Geology and Geophysics 303: Structural Geology
Course Notes

Fall Semester, 2003, 3.0 Units

Steve Martel
Department of Geology and Geophysics
University of Hawaii
Geology and Geophysics 303: Structural Geology
Fall Semester, 2001, 3.0 Units
Lectures: MW 10:30-11:20
Lab: W 1:30-4:20

Instructor: Steve Martel, POST 712A, 956-7797, martel@soest.hawaii.edu
Office Hours: After class or by arrangement

Texts: Basic Methods of Structural Geology, by Marshak and Mitra (MM)
Mechanics in the Earth and Environmental Sciences, by Middleton and Wilcock (MW)

Class Themes
The crust of the earth is deformed at many scales, locations, and times; this deformation produces identifiable structures in the crust such as fractures and folds. An appreciation of earth structures has both enormous practical value and profound intellectual implications for how we view this planet. This class deals with ways to recognize and characterize major structures in the earth's crust and ways to gain insight into how these structures form. The course develops skills in three-dimensional thinking that are essential for understanding crustal structures. It also explores techniques for determining the sequence in which structures form. Geometric and time-sequence information is integrated with fundamental material from course pre-requisites in mathematics and physics to introduce students to how the earth's crust can be viewed as a mechanical system. The class will focus on macroscopic structures but will also introduce students to some of the fascinating structures that form at the microscopic scale. The course has a laboratory and includes a field trip to the Big Island.

Our ability to understand geologic structures depends in large part on how we perceive them. Few geologic structures form by trivially simple processes, but depending on how we view geologic structures, they can appear horribly complicated or amenable to understanding; perspective is critically important. One key thread throughout the class will be ways of viewing the geometry, mathematics, and physics of geologic structures such that the underlying essential forms emerge clearly.

A second key thread is the usefulness of integrated knowledge. We can think of unrelated pieces of knowledge as unconnected nodes of a net. A cut-up net is not very useful for catching fish. However, if the nodes of a net are connected, a net is a wonderful device for catching fish. It is also light, strong, and flexible. The outstanding feature of a net that makes it so useful then is the connection of the nodes. Similarly, concepts are vastly more powerful when they are connected rather than isolated. The knowledge connection process is not easy to master, but it is a key part of thinking, problem recognition, and problem solution. For these reasons, integrating pieces of knowledge can be very satisfying. Links are forged here between disciplines (e.g., structural geology, mathematics, and physics) and between observations made at different scales, but the fundamental focus is on the connection process rather than the particular concepts that are linked.

Mathematical equations show how physical quantities and physical concepts relate formally. Equations are derived in this class to get insight into these relationships and to illuminate the principles behind the equations. Don't view equations just as something one "plugs into". This is the 21st century, and we will use mathematics and computers in quantitative analyses.

