University of Baghdad

College of Science

Department of Geology

MORPHOTECTONICS

Fourth Stage

Second Course

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2019-2020

Lecture One

Morphotectonic Definition:

The term morphotectonic can be apply to tectonic interpretation of geomorphological features of earth surface through focusing on study of the origin and development of these feature, and their tectonic and structural relationships, and it is rather considered as a synonym of tectonic geomorphology.

Active Tectonics: - Is the study of dynamic tectonic processes that shape the landscape and have an impact on human society.

Tectonic Geomorphology: - Is the part of active tectonics that is concerned with landforms produced by tectonic processes and the application of geomorphic principals to tectonic problems.

Tectonic geomorphology has become one of the principal tools in variety of applications, including identification of active faults, formation of geologic structures, seismic-hazard assessment, and the study of landscape evolution.

Tectonic geomorphology has proven tobe useful in these applications because tectonically produced landforms are created and preserved over time intervals ideal for recording landscape change.

- In practice, the morphotectonic approach frequently means using landforms or any other surface feature (i.e. drainage pattern) as an indicator to infer the existence of tectonic features in relatively stable areas where seismicity and present-day rates of uplift and subsidence are negligible.

Advances in topics such as buried reverse faulting, active fold growth, earthquake recurrence, climate change, isostasy, and long-term landscape evolusion continue to redefine our understanding of tectonic and geomorphic processes.

Geomorphology: - Is the study of the nature, origin, and evolution of the landscape.

Landforms are surficial features at all scales that constitute the landscape.

Landforms depend on geologic structure, rock and soil types, weathering, erosion, volcanism, and deformation.

Topography is a balance between erosion and tectonic uplift.

Neotectonics: - The study of the young and recent movements taking place at the end of the Tertiary and the first half of the Quaternary.

Neotectonics can be broadly described as tectonic events and processes that have occurred in post-Miocene time.

Morner(1990) takes the view that the neotectonics phase starts at different time in different places depending on the tectonic regime.

Neotectonic is a branch of tectonic concerned with understanding earth movements that both occurred in the past and continuing at the present day.

*Morphotectonic is the study of the relationship between neotectonic structures and landforms.

(it is referred to as tectonic geomorphology)

Time scales

● Tectonics – study of large scale deformation and earth evolution processes at scales of millions to tens of millions of years.

● Neotectonics – thousand to tens of thousand years.

● Active tectonics – happens during a persons lifetime.

INTERNATIONAL STRATIGRAPHIC CHART

International Commission on Stratigraphy

ICS | IUGS

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma
Phanerozoic	Cenozoic	Neogene (Quaternary *)	Holocene		0.0118
			Pleistocene	Upper	0.126
				Middle	0.781
				Lower	1.806
		Neogene	Pliocene	Gelasian	2.588
				Piacenzian	3.600
				Zanclean	5.332
			Miocene	Messinian	7.246
				Tortonian	11.608
				Serravallian	13.65
				Langhian	15.97
				Burdigalian	20.43
				Aquitanian	23.03
		Paleogene	Oligocene	Chattian	28.4 ±0.1
				Rupelian	33.9 ±0.1
			Eocene	Priabonian	37.2 ±0.1
				Bartonian	40.4 ±0.2
				Lutetian	48.6 ±0.2
				Ypresian	55.8 ±0.2
			Paleocene	Thanetian	58.7 ±0.2
				Selandian	61.7 ±0.2
				Danian	65.5 ±0.3
	Mesozoic	Cretaceous	Upper	Maastrichtian	70.6 ±0.6
				Campanian	83.5 ±0.7
				Santonian	85.8 ±0.7
				Coniacian	89.3 ±1.0
				Turonian	93.5 ±0.8
				Cenomanian	99.6 ±0.9
			Lower	Albian	112.0 ±1.0
				Aptian	125.0 ±1.0
				Barremian	130.0 ±1.5
				Hauterivian	136.4 ±2.0
				Valanginian	140.2 ±3.0
				Berriasian	145.5 ±4.0

* proposed by ICS

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma
					145.5 ±4.0
Phanerozoic	Mesozoic	Jurassic	Upper	Tithonian	150.8 ±4.0
				Kimmeridgian	155.7 ±4.0
				Oxfordian	161.2 ±4.0
			Middle	Callovian	164.7 ±4.0
				Bathonian	167.7 ±3.5
				Bajocian	171.6 ±3.0
				Aalenian	175.6 ±2.0
			Lower	Toarcian	183.0 ±1.5
				Pliensbachian	189.6 ±1.5
				Sinemurian	196.5 ±1.0
				Hettangian	199.6 ±0.6
		Triassic	Upper	Rhaetian	203.6 ±1.5
				Norian	216.5 ±2.0
				Carnian	228.0 ±2.0
			Middle	Ladinian	237.0 ±2.0
				Anisian	245.0 ±1.5
			Lower	Olenekian	249.7 ±0.7
				Induan	251.0 ±0.4
	Paleozoic	Permian	Lopingian	Changhsingian	253.8 ±0.7
				Wuchiapingian	260.4 ±0.7
			Guadalupian	Capitanian	265.8 ±0.7
				Wordian	268.0 ±0.7
				Roadian	270.6 ±0.7
			Cisuralian	Kungurian	275.6 ±0.7
				Artinskian	284.4 ±0.7
				Sakmarian	294.6 ±0.8
				Asselian	299.0 ±0.8
		Carboniferous – Pennsylvanian	Upper	Gzhelian	303.9 ±0.9
				Kasimovian	306.5 ±1.0
			Middle	Moscovian	311.7 ±1.1
			Lower	Bashkirian	318.1 ±1.3
		Carboniferous – Mississippian	Upper	Serpukhovian	326.4 ±1.6
			Middle	Visean	345.3 ±2.1
			Lower	Tournaisian	359.2 ±2.5

