
Contents

1	Elements of Map-Scale Structure	1
1.1	Introduction	1
1.2	Representation of a Structure in Three Dimensions	1
1.2.1	Structure Contour Map	3
1.2.2	Triangulated Irregular Network	3
1.2.3	Cross Section	3
1.3	Map Units and Contact Types	4
1.3.1	Depositional Contacts	5
1.3.2	Unconformities	6
1.3.3	Time-Equivalent Boundaries	6
1.3.4	Welds	7
1.3.5	Intrusive Contacts and Veins	7
1.3.6	Other Boundaries	8
1.4	Thickness	8
1.5	Folds	9
1.5.1	Styles	9
1.5.2	Three-Dimensional Geometry	13
1.5.3	Mechanical Origins	15
1.6	Faults	18
1.6.1	Slip	19
1.6.2	Separation	20
1.6.3	Geometrical Classifications	20
1.6.4	Mechanical Origins	22
1.6.5	Fault-Fold Relationships	24
1.7	Sources of Structural Data and Related Uncertainties	26
1.7.1	Direct Observations	26
1.7.2	Wells	27
1.7.3	Seismic Reflection Profiles	30
2	Location and Attitude	33
2.1	Introduction	33
2.2	Location	33
2.2.1	Map Coordinate Systems, Scale, Accuracy	33
2.2.2	Geologic Mapping in 3-D	36
2.2.3	Wells	37

2.3	Orientations of Lines and Planes	41
2.3.1	Stereogram	44
2.3.2	Natural Variation of Dip and Measurement Error	46
2.3.3	Tangent Diagram	47
2.4	Finding the Orientations of Planes	49
2.4.1	Graphical Three-Point Problem	50
2.4.2	Analytical Three-Point Problem	52
2.5	Apparent Dip	53
2.6	Structure Contours	54
2.6.1	Structure Contours from Point Elevations	54
2.6.2	Structure Contours from Attitude	55
2.6.3	Dip from Structure Contours	55
2.7	Intersecting Contoured Surfaces	55
2.8	Derivation: Tangent Diagram on a Spreadsheet	57
2.9	Exercises	57
2.9.1	Interpretation of Data from an Oil Well	57
2.9.2	Attitude	58
2.9.3	Attitude from Map	59
3	Structure Contouring	63
3.1	Introduction	63
3.2	Structure Contouring	63
3.3	Structural Style in Contouring	65
3.3.1	Equal Spacing	66
3.3.2	Parallel	66
3.3.3	Interpretive	66
3.3.4	Smooth vs. Angular	67
3.4	Contouring Techniques	68
3.4.1	Choosing the Neighboring Points: TIN or Grid?	69
3.4.2	Triangulated Irregular Networks	70
3.4.3	Interpolation	72
3.4.4	Adjusting the Surface Shape	75
3.5	Mapping from Profiles	76
3.6	Adding Information to the Data Base	78
3.6.1	Bedding Attitude	78
3.6.2	Projected and Composite Surfaces	79
3.6.3	Fluid-Flow Barriers	84
3.7	Exercises	85
3.7.1	Contouring Styles	85
3.7.2	Contour Map from Dip and Elevation	86
3.7.3	Depth to Contact	86
3.7.4	Projected-Surface Map	87
4	Thickness Measurements and Thickness Maps	89
4.1	Thickness of Plane Beds	89
4.1.1	Universal Thickness Equation	89

