
Contents

Introduction	XIII
Chapter 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	2
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	4
1.3.2 Unconformities	5
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	7
1.4 Thickness	8
1.5 Folds	8
1.5.1 Styles	9
1.5.2 Three-Dimensional Geometry	12
1.5.3 Mechanical Origins	13
1.6 Faults	17
1.6.1 Slip	18
1.6.2 Separation	18
1.6.3 Geometrical Classifications	19
1.6.4 Mechanical Origins	22
1.6.5 Fault-Fold Relationships	23
1.7 Sources of Structural Data and Related Uncertainties	25
1.7.1 Direct Observations	25
1.7.2 Wells	26
1.7.3 Seismic Reflection Profiles	29
References	30

Chapter 2	
Location, Attitude, and Thickness	33
2.1 Introduction	33
2.2 Location	33
2.2.1 Map Coordinate Systems, Scale, and Accuracy	33
2.2.2 Wells	36
2.2.2.1 Datum	36
2.2.2.2 Deviated Well	36
2.3 Orientation of Lines and Planes	39
2.3.1 Stereogram Representation	40
2.3.2 Natural Variation of Dip and Measurement Error	43
2.3.3 Tangent Diagram Representation	44
2.4 Finding the Orientations of Planes	45
2.4.1 Attitude of a Plane from Three Points	46
2.4.1.1 Graphical Three-Point Problem	46
2.4.1.2 Analytical Three-Point Problem	47
2.4.2 Structure Contours	49
2.4.2.1 Structure Contours from Point Elevations	49
2.4.2.2 Structure Contours from Attitude	50
2.4.2.3 Dip from Structure Contours	50
2.4.2.4 Intersecting Contoured Surfaces	51
2.4.2.5 Single-Unit Map Validation	51
2.5 Finding the Orientations of Lines	53
2.5.1 From Two Points	53
2.5.2 Apparent Dip	54
2.6 Thickness of Plane Beds	54
2.6.1 Map-Angle Thickness Equations	54
2.6.2 Pole-Thickness Equation	56
2.6.2.1 Angle Between Two Lines, Stereogram	56
2.6.2.2 Angle Between Two Lines, Analytical	57
2.6.3 Thickness Between Structure Contours	58
2.6.4 Effect of Measurement Errors	59
2.7 Thickness of Folded Beds	62
2.7.1 Circular Arc Fold	62
2.7.2 Dip-Domain Fold	63
2.8 Thickness Maps	64
2.8.1 Construction and Interpretation	64
2.8.2 Dip vs. Thickness	65
2.8.3 Location Anomalies, Dip and Thickness	66
2.9 Derivations	66
2.9.1 Location	66
2.9.2 Solid Geometry	67
2.9.2.1 Direction Cosines	67
2.9.2.2 Direction Cosines of a Line from Azimuth and Plunge	68
2.9.2.3 Azimuth and Plunge from Direction Cosines	68
2.9.2.4 Direction Cosines of a Line on a Map	69
2.9.2.5 Azimuth and Plunge of a Line from the End Points	69

2.9.2.6 Pole to a Plane	69
2.9.2.7 Attitude of a Plane from Three Points	70
2.9.3 Thickness	71
2.9.3.1 Trigonometric Method	71
2.9.3.2 Bed-Normal Form	72
2.9.3.3 Circular Arc, in Dip Direction	73
2.10 Problems	74
2.10.1 Interpretation of Data from an Oil Well	74
2.10.2 Attitude	75
2.10.3 Thickness	75
2.10.4 Attitude and Thickness from Map	76
2.10.5 Isopach Map	78
References	80
Chapter 3	
Structure Contouring	83
3.1 Introduction	83
3.2 Structure Contour Maps	83
3.2.1 Control Points	84
3.2.2 Rules of Contouring	85
3.2.3 Choosing the Neighboring Points: TIN or Grid	86
3.2.4 Triangulated Irregular Networks	87
3.2.4.1 Delauney Triangles	88
3.2.4.2 Greedy Triangulation	88
3.2.4.3 Biasing the Network	89
3.3 Contouring Styles	90
3.3.1 Linear Interpolation	90
3.3.2 Equal Spacing	90
3.3.3 Parallel	92
3.3.4 Interpretive	92
3.3.5 Smooth vs. Angular	93
3.3.6 Artifacts	94
3.4 Additional Sources of Information	95
3.4.1 Including the Bedding Attitude	96
3.4.2 Projected and Composite Surfaces	97
3.4.3 Fluid-Flow Barriers	100
3.5 Multiple-Unit Map Validation	100
3.5.1 Composite Surface	102
3.5.2 Contour Compatibility	103
3.5.3 Trend Compatibility	105
3.6 Problems	106
3.6.1 Contouring Styles	106
3.6.2 Contour Map from Dip and Elevation	106
3.6.3 Depth to Contact	106
3.6.4 Composite-Surface Map	107
3.6.5 Projected-Surface Map and Map Validation	107
References	111