Eonothem Eon	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma
					359.2 ±2.5
Phanerozoic	Paleozoic	Devonian	Upper	Famennian	374.5 ±2.6
				Frasnian	385.3 ±2.6
			Middle	Givetian	391.8 ±2.7
				Eifelian	397.5 ±2.7
			Lower	Emsian	407.0 ±2.8
				Pragian	411.2 ±2.8
				Lochkovian	416.0 ±2.8
		Silurian	Pridoli		418.7 ±2.7
			Ludlow	Ludfordian	421.3 ±2.6
				Gorstian	422.9 ±2.5
			Wenlock	Homerian	426.2 ±2.4
				Sheinwoodian	428.2 ±2.3
			Llandovery	Telychian	436.0 ±1.9
				Aeronian	439.0 ±1.8
				Rhuddanian	443.7 ±1.5
		Ordovician	Upper	Hirnantian	445.6 ±1.5
				Stage 6	455.8 ±1.6
				Stage 5	460.9 ±1.6
			Middle	Darriwilian	468.1 ±1.6
				Stage 3	471.8 ±1.6
			Lower	Stage 2	478.6 ±1.7
				Tremadocian	488.3 ±1.7
		Cambrian	Furongian	Stage 10	~ 492.0 *
				Stage 9	~ 496.0 *
				Paibian	501.0 ± 2.0
			Series 3	Stage 7	~ 503.0 *
				Stage 6	~ 506.5 *
				Stage 5	~ 510.0 *
			Series 2	Stage 4	~ 517.0 *
				Stage 3	~ 521.0 *
			Series 1	Stage 2	~ 534.6 *
				Stage 1	542.0 ±1.0

This chart was drafted by Gabi Ogg. Intra Cambrian unit ages with * are informal, and awaiting ratified definitions.

Eonothem Eon	Erathem Era	System Period	Age Ma
			542
Precambrian – Proterozoic	Neo-proterozoic	Ediacaran	~630
		Cryogenian	850
		Tonian	1000
	Meso-proterozoic	Stenian	1200
		Ectasian	1400
		Calymmian	1600
	Paleo-proterozoic	Statherian	1800
		Orosirian	2050
		Rhyacian	2300
		Siderian	2500
Precambrian – Archean	Neoarchean		2800
	Mesoarchean		3200
	Paleoarchean		3600
	Eoarchean	Lower limit is not defined	

Subdivisions of the global geologic record are formally defined by their lower boundary. Each unit of the Phanerozoic (~542 Ma to Present) and the base of Ediacaran are defined by a basal Global Standard Section and Point (GSSP), whereas Precambrian units are formally subdivided by absolute age (Global Standard Stratigraphic Age, GSSA). Details of each GSSP are posted on the ICS website (*www.stratigraphy.org*).

International chronostratigraphic units, rank, names and formal status are approved by the International Commission on Stratigraphy (ICS) and ratified by the International Union of Geological Sciences (IUGS).

Numerical ages of the unit boundaries in the Phanerozoic are subject to revision. Some stages within the Ordovician and Cambrian will be formally named upon international agreement on their GSSP limits. Most sub-Series boundaries (e.g., Middle and Upper Aptian) are not formally defined.

Colors are according to the Commission for the Geological Map of the World (*www.cgmw.org*).

The listed numerical ages are from 'A Geologic Time Scale 2004', by F.M. Gradstein, J.G. Ogg, A.G. Smith, et al. (2004; Cambridge University Press).

Lecture Two

Morphotectonic studies evolution:

1- Traditional morphotectonic studies:

During the 1960s and 1970s studies or simplistic morphtectonic studies were concerned with the more obvious associations between landforms and geological structure. The landforms were taken an indicators of their structure origin even before geophysical data were available to confirm the assumed link between form and structure (e.g. fault scarps, rift valleys).

2- Recent morphotectonic studies:

In recent years there have emerged a number of new approaches to the study of morphotectonic. These are:

A- Use of new techniques:

These studies are more complicated techniques of recording crustal deformation and surface movements, like Geodetic data and levelling (e.g. measurement of water levels).

These techniques provide data about present-day neotectonics while the traditional studies are concerned with the sum of effects over a longer period of time (e.g. since the Miocene).

B- New types of data:

This new data extend the range of morphological responses to tectonic activity such as river channel sinuosity, slope morphology and scarp slopes.

C- Application to earthquake prediction:

The role of morphotectonic in earthquake prediction has been small. Morphotectonic studies have been concentrated on postdication not predication.

These have been concerned with the study of landforms resulting from tectonics, not the prediction of tectonics.

3- Future morphotectonic studies:

Which consists the following

A- New data:

Since the coming of new dating techniques (e.g. C^{14}, U-series, amino acid racemization) more precise evidence has been gathering on the ages of landforms that have been involved in the morphotectonics.

B- Geomorphological theory has changed:

More changes happened in the concepts of geomorphological theories, e.g. river terraces are accepted by most workes in morphotectonic field as an indication to base level change or river incision is a response to tectonic uplift or tilting but it has been shown that river terraces can be created by changes in sediment load without any influence such as tilting or base level change.

C- New approaches:

Like remote sensing techniques, GIS and GPS in addition to geophysical methods in determining the neotectonic activity to the subsurface structures.

Neotectonic movement character:

1- The neotectonic movements are not affect on topography and surficial structures only but also on deep structures in earth crust.

2- Most of the neotectonic features are epiorogenic that represent uplift or subsidence movements.

3- Most of the neotectonic structures are inherited from older structures and other are superimposed structures.

The first neotectonic study in Iraq was (AEE) study (Atomo Energo Project) which drew a neotectonic map of Iraq scale 1:1000000. This study regarded the neotectonic beginning in Iraq was upper Miocene.