4.1.2	Thickness between Structure Contours	92
4.1.3	Map-Angle Thickness Equations	94
4.1.4	Effect of Measurement and Mapping Errors	95
4.2	Thickness of Folded Beds	98
4.2.1	Circular-Arc Fold	98
4.2.2	Dip-Domain Fold	100
4.3	Thickness Maps	100
4.3.1	Isopach Maps	101
4.3.2	Isocore Maps	102
4.4	Derivation: Map-Angle Thickness Equations	104
4.5	Exercises	106
4.5.1	Interpretation of Thickness in a Well	106
4.5.2	Thickness	106
4.5.3	Thickness from Map	106
4.5.4	Isopach Map	106
5	Fold Geometry	109
5.1	Introduction	109
5.2	Trend from Bedding Attitudes	109
5.2.1	Cylindrical Folds	109
5.2.2	Conical Folds	111
5.2.3	Tangent Diagram on a Spreadsheet	114
5.2.4	Example Using a Tangent Diagram	115
5.2.5	Crest and Trough on a Map	116
5.3	Dip Domain Fold Geometry	117
5.4	Axial Surfaces	119
5.4.1	Characteristics	119
5.4.2	Orientation	122
5.4.3	Location in 3-D	124
5.5	Using the Trend in Mapping	125
5.6	Minor Folds	126
5.7	Growth Folds	129
5.8	Exercises	130
5.8.1	Geometry of the Sequatchie Anticline	130
5.8.2	Geometry of the Greasy Cove Anticline	130
5.8.3	Structure of a Selected Map Area	131
6	Cross Sections, Data Projection and Dip-Domain Mapping	133
6.1	Introduction	133
6.2	Cross-Section Preliminaries	133
6.2.1	Choosing the Line of Section	133
6.2.2	Choosing the Section Dip	136
6.2.3	Vertical and Horizontal Exaggeration	137
6.3	Illustrative Cross Sections	142
6.3.1	Construction by Hand or with Drafting Software	142
6.3.2	Slicing	144

6.4	Predictive Cross-Section Construction	145
6.4.1	Dip-Domain Style	146
6.4.2	Circular Arcs	153
6.5	Changing the Dip of the Section Plane	159
6.6	Data Projection	160
6.6.1	Projection Along Plunge	162
6.6.2	Projection by Structure Contouring	168
6.7	Dip-Domain Mapping from Cross Sections	169
6.8	Derivations	172
6.8.1	Vertical and Horizontal Exaggeration	172
6.8.2	Analytical Projection along Plunge Lines	173
6.9	Exercises	176
6.9.1	Vertical and Horizontal Exaggeration	176
6.9.2	Cross Section and Map Trace of a Fault	176
6.9.3	Illustrative Cross Section from a Structure Contour Map 1	176
6.9.4	Illustrative Cross Section from a Structure Contour Map 2	177
6.9.5	Illustrative Cross Section from a Structure Contour Map 3	177
6.9.6	Predictive Dip-Domain Section	177
6.9.7	Predictive Cross Sections from Bedding Attitudes and Tops	179
6.9.8	Fold and Thrust Fault Interpretation	179
6.9.9	Projection	179
7	Properties of Faults	181
7.1	Introduction	181
7.2	Recognition of Faults	181
7.2.1	Discontinuities in Geological Map Pattern	181
7.2.2	Discontinuities on Reflection Profile	182
7.2.3	Discontinuities on Structure Contour Map	186
7.2.4	Stratigraphic Thickness Anomaly	187
7.2.5	Discontinuity in Stratigraphic Sequence	188
7.2.6	Rock Type	190
7.2.7	Fault Drag	191
7.3	Unconformities	191
7.4	Displacement	193
7.4.1	Slip	194
7.4.2	Separation	196
7.4.3	Heave and Throw from Stratigraphic Separation	198
7.5	Geometric Properties of Faults	200
7.5.1	Surface Shape	200
7.5.2	Displacement Distribution	200
7.6	Growth Faults	204
7.6.1	Effect on Heave and Throw	204
7.6.2	Expansion Index	205
7.7	Fault-Cut Correlation Criteria	206
7.7.1	Trend and Sense of Throw	207
7.7.2	Shape	208

