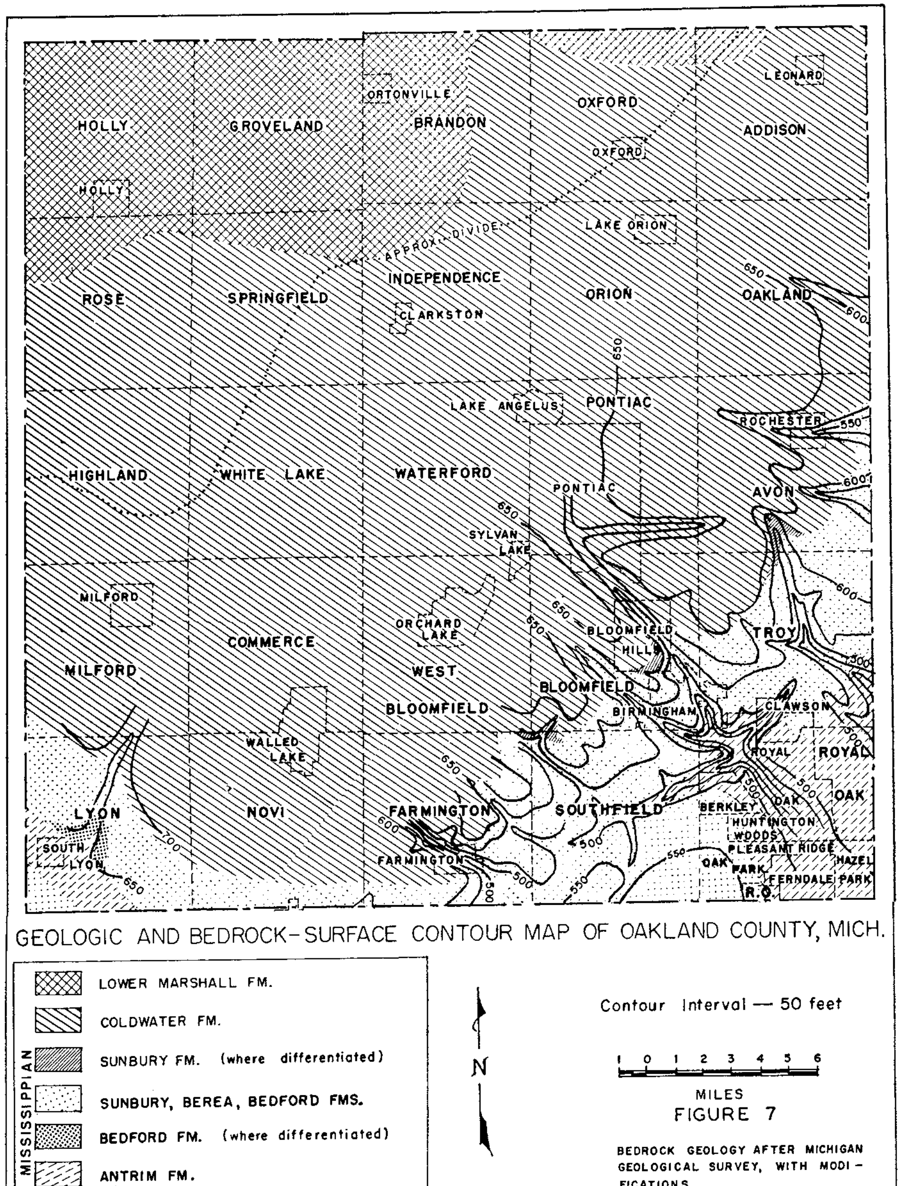
Oakland County is served by three railroads—the Grand Trunk Western, Pere Marquette, and New York Central. In addition to the railroads, the industries and populace of the area are also served by several inter-and intra-state truck freight forwarding companies and passenger busses. Air transport on a limited scale is available at the Municipal Airport located several miles northwest of the city of Pontiac near Williams Lake. Major air service, however, is provided from the air terminals at Willow Run and Detroit.

The principal Federal highways are U.S. 10 and U.S. 16. U.S. 10 traverses the county diagonally from southeast to northwest passing through the cities of Royal Oak, Birmingham, and Pontiac. U.S. 16 located in the southern part of the county trends west-northwest and east-southeast, passing through the city of Farmington and the villages of Novi, West Novi, and New Hudson. The county has 188 miles of state trunk line highways of the rigid concrete, bituminous or flexible bituminous type, 635 miles of primary roads (concrete, bituminous, gravel) and 1,697 miles of secondary roads (bituminous, gravel, earth). The total road mileage of all types is approximately 2,520 miles.

Electric power is furnished by the Detroit Edison Company for the entire county with the exception of Holly Township, for which service is supplied by the Consumers Power Company. Gas transmission lines are operated by the Consumers Power Company, which serves the principal towns of the county. Telephone service is provided by the Michigan Bell Telephone system.

Summation

The decade 1940-1950 has been a period of active residential and industrial construction, particularly in the southeastern part of the area under study. The county population of 393,467 has shown



GEOLOGIC AND BEDROCK-SURFACE CONTOUR MAP OF OAKLAND COUNTY, MICH.

FIGURE 7

BEDROCK GEOLOGY AFTER MICHIGAN GEOLOGICAL SURVEY, WITH MODIFICATIONS.

a gain of nearly 55 per cent since 1940 and is predicted to reach between 709,000 and 846,000 inhabitants by 1970. Industrial establishments have increased in number from 183 to 873 plants in the same decade; 465 of these plants have been classified as water-using industries.

The growth in population and the attendant construction of new residential dwellings together with the increase in number of industrial and commercial establishments have placed an added demand upon the groundwater supply. On the basis of a conservative estimate, a minimum of 30 million gallons is pumped daily, chiefly by communities and industries situated in the southeastern part of Oakland County. The continued growth of this county appears assured, and a knowledge of the geology and hydrology becomes an important factor in the future development of the region.

Chapter II

GEOLOGY OF THE AREA

The indurated sediments beneath the unconsolidated mantle of Oakland County are all of Paleozoic age. The surficial deposits are of Quaternary age, consisting of tills, outwash sands and gravels and lacustrine deposits of Pleistocene time and some recent alluvial deposits along the major streams. Knowledge of the indurated strata of the region is restricted in scope owing to the total absence of rock exposures and the limited number of deep borings in the county. The few but widely scattered deep wells that penetrate the bedrock formations are for the most part exploratory tests or wildcat wells in the search for petroleum or natural gas. Although the water wells greatly exceed the number of deep borings, the majority of them end in the surficial deposits of glacial origin and only a few reach or penetrate the rock for any appreciable depth. Many records lack adequate descriptions of the rock penetrated. Hence, the following discussion pertaining to the stratigraphy, structure and nature of the rock surface is based on limited data obtained from wells within the county and from available rock quarries found in areas adjacent to the region under consideration. Most of the formations exposed in neighboring areas have been more thoroughly studied. In order to avoid placing emphasis only on the lithologic characteristics of the rock strata as they occur in Oakland County, the following text includes only those parts of such studies that seemed most applicable.

The geologic map of Oakland County included herein (fig. 7) is adapted from the Centennial Geological Map of the Michigan Geological Survey with the contacts between formations or groups modified on the basis of additional data made available since 1936. Only 168 records indicate that consolidated sediments beneath the drift have been reached or penetrated. Fifteen records were detailed logs related to deep oil and gas borings, and the remaining records were logs of water wells and test holes, many of which did not describe adequately the nature of the rocks penetrated. The inferred outcrop areas of the Bedford and Sunbury formations were extended or added only wherever the data permitted a reasonable inference. Immediately beneath the surficial deposits, the county is underlain primarily by shales, sandy shales and sandstones of lower Mississippian age. Below these formations as indicated by deep borings are older Paleozoic sediments of Devonian and Silurian age consisting of limestones, dolomites, shales, sandstones, and beds of rock salt. These older strata in turn may be underlain by still older Paleozoics which finally rest upon the crystalline rocks of the pre-Cambrian floor.

STRATIGRAPHY

Silurian

SALINA GROUP (CAYUGAN SERIES)

Deepest of the consolidated sediments penetrated by exploratory oil or gas wells in the Oakland County area are those of the Salina formation. In general, the Salina consists of beds of rock salt of varying thicknesses and separated by dense to finely crystalline gray or brown dolomite much of which is gypsiferous, micaceous or shaly, and by some shaly sediments or beds of hard, gray to blue limestones. Since the underlying beds of the Niagaran series were not reached, on the basis of records available the total thickness of the Salina in Oakland County remains undetermined. Its base may not be too difficult to determine since the immediately underlying beds of the Lockport (Niagaran series) are hard, generally fine-grained, light-colored dolomites devoid of anhydrite, salt beds or appreciable thicknesses of shales. It is reported that the beds are easily recognized by drillers elsewhere because the "cuttings and wash on bailing have the color, thickness and viscosity of buttermilk." The upper limit of the Salina is more difficult to establish because of its lithologic similarity with the basal beds of the overlying Bass Island group, but the contact appears to be arbitrarily placed above the uppermost well defined layer of salt or anhydrite.