The notes for this class are in outline form, not in the form of a finished book. They allow students to concentrate on the main themes in class rather than on frantically scribbling down everything that is said or written. Also, in some ways the outlines highlight key points better than a book; key points don't get lost in a jumble of words. The notes will be most useful, however, if students annotate the notes as they use them.
<table>
<thead>
<tr>
<th>Week</th>
<th>Day</th>
<th>Date</th>
<th>Lecture</th>
<th>Subject</th>
<th>Reading</th>
<th>Lab Topic</th>
<th>Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>8/25/03</td>
<td>1</td>
<td>Intro/Course Philosophy</td>
<td>Notes</td>
<td>Strike &amp; dip</td>
<td>MM Ch.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Trend &amp; plunge</td>
<td>MM p. 105</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Poles to planes</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>8/27/03</td>
<td>2</td>
<td>Eqns. of lines &amp; planes</td>
<td>MW Ch. 1</td>
<td>Orthographic Projections</td>
<td>MM Ch.3</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>9/1/03</td>
<td>Holiday (Labor Day)</td>
<td>MM Ch. 3</td>
<td>2</td>
<td>MM Ch.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>9/3/03</td>
<td>3</td>
<td>Orthographic projections</td>
<td>MM Ch. 3</td>
<td>3 pt problems</td>
<td>MM Ch.3</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>9/8/03</td>
<td>Maps (Geol. &amp; contour)</td>
<td>MM Ch. 3</td>
<td>3</td>
<td>MM Ch.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X-sections 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MM Ch.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Maps (Geol. &amp; contour)</td>
<td>MM Ch.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 pt problems</td>
<td>MM Ch.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X-sections 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MM Ch.3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>9/10/03</td>
<td>5</td>
<td>Geologic map patterns</td>
<td>MM Ch. 3</td>
<td>4 X-sections 2 True dip</td>
<td>MM Ch.3</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>9/15/03</td>
<td>Scalars, Vectors, Tensors</td>
<td>MM Ch. 3</td>
<td>4</td>
<td>MM Ch.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X-sections 2 Apparent dip</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MM Ch.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Maps (Geol. &amp; contour)</td>
<td>MM Ch.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 pt problems</td>
<td>MM Ch.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X-sections 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MM Ch.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Maps (Geol. &amp; contour)</td>
<td>MM Ch.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 pt problems</td>
<td>MM Ch.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X-sections 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MM Ch.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Maps (Geol. &amp; contour)</td>
<td>MM Ch.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 pt problems</td>
<td>MM Ch.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X-sections 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MM Ch.3</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>9/22/03</td>
<td>6</td>
<td>Spherical Projections I</td>
<td>MM Ch.5</td>
<td>Stereonets I Lines &amp; planes</td>
<td>MM Ch.5</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>9/24/03</td>
<td>Spherical Projections II</td>
<td>MM Ch.6</td>
<td>5</td>
<td>MM Ch.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dip/apparent dip</td>
<td>Notes</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>9/29/03</td>
<td>7</td>
<td>Coord. transformations I</td>
<td>Notes</td>
<td>Stereonets II Rotations</td>
<td>MM Ch.6</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>10/1/03</td>
<td>Coord. transformations II</td>
<td>Notes</td>
<td>6</td>
<td>MM Ch. 7.1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>10/6/03</td>
<td>8</td>
<td>X-sections 3 X-products</td>
<td>MW Ch. 7</td>
<td>X-secions 3 X-products Line-plane int.</td>
<td>MM Ch.13.9</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>10/8/03</td>
<td>Kinematics II</td>
<td>MW Ch. 7</td>
<td>7</td>
<td>MM Ch.13.9</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>10/13/03</td>
<td>9</td>
<td>Line-plane int.</td>
<td>MW Ch. 7</td>
<td>8 Midterm Exam</td>
<td>MM Ch.13.9</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>10/15/03</td>
<td>Infinitesimal strain</td>
<td>MW Ch. 7</td>
<td>8</td>
<td>MM Ch.13.9</td>
<td></td>
</tr>
<tr>
<td>Week</td>
<td>Day</td>
<td>Date</td>
<td>Lecture</td>
<td>Subject</td>
<td>Reading</td>
<td>Lab Topic</td>
<td>Reading</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>------------</td>
<td>-----------</td>
<td>-----------------------</td>
<td>----------</td>
<td>-----------</td>
<td>----------</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>10/20/03</td>
<td>16</td>
<td>Stress I</td>
<td>Notes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>10/22/03</td>
<td>17</td>
<td>Stress II</td>
<td>Notes</td>
<td>Strain/fabrics</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>10/27/03</td>
<td>18</td>
<td>Stress III</td>
<td>Notes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>10/29/03</td>
<td>19</td>
<td>Stress IV</td>
<td>Notes</td>
<td>Stress</td>
<td>Notes</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>11/3/03</td>
<td>20</td>
<td>Rheology: elasticity</td>
<td>Notes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>11/5/03</td>
<td>21</td>
<td>Stress around a hole 1</td>
<td>Notes</td>
<td>Elasticity</td>
<td>Notes</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>11/10/03</td>
<td></td>
<td>Open</td>
<td>Notes</td>
<td>Photoelasticity</td>
<td>Notes</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>11/12/03</td>
<td>22</td>
<td>Stress around a hole 2</td>
<td>Notes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>11/17/03</td>
<td>23</td>
<td>Dislocations</td>
<td>MM Ch.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>11/19/03</td>
<td>24</td>
<td>Joints and fractures</td>
<td>12.1-12.3</td>
<td>Dikes in gelatin</td>
<td>Notes</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>11/24/03</td>
<td>25</td>
<td>Faults I</td>
<td>MM Ch.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>11/26/03</td>
<td>26</td>
<td>Faults II</td>
<td>11.3</td>
<td>Faulting</td>
<td>MM Ch. 11.3</td>
</tr>
<tr>
<td>15</td>
<td>M</td>
<td>12/1/03</td>
<td>27</td>
<td>Folds I</td>
<td>MM Ch.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>12/3/03</td>
<td>28</td>
<td>Folds II</td>
<td>11.2</td>
<td></td>
<td>MM Ch. 13</td>
</tr>
<tr>
<td>16</td>
<td>M</td>
<td>12/8/03</td>
<td>29</td>
<td>Grain-scale deformation</td>
<td>Notes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>12/10/03</td>
<td>30</td>
<td>Last lecture</td>
<td>Notes</td>
<td>LAB FINAL</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>M</td>
<td>12/15/03</td>
<td>FINAL EXAM</td>
<td>9:45-11:45</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Index