We conclude, the earth movements happened after Miocene age to present day are of more important in constitute the morphotectonic features to any region.

• The great challenge to scientists is the potential difficulty in the recognition between the geomorphic features that result from surface processes and these that formed by tectonic activity. Thus, the successful morphotectonic studies commonly required appropriate analyses using new (data, techniques), that concern testing and applying a suitable approaches to geomorphic problems according to the geological characteristics of studied area.

Remote sensing techniques:

The satellite images provide synoptic view of a wide coverage over the area of interest, and enabling the detection of regional geomorphological features. As well as important information such as structural patterns are extracted from images.

The direct recognition of the tectonic features on satellite images is based on the concept of morpho-structures. Faults, joints and lineaments most likely have a rectilinear exposure on images and their determination depends on morphological features or in particular patterns.

Satellite images were used to delimit fold shapes and to mark locations and diversions of the stream network.

Image interpretation:

A visual interpretation of the satellite images carried in terms of conventional elements of visual analysis are: tone, color, size, shape, texture, pattern, site and association of the object under investigation.

The nature of each of these interpretation elements is described below.

1- Tone: is a measure of the relative amount of light reflected by feature, and can be recorded on black and white or grey level. As it may be colored in the case of satellite images. Tone element is more related with the other elements such as texture, pattern, shape and shadow.

2- Shape: or form is an important factor in geologic interpretation of the remote sensing data. It describes the external feature of an object, such as alluvial fan, linear valleys.

3- Pattern: refers to the spatial arrangement of visibly discernible feature. This element was utilized for detecting of the drainage pattern of the rivers, and alluvial fan.

4- Texture: was defined as the frequency of tone changed within the image, and it is produced by the aggregation of unit features which are too small to distinguish individually on the image.

5- Association: the identification of features that one would expect to associate with other features may provide information to facilitate identification, such as ox-bow lake that associated with alluvial plain landforms.

Lecture Three

Quantitative Morphotectonic analysis methods:

Quantitative morphotectonic parameters:

Quantitative morphotectonic parameters such as morphotectonic features, basin area, basin relief, drainage density, stream frequency, hypsometric integral and drainage pattern analysis are used to study the active tectonics and morphological relationships.

These indices measure scale of the topography relative relief, texture of dissection and volume of rocks in drainage basins.

Geomorphic analysis of fluvial systems is a valuable tool for locating zones of active compressive tectonics.

The geomorphic indices that useful in studies of active tectonics include:

1- Stream longitudinal profile.

2- Stream length- Gradient index.

3- Sinuosity.

4- Ratio of valley floor width to valley height.

5- Drainage basin asymmetry and shape.

6- Hypsometric integral.

1- Stream longitudinal profile: -

The longitudinal profile is a property of stream geometry that can provide information about the underlying materials, geologic processes and the geomorphic history of the area.

Rivers: are among the most prominent landscape features that have impact on the earth surface through erosion and deposition processes.

It may consider sensitive to any changes in their grade caused by tectonic effects where it is closely associated with active structures which in true are responsible for variation in channel morphology, fluvial process, and hydrological characteristic of a river system.

Graded river: one in which the relationship between process and form is stationary and the morphology of the stream remains constant over the time.

When a river is in dynamic equilibrium with it is surrounding, it is slope, channel width and depth are adjusted to the discharge and load.

The equilibrium state of a river is a condition of balance between erosion and deposition, then the river is termed graded.

Any change in one of the controlling factors will displace the equilibrium.

The longitudinal profile of a graded river is steepest at the source and flattens smoothly toward the mouth. Irregularities in the profile are not uncommon and are called knick points.

Threshold of critical power in streams:

A geomorphic threshold is a transition point or period of time that separates different modes of operations within part of landscape system.

The threshold of critical power is defined as:

Stream power/Critical power = 1.0

Stream power: is the power available to transport sediment load while critical power is the power needed to transport sediment load.

Where stream power is more than sufficient to transport an imposed sediment load, and additional sediment load is obtained by vertical erosion that cuts V-shaped cross-valley profiles in bed rock. Where stream power is insufficient, parts of the saltating load will stop and the bed of the stream will aggrade.

Stream at the critical power threshold are sensitive to changes in climate, base level, and impact of human, these may change stream and/or critical power and result in aggradations or degradation.

In reaches where stream power exceeds critical power, vertical erosion predominates, but lateral erosion predominates where a stream is close to the threshold. Lateral erosion tends to be permanent as indicated by the presence of straths and flood plains.