The formation is economically important for brines and has been penetrated by many wells mainly along the Detroit River. From the available records, the Salina beds thicken northward. At Wyandotte, Michigan, the Salina between the limits defined is 780 feet and the aggregate thickness of the salt beds is 160 feet (Sherzer, 1916, p. 44). At the salt shaft in southwestern Detroit, the Salina is 929 feet with 600 feet of rock salt. Northward, in section 21, Royal Oak Township, the formation was reached at a depth of 1,543 feet (RO-68)[1] and penetrated for 950 feet of which 609 feet were rock salt. Approximately 23 miles to the west in

[1]Royal Oak Well No. 68.

section 21, Lyon Township, the Salina beds are at a depth of 2,025 feet below the ground surface. At this location the well (LY-5)[2] penetrated 1,585 feet of the indurated sediments of which 690 feet were salt. Individual beds of salt varied in thickness from 5 to 205 feet. In the Lyon Township well salt water was reported between the depths of 3,250 and 3,270 feet.

BASS ISLAND GROUP (CAYUGAN SERIES)

The Salina beds are succeeded by the Bass Island group which has an approximate thickness of 435 feet. The Bass Island is reached at depths of about 1,600 feet in the southern part of the county (Lyon and Royal Oak townships) and at 2,667 feet in the northern part (Brandon Township). Well records in Oakland County reveal the Bass Island to be dominantly composed of dense to finely crystalline dolomite, light gray, buff to brown in color with some chert and traces of anhydrite. Sandy, shaly or gypsiferous zones appear in the sequence. The basal contact of the Bass Island formation is difficult to recognize on the basis of well cuttings because of lithologic similarity with the underlying Salina and the rarity of fossils. However the contact with the overlying Sylvania sandstone is easily distinguished on the basis of lithology.

As shown on the geologic map of Michigan, the Bass Island group consists, in ascending order, of the Greenfield dolomite, Tymochtee shale, Put-in-Bay dolomite and the Raisin River dolomite. Exposures of the upper two formations are in quarries in Monroe County, south of Detroit. The dolomite formations are generally light to drab gray or brownish in color, thin bedded with some zones bearing ripple marks and mud cracks. Locally they may be cherty or siliceous or have some thin shales. Pyrite scattered throughout the beds, upon weathering produces brownish stains or spots. Crystal masses of calcite, celestite and fluorite are found in many cavities and seams. Some thin shales and oolitic beds may be observed. The lower two formations of the group have been noted in wells only. According to Sherzer (1916, p. 47), fossils are most abundant in the upper formations and are relatively lacking in the lower beds. The most characteristic fossil is a small brachiopod *Whitfieldella prosseri*. Stromatopora reefs are known to be in the Greenfield formation. It is possible that such fossils if recognized in cuttings may be significant in the recognition of the zones. Ehlers and others (1951, p. 10) classify the Greenfield and

[2]Lyons Well No. 5.

Tymochtee in the Salina group in contrast to the classification proposed by Lane and others in 1909.

Only two logs of deep borings in Oakland County indicate penetration of the total thickness of the Bass Island. The deep boring in Lyon Township (LY-5) reveals that the beds are dominantly dolomitic with no appreciable shale that might be equivalent to the Tymochtee shale, which the geologic map of the state records as 90 feet in thickness. The deep boring in Royal Oak Township (RO-68) shows 68 feet of "rotten lime or shale" at the bottom of the Bass Island. Whether this in part represents some of the basal shales in the Greenfield member of the group is not ascertained since the contact between the Salina and Bass Island is difficult to place on lithology alone. In logs from other areas both fresh and mineralized waters have been recorded.

Middle Devonian

DETROIT RIVER GROUP (ULSTERIAN SERIES)

On the basis of a classification proposed by Ehlers and others (1951, p. 10) the Detroit River group is of Middle Devonian age and consists, in ascending order, of the Sylvania sandstone, Amherstburg dolomite, Lucas dolomite and the Anderdon limestone formations.

The Sylvania sandstone formation rests disconformably on the Raisin River dolomite except where it may be underlain by Bois Blanc beds. Its contact with the Raisin River formation is well exposed in the Holland quarry, approximately 7.5 miles south of Silica, Ohio. At this locality the basal beds of the Sylvania contain pebbles of the Raisin River dolomite, and some fractures in the dolomite were noted to be filled with sandstone. The contact of the Sylvania with the Amherstburg is not clearly defined as many of the lower beds of the Amherstburg are dolomitic sandstones. The Sylvania is a white or light gray, fine to medium sandstone in which the individual grains are frosted, subangular to round in shape and poorly cemented. The sandstone is extremely friable upon exposure to weathering and when washed is compared to granulated sugar. Beds of light gray to brown dolomite, some of which are crystalline and contain some gray chert, may interrupt the sandstone. An exposure of the Sylvania in a quarry at Rockwood, Wayne County, Michigan, displays poorly defined and irregular bedding. Individual beds range in thickness from several inches to a few feet. The beds are nearly level or slightly tilted and in places show a lamination that is inclined to the bedding planes. This lamination and the frosted appearance of the sand grains suggest wind-transported sediments which at a later time were reworked by a transgressive Devonian sea. Cavities and seams lined with calcite and celestite are quite numerous and some rare native sulphur may be found. The formation is quite barren of fossils but the existence of former plants and/or animals is indicated by carbonaceous partings. Some suggestion of plant remains can be found in the higher beds exposed at the quarry. Ehlers and others (1951, p. 10) report a meager fauna consisting of crinoid columnals, *Favosites* sp., dendroid graptolite fragments and other indeterminable fossils. These forms were reported from the upper 33 feet of the sandstone exposed in the quarry. Beneath the floor of the quarry, the formation, formerly exposed along the walls of the crusher pit, consists of 12 feet of similar sandstone underlain by 15 feet of highly arenaceous dolomite which in turn is underlain by 30-35 feet of sandstone. The known total thickness of the formation at this quarry is 90-95 feet. In the arenaceous dolomite Ehlers and others (1951, p. 7) report bands of chert nodules and a fauna consisting of gastropod and pelecypod fragments, *Mesoconularia* sp., *Tentaculites* sp., and worn pieces of arthrodiran bone. Water seeps at the quarry have a strong odor of hydrogen sulfide. The thickness of the Sylvania in Oakland County indicated by the well records ranges from 250-325 feet in the southern part to 147 feet in the north. The latter figure may be incorrect since unstudied lithologic changes may disguise the true thickness of the formation. The occurrence of salt water in the formation was reported at a depth of 836 feet during drilling operations in Royal Oak Township.

The remaining three formations of the Detroit River group that succeed the Sylvania are difficult to differentiate in well records on the basis of lithology alone. The combined thickness increases from 325-350 feet in the southern part to 430 feet in the northern part of the county. The Amherstburg and Lucas beds are dominantly dense to finely crystalline dolomites, buff or light brown to brown in color, interspersed with some dark gray to black micaceous shale and with some limestone. Dolomite beds containing some anhydrite and gypsum (selenite or earthy gypsum) are found throughout the section. The lower beds contain an increased amount of angular to subangular quartz grains. The lower limit of the Amherstburg is easily recognized on the basis of lithology, but the upper limit of the Anderdon limestone (member of the Detroit River group) is more difficult since the beds of the overlying Dundee are also limestones. Differentiation of the individual beds in well cuttings no doubt can be made possible by thorough studies of insoluble residues, microfauna or spectrochemical analyses of trace elements. The spectrochemical method should be useful in distinguishing disconformities, since oxidizing conditions accompanying weathering should result in the concentration of such elements as iron, manganese and aluminum.

The formations of the Detroit River group are exposed in quarries in southeastern Michigan and northwestern Ohio. Though difficult to distinguish from the older Bass Island on the basis of lithology, the dolomites of the Detroit River group contain fewer oolitic limestone beds, but the presence of celestite, calcite, and sulphur is more noticeable. The deep oil and gas well borings in the Oakland County area show the occurrence of porous zones in the sequence which, when penetrated, yielded water some of which was black in color. At Sibley quarry near Wyandotte, Michigan, beds of the Detroit River are exposed along the quarry floor. Near the approximate center of the quarry are several artesian springs which have a combined flow of approximately 600 gallons per minute. The water has a strong sulphur odor and taste.

The formations comprising the Detroit River group are best recognized by the fossil assemblages contained in each rather than by lithologic characteristics alone. Many of the fossils are small forms occurring as external and internal molds, and hence coarse cuttings from wells, if carefully examined, may yield enough fossils to permit recognition of the horizons. The following fossil list is taken directly from the work of Ehlers and others (1951, p. 23).

a. Amherstburg fm. in Livingston Channel, Amherstburg, Ontario. Molds of *Zaphrentis carinata* (Sherzer and Grabau), *Heterophrentis alternata* Sherzer and Grabau, *Prosserella modestoides* Sherzer and Grabau, *Schuchertella amherstburgense* Grabau, *Stropheodonta homalostriata* Sherzer and Grabau, *S. vasculosa* Sherzer and Grabau, *Spirifer submersus* Sherzer and Grabau.

b. Lucas fm. in southeastern Michigan and northwestern Ohio. Excellent guide fossils for correlation of Lucas strata in the two regions are *Prosserella lucasi* Sherzer and Grabau, *P. planisinosa* Sherzer and Grabau, *Acanthonema holopiforme* Sherzer and Grabau, *Murchisonia subcarinata* (Grabau).

c. Anderdon fm. near Amherstburg, Ontario; Sibley, Michigan, and Silica, Ohio, recognized by occurrence of *Conocardium sibleyense* La Rocque, and several small pieces of gastropods that remain undescribed.