Chapter 4	
Fold Geometry	113
4.1 Introduction	113
4.2 Form and Trend from Bed Attitudes	113
4.2.1 Cylindrical Fold	113
4.2.2 Conical Fold	115
4.2.3 Planar Dip Domains and Hinge Lines	117
4.3 Plunge Lines	120
4.3.1 Projection Along Plunge Lines	120
4.3.2 Example	122
4.4 Crest and Trough	123
4.5 Axial Surfaces	125
4.5.1 Characteristics	125
4.5.2 Orientation	128
4.5.3 Predicting Thickness Changes	131
4.6 Dip-Sequence Analysis	132
4.6.1 Curvature Models	133
4.6.2 Dip Components	135
4.6.3 Example	139
4.7 Minor Folds	142
4.8 Growth Folds	145
4.9 Derivations	146
4.9.1 Relationships Between Lines and Planes	146
4.9.2 Angle Between Two Lines or Planes	146
4.9.3 Line of Intersection Between Two Planes	147
4.9.4 Plane Bisecting Two Planes	148
4.9.5 Axial Surface Geometry	150
4.10 Problems	151
4.10.1 Geometry of the Sequatchie Anticline	151
4.10.2 Geometry of the Greasy Cove Anticline	151
4.10.3 SCAT Analysis of the Sequatchie Anticline	151
4.10.4 Structure of a Selected Map Area	153
References	154
Chapter 5	
Faults and Unconformities	155
5.1 Introduction	155
5.2 Recognition of Faults	155
5.2.1 Discontinuities in Geological Map Pattern	155
5.2.2 Discontinuities on a Reflection Profile	157
5.2.3 Discontinuities on a Structure Contour Map	157
5.2.4 Stratigraphic Thickness Anomaly	159
5.2.5 Discontinuity in Stratigraphic Sequence	162
5.2.6 Rock Type	163
5.2.7 Fault Drag	164
5.3 Dip Sequence Analysis	165

5.3.1	Fault Interpretation	165
5.3.2	Example	169
5.4	Unconformities	172
5.5	Displacement	175
5.5.1	Slip	175
5.5.2	Separation	177
5.5.3	Heave and Throw from Stratigraphic Separation	178
5.6	Geometric Properties of Faults	180
5.6.1	Surface Shape	180
5.6.2	Displacement Distribution	180
5.7	Growth Faults	184
5.7.1	Effect on Heave and Throw	184
5.7.2	Expansion Index	185
5.8	Problems	187
5.8.1	Fault Recognition on a Map	187
5.8.2	Fault Recognition on a Seismic Line	187
5.8.3	Fault Cuts	187
5.8.4	Dip Sequence Analysis	187
5.8.5	Fault Offset	187
5.8.6	Estimating Fault Offset	192
5.8.7	Growth Faults	192
References	193