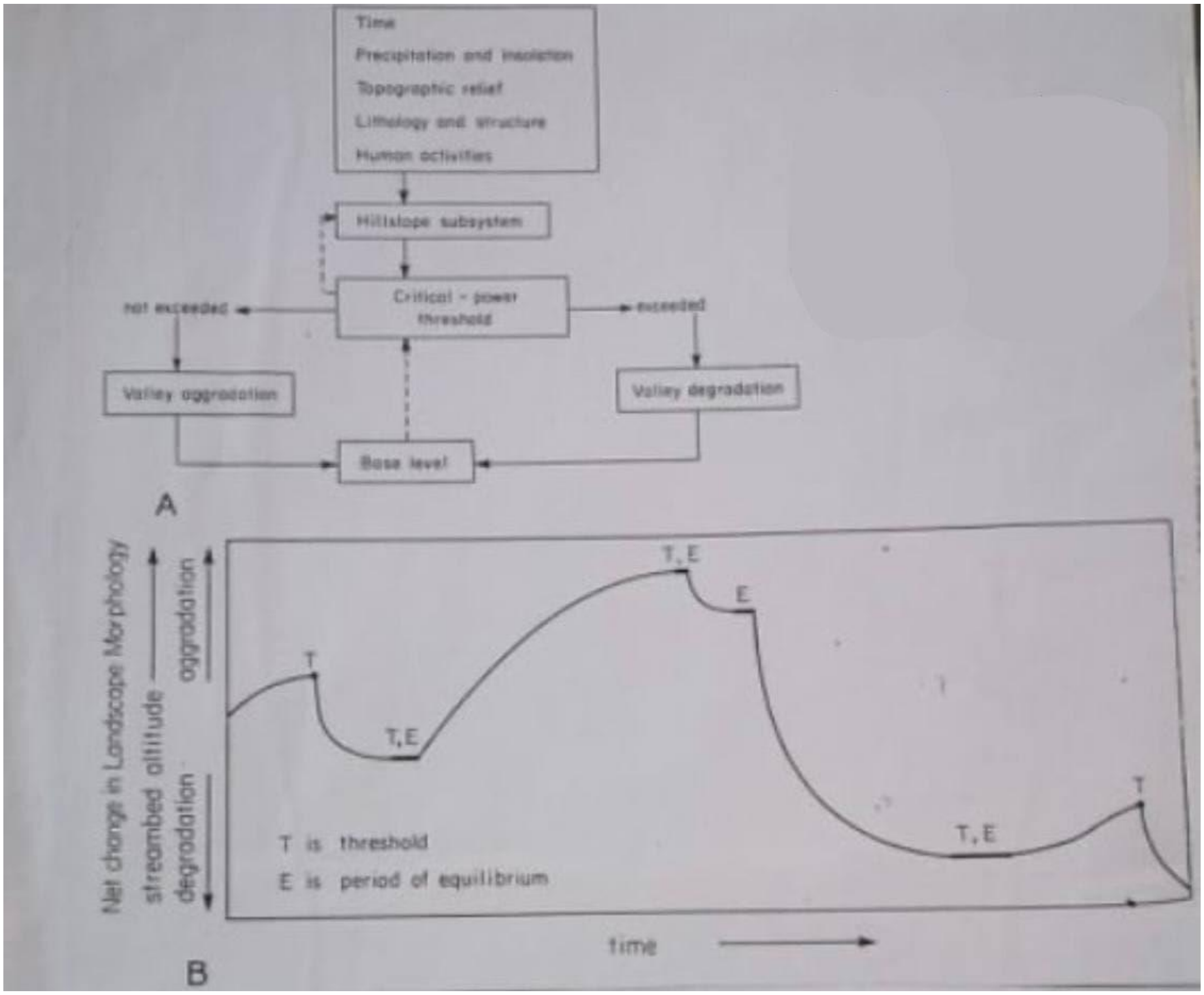


Fig. 1. Basic elements of fluvial system. A. Intercalations of variation and threshold. Feedback mechanisms shown is dashed line with arrow. B. Digressions sketch showing difference between threshold and equilibrium concept lie hypothetical swean subry. Huruupans of curve represent times of no change in stream bed altinule.

The interrelation between a threshold and feedback mechanism is outlined in fig. 1, A. Change in base level affects the gradient, and thereby stream power, which determines whether sediment only transport or net aggradation or degradation occurs at the foot of a hill.

B. Shows the difference between the threshold and equilibrium concepts. Periods of equilibrium are threshold when they separate different modes of operation of the system.

Lecture Four

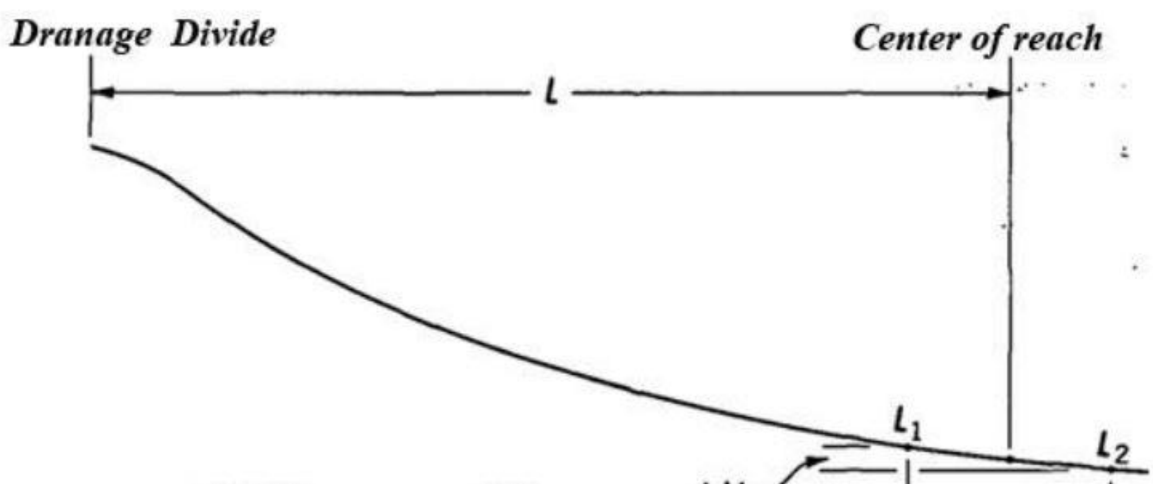
One method of analyzing the longitudinal profile is the: -

2- Stream length- Gradient index : SL or GI

This index relates the slope of a stream at a locality to its length at the locality and provides a basis for comparing stream reaches of different sizes.

Calculating of Gradient Index: -

The gradient index can be measured on topographic maps, on aerial photographs using photogrammetric methods, or by ground surveys.



$$SL = \frac{\Delta H \times L}{\Delta L} \text{ or } \frac{\Delta H}{\log_e L_2 - \log_e L_1}$$

Figure 1

L: Is the stream length measured from the drainage divide at the source of the longest stream in the drainage basin.

ΔH: The difference in elevation between the ends of the reach.

ΔL: The length of the reach.

The reach must be long enough.