Cazenovia Group (Ulsterian Series)

The Cazenovia group consists of the Rogers City and Dundee formations in the northern part of the Southern Peninsula of Michigan. If the Rogers City extends to southeastern Michigan the two formations have not been differentiated as well records refer only to the Dundee. The Dundee formation consists largely of gray, buff to light brown limestone beds that are finely to coarsely crystalline in texture and contain varying amounts of chert and a little gray to black shale. The upper limit is marked by the gray shales and limestones of the Traverse group. Where it is in contact with the shale, the top of the Dundee is easily defined, but when overlain by a limestone layer, the separation between the Dundee and Traverse is more difficult and unsatisfactory. The lower contact, as previously stated, is difficult to place since it rests disconformably on the Anderdon limestone. The formation exposed along the upper part of the wall at Sibley quarry is a gray, buff to bluish, thinly bedded to massive limestone, in several places displaying fine straticulation. Chert and secondary calcite are common, and in places the limestone becomes somewhat siliceous. Many carbonaceous partings may be noticed and some cavities have a slight show or suggest evidence of petroleum. Frosted quartz grains are abundant in the basal bed of the Dundee limestone. The formation is fossiliferous and contains the forms *Atrypa elegans* Grabau and *Brevispirifer lucasensis* (Stauffer) which are restricted to the Dundee according to Ehlers and others (1951, p. 23). The same species are present in northwestern Ohio, southwestern Ontario and near Rogers City in northern Michigan, and this is suggestive of the widespread nature of the Dundee sea.

The thickness of the Dundee in Oakland County, indicated by well records, ranges from 150 to 260 feet. Natural gas, sulfate and salt water which is generally artesian, have been reported in many records from various areas. In Royal Oak Township salt water was found in the Dundee.

TRAVERSE GROUP (ERIAN SERIES)

The Traverse group is undifferentiated in the well records of southeastern Michigan. It consists of a series of limestones and shales which occupy a stratigraphic position between the underlying gray to light brown Dundee limestones and the predominantly black to brown Antrim shales above. Available well records report that the limestones are dense to coarsely crystalline with a gray or buff to brown color. Most of the interbedded shales are blue-gray but some are brown in color. Some strata of magnesian limestone or dolomite appear in the sequence. In places the limestone strata are so fossiliferous that the term "shell limestone" is frequently used by well drillers to describe them. Chert and pyrite are present in both the limestone and dolomite strata. The Traverse-Dundee contact may be difficult to recognize in areas where a limestone bed of the Traverse rests directly upon Dundee limestone. In the Mackinac Straits region the Traverse beds lie disconformably on the Rogers City limestone (Ehlers, 1949, p. 114). In general, however, the limestones of the Traverse contain a large percentage of argillaceous matter, and this characteristic may be used to distinguish them when samples are collected (Sherzer, 1916, p. 58).

The Traverse in Oakland County increases in thickness northward from 215 to 363 feet as indicated by records of deep borings. Stratigraphic sections (fig. 8) in Oakland County suggest that the upper part of the Traverse consists largely of limestones, and that the lower strata are more shaly and interbedded with limestone or dolomite. Oil and gas shows have been indicated on several of the well records, and the occurrence of salt water in the Traverse has been reported in Pontiac Township.

Mississippian

KINDERHOOK GROUP (IOWAN SERIES)

Antrim Shale

The Antrim shale is the oldest formation that occurs immediately beneath the surficial deposits of Oakland County. Its outcrop area beneath the drift is relatively small and is restricted to the southeastern half of Royal Oak Township and to the southwestern part of Lyon Township. On the geologic map (fig. 7) the relationship of the outcrop area of the Antrim with the next succeeding younger formation is suggestive of buried rock valleys. The formation, composed largely of black to brown with some dark gray to greenish-gray shales, is between the uppermost bluish-gray shales

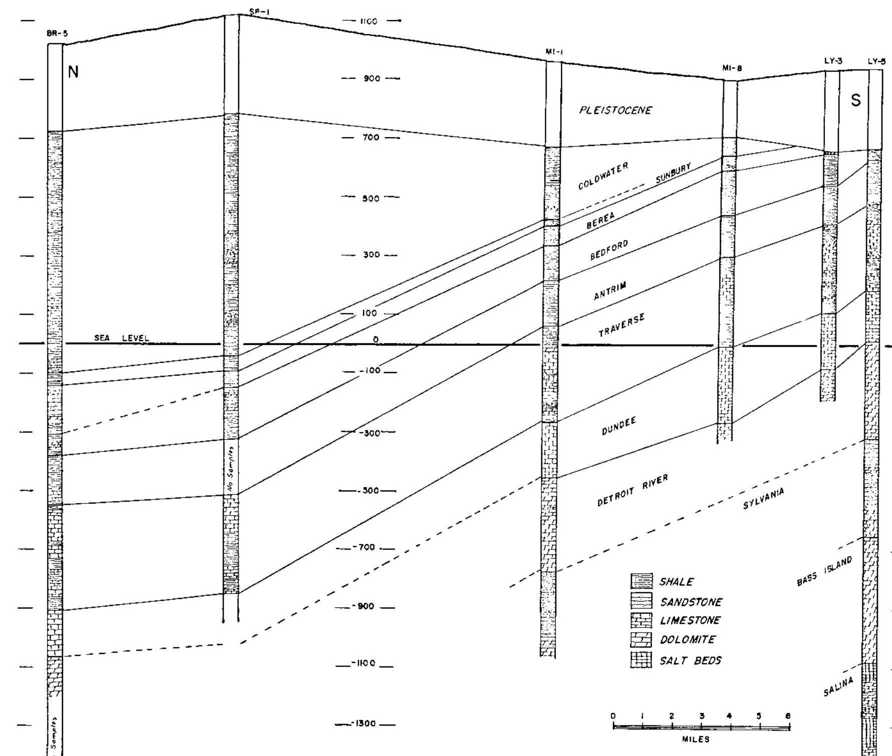


FIGURE – 8 COLUMNAR SECTIONS – OAKLAND COUNTY, MICHIGAN

and limestones of the Traverse and the Bedford-Berea formations. Its thickness ranges from 124 to 168 feet. Calcareous phases are in the sequence and occasionally a reference to limestone or brown dolomite is made in well records. Descriptions of the Antrim, in other areas of the state where actual exposures are available, report the presence in the shale of large calcareous concretions of considerable range in diameter and thickness whose centers may contain crystals of calcite and siderite, and/or fossils. These concretions, when penetrated during drilling, may erroneously be called limestone beds. The well cuttings reveal that pyrite and marcasite are in the shale. On decomposition they stain the shale with iron oxides and affect the quality of percolating waters. Samples collected from a well recently drilled in Royal Oak Township (RO-52) show that the shale is black, highly carbonaceous, finely laminated, fissile and hard; the hardness often impels the driller to record it as "slate rock." Natural gas was encountered during drilling immediately upon penetration of the shale beneath the drift, and the water subsequently pumped showed traces of petroleum. The carbonaceous matter of the shales has been attributed to the presence of large numbers of sporangites (*Protosalvinia huronensis*), disc-like objects with thick walls which are believed to be the fossil spores of floating plants.

Bedford Formation

The Bedford formation occupies a position between the dark brown to black Antrim shales and the overlying Berea sandstone. In the absence of actual exposures the problems of thickness determination and areal distribution of the Bedford formation within the county are difficult to ascertain on the basis of a few well records, especially when the overlying and underlying beds have a similar lithology or when the available logs contain inadequate descriptions. From the information available, the Bedford is dominantly a gray to dark gray shale with scattered beds that are blue-gray in color and slightly micaceous. Some sandy, gray dolomite or micaceous sandstone may be present in the sequence. The lower limit of the Bedford formation is generally placed above the last beds of black or dark brown shales of the Antrim. The upper limit is more difficult to place since the overlying Berea, though dominantly sandstone, contains beds of gray shale of different thicknesses between the sandstone layers. Because of this difficulty in recognizing the upper limit, the Berea and Bedford formations are usually grouped as a single unit in the well records. However, from the best records available, the thickness of the Bedford in the county ranges from 65 to 155 feet. A deep well (LY-5) in section 21, Lyon Township, indicates the presence of the Bedford immediately beneath the drift deposits. The areal distribution of the Bedford in that area is tentatively indicated on the geologic map.

Berea Sandstone

Included in the Berea formation are fine grained, gray to light drab or brown, micaceous sandstone layers of different thicknesses which are nearly everywhere separated by beds of light gray to blue-gray shales that in places contain calcareous or dolomitic zones. The sandstone layers are generally well cemented, but friable zones, which are water-bearing, appear in the section. The reported thickness within the limits of the county is from 55 to 236 feet. The upper boundary of the Berea is placed just below the lowest brown to black shales of the Sunbury formation. Its areal distribution beneath the drift in Oakland County is an arc, two to five miles in width, extending from Troy Township southwestward to Farmington Township and thence swinging northwestward into Lyon Township. Salt water is present in the formation, and its occurrence was reported at depths of 1,017, 1,040, and 1,112 feet in a well (IN-15) drilled in Independence Township. At the first depth of 1,017 feet, the brine overflowed the top of the casing (approximately 1,005 feet above sea level), and then dropped to 40 feet and to 312 feet below ground level as the well penetrated the second and third depths.

