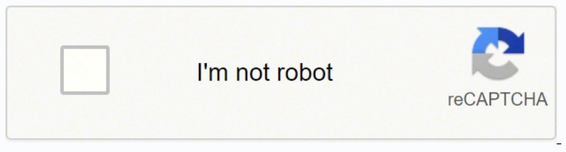

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27346200.351351 9876104047 35424139.444444 20878912.794118 22580291.694444 39934449.388889 24029838.089744 105442764840 11448345.045455 6441228940 33196521.971429 21596516896 20952294.551282 18848372.915493 67957867376 106802267631 15831079.941176 33667056.057692 53002225.421053 30021340.733333 70432572.296296 14683560.032967 5693169724 5670306.8958333 208199885 87894797145 33655839516 10322489.615385

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b) Caleulate how much is saved by the cheaper transection as compared to a straight ditch from PtoS. It usually, also, deter- mines to some extent the method of construction to be adopted. The visual image of cross-sec- tions allows us to appreciate the shape and orien- tation of geological structures. 428º 44097] 1500 1000 m “E Figure 5-14: Geological map, showing outcrop pattern of the lithologies on a base map of topographic contours. tio Figure 5-15: Geological map, showing outcrop pattern of the lithologies on a base map of topo- graphic contours. c) Name the structure seen in the map of Figure 5-6b. Figure 2-2c is a contour map of a steep-sided canyon. The azimuth line CHAPTER 3: Strike, Dip and Map Notation 38 WelJERMARS - Structural Geology and Map Interpretation Azimuth for Direction of dip and azimuth line “= Figure 3-4: The azimuth line is always horizontal and normal to the strike line. The strike of a strike line is always ex- pressed as an angle, but there are several ways to express the compass direction of this angle. Formal acceptance of stratigraphic subdivisions is a process of accreditation by peers, endorsed at meetings of professional societies. DJExercise 3-5: Assume a contractor asks you to plan the cheapest way to construct a narrow, five-meter-deep trench between locations P and S. Estimate the true thickness of the aquifer, using: (a) equation (4-2), and (b) the nomogram of Figure 4-11. 1-9a to c). 4 WeERMARS - Structural Geology and Map Interpretation The structure of rock units beneath the ground surface cannot be seen directly. CHAPTER 4: Geological Cross-Sections 58 WEIJERMARS - Structural Geology and Map Interpretation cal contact surfaces, but, in addition, visually distorts the thickness of all layers, except for vertical beds. This is exactly what the book was written and published for in the first place. 2- 3). b) Properly used symbols follow form lines of the bedding. A provisional outline, sample chapters, and a resume of the principal author(s) should be sent to: Publications Manager, Mr. J. The V-rule is introduced, and simple cross-sections are drawn. sources, (b) preven- CHAPTER 1: Introduction to Structural Geology WEIJERMARS - Structural Geology and Map Interpretation Figure 1-4: Geological structures in a hypothetical region and potential locations for water wells. Any pronounced relief in the ground surface affects the shape of the outcrop pattern, as explained in section 2-2. Visual distortions occurring in differentially scaled cross- sections are outlined in section 4-3. Such unequal length scales are sometimes adopted when base lines are extremely long, and this is particularly common for cross-sections based on the interpretation of seismic reflection profiles. WeiERMARS - Structural Geology and Map Interpretation Exercise 5-5: a) Construct structure contours for both the top and bottom of the sandstone formation in the map of Figure 5-11a. The topographic relief of the landscape can be represented by a series of smoothly curved lines, called contour lines. This id fragmentary infor- «70004 E mation from the E surface geology and -8000 | near-surface struc- tures has to be com- piled into a complete synthesis of the geological subsurface structure. This is because the dip of inclined layers may, in cross-sections without scale exaggeration, vary between zero and the true dip, depending upon whether the profile line is parallel or perpendicu- lar to the strike of that plane. b) Cross-section A-B across the map of (a) illustrates a single homoclinal bed. Figure 4-11: Nomogram relating the true dip, a, to the normalized exaggerated thickness of a layer, T*/T, for a range of vertical exaggeration factors, V. Monitoring the activity of volcanoes is another important field of geological studies. Nevada. The formations in the northwest have been mapped from an aerial photograph and were transferred to a topographic map of the same scale. Answers to the exercises are given in the back of the book. CHAPTER 3: Strike, Dip and Map Notation Chapter 4: Geological Cross-Sections T HE THREE-DIMENSIONAL structure of an area may be effectively illustrated by the combination of a geological map and one or more cross-sections. b) What is its vertical thickness? Civil engineering works involv- ing ground movement include open excavations; drainage networks; trenches; tunnels; under- ground repositories; foundations of dams; bridg- es; and buildings; road cuts; railways; airfields; harbors; land reclamation; and docks (Fig. Originally horizontal strata, which have been warped into domes by tectonic processes, will display eroded outcrop patterns with V-cusps pointing outward from the core of the dome (Figs. If the ground surface is flat, the top and bottom planes of a planar, though inclined, bed will appear on the map as a set of parallel lines. It, therefore, is absolutely essen- the structure of the subsurface. The azimuth/dip notation is shortest and, also, most practical for later ma- nipulation of the directional data in stereonets (treated in Principles of Geological Mapping). Chapter sixteen highlights the importance of aerial photographs and satellite images for map- ping the ground surface. Figure 1-Sa is a snapshot of the destruction caused in the Marina district, San Francisco, by the Loma Prieta earthquake of October 17, 1989. Chapter nine outlines maps of terrains that in- clude various types of unconformities. One danger associated with the interpreta- tion and study of both constructed and natural cross-sections is that sectional distortions are overlooked. d) Map pattern of the 1000+ Gan = [EEE | 1000 sandstone. Contours in thousands of feet below sea level. For example, one possible notation for the strike of the plane in Figure 3-3 is N30ºW, measuring 30º in anti-clockwise direction away from N toward the W, so that the strike line trends NW. Such situations are traditionally referred to as three-point problems, and many examples are included in this chapter. Consequently, the orienta- tion of the layer of Figure 3-3 can be written as: N30ºW/40ºNE or NW30º/40ºNE or N150ºE/40ºNE. Geologists must be aware of these kinds of visual distortions, especially when examining field exposures of rock structures. 2-7a & b). 