As L/ΔL is a dimensionless ratio, the measurements of horizontal distance can be in any unit of measure.

As the contours on map in feet for example then the quantity ΔH will be calculated in feet.

Also profiles can be studied graphically by plotting on semi logarithmic graph paper or by converting length measurements to logarithms and plotting on arithmetic scales.

The gradient index is a significant quantity because it is related to the power of a stream of transport material of a given size and to the characteristics of the channel that resist flow.

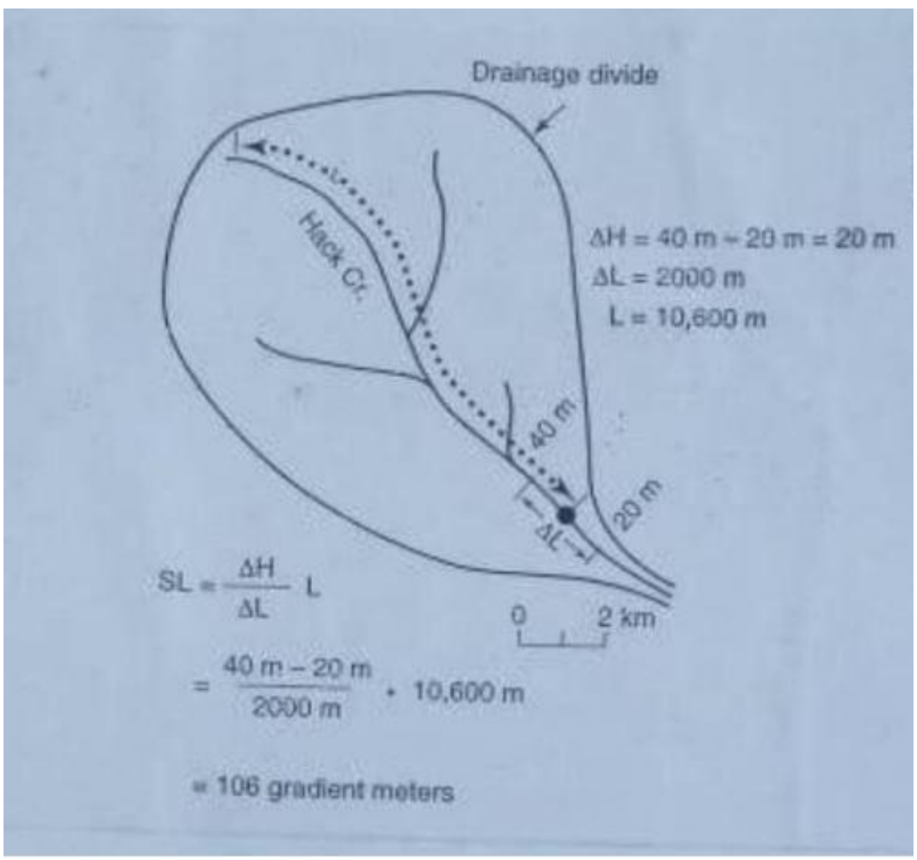


Figure 2. Idealized diagram showing how stream length -gradient SL index is calculated for the hypothetical Hack Creek.

The SL index is sensitive to changes in channel slope, and this sensitivity allows the evaluation of relationships among possible tectonic activity, rock resistance and topography.

The index increases significantly where the river crosses the relatively hard rocks (Metamorphic, Carbonate and S.st rocks), while the index decreases on relatively soft rocks (Shale, Siltstone).

The SL index is used to identify recent tectonic activity by identifying high index values on a particular rock type.

High value suggests perhaps an active fault zone along the river profile or high uplift rate.

Field work need to examine evidence for presence of resistance rocks or active tectonics will help differentiate between various interpretations concerning the pattern of values of the SL index.

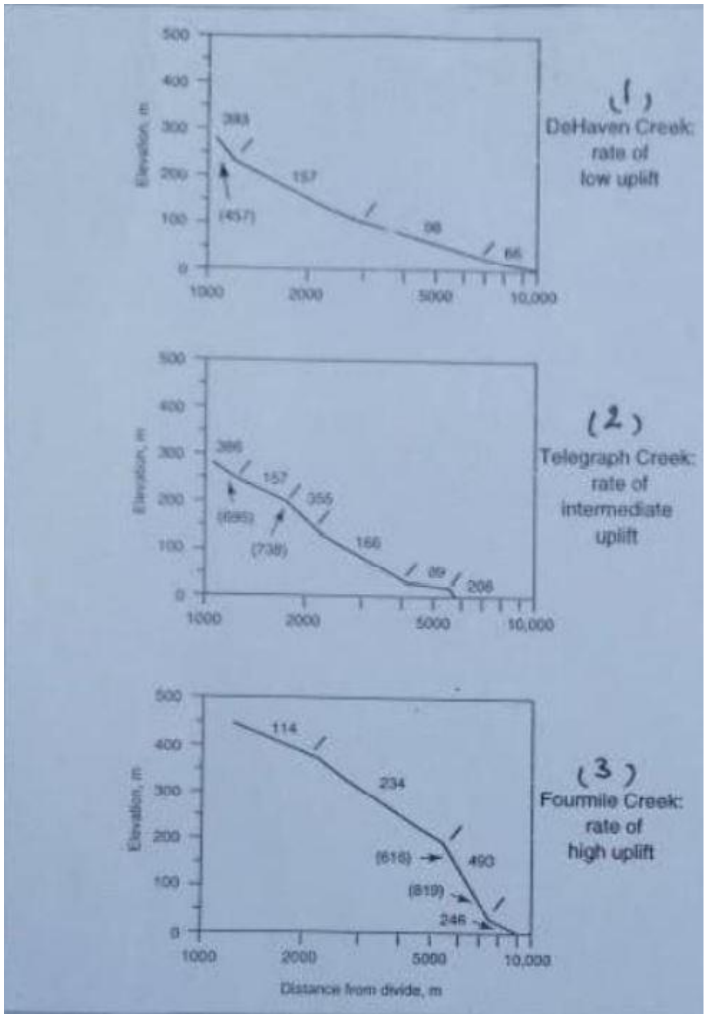


Figure 3. Stream length gradient (SL) indices for streams in areas of contrasting rates of uplift.