Sunbury Shale

Succeeding the Berea sandstone is the Sunbury shale, whose thickness in the county, as reported on well records, ranges from 20 to 50 feet. Although the data available are meager, they indicate that the formation thickens northward. Position of the Sunbury in the section is easily recognized on the basis of lithology and change in color. Lithologically, the Sunbury formation is a hard, dark brown or dark gray to black shale with traces of dolomite. Some gray sandstone or light gray micaceous sandy shale is within its defined limits. The comment "looks like Antrim" is occasionally used by the drillers to describe the formation.

Coldwater Formation

Twenty-two of the twenty-five townships of the county are immediately underlain by the Coldwater formation. Its outcrop area, beneath the drift, is a broad belt as much as twenty-five miles wide trending northeast-southwest across the county. Only small areas exist in the northwestern and southern parts of the county that are underlain by younger and older formations respectively. Stratigraphically, the Coldwater lies below the Marshall formation and above the Sunbury shale. Its lower contact is easily recognized by the definite appearance of the dark brown or black shales of the Sunbury formation. The upper contact, according to Newcombe (1933, p. 54), is more difficult to recognize since it grades upward without sharp demarcation into the basal beds of the Lower Marshall formation. The change from Coldwater to the Marshall is indicated by the occurrence of several varieties of mica. Total thickness of the Coldwater in southeastern Michigan is approximately 850 feet. The formation is dominantly a blue to gray, micaceous shale or sandy shale becoming more arenaceous upward, and interspersed with limestone or dolomite beds, ten or less feet in thickness, which are not continuous over large areas. Interbedded shales and sandstones are in some parts of the section, but such zones are not persistent, or were missed by some of the drillers and hence not indicated on all logs. Reddish, greenish-gray or purplish shales may be near the base of the section, as revealed by two logs. The paucity of data does not permit this criterion to be established as a horizon marker.

A notable feature of the formation, where exposed elsewhere in the state, is the zones of clay-ironstone nodules. These are small to fairly large concretional masses characterized by shale centers surrounded by concentric limonitic shells. From the type area of the Coldwater in Branch County, Wooten (1951, p. 33) describes the presence of "ball" and "pillow" shaped clay-ironstones, the former averaging six inches in diameter, usually spherical, with a limonitic shell about a nucleus of dark, dense, micaceous shale. Many of the shale nuclei contained ammonoids (undescribed). The latter type of clay-ironstone is pillow-shaped and the largest found is 42 inches in diameter. Many contain a nucleus with septarian-like structure with secondary mineralization—usually of pyrite, sphalerite and barite (some barite has been reported as calcite). Fossils are rare, but Wooten (1951, p. 35) reports a fossiliferous zone from the same area which contained a variety of brachiopods, bryozoa, ostracodes and gastropods. Correlation of the Coldwater formation is difficult inasmuch as most of its lithologic characteristics or features are local in extent. It appears that deposition of these sediments was complicated by the transgressive and regressive nature of the Coldwater sea, which resulted in rapid changes in lithology. Salt water* and some gas are known to occur in this formation as reported in the records of wells (HO-5 and IN-15) drilled in Holly and Independence townships.

Marshall Formation

A single well record (HO-5) indicates the presence of the Lower Marshall beds in the northwestern part of the county. The outcrop area of the formation and its contact with the underlying Coldwater as shown on the geologic map can be made problems of debate. The well at Holly penetrates 125 feet of supposedly Lower Marshall beds which are described as "light drab shales with shells of sandstone." This description can easily be applied to the upper beds of the Coldwater formation. Data pertaining to the occurrence

*Fresh water is in the so-called Coldwater Limestone in the western part of the state. See Part I of this report. *Editor.*

of this formation in Oakland County are lacking, and hence it is not possible to describe its occurrence in the area more adequately.

STRUCTURE

The Southern Peninsula of Michigan is a structural basin which extends into parts of northwestern Ohio and northern Indiana and beneath lakes Michigan and Huron. The center, and hence structurally the deepest part, of the basin is in the approximate center of the Southern Peninsula, toward which the Paleozoic strata dip from all sides. According to Sherzer (1916, p. 91), deposition of the Paleozoic sediments was nearly horizontal but with a slight central dip conforming with the basin-like structure. Subsequently the area underwent gentle tilting and warping, the effects of which accentuated the central dip and also produced local structures. In the southeastern part of Michigan, which includes Oakland County, the regional strike of the rock strata is northeast-southwest with the beds dipping gently in a northwesterly direction. The regional dip of the formations in Oakland County is somewhat modified by the extension of the Howell anticline (Livingston County) into the southwestern extremity (Lyon Township) of the county, as shown on the geologic map (fig. 7). Thus within the limits of the county, dip and strike determinations on top of the Antrim formation show that the rock strata have a more northerly dip and therefore an approximate east-west strike. In the southern part of the area the rate of dip is approximately 40 feet per mile, increasing to 45 or 50 feet at Pontiac and thence decreasing to 25 feet per mile in Independence Township near the village of Clarkston. Dip of the beds on the northeastern limb of the local anticlinal structure trending northwest in Lyon Township (Howell anticline) is approximately 87 feet per mile. The trend of the structure itself is nearly at right angles to the northeast-southwest regional strike of the strata in southeastern Michigan. The occurrence of other local structures cannot be determined with the data available.

BEDROCK TOPOGRAPHY

The configuration of the bedrock surface (fig. 7) over most of Oakland County remains incomplete inasmuch as only 168 well logs, of the 1,138 collected, indicated that consolidated sediments were reached or penetrated. The greater number of these wells are within the limits of the glacial lake plain section of the county.

Bedrock elevations were obtained from the available records by subtracting the depth to rock from the ground elevation of the well. Elevations thus obtained were plotted on a base map of the region and contours were then drawn on the basis of these elevations and the bedrock-surface map of Michigan, which was used to establish the major trends of the divides with the adjacent areas. After initial contouring, the deep wells ending in drift were used to modify or to adjust the contours as much as the data would permit. This was accomplished by selecting the deep wells ending in drift and determining the bottom-hole elevation with respect to sea level. With these elevations plotted on the base, the positions of the contours were altered wherever necessary. All rock elevations used in the preparation of this map have been filed with the State Geological Survey so that they may be verified or eliminated as new data become available. In time new data will give a more detailed picture of the rock surface. From data available, the total relief of the area is approximately 550 feet. The known highest bedrock elevation of 967 feet was reported from section 24, Oxford Township, and the lowest elevation of 395 feet from section 6, Royal Oak Township. The principal bedrock divide trends northeast-southwest. It is in the northwestern third of the county, approximating the topographic divide, and declines in elevation toward the southwest as it passes from Oxford Township through Highland Township. From the position of this bedrock divide most of the rock surface slopes to the southeast excepting a small area in the extreme north and northwest parts of the county.

The physiographic subdivisions of the bedrock surfaces are twofold and consist of (1) the rock lowland of the Erie-Huron plain and (2) a part of the southeastern slope of the Thumb Upland rock surface. Geographically the rock lowland is in the southeastern extremity of Oakland County. It is developed partly on the Berea sandstone and older formations. Its elevation is generally 500-550 feet above sea level, except where the surface is incised by valleys. The major part of the county occupies a position along the southeastern slope of the rock upland (underlain by formations younger than the Berea), the elevation of which increases northwestward from 550 feet to 967 feet above sea level, the highest known point of the bedrock divide. Perhaps separating the two units is a low but somewhat steeper and dissected slope formed by the more resistant sandstone beds of the Berea formation. Excepting a small area northwest of the principal bedrock divide, pre-

glacial drainage of the county was predominantly to the southeast.

Since the greater number of rock wells and test holes were drilled in the southeastern part of the county, only the bedrock-surface configuration of the Erie-Huron lowland and the immediately adjacent upland slope can be shown on the bedrock-contour map (fig. 7). The most prominent pre-glacial valley extends from the city of Pontiac southeastward through the towns of Birmingham and Royal Oak and thence into Wayne County. Precise delineation of this valley between Birmingham and Pontiac was not possible because of lack of additional controls. Smaller valleys trending northwest-southeast which dissect the lowland and breach the lower part of the adjacent upland slope are likewise present. Whether these valleys extend in a northwesterly direction, beyond the upper limits of the Berea sandstone, is unknown, but very likely they become less significant as the regional bedrock divide is approached to the northwest. As shown on Figure 7, such small valleys are present in Farmington, Franklin Village, west of Birmingham, the Troy-Big Beaver area, Auburn Heights and Rochester Village—all in the southeastern part of the county. The delineation of major valleys and their tributaries in the upland area must await additional data from borings or geophysical surveys. Their presence is suggested by the few scattered known bedrock elevations on both sides of the divide. A buried valley of some prominence is suggested in the vicinity of the village of Ortonville in the northwest part of the county.