7.7.3	Stratigraphic Separation	209
7.7.4	Growth History	211
7.8	Exercises	212
7.8.1	Fault Recognition on a Map	212
7.8.2	Fault Recognition on a Seismic Line 1	213
7.8.3	Fault Recognition on a Seismic Line 2	213
7.8.4	Finding Fault Cuts	213
7.8.5	Correlating Fault Cuts	213
7.8.6	Estimating Fault Offset	214
7.8.7	Fault Offset	216
7.8.8	Growth Faults	216
8	Faulted Surfaces	219
8.1	Introduction	219
8.2	Geometry of a Faulted Surface	219
8.2.1	Heave and Throw on a Structure Contour Map	219
8.2.2	Stratigraphic Separation from a Structure Contour Map	221
8.3	Constructing a Faulted Marker Horizon	222
8.3.1	Locating the Fault	223
8.3.2	Joining Offset Marker Surfaces to a Fault	225
8.4	Fault Cutoff Maps and Allan Diagrams	229
8.4.1	Construction	229
8.4.2	Determination of Fluid Migration Pathways	232
8.4.3	Determination of Fault Slip	233
8.5	Faults on Isopach Maps	235
8.6	Displacement Transfer	237
8.6.1	Relay Overlap	239
8.6.2	Branching Fault	240
8.6.3	Splay Fault	241
8.6.4	Fault Horse	243
8.7	Crossing Faults	243
8.7.1	Sequential Faults	243
8.7.2	Contemporaneous Faults	251
8.8	Exercises	252
8.8.1	Heave and Throw from a Map	252
8.8.2	Construct the Fault Trace	252
8.8.3	Construct the Fault Trace	254
8.8.4	Reservoir Structure	254
8.8.5	Normal Fault	255
8.8.6	Reverse Fault	257
8.8.7	Faults on an Isopach Map	258
8.8.8	Cutoff Map of Normal Fault	258
8.8.9	Cutoff Map of Reverse Fault	258
8.8.10	Fluid Migration across a Fault	258
8.8.11	Thrust-Faulted Fold	258
8.8.12	Relay Zone	258

8.8.13	Branching Fault	262
8.8.14	Splay Faults	262
8.8.15	Sequential Faults 1	263
8.8.16	Sequential Faults 2	263
9	Dip-Sequence Analysis	265
9.1	Introduction	265
9.2	Curvature Models	267
9.3	Dip Components	268
9.4	Analysis of Uniform Dip	270
9.5	Analysis of Folds	270
9.6	Analysis of Faults	276
9.7	Exercises	282
9.7.1	SCAT Analysis of the Sequatchie Anticline	282
9.7.2	SCAT Analysis of Bald Hill Structure	282
9.7.3	SCAT Analysis of Greasy Cove Anticline	282
10	Quality Control	285
10.1	Introduction	285
10.2	Data Errors and Contouring Artifacts	285
10.2.1	Data Errors	285
10.2.2	Edge Effects	287
10.2.3	Excessive Detail	288
10.3	Trend Incompatibilities	289
10.4	Bed Thickness Anomalies	292
10.4.1	Compatibility between Structure Contour Maps	292
10.4.2	Compatibility of Thicknesses on Cross Sections	294
10.4.3	Realistic Growth History	296
10.5	Unlikely or Impossible Fault Geometries	298
10.5.1	Fault Shape	298
10.5.2	Fault Separation	299
10.5.3	Fault Cutoff Geometry	301
10.6	Exercises	302
10.6.1	Cross-Section Quality	302
10.6.2	Map Validation	303
10.6.3	Map and Fault Cut Validation	304
11	Structural Validation, Restoration, and Prediction	305
11.1	Introduction	305
11.2	Restoration and Balance	308
11.2.1	Boundaries	308
11.2.2	Palinspastic vs. Geometric Restoration	309
11.2.3	Sequential Restoration	311
11.3	Strain and Strain Partitioning	314
11.4	Area-Balance Methods	316
11.4.1	Area Restoration	316

12.4	Vector Geometry of Lines and Planes	377
12.4.1	Angle between Two Lines or Planes	378
12.4.2	Line Perpendicular to Two Vectors	378
12.4.3	Line of Intersection between Two Planes	379
12.4.4	Plane Bisecting Two Planes	380
	References Cited	383
	Index	393