4-4c). The vertical sides of such block diagrams effectively show cross-sectional views of the subsurface. Such layers form geologi- cal boundaries with V- shapes where incised by river valleys (Fig. Drilled Domestic 130 450 Cavernous zo0e in marblo. However, the various strike/dip notations are employed by many geolo- gists, and, therefore, one must be able to understand all systems used. A layer which dips 90º is vertical. and we can save 700 lira by not tak ing soil tests.” Figure 1-10: Geological site investigations detect unstable ground conditions, which, if undetected, might generate grave problems for the safety and longevity of overlying construction. These can be projected orthogonally on the map surface to obtain a structure-contour map. The strike orientation of the bed immediately follows from the trend of the contours, which is parallel to the strike. Consequent- ly, instructors have to make difficult choices on what material should be covered and what can be left out. TT Suggestions for auxiliary reading are given in Appen- dix A. What will be the thickness as seen in the canyon wall? O Course plan This book is aimed at undergraduate students, already familiar with some of the basic principles of geology as introduced by courses in physical geology or historical geology. b) Determine the true or stratigraphic thickness of the indicated sandstone unit. a) Explain why the contact between the Paleozoic and Precambrian beds seems concordant in the right part of the picture, whereas an angular unconformity appears in the left part. Once it is realized that the lithological contacts are, in fact, outlining the topographic contours themselves, albeit at an un- even spacing, it becomes simple to understand the structure of an area with horizontal beds. Azimuth: Perhaps more practical and straight- forward is to represent a plane not by strike/dip notation, but by its azimuth/dip. The need to combine theoretical explanations with practical exercises applies to many subjects within the geosciences. His degrees were obtained from Beloit College (B.S.), University of Puget Sound (J.D.), and University of Utah (LLM.), USA. The dip of this unit in cross-section will not be the same as the true dip. The eruption of hot magma from the Earth's interior is often localized in zones of structural weakness. a) Before constructing structure contours, infer the approximate direction of dip from the V-rule. Contributions to its development have come, also, from civil engi- neering studies of large construction projects, from the academic community, and from the geological surveys of many nations. CHAPTER 2: Topographic and Geological Maps WENJERMARS - Structural Geology and Map Interpretation 27 Figure 2-11: a) Perspective diagram of a subcircular basin with strata dipping toward the center of the basin. Answer the following questions: a) Which wells have the largest and smallest yields? 5-10d). quence. The base map contains a scale bar, geographical north arrow, geographical gridlines, and location names. Such sections are complementary to geological maps, and their preparation and proper interpretation deserves careful attention. The length/thickness ratio of the central, horizontal sandstone layer, located be- tween the fault plane and the unconformity in Figure 4-10b, is markedly decreased, as com- pared to that in the true-to-scale section in Figure 4-10a. Structural Geology and Map Interpretation provides for students a series of exercises on geological maps, integrated with explanations of basic structural geology. The legend lists the layers with the oldest units below and the youngest units above, maintaining their proper se- Figure 4-5: a) & b) Symbols in cross-sections: a) Inappropriate use of symbols. CHAPTER 5: Structure Contours for Planar Beds Chapter 6: Three- Point Problems and Insertion of Outcrops HE INTERPRETATION Of map patterns, using structure contours, is further explored in this T chapter. which remain as yet undetected due to temporary seismic si- lence. Bound- aries of horizontal layers remain entirely parallel to topographic contour lines and appear as V- shaped stream intersections on the topographic Figure 2-6: Orthographic aerial photograph of a terrain, exposing horizontal beds in the walls of the valleys and on the hillsides. 1-3b). a) Use structure contours to construct the exact azimuth/dip of the layers. The latter method for representa- tion of planar features is strongly recommended and will be adopted throughout this book. The extent of a formation must be large enough to be mappable at the surface or traceable in the subsurface. Figure 5-5a shows a structure-contour map. The layer thickness, T, is artificially enhanced in the exag- gerated section to T+. d) The thickness of most units can be determined; but which two units are of unknown thickness? 2-4). The walls of natural canyons and man-made road cuts are likely to be oblique to the structural strike. More commonly columnar sections are based on detailed strati- CHAPTER 2: Topographic and Geological Maps WEIJERMARS - Structural Geology and Map Interpretation Tr = BUKIT KECIL f Tmoccesaie BUKIT KALONG je cos Bo) % e 13 to are T o 70 z 12 e 6 elaine E vp |s EEE 9 < E — E IA cd (2º Eira) Ê Q >|0/e [EEE q & E 5 < ESSES Z E po preces Pas 15 Essas E o O [ole le Ba »Q BI = Psp no] EE O fele/s E I hi Z os & =: brotam beds 2sjio ab a 14 Ollrlsla ; z T q A oo: W E — 70 à e ! x == E 7 20/3 Eca gs é E Eds E MRE é = Edil : 4 xm dis É é — erssee desing 10 7 ELEEIE) hiaeh ima mário ni /BS tomecstonas se a “ ES e mera” es a 2 Esses & foraminiters istmo mese É I estos cong Ho cine 51 (oeobiy " mudatone”) véi d siheieiostie mudssono ima bdodiy exposed e radioioria Figure 2-17: Columnar section of the Kodiang Formation. 2 is recommended as a full-semester course in combination with many short outdoor trips to demonstrate mapping principles. It has been quoted time and again and, thereby, has become common intellectual proper- ty. Outer mining (of natutal e contour is 10,400 feet below the seabed. [Exercise 3-8: A sandstone aquifer strikes N90ºE and dips 42ºS. Chapter ten summarizes techniques for the 3-D visualization of geological structures, using various types of block diagrams. See exercise 4-4, d) Apparent thickness change The thickness of dipping layers is affected, either more or less, by exaggerating the vertical length scale, depending upon the initial or true dip of the beds. At pres- ent, separate laboratory manuals are some- times used in combination with textbooks covering the contents of lectures. Many existing textbooks in geoscience tend to include increasingly detailed explanations. Courtesy Thomas Lundqvist. b) 2,200 000 1,800 1,600 1,400 Figure 5-11: a) Topographic map with ourcrop pattern of a thick sandstone bed. For example, straight sections through plunging folds cannot show all true dips (see, also, exercise 4-10). Structural geology, also, provides guidelines for the produc- tion and interpretation of geological maps. a) Map view b) Cross-section STS CT Figure 3-14: Map view (a) and cross-section (b) of three igneous dikes of identical thickness (A, B, and C). Guidelines for subsurface interpretation are poor, and the extrap- olation is largely a matter of personal style and experience. The true dip of any layer will N30ºW E North es 40ºNE É - Strike-angle clockwise S150ºE be obtained only if measured | between the azimuth and plunge lines (Fig. CHAPTER 4: Geological Cross-Sections WEIERMARS - Structural Geology and Map Interpretation 53 direction and amount of dip for all the geological contacts involved (Fig. Similarly, apparent dips, as seen in oblique cross-sections, may be converted to true dips measured in field outcrops. This chapter outlines the nature of these distortions, and provides guidelines for selecting section lines that show the most appropriate view of the subsurface. The orientation of any flat, inclined geological surface can be determined using the elevation of at least three points on that surface. 