GEOLOGIC HISTORY

Pre-Pleistocene

The geologic history of the region may be briefly summarized as one of sedimentation, subareal denudation and glaciation. The earliest physical event is of Paleozoic sedimentation within a basin whose structural feature was apparently developed by late Silurian time, but whose development prior to such time was not of the same pattern. According to Kay (1951, p. 21), sediments of Cambrian and Lower Ordovician times, in the Southern Peninsula of Michigan, were deposited in a southwest plunging pre-Middle Ordovician trough that was not restricted by the Kankakee axis on the southwest as the present basin is. The thickness of such sediments increases southwestwardly but diminishes appreciably on the flanks of the trough. Middle and Upper Ordovician deposits are thickest just to the southeast of the center of the Southern Peninsula, which suggests that deformation began and initiated the present structure. Through continued sedimentation the warping became more prominent so that by late Silurian time, according to Kay (1951, p. 21), the present autogeosynclinal structure was well developed. The term autogeosynclinal is restricted to a basin structure developed within a hedreocraton (stable shield) but without adjacent highlands. Devonian and Mississippian sediments increase in thickness toward the center of the structural basin and, although principally of terrigenous debris, the sediments came from adjacent low lying lands or else from distant highland areas, inasmuch as nearby adjacent highlands are not associated with autogeosynclines. The youngest preserved sediments of Pennsylvanian age likewise are thickest in the center of the Southern Peninsula of Michigan. Owing to the fluctuating seas and the constantly changing environments, the sediments deposited, particularly in late Paleozoic time, were unlike lithologically in areal distribution and in geologic range. Since deposition was not uniform, a variety of rock formations now fills the structural basin. Paleozoic sedimentation was terminated by the Appalachian revolution, which probably started in Mississippian time and continued with increased intensity through the Permian period. This orogeny resulted in the general elevation of eastern North America and involved the closing of the Appalachian geosyncline through the folding, faulting, and jointing of the rock strata contained therein. In the Michigan basin the Paleozoic deposits were not greatly deformed, the general effect upon the region being wholly one of simple uplift.

With the exception of the Pleistocene, post-Paleozoic sediments are absent in Michigan. Because of this absence the number of erosion cycles that have been initiated and subsequently completed (peneplanation), or else interrupted is not known. This is a difficult problem to solve, considering the long interval involved and the fact that data to complete a detailed map of the rock surface are still unavailable. However, it is not unreasonable to assume that erosion cycles were initiated after each of the uplifts resulting from the orogenies that closed the Paleozoic and Mesozoic eras and from the disturbances at the close of the Miocene and Pliocene periods. Thus, following the Appalachian orogeny which terminated Paleozoic sedimentation, the Mesozoic history of Michigan was primarily one of prolonged subareal erosion of an uplifted basin. The number of erosional cycles initiated or completed during this long interval remains undetermined, but peneplanation of the area, whereby the

gently dipping formations were beveled, probably occurred by the close of the Mesozoic era.

The Laramide revolution marking the close of the Mesozoic era probably resulted in simple uplift of the Michigan area, thereby initiating a new erosion (second) cycle of early Tertiary. It is conceivable that early Tertiary time may have been of sufficient length to result in peneplanation, thereby leaving no record, as far as is known, of the earlier peneplain. Since the basin structure of the Southern Peninsula remained unchanged, except for elevation, the resulting landscape changes throughout the early Tertiary cycle must have been similar to changes of the Mesozoic. The major drainage courses probably had similar positions and the escarpments, resulting from differential erosion of the more resistant formations, continued to shift in the direction of dip. The early Tertiary beveled surface was uplifted as the result of the Miocene disturbance that initiated but did not complete the third cycle of erosion. The less resistant rocks, stratigraphically below the Berea sandstone, are along the outer rim of the basin structure and hence were first to be reduced to the new base level which is now indicated by the bedrock surface of the Erie-Huron lowland. Its northwesterly limit is differentiated by the more resistant sandstone beds of the Berea formation. To the northwest the uplifted surface (Thumb Upland area) of the second cycle, being underlain by more resistant beds, was gradually incised by many new valleys. Fenneman (1938, p. 468) suggests that the uplands of Michigan represent the Highland Rim (Lexington) peneplain that has been extended with some certainty from Tennessee to western Ohio and into the Great Lakes section.

Inasmuch as the present rock surface (500-550 feet a.s.l.)[1] of the Erie-Huron lowland is incised by several valleys which also breach the Berea beds, it is suggested that the third cycle was interrupted by renewed uplift in Pliocene time or later. The present valleys in the rock lowland in Oakland County are not more than 75 to 150 feet deep and appear to be in the youthful stage (fig. 7), despite the fact that their original depth and characteristics were modified, no doubt, by subsequent and repeated glaciation. This fourth cycle, initiated by the Pliocene disturbance, was interrupted by repeated glaciation of Pleistocene time which modified the pre-glacial surface. The events as discussed concur with the work of Rhodehamel on the pre-Pleistocene geomorphology of the Saginaw lowland, where

[1]Above sea level.

the configuration of the bedrock surface is much better known. Rhodehamel (1951, p. 152) states that the last cycle may have been initiated as late as Pleistocene but prior to Illinoian glaciation. In this respect it is conceivable that several small uplifts in late Pliocene and Pleistocene times may have occurred, but if base level by streams was attained each time, then their straths, or evidences of entrenchment, have not been recognized or more probably destroyed through abrasion by subsequent and repeated glaciation. The possibility that small uplifts occurred during the interglacial stages of the Pleistocene epoch is not precluded. This could result in the entrenchment of streams into the strath beveled by the previous cycle, provided the factors of time and thickness of drift mantle were favorable. Inasmuch as the glacial deposits form the most important hydrologic unit for groundwater recovery, the Pleistocene history and nature of its deposits are treated separately.

Pleistocene

The published results of earlier workers suggest several probable invasions of glacial ice in southeastern Michigan, the areas of accumulation of the ice sheets being either the Keewatin or Patrician centers (Sherzer, 1916, p. 104). That some of the earlier ice invasions fell short of later advances is strongly suggested in southeastern Michigan, but the problem of recognizing and dating the various invasions remains inconclusive since the evidence thus far gathered is insufficient. Drift deposits of earlier glaciation have either been destroyed or covered by deposits laid down by younger ice. Thus, the recognition of different tills in Oakland County must be made primarily from well records. Earlier glaciers in their retreating phase of the cycle must have deposited a system of moraines and glacio-fluvial features which have yet to be recognized. A facet of the current investigation was an attempt to extend the mapping of the glacial deposits as exposed at the surface so as to include the full thickness of the glacial drift with a view of locating favorable areas for present and future groundwater projects. Recognition of buried deposits of the different glacial stages or substages necessitates a study of till fabrics. Except for small areas of recent alluvial deposits along streams, practically all of the surficial cover of Oakland County is related to the Wisconsin, or latest, glacial stage. Thus earlier drifts are covered, and their recognition on the basis of well data alone is exceedingly difficult. The fabric of the materials penetrated by wells is more often inadequately indicated on the logs, or if indicated, cannot be extended areally for any particular horizon owing to the absence of records, or to inconsistencies on the part of the drillers in their use of terminology, particularly the term "hardpan." The criterion of color and the nature of the clay in the majority of drill holes were completely disregarded, thereby adding difficulty to the interpretation of the available data.

ILLINOIAN DEPOSITS

The first ice movement over southeastern Michigan for which we have some direct evidence is the Illinoian glaciation. Sherzer (1916, p. 105) cites the presence of Illinoian till resting on the Detroit River formation which was temporarily exposed in the bed of the Detroit River during the excavation of the Livingston Channel near Stony Island. This till is more stony than the till of Wisconsin age exposed at Sibley quarry. The Wisconsin till is somewhat more laminated horizontally and is nearly free from pebbles. Some additional evidences of the Illinoian zone are indicated in several test borings that were drilled to bedrock along the Detroit River waterfront. The boring records indicated for the most part a blue clay, containing some sand, gravel, or sand and gravel zones, resting upon several feet of compact, stony, gravelly or sandy brown clay, poorly to well cemented which generally yielded sulphur water. This zone in turn is underlain by bedrock usually described as limestone which could represent strata of either the Dundee or Detroit River formations.

Stanley (1936, p. 22) calls attention to what seems to be Illinoian till exposed along the bed and lower slopes of the Grand Trunk Railroad cut through the Inner Defiance Moraine just east of Bloomfield Center. The Illinoian till is described as gray in color and more indurated than the overlying Wisconsin till. The two tills are separated by a bed of sand and gravel which in places is well cemented by lime. Data secured by the writer's examination of the cut, show that it can be argued that the sequence and nature of the materials exposed in the cut may be related to the fluctuation of the ice front during a substage of Wisconsin glaciation. It is apparent that the evidence is much too inconclusive to say definitely that the lower till is of Illinoian age. Other indirect evidences cited by Stanley (1936, p. 22) on the pre-Wisconsin are descriptions of two areas where vegetal matter was encountered during the drilling of water wells. Pieces of black wood were found at depths of 50 feet (710-760 feet a.s.l.) during the drilling of several wells for the Oakland Hills golf course in section 33, Bloomfield Township. A two-foot log (guessed to be tamarack) was found at a depth of 150 feet (750-800 feet a.s.l.) in a well drilled in section 17 of the same township to a depth of 363 feet without encountering bedrock. The writer was informed by a driller that fragments of wood were taken out from a well (TR-2) at a depth of 224 feet (525 feet a.s.l.) which was drilled in the southwest quarter of section 3, Troy Township (Profile A, fig. 12). At this location rock was reached at 242 feet or at an elevation of 508 feet above sea level. From none of the drillings were samples reported saved for botanical examination or age determination by the carbon 14 method. Whether the plant matter represents the same time interval or different intervals in the glacial history remains uncertain. The occurrence of wood in drift so near the bedrock surface might well represent Illinoian till since it so nearly corresponds in position to the occurrence of brown till just above bedrock in the Detroit area. The other occurrences perhaps may represent a substage of the Wisconsin. The widely scattered nature of this evidence does not permit more than conjecture on the part of the writer.