Analytic geometry ......................................................Lab 1
Angles ........................................................................
  between lines........................................................Lab 6, 7-1, 7-2
  between planes........................................................Lab 6, 7-1, 7-2
Apparent dip.................................................................Lab 7
Arbitrary cross sections............................................Lab 3
Attitude symbols.........................................................Lab 1-4
Boudinage....................................................................27
Contours .....................................................................Lecture 4-1
Conversion factors.....................................................1-3
Coordinate systems.....................................................Lab 1
  Cartesian..............................................................Lab 1-2, Lab 1-3
  Cylindrical...........................................................Lab 1-3
  Spherical..............................................................Lab 1-3
Cramer's Rule ............................................................Lab 5
Cross product.............................................................7-2
  Normal to a plane..................................................Lab 4
  For finding fold axes.............................................Lab 4
  Determinants.........................................................7-2, 7-4
Cross sections...........................................................Lab 3
  Arbitrary.............................................................Lab 3
  Strike view..........................................................Lab 3
  Cylindrical fold....................................................Lab 4
Descriptive geometry.................................................1-2
Determinants..............................................................7-2
Dikes..........................................................................17
Dip...........................................................................Lab 1
  True dip................................................................Lab 1
  Apparent dip........................................................Lab 4-2
Direction cosine........................................................Lab 1, 2-1
Displacement ................................................................6-1, Fig. 8.1
Dot Product.................................................................7-1, 7-4
Down-plunge view.....................................................Lab 4
Drafting equipment....................................................1-2
Drill core problems...................................................Lab 7, Lab 8, Lab 9
Elasticity ....................................................................13-1
Equal-angle projection...............................................Lab 6
Equal-area projection.................................................Lab 6
Equations
  Equation of a line..................................................2-1
  Equation of a plane................................................2-2, Lab 5
Excel...........................................................................
Fabrics........................................................................
Faults........................................................................20
  dip-slip...............................................................Fig. 19.1, 20
  normal.................................................................20
  relative displacement across............................19-2
  reverse.................................................................20
  slip.................................................................Fig. 19.1, 20
  strike-slip.........................................................Fig. 19.1, 20
  thrust.................................................................20
Fields.........................................................................15-1
Flexures .............................................................. Lab 13
Fluids ................................................................. 13-3
Folds .................................................................... 24, 25
  Fold axis ............................................................
  Axial surface ...................................................
  Hinge ...............................................................
  Crest ............................................................... 24
  Limb ............................................................... 25
Fracture mechanics ........................................... 19
Fractures ........................................................... 13-3, Fig. 16.1, 21
GPS ................................................................. Lab 6
Great circle ........................................................ Lab 6
Intersection ........................................................ Lab 5
  intersection of three planes ............................. Lab 5
  intersection of a line and a plane ..................... Lab 5
Invariants ........................................................ 7-3
Joints .................................................................. 16
  hackles ............................................................ Fig. 16.2
  origin ............................................................. 16-2
  plumose structure .......................................... Fig. 16.2
  ribs ............................................................... Fig. 16.2
  terminology ................................................... 16-3
Kinematics ....................................................... 1-2
Laccoliths .......................................................... 17-1
Lines ................................................................... 2-1
  orientation of ................................................... Lab 1-4
  equation of .................................................... Lab 1-2
  length ............................................................ Lab 1-2
  pitch, definition ............................................. Lab 1
  plunge, definition ........................................... Lab 1-4
  trend, definition ............................................ Lab 1-4