13 “,.. Their helpful suggestions and comments contributed to esta- blishing a reliable text in a tedious process of writing, rewriting, and editing. c) Exaggerated thickness Exaggerating the vertical length scale in cross- sections not only exaggerates the dip of geologi- vertical exaggeration = 1 vertical exaggeration = 8 Figure 4-10: a) & b) Distortion of angles occurs in non-isometrically scaled sections. 57 b) Distortion of angles Figure 4-10a illustrates a cross-section, with horizontal and vertical scales equal, portraying a faulted sequence unconformably overlain by another, onlapping sequence of sedimentary rocks. 3-15a): T=Wsina (3-2) CHAPTER 3: Strike, Dip and Map Notation WEIJERMARS - Structural Geology and Map Interpretation 47 a) e180 Chalk (Limestone) North Downs e 200 Ui PPer Greensana (Estj Gault (Mudstone) e 100 1100 6 e 100 Lower Greensand (Sandstone) 105 Wealden Beds (Mudstone) e 100 e190 “190 200 m e 200 98 e b) 200m 100 - Figure 3-18: a) Geological map of part of the English basin. The outcrop pattern on the flat ground surface is formed by the two traces of the top and bottom surface, which are two lines of constant spacing if topographic relief is negligible (Fig. They, also, may reveal the necessity of specific measures needed to stabilize the foundations of the work and other rock faces nearby. True Acute angle between strike and line of section, à dip, 025 5 10 15 20 25 30 35 40 as so ss so 6s 70 80 90 a ooo o o o o o o 0 º 0 0 0 o o o o o 5 000 05 10 1.5 20 20 25 30 30 3.5 40 40 45 45 50 50 5 10 0 05 10 20 25 3.5 40 50 60 65 70 80 80 85 90 9.5 10.0 10 15 0 10 1.5 30 40 50 6.5 80 9.0 10.0 11.0 11.5 12.5 13.0 13.5 14.0 15.0 15 20 0 10 20 35 5.5 70 9.0 10.0 120 13.0 14.5 15.5 16.5 17.5 18.0 19.0 20.00 20 25 0 10 20 45 70 9.0 11.0 13.0 15.0 170 18.0 20.0 21.0 220 23.0 240 25.0 25 30 0 1.5 30 60 80 11.0 140 16.0 18.5 20.5 220 240 25.0 26.5 27.5 28.5 29,5 30 35 020 3.5 7.0 10.5 13.5 16.5 19.5 22.0 240 26.5 28.0 30.00 31.0 32.5 33.5 35,5 35 4 020 40 80 120 16.0 19.5 23.0 26.0 28.5 30.5 33.0 340 36.0 37.0 38.5 39.5 40 4 0 2.5 5.0 10.0 14.5 19.0 23.0 26.5 30.0 33.0 35.0 37.0 390 41.0 420 43.0 44.5 45 So O 3.0 60 11.5 170 220 270 31.0 34.5 37.5 40.0 42.5 44.0 46.0 47.0 48.0 49.5 50 55 0 40 70 14.0 200 26.0 31.0 35.5 39.5 42.5 45.0 47.5 49.5 S10 52.5 53.5 545 55 60 O 45 85 16.5 240 30.5 36.0 41.0 45.0 48.0 S10 530 55.0 56.0 57.5 58.5 59.5 60 65 O 5.5 10.5 20.5 29.0 36.0 42.0 470 51.0 S40 56.5 58.5 60.0 620 63.0 63.5 64.5 65 7 O 6.5 13.0 25.5 35.0 43.0 49.0 54.0 57.5 60.5 630 64.5 66.0 67.0 68.0 69.0 69.5 70 75 O 9.0 18.0 33.0 44.0 520 57.5 62.0 65.5 67.5 69.0 70.5 720 730 73.5 740 750 75 80 O 13.5 26.5 44.5 56.0 63.0 67.5 70.5 73.0 74.5 76.0 770 780 78.5 79.0 79.5 80.00 80 85 O 26.0 45.0 63.5 71.5 75.5 78.0 80.0 81.5 820 83.0 83.5 840 840 84.5 84.5 85.0 85 90 - 90 90 90 90 90 90 90 90 90 90 90 90 90 90 90 90 90 90 90 DJExercise 3-3: Figure 3-1la shows a map, and the true dip of the layer is constructed in a section normal to its line of strike. DJExercise 2-6: Construct a columnar section scaled for the stratigraphic units of the area mapped in Figure 2-14. The map patterns of both upright horizontal and plunging folds are ex- plained. This book, was written in the 1990s, and sponsored by Uppsala University (Sweden) and King Fahd University of Petroleum and Minerals (Saudi Arabia). 3-3). is similarly divided into 90 degrees of south- ern latitude. The geological conditions are best considered before any design or construction starts - in order to avoid major trouble and cost escalation that may otherwise develop during or subsequent to the construction project (Fig. Conversely, it is simple to infer the strike and dip of the original bed from its structure contours. Other notations write NW30º, instead of N30ºW. Chapter three explains the use of dip, strike, and azimuth of units for characterizing the orientation of geological features. Exercise 5-2: Figures 5-6a and b are structure-contour maps for the top of a limestone bed. The coastline of an oceanic island outlines the contour line at sea level (Fig. I encourage readers to bring any suggestions for further improvement of any aspect of this work to my attention. If the surface trace of the profile is oblique to the structural trend, an apparent thick- ness of layers would be seen rather than the true thickness. 2-4 Columnar sections Geologists divide sedimentary rocks into formations. c) Which is the least representa- tive? A/boran Science Pub- lishing welcomes inquiries from experienced geoscientists, who would like to contribute to its program with original titles. Exercise 2-5: Construct a N-S vertical eross-section along trace A-B across the map of Figure 2-14. CHAPTER 2: Topographic and Geological Maps WENERMARS - Structural Geology and Map Interpretation 37 True dip: The true dip of a layer is measured within an imaginary vertical plane, normal to its strike line (Fig. e) Where is the highest peak of the area? Such exhaustive books are very helpful for use in advanced studies and in research pro- grams. (3-1)]. The true dip is an angle varying between 0º and 90º. Dr. Weijer- mars joined the Department of Earth Sciences at KFUPM in 1992. The salt is mechanically excavated, rather than dissolved - a common technique for salt extraction elsewhere - and is used as a raw substrate for industrial processes. A detailed understanding of the fundamental techniques of geological map inter- pretation is more important than ever, and the many exercises in this book aim to help the user achieve this end. represents the angle of dip. The use of the V- cusps, outlining the litho- logical boundaries where transected by drainage patterns, to estimate the dip direction of the rock contact is known as the V-rule for dipping strata. Active marketing and distribution ceased in 2001, but bookshops from around the world kept ordering the book for their clients. b) Complete the outerop pattern of the entire map, assuming that no faults transect the un- mapped area. On such geological maps, local irregularities in the terrain greatly affect the map pattern of rock formations. include folds, uniformly tilted strata, unconform- ities, faults, fractures, intrusions, and collapse features, all of which are outlined in this book. The Figure 3-3: The geographical orientation of the strike line is measured as an angle away from the north, but may be measured either clockwise geographical orientation of strike lines is mea- sured as an angle away from the north but may be measured either clockwise or anti-clockwise. 