Other evidences of earlier glacial stages, or substages of the Wisconsin, may be indicated by the presence of brown, red, or purplish clays and scattered sands that have been reported below the surface. If the change in color of the clays from the usual blue or gray represents oxidation, then the oxidized zones perhaps can be used to determine the sequence of glacial events if sufficient and properly distributed data are made available that show color changes with depth of materials penetrated. A well in section 12, Bloomfield Township (BL-18) showed 14 feet of purple clay resting on the gray shale at a depth of 208 feet (662 feet a.s.l.). In the northeast quarter of section 20, Pontiac Township, red clay or red stony clay was encountered in three wells (PO-37, PO-39, and PO-40) at depths of 233, 175, and 169 feet respectively or between horizons of 742 and 775 feet above sea level (fig. 9). Other records in which oxidized horizons are indicated are shown plotted on the three profiles drawn across the glacial lake plain of southeastern Oakland County (Profiles A, B, C, fig. 12). The purple "gumbo" clay just above the bedrock may be interpreted as Illinoian till, and the red clays in section 20, Pontiac Township, which are at a considerable distance above the bedrock in that area, represent a stage of Wisconsin glaciation (Cary?). The brown clays of the lake plain may be interpreted as substages, or fluctuations within the latest substage,

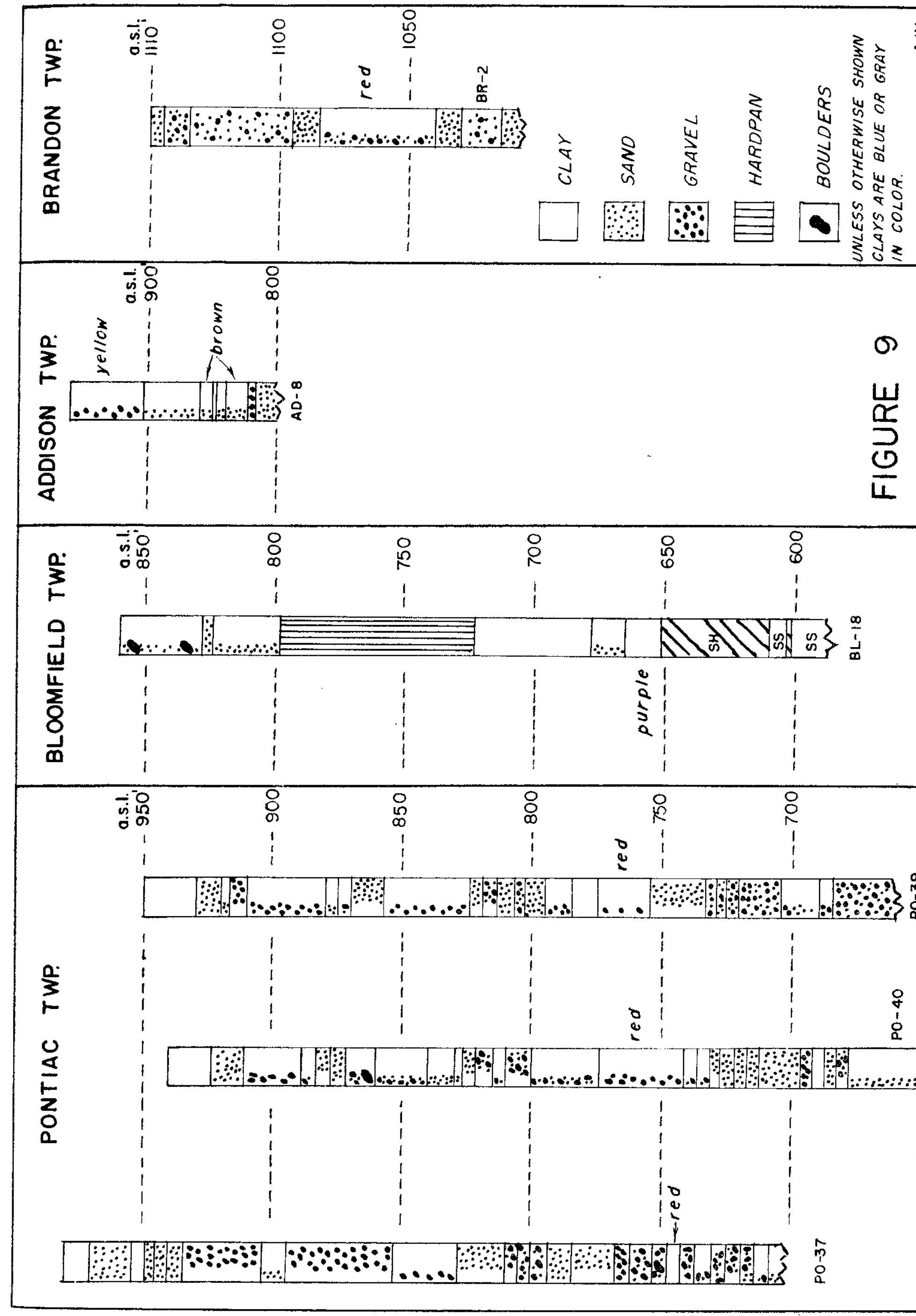


FIGURE 9

of Wisconsin glaciation. This, again, is only conjecture based on rather fragmentary data, and other interpretations are quite apparent. However, the area under investigation is underlain by tills of several ice advances.

The problem of time designation for each of the horizons indicated can only be conjectured until more data become available. Although the results presented in this study are discouraging, the sequence of glacial events can be interpreted if a satisfactory procurement of data can be arranged. What is needed most is a series of detailed profiles, if not for the entire county, then at least for the southeastern part. Cooperation of the drillers is also needed to the extent of providing the State Survey with samples of plant matter found in drilling, and with detailed well records. Only then can much be added to the present knowledge of Pleistocene history in Oakland County. A more complete picture of the bedrock surface would help materially since the older tills are more apt to be preserved in the rock valleys than on the ridges. The botanical examination and age determination of wood fragments would permit some delineation of the tills, and the oxidized zones could be used to extend the correlations into areas where more positive evidence is lacking. Such samples and related data will require the cooperation of the drillers who in turn must be shown the mutual benefits that may be derived from such a program. Because the old land surface slopes to the southeast it is reasonable to believe that earlier Wisconsin or pre-Wisconsin glacial lakes existed and built beaches, the recognition of which would prove useful to the drillers and certainly to the intelligent selection of future well-drilling sites.

Wisconsin Glaciation

The entire area of Oakland County was covered by two lobes of the Wisconsin glacier: The Saginaw lobe which advanced from the north and the Erie-Huron lobe from the southeast. Both lobes joined approximately along the northeast-southwest line of hills that stands above the present outwash plains as shown on the glacial maps of Oakland County (fig. 2). The withdrawal of the ice from the county began with the development of a re-entrant between the two lobes that first uncovered the area in the vicinity of Milford Village, and then gradually extended and widened in a northeasterly direction. As the two lobes separated, the meltwaters discharged by the ice front from all sides of the re-entrant deposited outwash sands and gravels in the form of plains that increase in elevation northeastward. The southernmost, and hence earliest formed, is the Commerce Plain which is centered about the village of Commerce. The highest part of this plain is adjacent to the Fort Wayne Moraine immediately to the southeast and has an elevation of 950 feet above sea level. From this line the plain slopes northwestward indicating the direction of meltwater flow when the Erie-Huron ice front stood along the position marked by the Fort Wayne Moraine. The Drayton Plain, named after the village of Drayton Plains, lies to the northeast of Commerce Plain and was the second to form. It attains an elevation of 1,000 feet and has a general slope to the southeast, suggesting deposition primarily by meltwaters coming from the Saginaw lobe ice front. The Clinton River roughly parallels the southeastern edge of this plain and thereby drained the meltwaters during its formation. The northeasternmost plain, and the last to be developed in the county, is known as the Oxford Plain in the vicinity of Oxford Village. Its elevation ranges from 1,060 to 1,085 feet and slopes generally to the southwest, and may have been formed by the meltwaters derived from both lobes but more probably from the Saginaw lobe. It is interesting to note the position of the line of kames and morainic hills with respect to the outwash sand and gravel area shown on the glacial map (fig. 2). The line of hills appears to divide the area into almost equal parts. Leverett (1915, p. 187) postulates the origin of the kames to have taken place in sags of the ice while the Saginaw and Erie-Huron lobes were still in contact. With this assumption then these kames are older than the moraines and gravel plains of the area.

During the development of the outwash area, the Erie-Huron lobe occupied a position along the Fort Wayne Moraine, and the Saginaw lobe a position coincident with the northerly range of morainic hills and till plains in the northwest part of the county. The elevation of this northerly range decreases northwestward from 1,100 feet to 850 feet and marks the direction of recession of the Saginaw lobe from the county. From the Fort Wayne Moraine, the next known position taken by the Erie-Huron lobe is marked by the Outer Defiance Moraine. Its northwestern boundary is not clearly defined in the county since it lies against and hence is confused with the Fort Wayne Moraine. However, southwest of the county and in the vicinity of Ann Arbor, an outwash area separates the two moraines. The next position of the Erie-Huron ice front is marked by the Inner Defiance Moraine, a narrow hilly belt not exceeding three miles in width, which enters the county in southeastern Novi Township and extends northeastward through Franklin Village and Bloomfield Hills, finally becoming confused with the Outer Defiance and Birmingham moraines southwest of Rochester Village. The moraine is generally lower in elevation and less rugged than either of the previously formed moraines. To the northwest it is separated from the Outer Defiance by a sand- and gravel-filled channel which represents the marginal drainage from the ice front while it remained at its new position. To the southeast the Inner Defiance is separated in part by the Birmingham Moraine and the highest beach of the glacial lake plain. Eskers are associated along the southeastern slope of this moraine, but all of them are poorly developed and of short length. The Fort Wayne and the Outer and Inner Defiance moraines comprise the southerly range of hills, mentioned earlier in the report, which has a trend across the county similar to the trend of the northerly range of hills.