Chapter 6

Mapping Faults and Faulted Surfaces	197	
6.1	Introduction	197
6.2	Fault-Cut Correlation Criteria	197
6.2.1	Trend and Sense of Throw	198
6.2.2	Shape	200
6.2.3	Separation	203
6.2.4	Growth History	205
6.3	Faulted Surfaces	207
6.3.1	Fault Trace on a Structure Contour Map	208
6.3.2	Measures of Separation	208
6.3.3	Map Validation	211
6.4	Contouring Across Faults	213
6.4.1	Projected Fault Cutoffs	214
6.4.2	Restored Vertical Separation	216
6.5	Displacement Transfer	217
6.5.1	Relay Overlap	218
6.5.2	Branching Fault	218
6.5.3	Splay Fault	220
6.5.4	Fault Horse	221
6.6	Crossing Faults	222
6.6.1	Sequential Faults	222
6.6.2	Contemporaneous Faults	228
6.7	Faults on Isopach Maps	231

6.8 Problems	243
6.8.1 Normal Fault	324
6.8.2 Reverse Fault	234
6.8.3 Reservoir Structure	235
6.8.4 Method of Projected Fault Cutoffs	235
6.8.5 Method of Restored Tops	236
6.8.6 Thrust-Faulted Fold	237
6.8.7 Correlating Fault Cuts from Fault Attitude	237
6.8.8 Map Validation	238
6.8.9 Relay Zone	238
6.8.10 Branching Faults	239
6.8.11 Splay Faults	239
6.8.12 Sequential Faults 1	241
6.8.13 Sequential Faults 2	241
6.8.14 Faults on an Isopach Map	242
References	244
Chapter 7	
Cross Sections	245
7.1 Introduction	245
7.2 Choosing the Line of Section	246
7.3 Vertical and Horizontal Exaggeration	248
7.4 Transferring Data from Map to Cross Section	253
7.4.1 Data Located on the Section Line	254
7.4.2 Projecting Data to the Section Line	256
7.4.2.1 With Structure Contours	258
7.4.2.2 Along Plunge	259
7.4.2.3 Within Dip Domains	263
7.5 Section Drawing Techniques	263
7.5.1 Planar Dip Domains	264
7.5.1.1 Method	265
7.5.1.2 Cylindrical Fold Example	266
7.5.1.3 Non-Cylindrical Fold Example	271
7.5.2 Circular Arcs	273
7.5.2.1 Method	273
7.5.2.2 Dip Interpolation	275
7.5.3 Cubic Curves	277
7.6 Changing the Orientation of the Section Plane	279
7.7 Fault Cutoff Maps	281
7.7.1 Construction	281
7.7.2 Determination of Fault Slip	282
7.7.3 Determination of Fluid Migration Pathways	285
7.8 Derivations	286
7.8.1 Vertical and Horizontal Exaggeration	286
7.8.2 Analytical Projection Along Plunge Lines	288
7.9 Problems	290
7.9.1 Vertical and Horizontal Exaggeration	290

7.9.2	Cross Section and Map Trace of a Fault	290
7.9.3	Cross Section from a Structure Contour Map: Parallel Faults and Folds	291
7.9.4	Cross Section from a Structure Contour Map: Two Normal Faults	292
7.9.5	Cross Section from a Structure Contour Map: Two Reverse Faults	292
7.9.6	Dip-Domain Section	292
7.9.7	Cross Sections from Attitudes: Different Styles	293
7.9.8	Fold and Thrust Fault Interpretation	294
7.9.9	Cutoff Maps: Reverse Faults	294
7.9.10	Cutoff Maps: Normal Faults	295
7.9.11	Fluid Migration Across a Fault	295
	References	296
 Chapter 8		
	Restoration and Validation	299
8.1	Introduction	299
8.2	Rigid-Body Restoration	302
8.3	Flexural-Slip Restoration	303
8.4	Simple-Shear Restoration	305
8.5	Area Restoration	308
8.6	Area-Depth Relationship	309
8.7	Problems	312
8.7.1	Rigid-Body Restoration	312
8.7.2	Flexural-Slip Restoration 1	312
8.7.3	Flexural-Slip Restoration 2	313
8.7.4	Restoration of Folded and Faulted Section	814
8.7.5	Simple-Shear Restoration	314
8.7.6	Length and Area Restoration	315
8.7.7	Area-Depth Graph and Area Restoration	317
	References	317
	 Index	319