800 f E 800 600 - 600 400 400 200 200 Sea level - - Sea level Figure 5-lla shows the outcrop pattern of another sandstone formation, dip- ping eastward in a terrain of steep topographic relief. Figure 1-3a shows a view inside the Jefferson Island Salt Mine, Louisiana. 4-3 Scaling of sections Kt is vital to understand the detailed geometric implications of vertical exaggerations in structural profiles. The labeling of the section may be done either by lettering (Fig. The mathematical expression used to obtain true dips from apparent dips of strata in sections oblique to strike was given in chapter three [eg. CHAPTER 4: Geological Cross-Sections 64 WeiJERMARS - Structural Geology and Map Interpretation form true dips from geological maps to apparent dips on cross-sections, and vice versa. 3-14a & b, dike C). b) Explain why the thicknesses of the Precambrian beds in the left and right parts of the picture appear almost similar, despite the different orientations of the canyon slopes. Figure 5-7a illustrates the outcrop pattern of a very thin limestone layer in a terrain of topographic relief. Show both the topography and the position of the coal seam. CHAPTER 1: Introduction to Structural Geology WELJERMARS - Structural Geology and Map Interpretation in those particular regions where conditions of slope instability occur. The main text is further developed as follows. The azimuth is always measured clockwise away from the north. Contour lines trend up the valley, cross the stream, and extend down the valley on the opposite side. CONVERSION FACTORS OF LENGTH SCALES ARE GIVEN IN TABLE 1-2. Exercise 1-2: Refer to the map of Figure 1-7b. Fax: + 31 20 364 0145. Users praised the book for its practical approach. A very informative example of this effect occurs on layers of constant thickness, but with gradual changes in the amount of dip (Fig. Further instructions for profile construction are given in section 4-2. 5-5b): a=tan'!(x/d) (5-1) The map of Figure 5-Sa immediately reveals the azimuth/dip of the contoured layer as 270º/45º. Each of the four cases shown includes a single straight rock formation, sloping (or dipping): (a) west- ward, (b) vertically, (c) eastward, and (d) hori- zontally. Chapter fificen summarizes the geological map patterns related to meteoritic impacts, landslides, sinkholes, and glacier movement. 4-13a), which appear on the exaggerated cross-section with lateral changes in thickness (Fig. Correspondingly, four basic map inter- CHAPTER 2: Topographic and Geological Maps WEIJERMARS - Structural Geology and Map Interpretation 23 a) Downstream dip b) Vertical dip (A c) Upstream dip d) Horizontal dip Ts Figure 2-4: a) to d) Perspective views and map patterns of a simple valley, cutting into a single straight bed in various orientations. [JExercise 2-2: Determine the geographical coordinates of your own location using a geo- graphical atlas or maps avail- able to you. b) E-W section across the map of (a). Such sections serve to clarify the sub- surface structure. This book is intended for self-study, use in university courses and/or professional training. Angular differen- ces between steeply dipping surfaces are reduced. These distortions depend on: (1) the relative scaling of the horizontal and vertical axes in the section, and (2) the way in which the section cuts the 49 actual structure. Figure 2-2d shows the margin of a mountainous area in the southeast with a drainage pattern running off toward the more gently sloping terrain in the northwest. Doubly plunging and recumbent folds are, also, briefly outlined. The V's on map patterns of Figures 2-5b and 2-7b differ in the sense that the Vºs point more or less randomly in the dendritic erosion pattern of Figure 2-5b but point in uniform direction for the dipping layers of Figure 2-7b. 2-9a & b; 2-10). d) Topographic contours have not been drawn separately on the map, but indicate all contour elevations, given that the contact between bed O and S is at 1000 meters above sea level and all other beds are 100 meters thick. The lectures are carefully organ- ized and balanced in approach. Similarly, the central Figure 4-13: a) & b) Appearance of folded layer of constant thickness in: (a) isometrically scaled, and b) vertically exaggerated cross-section, two- fold (V=2). Methods are outlined to aid the interpretation of such remote sensing maps. Ameeruddin. c) Color the parts of the map where the subsurface does not contain coal. The following preparatory 17 courses are recommended: (1) physical geology for a broader understanding of geological pro- cesses that shape the Earth's interior and exterior and (2) sedimentology, mineralogy, and petrology for a better understanding of the matter of which rocks are built. Figure 5-10a illustrates a sandstone forma- tion, dipping gently eastward. CHAPTER 4: Geological Cross-Sections WEERMARS - Structural Geology and Map Interpretation 59 a) Horizontal & vertical scale equal 10º a 55º vw “= Figure 4-12: a) & b) Isometric and vertically exaggerated cross-sections (V=8). 1-10). He is a member of the American Association for the Advancement of Science, the Geological Society of America, the American Association of Petroleum Geologists, and the New York Academy of Sciences. Figure 5-6: a) & b) Two structure-contour maps, studied in exercise 5-2. If a layer dips close to (but not exactly) 90º, it is said to be subvertical (meaning more or less vertical). The episodic series of earthquakes in California is caused by horizontal slip over segments of the San Andreas fault system. a) Construct five different cross- sections: along lines P-Q, P-R, P-S, P-T, and P-U. The vertical plane of measurement intersects the dipping layer along an inter- Strike-angle anticlockwise section line or plunge line. But, in some circumstances, depth scales of cross-sections are deliberately exaggerat- ed with respect to the horizontal scale. Structural geology is a practically oriented branch of the earth sciences which aims to study the architecture of the solid Earth and other plan- ets. b) Construct one W-E cross-section, passing over the two mountain peaks in the map area. See exercise 5-7. DExercise 4-7: A sandstone bed dips 60º due east. Cross- sections provide a powerful means to demonstrate the geological structure of an area. CHAPTER 2: Topographic and Geological Maps 28 WeEaMaas - Structural Geology and Map Interpretation DJExercise 2-3: Figure 2-13 shows a geological outcrop pattern of horizontal strata in an area eroded by a dendritic drainage pattern. The longi- tude lines of 180º E and 180º W coincide in a meridian which, theoretically, defines the international date line. Weathered rock zones and alluvium usually provide extremely good well-sites, especially if hydrologically connected to streams and lakes. Potential contributors are encouraged to submit comprehensive proposals. In the latter case, the strati- graphic thickness of the mapped units is estimated from the map and compiled in a columnar section to illustrate their relative thickness. Figure 3-12: Geological map of a stratigraphic sequence with units A to D. See eg. Figure 2-14: Topographic map with incomplete geology to be analyzed in exercise 2-4. 