Succeeding the Inner Defiance is the Birmingham Moraine, the southwestern part of which was deposited in the waters of glacial Lake Maumee and the northeastern part on land. The land moraine extends from East Long Lake Road northeastward to Rochester Village, and the waterlaid part of the moraine southwestward toward the city of Birmingham. Its characteristics are comparable to the previously formed moraines but the relief is not as conspicuous. Taylor (1915) describes the Birmingham Moraine as being formed by the readvance of the ice after it had previously withdrawn from the Inner Defiance to a position several miles to the southeast. The Detroit Interlobate Moraine was deposited contemporaneously with and at right angles to the Birmingham Moraine. It trends southeastwardly through Southfield and Royal Oak townships and thence into Wayne County. It is a broad, low, smooth ridge apparently deposited under the ice along the contact of the Huron and Erie lobes and below the level of Lake Maumee to the west. Topographically it is neither conspicuous nor easily recognized, but it influenced the drainage at the time, and its position is now indicated by the sharp change in trend of the glacial lake beaches and by the contours on the topographic map. The position of this interlobate moraine is of interest with respect to the trend of the major rock valley in southeastern Oakland County. It appears that the shallow rock valley was influential in the subglacial deposition of the moraine along the line of contact of the two lobes. Both waterlaid moraines have been reworked in part

by the waters of glacial Lake Maumee and are covered now by lacustrine clays, sands and gravels.

Since the natural slope of the topography was to the southeast, a series of glacial lakes was formed between the moraines to the north and the ice front to the south as the glacier receded. The sequence of these glacial lakes has been determined by Leverett and Taylor (1915). Several beaches of the earlier formed glacial lakes are well represented in Oakland County. The individual glacial lake beaches are at progressively lower elevations southeastward and represent the gradual withdrawal, and temporary readvances, of the ice as it receded from the area. Drainage of the earlier formed lakes was to the west; at first through the Fort Wayne Outlet by way of the Maumee River (which flowed in a reverse direction to the present day Maumee River) and later by the Grand River channel. Eventually drainage of the glacial lakes to the Atlantic was made possible after an outlet was uncovered by the retreat of Wisconsin ice near Syracuse, New York. This outlet established the level of glacial Lake Wayne in southeastern Michigan. Thus the southeastern extremity of Oakland County consists of a glacial lake plain which is in part developed over the waterlaid Detroit Interlobate and Birmingham moraines. The surface of the plain is characterized by clayey and sandy sediments and coarser clastics associated with such surface features as beaches, eskers, deltas and river terrace gravels.

NATURE AND STRUCTURE OF THE DRIFT

Unconsolidated materials which are predominantly of glacial origin and which have been deposited on a surface directly by the ice, or indirectly by meltwaters derived from the glacier, are termed "drift." Deposition accomplished by the glacier directly results in a mantle of rock waste which consists largely of unassorted particles of various sizes and composition. Such deposits are frequently called "tills" or "unstratified drift." Where the action of meltwaters has been the dominant agent of deposition, the materials deposited though heterogeneous in size and composition, are for the most part sorted into layers, lenses or beds in accordance with the laws of running water. In contrast to the unstratified tills, these glacial deposits fall under the heading of "stratified drift," and are associated with such glacio-fluvial features as outwash plains, kames and eskers.

Moraines and Till Plain Deposits

The moraines forming the northerly and southerly belts of hills in Oakland County are composed largely of unassorted till deposits. The particles comprising the till range in dimension from fine clays to large boulders. Nearly everywhere the finer materials form the matrix in which the coarser fragments are imbedded. Porosity of such deposits may be high and hence capable of storing large quantities of water, but permeability on the other hand can vary greatly, depending upon whether the matrix is predominantly clay or a matrix that is sandy or gravelly. Within the morainic and associated till plain areas, layers of sand and gravel may be the result of deposition by meltwaters which are always associated with large ice masses. These sands or gravels may be at or below the surface, their intercalation throughout the morainic and till plain areas being "chaotic." These pockets of more permeable materials are not always extensive in areal distribution, nor are they present at any established depth or thickness beneath the surface. This condition has, on occasions, resulted in misunderstanding between driller and client since neighboring wells may have great differences in depth within relatively short distances. Because of the complex nature of glacial deposition, the correlation of the materials from well to well is not possible, and test holes or wells reveal only the nature of the sediments for the point drilled. Many buried layers of sand and gravel when penetrated yield adequate water supplies for most domestic and farm purposes, and in some places a larger stratum is found which is capable of development for an industrial or municipal supply. The city of Pontiac has its water supply drawn from sand and gravel deposits which are traceable for a distance of several miles. These deposits, in all probability, represent outwash material deposited earlier in the glacial history of the area and subsequently buried by younger deposits of till that now constitute the present morainic hills and till plains.

The absence of sufficient bedrock-surface elevations in the county made it difficult to evaluate the thickness of the surficial cover. In the area covered by the moraines and assorted till plains, the thickness of the drift, as indicated by well records, has been as much as 390 feet, and an average thickness of 250 feet is not unreasonable to assume for the entire area. Inasmuch as the greater part of the morainic deposits is on the dissected rock surface of the Thumb Upland, thicknesses in excess of 390 feet may be more frequently reported. From the drift-thickness map (fig. 2) the

greatest thickness, from 300 to 390 feet, is seen to be over an area marked approximately by the junction of the outwash plains with the Fort Wayne Moraine and trending roughly northeast-southwest. The meager data available suggest that the thickness increases in a northeasterly direction, which harmonizes with the retreat of the re-entrant that developed between the Saginaw and Erie-Huron ice lobes as the ice masses wasted away. It is also noted that the greatest thickness of drift reported has been deposited southeast of the bedrock-surface divide. In section 28, Oakland Township, near the unincorporated settlement of Goodison, a well penetrated 550 feet of morainic deposits before bedrock was reached. Unassorted till 300 to 345 feet thick is reported in the till plain and the moraines that were primarily deposited by the Saginaw lobe. These areas appear slightly northwest of the bedrock-surface divide. More precise delineation than is shown on the drift-thickness map could not be made for lack of additional bedrock data.

The possibilities of securing adequate water supplies in the morainic belts for most domestic, farm, and commercial purposes are reasonably good considering the number of sands and gravels that may be encountered during drilling. Where larger water supplies are desired, it may be advisable that each of the sand and gravel strata below the level of groundwater saturation be developed and screened. The proximity of the morainic belts to the more highly porous and permeable outwash deposits, which are of considerable areal extent, favors adequate indirect recharge since movement of groundwater through the unassorted till and into the "pockets" is accomplished regardless of the varying and changing permeabilities of the sediments. Direct recharge of the buried sands and gravels by precipitation is also favored since the moraines are characterized by morainic lakes and depressions which act as reservoirs for surface run-off.

Outwash Deposits

The largest area of stratified drift is in the outwash plains separating the two morainic hill belts of the county. Smaller areas of stratified deposits occur between the Inner and Outer Defiance moraines, and in the morainic tract deposited by the Saginaw lobe in the northwestern part of the county. In the interlobate area, 300 feet of surficial mantle, principally of sand and gravel, has been reported. Clays are generally subordinate except in the scattered areas of morainic hills that rise above the level of the plain. Clays were almost or wholly absent in several wells 200 feet deep. It is probable that parts of the outwash plain may extend beneath the morainic belts since it is conceivable that the fronts of the ice lobe fluctuated during the glacial period. The stratified and sorted character of the sands and gravels is evidence of abundant meltwaters that were derived from all sides of the re-entrant developed between the Saginaw and Huron lobes. The degree of coarseness of the sediments from layer to layer varies considerably, but generally the materials of the outwash are of greater permeability than deposits in the moraine, till plain and lake plain sections of the county. The absorbent character of the outwash materials is indicated by the nearly complete absence of erosion, principally gullying along the steep slopes. In addition, the pitted nature of the outwash plain surface, and its numerous lakes, make this the most favorable catchment area for the precipitation that falls upon it. Therefore from the outwash storage reservoir gradual indirect recharge of the more permeable zones in the moraines and glacial lake plain sections of the region is possible.

Several of the natural lakes, as well as the lakes formed in abandoned gravel pits, are without inlets or outlets. Thus the water surfaces of such lakes represent the surface extension of the water table. In many places the static water-level elevations as measured in wells coincide with the water-surface elevations of the lakes in the vicinity. Some of the scattered clusters of hills that rise conspicuously above the level of the outwash plains are kames that formed along the junction of the two lobes, or are cross-moraines consisting of unassorted till which were probably deposited by ice bridges connecting the two lobes, or else may represent static conditions of the re-entrant as the ice retreated northeastward. Excepting the wells drilled in the kames, the static water levels of many wells in the cross-moraines are not in harmony with the water-surface elevations of the lakes. Most wells drilled in this section of the county are reported successful and have very favorable yields. Driven wells are most abundant around the beaches of the many inland lakes that have been developed in the past decade for recreational activities, domestic residences and estates.