SL index allow discrimination between streams characterized by high to intermediate uplift rates and stream characterized by low uplift rates.

Figure shows the profiles of three streams along with average SL index for stream reaches. In (1) an area with a low uplift rate, less than 1mm/yr, and SL index is also low, except in the head ward part of the stream profile. In (2) an area of intermediate uplift rate, and the SL also of intermediate value. In (3), an area of rapid uplift and has high SL value, as well as a convex profile that is characterized of streams undergoing rapid uplift.

Lecture Five

Knick points:

The longitudinal profile of graded river is steepest at the source and flattens smoothly toward the mouth.

Irregularities in the profile called Knick points, or when a reach of a stream is steepened with respect to the adjoining reaches, it defines a topographic Knick points.

Knick points generally reflect factors that tend to disturb the equilibrium state of the river.

Knick points causes (K.P.)

1. Knick points when a river traverses relatively hard, erosion resistant rocks. (Knick point exist when the differential resistance to erosion persists).

2. Knick point could develop in the absence of tectonism (or eustatic change), when lowering of the base level happened (usually taken S.L.).

The drop in sea level steepens the gradient in the newly exposed reach of the river and increase the capacity of downward erosion. In this case the K.P. marks the intersection of the new, steeper profile with older flatter one.

3. Tectonically generated Knick points can be formed through differential folding or faulting.

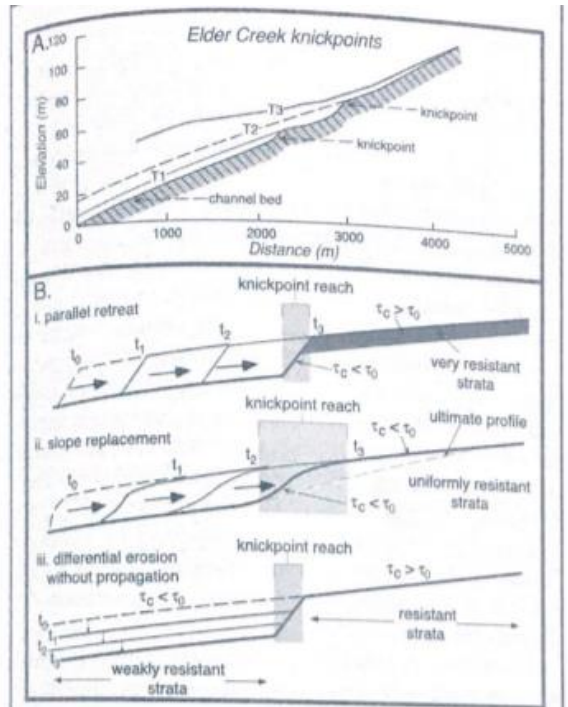
A. Normal faulting: in which the down thrown (H.W.) block is in the downstream direction causes a step (K.P.) to develop in the long. profile of the river.

B. Thrust faulting that uplifts an upstream reach with respect to the downstream reach will create a K.P. .

In either case, the base level of erosion of the upstream segment of the river has been lowered across the fault. Because the river is no longer in equilibrium, it will begin to adjust the longitudinal profile.

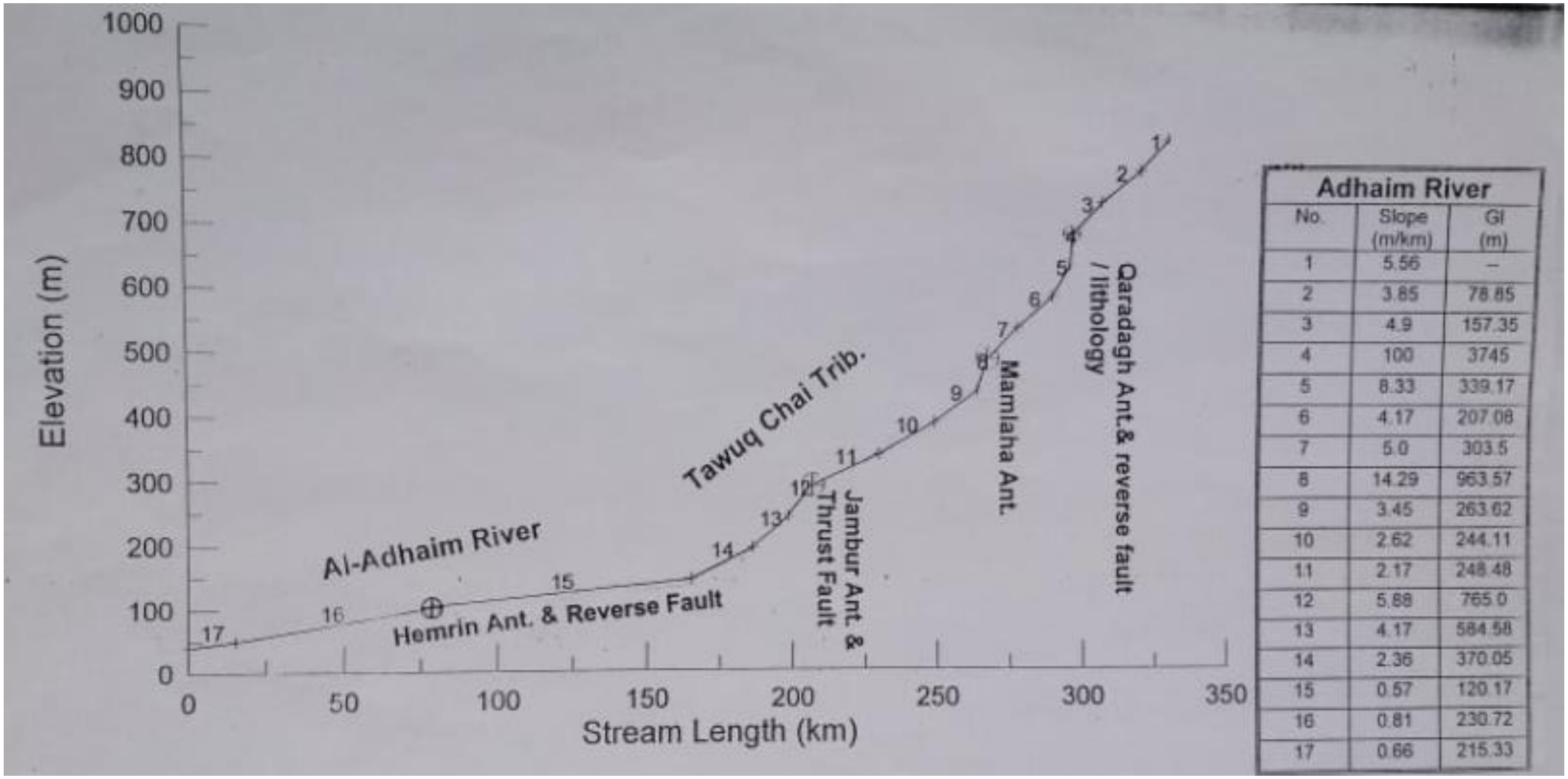
Across the steepened K.P., the stream power will increase due to the increased slope, and erosion of the stream will be enhanced.