4-6b & c). Contours are in feet. a) Sketch in red pencil, on the map of Figure 3-12, the cheapest pathway of the trench. Rock samples, carefully -2000 indicated on sample location maps, are collected for further “aoog a study by light mi- -3000 7 croscopy of thin -5000 + sections or other ad- O vanced analyses. This course is ideally followed by a coordinated field project (no. The true or normal thickness, T, is seen on a map only if the layers are exactly vertical (Fig. Layers of dip, a, and map width, W, have, in vertical cuts at angle ô to their strike, an apparent thickness, T,: TA=W sinftan'(tan o sin 0)J/sin à (44) The true thickness, T, relates to map width, W, and dip, «, by: T=Wsina (45) Consequently, the thickness exaggeration factor, TWT, is: Ta/T=sinftan“(tan a sin 6)]/(sin a sin 6) (4-6) 63 Equations (4-4) and (4-6) are invalid if ô equals zero. The determination of azimuth/dip from three elevation points of a rock surface and the completion of the associated map patterns are discussed in sections 6-3 and 6-4 for surface and subsurface data, respectively. The first part refers to a locality where the formation is clearly exposed; the second part of the name indicates the dominant rock type. Figure 1-6a illustrates the eruption of hot lava from the Surtsey volcano, off the coast of Iceland, which first emerged above the sea in 1963. Attempt to be as realistic as possible, and, therefore, use the surface observations close to the line of section as a starting point. Drillod Observation 125 15.0 Alluvium and fractures near diko, S. Careful mapping of existing sinkholes may reveal the movement path of major subsurface flows and, thereby, delineate areas threatened by future sink- hole formation. Four major application areas of structural geology can be distinguished: (a) rock structures. Site investigations will help avoid upward spiral- ling of costs during construction and minimize the risk of an unexpected geological hazard damaging the work. This assumes equal horizontal and vertical scales. The normalized exaggerated thickness, T'T, is dependent on the vertical exaggeration factor, V, and the original layer dip, a: T'/T=[V/cos a] cos[tan!(V tan 0)] (4-2) Instead of using [Exercise 4-4: Figure 4-12a is a true-to-scale cross-section, illustrating two verti- cal igneous dikes separated by a sedi- mentary sequence tilted at 10º. The variations in width of the various lithological units is only apparent and arises from the way in which the ground surface intersects the southward-dipping beds. He received a Ph.D. in geodynamics from the University of Uppsala in 1987, and BS and MS degrees in geology and structural geology, respectively, from the University of Amsterdam. -9000 + -10000 -11000 | õ Structural geology is here principally considered as the descriptive study of structural geology Structural geology describes rock struc- tures not only for the sake of academic interest. Discussed are: inliers and outliers, three-point problems, and the insertion of outerops. The chapters are organized as outlined below. e) Determine the true or stratigraphic thickness of each layer, and represent the result as a columnar section. Contents: The basic principles of elevation contours are explained in section 2-1. These suggestions will be taken into account and will help to prepare any updated version of this book. Similarly, volcanogenic structures include a range of associated fissure patterns and, therefore, deserve some attention in an intro- ductory text of structural geology. A connection must be made between what is perceived on the map and other knowledge. In folded terrains it is common to as- sume that the stratigraphic thickness of the layers will remain constant within the plane of the cross- section (Fig. The corre- sponding thickness exaggeration factor then becomes: T,/T=1/sin(90º-a). Secretarial support was provided by Gulam Khan, Khaled Khan, Azeez “An easy to follow and very well-illustrated book on a diffi- cult subject” - M.l. HUSSEIN, President Gulf Petrolink. However, a short introduction to computer programs, aiding the interpretation of geological maps, is given in the final chapter. Cross-sections serve to clarify the subsurface structure, usually as seen in a vertical plane. CHAPTER 5: Structure Contours for Planar Beds 72 WeisERMARS - Structural Geology and Map Interpretation Exercise 5-4: The map of Figure 5-9 shows the outerop pattern of a thin coal bed traced from an orthogonal aerial photograph and transferred to a topographic contour map of the same scale. Figure 1-4 shows how groundwa- ter availability and its use, in a hypothetical region, relate to the geological features in the Table 1-1: Well data for Figure 1-4. The understanding of rock deformation struc- tures is of great eco- nomic importance. 6-1). Finally, the cross-section will be complete only if the units are clearly labeled and their symbols are explained in a legend of the units. For example, the true unconformity angle is 5º, but it appears as 27º in the exaggerated section. Driled Farm 20 250 Weathered granito and fault zone. BREMBERG s technical editor for the Alboran Lecture Series. One important aspect is the apparent increase in the dip of both the faults and the layers. The structure contours of the top surface and bottom surface of the formation are mapped in Figures 5-10b & c. 2, Drilled None 200 0.1 Very small amount from joints. If small local deviations in dip of several degrees occur, the sheet is termed subhorizontal, which means the layer is more or less horizontal. The geological structures of interest may CHAPTER 1: Introduction to Structural Geology 14 wesERMARS - Structural Geology and Map Interpretation GEOLOGICAL MAP OF THE gyesim MUSCHELKALK. Chapters eleven and twelve concentrate on map patterns of faulted rock units. Chapter eight discusses the use of form lines and explains the principles of structure contours in analyzing map patterns of horizontal and plunging folds. Contours are in meters. b) Where does the water of the fault zone in well number one come from? E sl el o 8 8) 8 el | d al q a 2 ss S g 8 8 FS Sagas c) Bottom contours E sagas d) Surface map oo É ago = CHAPTER 5: Structure Contours