Maps ................................................................... 4
  Contour .......................................................... 4-1
  Geologic .......................................................... 4-2, 5-1
    Interpretation of ........................................... Lab 3, 4-2
  Isopach .......................................................... 4-2
  Structure ........................................................ 4-2
  Topographic ................................................... 4-1
Matrices ............................................................ 6, 7
  Multiplication ................................................ 6-5
Mechanics ......................................................... 1-2
Method of images ............................................. 18
Microstructural deformation ............................ 13-2, Fig. 13.3
Mohr circle ....................................................... 10, 11
Mullions ............................................................ 27
Orthographic projections .................................. Lab 2, 3-1
Photo-elasticity ................................................ Lab 10
Pitch ................................................................. Lab 1
Plasticity .......................................................... 13-1
Planes ................................................................... 2-2
  dip ................................................................. Lab 1-4
  equation of .................................................... Lab 1-2, Lab 1-3
  normal to a plane ........................................... Lab 1-1
  pole .............................................................. Lab 1-4
strike .......................................................... Lab 1-4
Plunge .......................................................... Lab 1-4
Pressure solution ...................................... 13-3
Projections ..................................................... Lab 2, Lab 3, Lab 4, Lab 6
Rheology .......................................................... 13
Rotation .......................................................... Lab 7, Lab 8
  Rotation of coordinate systems using matrices ... Lab 8
  Rotation problems using stereonets ............... Lab 7
Rule of vees .................................................. Lab 3
Scalars .......................................................... 6-1
Scalar triple product ................................... 7-3
Scientific Method ............................................ Fig. 1.1
Sills ................................................................. 17-1
Small circle .................................................... Lab 6
Spanish Peaks ................................................. 18
Spherical projection .................................... Lab 6
  of a line ..................................................... Lab 6
  of a plane .................................................. Lab 6
Stereonets (see Spherical projection)
Strain .......................................................... 8-1, Fig. 8.1
  ellipse ......................................................... 9-1
  extension .................................................... 8-2
  finite ........................................................ 9-1
  homogeneous ......................................... 9-1
  measuring ................................................ 9-2
    Wellman's method .................................. 9-2, Fig. 9.2
    pitfalls ................................................ 9-2
  stretch ..................................................... 8-2
  dilation .................................................... 8-2
  path .......................................................... 8-2
  shear ......................................................... 8-2
    pure shear ............................................. Fig. 9.1
    simple shear ......................................... Fig. 9.1
Stress .......................................................... 10, 12
  at a point ............................................... 10-1
  concentrations ....................................... 15
    around a circular hole ................................ Fig. 15.1, Fig 15.2, Fig. 15.3, Fig. 15.4
  conventions ............................................. Fig. 10.2
  definition ................................................ 10-1
  maximum shear ....................................... 10-4
  mean normal .......................................... 10-4
  Mohr circle ............................................. 10-2, 10-3, 10-4, Fig. 10.1, Fig. 10.3,
    .......................................................... 11, Fig. 11.1
  normal .................................................... 10-1
  principal ............................................... 10-2, 11-4, 11-5, 11-7, 11-8, 11-9
  shear ........................................................ 10-1
  transformations ....................................... 10, 11, 12
  vectors ................................................... 10-1
Strike .......................................................... Lab 1
  definition ................................................ Lab 1
  determination from geologic maps ............. 5-1
  solution using three-point problem ........... Lab 3
  solution using cross product .....................
Strike-view cross sections ................................ Lab 3
<table>
<thead>
<tr>
<th>Topic</th>
<th>Pages/References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure contour</td>
<td>5-1, Fig. 5.1</td>
</tr>
<tr>
<td>Tensors</td>
<td>6-1, 6-2, 6-3</td>
</tr>
<tr>
<td>Three-point problem</td>
<td>Lab 3.2</td>
</tr>
<tr>
<td>Trace</td>
<td>4-2</td>
</tr>
<tr>
<td>Traction</td>
<td>10-1</td>
</tr>
<tr>
<td>Transformations</td>
<td>6-2, 6-3</td>
</tr>
<tr>
<td>of coordinate systems</td>
<td>Lab 8</td>
</tr>
<tr>
<td>of stresses</td>
<td>11-1, 11-7, 11-8, 11-9</td>
</tr>
<tr>
<td>of tensors</td>
<td>7-5, 12</td>
</tr>
<tr>
<td>of vectors</td>
<td>Fig. 6.1, Fig. 6.2, 7-5, Lab 8</td>
</tr>
<tr>
<td>Trend</td>
<td>Lab 1-4</td>
</tr>
<tr>
<td>Vectors</td>
<td>2-2, 6-1, 6-3</td>
</tr>
<tr>
<td>Vector products</td>
<td>7-1</td>
</tr>
<tr>
<td>Viscosity</td>
<td>13-1</td>
</tr>
<tr>
<td>Wellman's method</td>
<td>9-2, Fig. 9.2</td>
</tr>
<tr>
<td>Wulff net (See Equal-angle projection)</td>
<td></td>
</tr>
</tbody>
</table>
Laboratory Items