The effect of this erosion is to cause the K.P. to migrate or propagate upstream.



A. Longitudinal river profile of Elder Creek, California, showing two knickpoints. The knickpoints are carved in bedrock. T_1 and T_2 represent strath (bedrock) terraces that appear graded to the crest of individual knickpoints. Modified after Seidl and Dietrich (1992). B. Models for knickpoint migration or formation. τ_c = threshold stress to initiate erosion of bed. τ_0 = actual bed shear stress. i) Parallel retreat of the knickpoint through time with the initial shape being maintained. A resistant rock unit caps the units that are being incised. ii) Knickpoint propagation in uniformly resistant rocks with slope replacement during migration. iii) Knickpoint formation due to differential erosion of strata with contrasting resistance to erosion. No propagation is required here. Modified after Gardner (1983) and Seidl and Dietrich (1992).

Figure 1. Development of fluvial knickpoints.



No.	Slope (m/km)	GI (m)
1	5.56	–
2	3.85	78.85
3	4.9	157.35
4	100	3745
5	8.33	339.17
6	4.17	207.08
7	5.0	303.5
8	14.29	963.57
9	3.45	263.62
10	2.62	244.11
11	2.17	248.48
12	5.88	765.0
13	4.17	584.58
14	2.36	370.05
15	0.57	120.17
16	0.81	230.72
17	0.66	215.33

Figure 2. Longitudinal profile of Adhaim River.

Lecture Six

River sinuosity and its relation to active tilting:

The stream channel sinuosity has been defined as the degree to which a river departs from a straight line. The distance between two points on the stream measured along the channel divided by the straight line distance between two end points is called sinuosity ratio which is used to determine whether a channel is straight or meandering.

$$\text{Sinuosity index} = \frac{\text{Talwag line length or channel length}}{\text{Length of meander belt axis}}$$

$$\text{Or } S = \frac{\text{channel length}}{\text{valley length}} = \frac{C}{V}$$

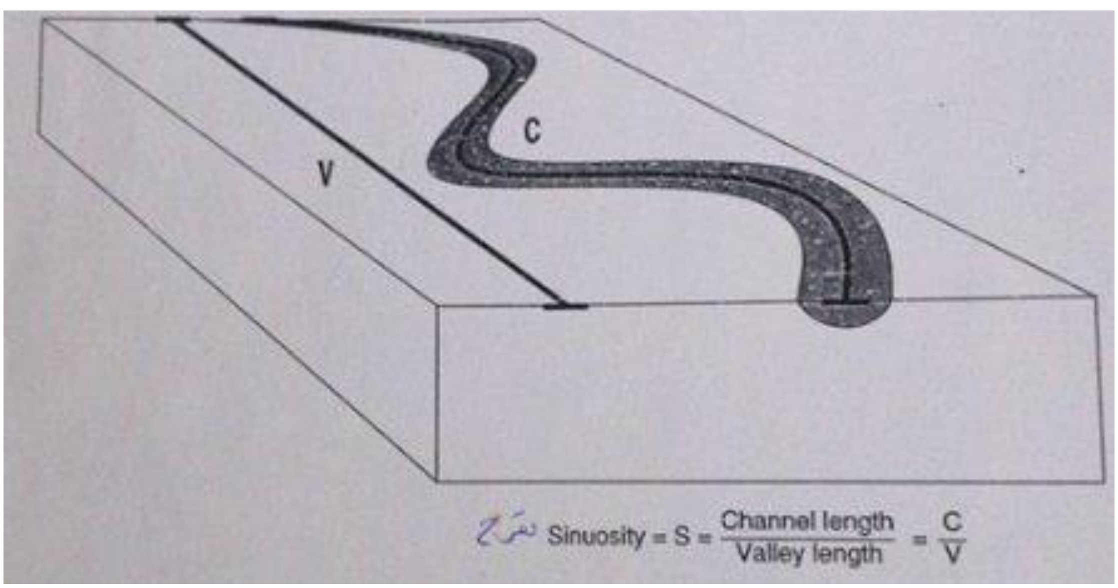


Figure 1. Definition and calculation of the sinuosity of a meandering river channel.