for Planar Beds 74. The terms formation (lower case f) and Formation (upper case F) are used to distinguish between informal and formal use of a stratigraphic unit. However, various kinds of dis- tortion of the form and orientation of rock struc- tures may arise in such cross-sections. The thick- ness of sedimentary beds, visually exaggerated in sections oblique to the strike of the beds, can, also, be inferred using the thickness exaggeration factors, included in the nomogram of Figure 4- 18. a) Map N so Section Section e) Figure 3-11: a) Map view and section of a bed dipping westward. Structural field mapping, therefore, is an important means of gaining understanding of seis- mic hazard zones. Columnar sections show the sequence of rocks and their characteristics and include the subdivi- ion into formations and members (Fig. T T s0ºE OE Precambrian Basement at Surface Contours in thousands of feet Figure 5-3: Structure-contour map of the top of the Precambrian basement of the Arabian Peninsula. Careful mapping of the geological structures outlines both the extent of previous mass wasting and may help to identify potential future slide masses. In other words, the outcrop pattern is the intersection of the structure and the topography as defined by their contours. Dhahran, 23 June 1996 Chapter 7: Introduction to Structural Geology A GEOLOGICAL MAP is a medium of communication that uses graphic symbols to represent spatial relationships among geographical and geological feautures. This relieves instructors from painstaking compilation work. Each chapter requires about one or two lectures and one laboratory session. Angular differences between shallow dipping contacts are increased. 1-2 Importance of formations are pre- sented in structural maps, field sketches, and photographs. The symbols used in cross- sections are classically bound to a particular lithology (Fig. The contours form a V-shape, pointing upstream and uphill near the stream origin. This will necessitate examination of the site of the work. Isopach maps are, also, discussed. A formation may be subdivided into members, which in turn may include distinctive beds. The dip of the bed, a, can be inferred from the horizontal spacing between the projected contour lines, d, and the contour interval, x, using (Fig. The map pattern of Figure 5-lla is much more com- plex, solely due to the way in which the eroded topo- graphy cuts the bed. Igneous intrusives are associated with ring dikes, cone sheets, and mantled gneiss-domes, all of which vii The author, using geological maps to discuss the geological setting of the Mylonite Zone at Vaermlandsnaes, during a short course for the Geological Survey of Sweden, 1992. The site study must always be considered in conjunction with, and is condi- tioned by, information available from previous geological studies of the area. The geological conditions at the site of construc- tion will determine the cost of the operation. This book concentrates on the principal terms and techniques employed in the description and map representation of geological structures. The present book further differs from other texts through the inclusion of concise chapters on igneous structures (chapters 13 and 14), exogenic structures (chapter 15), and the use of remote-sensing maps (chapter 16). a) Color the scar of the 1925 Gros Ventre slide in red, the slide deposit in green, and the Gros Ventre Lake in blue. It is simply impossible to trace the genuine origin of the concepts discussed, because each of them has evolved slowly by incremental contributions of numerous scientists. The construction of cross-sections across any geological structure involves the risk of several geometric distortions. CHAPTER 4: Geological Cross-Sections WELJERMARS - Structural Geology and Map Interpretation [Exercise 4-3: The Clemente-Tomas and Corsair fault systems are prominent structural features beneath the sub- merged floor of the Gulf of Mexico. A canyon cuts the bed at 45º to its strike. Conventionally mea- sured clockwise, azimuth may vary between 0º and 360º. In this textbook, the geometric description of geological structures is deliberately separated from genetic interpretations concerning their for- mation. Faulted, homoclinal Table 1-2: Conversion of length scales. The apparent dips and thicknesses in oblique cross-sections may give misleading views of the structure of a re- gion. Another important reason for orienting profile lines normal to the regional strike of sedimentary layers is that their thick nesses appear as true thicknesses, unlike those in (b) by using equation (3-2). The rock types in such sections are indicated by conven- tional symbols. Thickness exaggeration relates to the true dip, «, through the section angle, ô. The steepness of the domes is entirely artificial, due to exaggeration of the depth scale. If only one course is available to cover all elementary aspects of structural geology, then topics on stress and strain have to be included as well, For such condensed courses, selected chap- ters of this book can be supplemented with material and exercises on stress and strain from the companion text, Principles of Rock Mechan- ics. 2-1a). Figure 2-13: Geological map studied in exercise 2-3. Groundwater, excluding the amount of water trapped in ice sheets and glaciers, accounts for about ninety percent of the available freshwater. 1-5b). Professional topographic maps are framed in an outline with tick marks indicating latitude and longitude in degrees and minutes. corbonate root Sia Ssomice zen BUNTSANDSTEIN: clostie rock PaLgozoic PERMIAN endesite formetion am A isa quortaite) Vallejo Hondo E auortne) coimodorro Lustal shote formetion 4 pesaing route “with sense of O displocement. Sinkholes, or sudden collapse features, occur in limestone strata due to subsurface solution by carbondioxide-charged acidic groundwater. There is a growing trend in the industry to remove such exaggerations where possible, because they introduce problems to structural interpretations. But, fre- quently, the material of textbooks and sepa- rate laboratory manuals do not easily blend. However, lithological notation is not standardized and many different symbols are in use throughout the world. [Exercise 2-4: Figure 2-14 shows an incomplete geological map. b) Map view and section oblique to the strike of the bed. c) Planning and site investigation Every new construction operation is likely to cause changes in the existing condition of the ground surface. See exercise 5-4. The true thickness and true dip of sedimentary beds are seen only if the cross- section is oriented perpendicular to the strike of the beds. CHAPTER 2: Topographic and Geological Maps WEIJERMARS - Structural Geology and Map Interpretation 29 Tf layers dip uniformly, their direction of dip can commonly be inferred from aerial photographs and geological maps. SCIENCE lboran € About the author Dr. Ruud Weijermars is Associate Professor