“Details are trifles, but trifles make perfection, and perfection is no trifle.”
Benjamin Franklin

The course involves a substantial amount of graphical work. Good drafting equipment and good paper are essential. Good quality materials, although somewhat expensive, are durable and make the work easier to do, much less time-consuming, and will yield pleasing results in the hands of diligent students. This equipment can be purchased from a drafting or art supply store. Examples can be found, for example, at http://www.reuels.com/reuels/index2.html

Required Equipment (Bring to each lab)
0.5 mm mechanical pencil or drafting pencils with a pencil pointer
Soft rubber eraser (“Jet” erasers are good)
Pad of engineering paper (the green ones with light green gridlines)
Pad of 8.5”x11” Clearprint tracing paper (preferably with light blue “fadeout” grid lines).
Clearprint is excellent paper. Other brands of tracing paper have yielded poor results.
Clipboard
Protractor (preferably 6” [15 cm] in diameter)
6” pencil compass
30-cm metric triangle scale with scales of 1:10(0), 1:20(0), and 1:50(0)
(Note: this is NOT an engineer’s scale!)
30° and 45° acrylic triangles (diagonal edges ~11.5” long are best)
Drafting tape

Recommended Equipment
French curve

Nice-to-have (but not required) equipment
Technical drawing pen (e.g., Rapidograph 000) if you like to ink in your work
Good black drafting ink

Grading

The lecture and laboratory material is tightly integrated in this course. The course requires students to “learn by doing”, so the laboratory exercises (which also constitute “homework”) are heavily weighted.

Final for lecture 25%
Final for Lab 20%
Lecture midterm 15%
Laboratories/homework 30%
Class participation 10%
TOTAL 100%

Students are encouraged to work together on the homework; note that “working together” is not the same as “copying”. Neatness, clarity of expression, and completeness are essential in order for full credit on the exams, laboratories, and homework. Exams are open note.
INTRODUCTION AND COURSE PHILOSOPHY

I Main Topics
A What is science?
B Course philosophy

II What is science?
A Possession of knowledge as distinguished from ignorance or misunderstanding;
B Knowledge attained through study and practice
C Knowledge covering general truths or the operation of general laws especially as obtained and tested through the scientific method
D Scientific Method
Principles and procedures for the systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of hypotheses.

II Course philosophy
A Geology can be treated as a scientific discipline
B Course emphases
1 Concepts (not vocabulary)
2 Critical thinking (not “cookbooks”)
3 Fundamentals (not fashion)
4 Quantitative predictions (Where? When? How big?)
C Topics of this course

<table>
<thead>
<tr>
<th>Topic</th>
<th>Definition</th>
<th>Application to structural geology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive geometry</td>
<td>The representation of the spatial relationships of points lines and planes by means of projections</td>
<td>Used to describe the geometry of deformed or undeformed bodies Focus of first half of class</td>
</tr>
<tr>
<td>Kinematics</td>
<td>The study of the position of bodies through time without regard to the causative forces</td>
<td>Used to describe how a body changes shape and/or position through time</td>
</tr>
<tr>
<td>Mechanics</td>
<td>The study of forces and their effects (e.g., how bodies deform in response to forces)</td>
<td>Used to understand and predict how bodies deform</td>
</tr>
</tbody>
</table>
Scientific Method

1. Complicated natural phenomena
2. Limited existing observations of natural phenomena
3. Simplified conceptual model
   - Ad hoc theory (i.e., case-specific theory)
   - General theory (e.g., Newton’s Laws of physics)
4. Recognize unexplained phenomena
5. Form one or more hypotheses
6. Test hypotheses:
   - Make new, carefully-considered observations;
   - analyze observations;
   - interpret analyses in light of theory predictions
7. Revise model if necessary & add to stockpile of observations

Note: consider predictive power of ad hoc theories versus general theories
Why Use Geometry, Kinematics, and Mechanics?