Glacial Lake Plain

The surficial mantle of the lake plain that overlies the rock surface of the Erie-Huron lowland area ranges in thickness from 75 to 345 feet. In general the mantle has a thickness of 100-150 feet in the southeasternmost part of the lake plain and increases to 150-200 feet northward as the southern morainic belt of hills is approached. The greater thicknesses, as far as well records show, are in the bedrock valleys that were carved by pre-glacial streams. One well penetrated 345 feet. In comparison to the other drift areas, the mantle of the lake plain region consists of unassorted till, sandy and clayey sediments of lacustrine origin, and sorted sands and gravels of the beaches, spits, bars, deltas and river terraces. The unassorted till deposited directly by the ice is in part waterlaid and thus partially reworked by water, at least in its upper part. Although well records report abundant clay in the glacial lake plain, most of it is clay having various admixtures of sand, gravel, pebbles, or even boulders. The surface of the lake plain is veneered for the most part with lacustrine materials such as sandy clay or clay and in addition characterized by fine to coarse sediments that have been sorted by wave action or running water. The glacial lake beaches and sand bars composed of sediments ranging from fine sands to coarse gravels are the result of wave action of glacial meltwaters that were ponded between the morainic belt and the ice front. The Lake Whittlesey spit in Southfield Township was developed by shore currents that prevailed at the time of deposition. The deltas and river terraces, composed of coarser clastics mainly well sorted, stratified and crossbedded, are features deposited by streams flowing southeastward from the outwash and morainic areas and discharging into the glacial lakes. As lower outlets were uncovered by the receding ice, the lake levels declined, thereby establishing new base levels for the streams of the area. This led to the dissection of the deltas and also to the development of river terraces. The origin of these features and their sequence of development have been adequately described by Bay (1938, p. 13).

The nature of the sediments and the surface features just discussed is attributed to the last withdrawal of the ice. Bearing in mind the southeastward slope of the rock surface and considering the available evidence of earlier periods of glaciation, or substages of the Wisconsin glaciation, it appears valid to assume that similar events may have occurred more than once in the area. Thus similar depositional features that are geologically older may be beneath the surface but have yet to be recognized. No doubt some of the earlier formed beaches or other sorted deposits of sand and gravel were completely obliterated, altered, covered, or partially destroyed by later ice advances. And to all of this may be added the changes resulting from the fluctuation of an ice front of any particular glacial stage. Thus the lake plain area, because of its complex history, is composed predominantly of a heterogeneous assortment of sediments characterized by a wide range in porosity and permeability. Associated with the till and lacustrine deposits are sand, gravel, or sand and gravel deposits which are frequently called "veins, pockets or lenses" by the drillers. This distribution within the lake plain mantle has often been described as "chaotic," which in a sense is not truly descriptive. Rather, the distribution of the permeable zones should be described as "complex" since the details of glacial erosion and deposition cannot be interpreted to a final degree. The "pockets or veins" range in thickness from a few inches to tens of feet. They vary greatly in porosity and permeability, and rapidly lense out or grade into finer sediments or they interfinger with the waterlaid till or the material of lacustrine origin. Despite the complex distribution of the coarser and sorted zones, it appears that they are by simple and devious ways interconnected or closely interrelated with each other, thereby permitting the percolation of groundwater from the intake areas to the north.

The buried sand and gravel zones represent depositional features that are difficult to recognize or correlate on the basis of well records alone. Correlation of well records is made difficult by the complex nature of sedimentation by both ice and water, also the lack of uniformity among drillers in recording the nature of materials penetrated does not reveal the "till fabric." In addition, wells are constructed where they are needed, hence their records, if obtained, are not evenly distributed over the area but are bunched together. These factors make the problem of recognizing buried features extremely difficult, and the development of large water supplies is dependent upon the discovery of large sand and gravel bodies.

Chapter III

GROUNDWATER HYDROLOGY

OCCURRENCE OF GROUNDWATER

Water beneath the earth's surface which occupies the pore spaces or other interstices of both primary and secondary origin is generally termed subsurface water. This water lies in that part of the earth characterized by the presence of pores, fractures, voids and other openings, and is differentiated from magmatic or internal water that exists deep within the earth where no voids exist and hence where the water is in molecular association with other earth materials. The water in the upper zone is of prime importance to man since it is a natural resource in part recoverable for his use.

Subsurface water reservoirs may be subdivided into two zones, namely, the zone of saturation and the zone of aeration. The plane of separation between the two zones is known as the water table. In the zone below the water table, all the interstices of whatever origin are occupied by water, and thus the zone is properly called the groundwater zone. It is primarily from this zone that water is recovered by means of wells and springs for water-supply purposes. Above the water table in the zone of aeration the interstices are not filled with water excepting for periods of short duration during rainfall. In contrast to the underlying zone, the water that is present in the zone of aeration is not under a hydraulic pressure but is held within the zone either by molecular attraction or by capillarity. According to its occurrence within the zone of aeration, the water in this zone is classified as soil water, intermediate water and also as capillary fringe water which rises above the water table in capillary interstices.

MOVEMENT OF GROUNDWATER

The movement of water in permeable water-bearing formations within the saturated zone is accomplished by the differences in hydraulic head in different parts of the formation. The relationship between the various factors that control the quantity of water flow in permeable beds has been expressed by Darcy's law:

$Q=TIW$ where,

Q=flow in gallons per day through a strip of water-bearing material one foot wide and a depth equal to the saturated thickness of the material.

T=coefficient of transmissibility in gallons per day per foot of width of saturated material under a gradient of 100 per cent.
I=Hydraulic gradient in feet per unit distance in the direction of flow.
W=Width of water-bearing material at right angles to the direction of flow.

The difference in head between the place of water intake and the place of discharge provides the energy that keeps water in motion in the zone of saturation against the internal friction which is inherent in any permeable formation. The cross sectional area can be determined approximately from well logs and the factor of transmissibility from the thickness and physical properties of the water-bearing material. In the latter instance, the size, shape, arrangement and uniformity of grains that make up the formation, together with the degree of cementation, determine the amount of frictional resistance of the material to the movement of groundwater.

CONFINED AND UNCONFINED GROUNDWATER CONDITIONS

Groundwater beneath the level of saturation may be confined or unconfined. Unconfined groundwater conditions generally exist in areas covered by a mantle consisting of materials of uniform or nearly uniform characteristics. The top of the zone of saturation becomes the water table and the groundwater is thus stated to be under "unconfined or water-table conditions." In such a deposit of structureless material, the principal movement of the water is laterally in the direction of the hydraulic gradient. When permeable formations below the level of saturation are between beds of lesser permeability, then artesian or confined groundwater conditions are established. In artesian structures, the water is under a pressure which is determined by the position of the water table in the highest part of the formation or at its intake area. From the intake area the water moves down the dip of the confined aquifer, but in its later course it may move up or down depending upon the deformation or structure of the water-bearing bed. The height to which confined water will rise in wells penetrating the aquifer is designated the piezometric or pressure-indicating surface. If the loss in head due to seepage and the frictional resistance of the aquifer is less than the total physical descent of the water-bearing material, then the water will rise in wells to some level above the top of the confined bed. On the other hand, if the loss in head is less than the slope of the land surface, the artesian pressure may be sufficiently high to result in flowing wells. Therefore, depending upon the loss in head due to frictional resistance, the water in wells penetrating a confined aquifer may rise (1) just above the confined bed, (2) above the water table but not to the land surface or (3) above the land surface.

The effects of pumping on groundwater levels are indicated in Figure 10. The pumping or dynamic water level is lower than the static water level, and the difference between the two is called the "drawdown," which results as water is withdrawn from a well. Under water-table conditions it is an actual lowering of the water-table surface; whereas under confined conditions it is a decrease in the artesian pressure or piezometric surface. In the water-table conditions, a cone of depression develops about a pumped well and, in the confined conditions, a cone of pressure relief. The amount of lowering and the size of the cone developed in either case depend upon the period and amount of withdrawal versus the rate of recharge. The greatest drawdown takes place near the well and becomes less as the distance from the pumped well increases.

It may be pertinent at this point to mention that under water-table conditions, the water pumped initially comes from storage in that part of the aquifer immediately surrounding the well. The cone of depression thus created gradually increases in depth and in area with continued pumpage until the cone diverts into the well an amount of water equal to the withdrawal. The rate of growth and shape of the cone depend upon the storage capacity and the permeability coefficient of the aquifer, and therefore the greater the capacity the slower the development of the cone. The cone of pressure relief of an artesian aquifer (confined conditions) develops more rapidly than the cone of depression of a water-table aquifer simply because its storage capacity may be many times smaller.

WATER-BEARING PROPERTIES OF CONSOLIDATED AND UNCONSOLIDATED SEDIMENTS

The quantity of water that may be contained in consolidated or unconsolidated sediments is determined by its porosity, but the amount that may be recovered from such storage is measured by its coefficient of storage. Under unconfined conditions the coefficient of storage may be considered to be the same as the specific yield of the water-bearing material which is the difference between