at King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia. The even spacing indicates a homo- clinal bed. Their feedback has helped to test the adequacy of the text and exercises and has resulted in the improvement of this first printing. [Exercise 4-8: A subhorizontal Paleozo- ic top sequence (1.5 Kkilometers thick) rests unconformably on the Precambrian Grand Canyon Series, which dip gently to the NW (Fig. Contents: Section 6-1 introduces the terms inlier and outlier, commonly used to describe map patterns. CHAPTER 3: Strike, Dip and Map Notation WENJERMARS - Structural Geology and Map Interpretation 39 Map symbols: The strike line and dip direc- tion of a layer are repre- sented on the geological map by structural sym- bols, as indicated in Fig- ure 3-5. It needs to be inferred by making skillful use of the data avail- able from surface studies of rock outcrops in road cuts, mountain slopes, and other erosional surfac- es. Contents: The aims and nature of structural geology as a discipline are discussed in section 1-1. Spot elevations (dots) are in meters. The engineering of large constructions carved into or anchored in solid rock requires detailed knowledge of the subsurface geologic structure. Criteria for the selection of a section line and the various sources of distortions in sectional views are outlined. Obtain the answer in two different (but similar) ways: (a) ap- plying equation (4-1), and (b) using the nomogram of Figure 4-8. CHAPTER 3: Strike, Dip and Map Notation WELJERMARS - Structural Geology and Map Interpretation 43 Exercise 3-4: Figure 3-12 is a geologi- cal map with stratigraphic units labelled A to D. Structural Geology and Map Interpretation Ruud Weijermars Alboran Science Publishing Detailed Contents Structural Geology and Map Interpretation Preface to the series Outline of the series Preface for this book Chapter 1: Introduction to Structural Geology 1-1 What is structural geology? Outhuis, Laurierstraat 132A, Amsterdam 1016 PR, the Netherlands. If not observed in the field, the relative resistance to erosion, indi- cated in the relief of the stratigraphic column, can be tentatively inferred from the rock type. An effective teaching program covering most aspects of structural geology in a systematic fashion could include the following core courses: (1) structural geology and map interpretation, (2) geological field mapping and report writing, (3) field project, (4) mechanics of rock deforma- tion, (5) tectonics, and (6) modeling of rock deformation. d) What is the true thickness of the sandstone formation? He is registered with the Board of Registration for Professional Geologists, State of Wyoming, and serves on the Editorial Advisory Board of the Journal of Natural Re- sources & Environmental Law. d) Regional mapping The geological survey teams of all modern nations are continually engaged in the preparation of detailed geological maps of their countries. True and apparent thicknesses are partly controlled by the angle, ô, measured between the section line and the strike Table 4-1: Factors of thickness exaggeration for layers of true dip, a, cut oblique at angle ô. b) Which section gives the best view of the subsurface strue- ture? See exercise 4-8. Chapter one has provided an introduction to the subject of structural geology by explaining the practical situations that led to its development as a scientific discipline and its applications. part of depocenters may appear thickened on vertically exaggerated seismic sections, purely as an apparent visual, rather than a real, feature. The dip of this formation is similar to that occurring in the map of Figure 5-10d. 6-1 Inliers and outliers Shallow dipping rock strata tend to give very intricate outcrop patterns on the map in terrains of pronounced topography (Fig. Determine the true thickness of the aquifer: (a) by construction of a sketch map and a cross-section, and oblique sections. The inclusion of nu- merous exercises urges receptive and reflective study of the subject matter. Lime- stone and sandstone commonly form steep cliffs, while shale and marl are much softer and erode more rapidly into gentle slopes. The discipline has emerged from the need in the mining and petroleum industry to understand better the structure of rock formations that host mineral and energy resources. And because most geoscience courses include weekly laboratory sessions, instructors, also, have to find suitable exer- cises to help students deepen their grasp of the subject. If no single rock type dominates the formation, it is simply referred to as the Rus formation, Dammam formation, and so forth. A thorough understanding of the variety of geological structures is particularly important, because it helps to determine the nature of subsurface structures from geological maps. 3) of several weeks where students can develop their individual mapping skills. d) Complete cross-sections A-B and C-D. 52 WeiJERMARS - Structural Geology and Map Interpretation a) Topographic profile Contacts (at correct angles) and temporary labels Partially completed section Completed, partially labeled section Figure 4-4: a) to d) The construction of geological cross-sections: a) Topographic profile, b) Transferral of surface dips from map to section, c) Extrapolation of surface data to depth, d) Completed section. Alboran's Lectures in Geoscience integrate exercises intimately with explanations of basic principles. 79 The people of Iceland are extremely familiar with recurrent Figure 1-6b: Iceland is split between two worlds. c) Color the part of the map where the subsurface does not contain the sandstone formation. If these two scales are un- equal, both the dip and thickness of layers will be only apparent and not true, as explained in detail in the next chapter. Such contours can be used to determine geological strikes and dips. Cross-sections intend to show the form and orientation of geological structures in the subsurface. b) Give the azimuth/dip for the top of the Pre- cambrian basement for the area to the east of its surface outcrop. All of the material discussed is well-established among experts. 