Geometry and Kinematics

Explanations permitted by geometric data  
Explanations permitted by kinematic analysis

Range of possible explanations

Geometry, Kinematics, and Mechanics

Explanations permitted by geometric data  
Explanations permitted by kinematic analysis

Range of possible explanations

Unacceptable explanations that violate Newton’s Laws

Explanations permitted by mechanical analysis

Fig. 1.2
## Conversion Factors

### Prefixes
- µ (micro) $10^{-6}$ g
- m (milli) $10^{-3}$
- k (kilo) $10^3$
- M (mega) $10^6$
- G (giga) $10^9$

### Key constants
- g $9.8$ m/sec/sec

### Quantities
#### Mass
- 1 kg 1000 grams 2.205 lbs
- 1 ton 2000 lbs
- 1 lb 0.4536 kg
Note: tons and pounds are really weights (i.e., forces), not masses

#### Length
- 1 inch 2.54 cm
- 1 meter 39.37 inches 3.281 feet
- 1 foot 0.3049 m
- 1 km 0.622 miles
- 1 mile 1609 meters 1.609 km

#### Time
- 1 year $3.1557 \times 10^7$ sec
- 1 hour 3600 sec

#### Density
- 1 g/cm$^3$ 1000 kg/m$^3$

#### Force
- F = ma
- 1 kg weight 9.807 N
- 1 ton 2000 lbs
- 1 lb 0.4536 kg
- 1 kg 2.205 lbs
- 1 N $10^5$ dynes

#### Pressure
- (P = F/area)
- 1 Mpa $10^6$ Pa
- 1 atm $1.013 \times 10^5$ Pa
- 1 bar $10^5$ Pa
- 10 bars $10^6$ Pa
- 1 psi 689.5 Pa
- 10 m water $\approx 10^5$ Pa
- 1 MPa $0.1013$ MPa $145.03$ psi
- 0.1 Mpa $14.7$ psi
- 1Mpa 145.03 psi
- 1 psi $689.5 \times 10^{-3}$ MPa
- $\approx 0.1$ Mpa $\approx 14.7$ psi

#### Energy
- 1 calorie 4.184 joule
- 1 joule $10^7$ ergs

#### Power
- 1 watt 1 joule/sec
Note: Power = energy / unit time

"Permeability" (hydraulic conductivity) The hydraulic conductivity (K) depends on the density & dynamic viscosity of the fluid and the intrinsic permeability (K_i) of the medium {Q = -K A (dh/dl); K = K_i(ρg/µ)} . K has dimensions of speed; K_i of area. For water at 15.6° C:

If K=1 m/sec, then...
- K_i=1.161 x $10^5$ Darcies
- K_i=1.15 x $10^{-3}$ cm$^2$

If K_i=1 Darcy, then...
- K=8.61 x $10^{-6}$ m/sec
- K_i=9.87 x $10^{-9}$ cm$^2$
Addendum
Middleton, G.V. and P.R. Wilcock "Mechanics in the Earth and Environmental Sciences"

List of known corrections to First Printing
(http://www.science.mcmaster.ca/geo/mwcorrect.htm)

p.49, unnumbered equation above (2.89): delete minus

p.49, lines 2-3 above bottom: delete sentence beginning "The new coordinates..."

p.81, in Equation (3.16) 6 should be 24, i.e. $C_\circ = 24/Re$

p.106, line 23: certain should be shear

p.121, line 10: should read clockwise: $\tau_{xy}(\delta x)^3$ anticlockwise: $\tau_{yx}(\delta x)^3$ i.e., the gammas should be taus, and the exponent should be 3 not 2.

p.207, line 7: in the formula $K$ should be $(k/g)$

p.289, line 1: grad should be div.

p.293, line 2 from bottom: RHS of equation $\rho c_o^2/\lambda$ i.e., switch the numerator and divisor.

p.294, line 4-5: should read between the representative velocity and the speed of sound $C$, in the substance.

p.405, last line of Equation (12.21): RHS should be $XY - bZ$