4-4b). Figure 1-9b: Underground marine dock, excavat- Figure 1-9c: Geological site investigations en- ed in the Precambrian rocks of the Baltic shield, sured the stability of the walls and floor of the Sweden. Detailed study of the site itself, including full-scale tests of the rock in situ, is a desirable means of further eliminating some of the uncertainties arising from the prepar- atory studies in major rock stability investiga- tions. DExercise 1-1: Study the block diagram of Figure 1-4 and the associated data of Table 1-1. Accessory fea- tures, also, may be indicated by special symbols, and their meaning is explained in a legend to the columnar section. The increasing importance of computerized data manipulation, connected to geological maps and other display methods, is outlined. Exercise 3-1: Refer to Figure 3-7, and consider the layer attitude in the locations marked A and B. The smaller the dip of such inclined layers, the greater their apparent thickness or width, W, as seen on maps cutting obliquely through them (Fig. It investigates the de- Figure 1-1: Structure contours (in plan projection and exploration for and tailed structure of Felief view) of the Ekofisk oilfield, North Sea. That is why instructors commonly resort to working through exercises from a variety of sources, and often supplied to students in the form of a collection of photocopies. are basic geological structures with intricate map patterns. These may include field trips, computer demonstrations, and additional reading and exercises. Only sections oblique to the regional structures and parallel to the trace of the planned trenches and tunnels can show what rock units will be encountered and where (see exercises 3-4 & 3-5). 3, Drilled Stock 690 0.5 Small amount, aresian, from joint, 4. CHAPTER 4: Geological Cross-Sections WENERMARS - Structural Geology and Map Interpretation TE DiExereise 5-1: a) Examine the map of Figure 5-3, and calculate the average slope of the top of the Precambrian. Preface for this book O Emergence of this book - Why? Moreover, strikes of all units are not always parallel. Figure 4-19: View of the Grand Canyon from Lipan Point, about fifty kilometers east from the visitors" center. beds are discussed first, followed by fold patterns displaced by several types of faults. smaller cinder cones. The thickness of inclined layers in vertical cuts oblique to strike is exaggerated and appears with an apparent thickness, T,. The strain ellipse scales the exagger- ation. I am grateful to the following reviewers for their efforts on the quoted chapters of Structural Geology and Map Interpretation: Richard Lisle, University of Wales, UK (Chapter 1); Moujahed Husseini, Gulf Petrolink, Bahrain (Chapter 2); Steve Rey- nolds, Arizona State University, USA (Chapter 3); Ben van der Pluijm, University of Michigan, USA (Chapter 4); David Roberts, Geological Survey of Norway (Chapter 5); Peter Johnson, US Geological Survey Mission, KSA (Chapter 6); Peter Hudleston, University of Minnesota, USA (Chapter 7); Ian Davison, University of London, UK (Chapter 8); Clive Boulter, University of Southampton, UK (Chapter 9); Martin Jackson, University of Texas, USA (Chapter 10); Adrian Pfiffner, Univerity of Bern, Switzerland (Chapter 11); Steven Wojtal, Oberlin College, USA (Chapter 12); Jean-Luc Bouchez, Université Paul-Sabatier, France (Chapter 13); John Roobol, Deputy Ministry for Mineral Resources, KSA (Chapter 14); David Gee, University of Lund, Sweden (Chapter 15); Weston Gardner, KFUPM Research Institute, KSA (Chapter 16); Gabor Korvin, King Fahd University of Petro- leum and Minerals, KSA, Brian Gratto, Saudi Aramco, KSA, and Paul Williams, University of New Brunswick, Canada (Chapter 17). 4-1 Location of sections Geological maps are commonly accompanied by cross-sections, illustrating the geological struc- ture of the region. Each unit is shown with the stratigraphic thick- ness scaled vertically, so that the relative thick- ness of units and the contact relationship between them become clear at a glance. The movement of groundwater is largely con- trolled by the nature and structure of the geologi- cal formations. A better understanding of each of these hazards comes from careful 1=San Andreas Fault 2=Calaveras Fault 3= Hayward Fault 4 = Garlock Fault 5= Santa Ynez Fault 6 = Nacimiento Fault 7 = San Gabriel Fault 8 = Elsinore Fault 9 = San Jacinto Fault investigations of the geological structures associated with these phenomena. Consequently, the thickness of a folded sequence will be attenuated in seismic sections on the hinge zones. If the layer dips upstream, a V-shaped intersection reappears on the topographic map and the V points down dip (Fig. c) Are there any unconformable stratigraphic relationships? MACIZO DE NEVERA tolas Figure 1-11a: Geological map of'the Macizo de Nevera, Sierra de Albarraccin, central Spain. Likewise, dips of layers in such oblique sections are apparent rather than true. a) Original isometric section. Chapter seventeen is the final chapter of this book. The orientation of strike lines should not be confused by ways of measurement, and it is, therefore, useful to agree upon which convention you follow when exchanging data on strike angles. d) A lime- stone bed concordant with the sandstone bed is known to have a true thickness of 200 meters. Amount of dip is indicated. Chapters thirteen and fourteen outline the map pattern and tectonic aspects of intrusive and extrusive igneous structures. It is, therefore, extremely important always to include in any cross-section clear information, concerning the vertical exaggeration factor. 4-4d) or by using litho- logical symbols. Technical assistance was provided by many professionals: Jeanette Bergman Weihed, with her efficiency in digital drafting; Bertel Giôs and Christer Beck, with their high quality pho- tography; and Nancy Taylor and Blair Bremberg, with their superb editing. a) Map E E E E 8 8 8 8 2 & 8 s — d+ |-— d— |. In such oblique cross-sections, all true dips need to be transformed to apparent dips. The usual conven- tion (USA) is that the first letter denotes the direction from which to measure the angle and the last letter denotes the direction to measure in. therefore, do not correspond to any non-horizon- tal slope of the beds. Figure 5-9: Topographic contour map with outcrop pattern of a thin coal bed. Use the same symbols as on the map. 4-19). Transla- tions of the introductory text on the back cover of this book have been provided by: Abdul-Latif Qahwash, King Fahd University of Petroleum and Minerals, KSA; Vladislav Alekseev, Univer- sity of Graz, Austria; Lu Chia-Yu, National Taiwan University; Julia Cuevas, Universidad del Pais Vasco, Spain; Jean Louis Vigneresse, CREGU, France; and Stefan Schmid, University of Basel, Switzerland. The well-yields depend upon the hydrogeological subsurface structures (Table 1-1). 9.Dug Now 1502 Small amou from joinis, 10. The implications of this relationship are as follows: (1) Structure contours can be con- 69 structed if the outcrop pattern and the topographic contours are known. A considerable number of engineering disasters could have been averted by careful geological site investigation. It is often hard to conceive that such sections of real rock surfaces may show misleading, distorted views. However, faults can be traced in the field by care- fully mapping of the abrupt displacements of otherwise smooth geological bound- aries, even in the ab- sence of any seismic noise. Part of the problem of accurate forecasting of any future earthquakes is that newly formed faults may emerge anytime and generate new earth- quakes. Drillod Industry 160 35.0 Alhuvium end fault zone. 6. — d— 100m b) Section 400 m : | x=dtana

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