To measure the sinuosity index (S), topographic map, aerial photos and satellite images can be used. By using measuring wheel or digital methods to measure the lengths.

For river sinuosity to adjust to crustal tilting, the river must be free to migrate laterally and vertically and so must flow on alluvium and not be narrowly bound between rock bluffs.

Any tectonic deformation that changes the slope of a river valley may result in a corresponding change in sinuosity to maintain the equilibrium channel slope.

Tilting along the profiles can have two directions:

- Positive tilt (uplift or anticline) tends to decrease the gradient of the river valley and becoming less sinuous and straightening its channel.

- Negative tilt (subsidence, syncline) tends to increase the gradient and becoming more sinuous.

Tectonic deformation is not the only cause of river sinuosity change, and sinuosity change is the only river adjustment to deformation.

Bull and Mc Fadden (1977) determine the river sinuosity values and classify the sinuosity into three classes according to the activity of tectonic movement that involved in the regions:

- Sinuosity index between 1.2-1.6 indicate active tectonics

- Sinuosity index approached to 3 indicate moderate to slightly tectonic

- Sinuosity index greater than 7 indicate tectonically in active

Ratio of valley floor width to valley height (V_f)

$V_f = 2V_{fw} / [(E_{ld} - E_{sc}) + (E_{rd} - E_{sc})]$

Where V_f is the valley floor width-to-height ratio

V_{fw} is the width of valley floor

E_{ld} and E_{rd} are elevations of the left and right valley divides

E_{sc} is the elevation of the valley floor

When calculating V_f, these parameters are measured at a set distance from the mountain front for every valley studied.

This index differentiates between broad-floored canyons, with relatively high values of V_f, and V-shaped valleys, with relatively low values.

- High values of V_f are associated with low uplift rates, so that streams cut broad valley floors.

- Low values of V_f reflect deep valleys with streams that are actively incising, commonly associated with uplift.

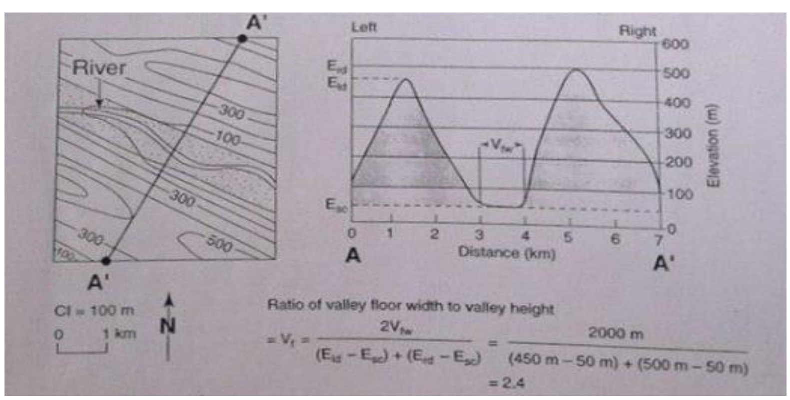


Figure 2. Idealized diagram illustrating how the ratio of valley floor width to valley height (V_f) is calculated. Note: Left and right are determined by looking downstream.

Lecture Seven

Drainage Basins Asymmetry:

Where drainage developes in the presence of active tectonic deformation, the network often has a distinct pattern and geometry.

The asymmetry factor was developed to defect tectonic tilting transversals to flow at drainage basin. The asymmetry factor (AF) is defined as: AF = 100 (Ar/At).

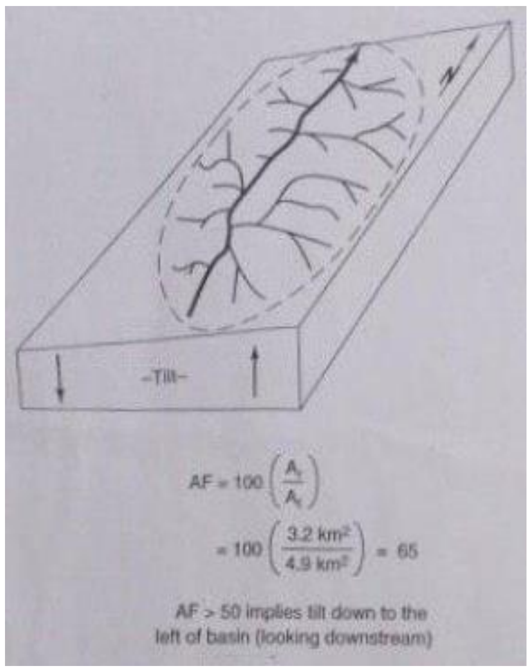


Figure 1. Block diagram showing how the asymmetry factor is calculated.

where A_r is the area of the basin to the right (facing downstream) of the trunk stream, and A_t is the total area of the drainage basin. For most stream networks that formed and continue to flow in stable settings, AF should equal about 50. The AF is sensitive to tilting perpendicular to the trend of the trunk stream. Values of AF significantly greater or less than 50 may suggest tilt. For example, in a drainage basin where the trunk stream flows north and tectonic rotation is down to the west (Figure 1), tributaries on the east (right) side of the main stream are long compared to tributaries on the west side, and AF is greater than 50. If the tilting was in the opposite direction, then the larger streams would be on the left side of the main stream and the AF would be less than 50.

Like most geomorphic indices, the AF works best where each drainage basin is underlain by the same rock type. The method also assumes that neither lithologic controls (such as dipping sedimentary layers) nor localized climate (such as vegetation differences between north- and south-facing slopes) causes the asymmetry [12]. Finally, tributaries to streams that flow down steep regional slopes may be asymmetrical without active tilting, with longer distances between the channel and the drainage divide on the "high" sides of the basin [13].

Another quantitative index to evaluate basin asymmetry is the **Transverse Topographic Symmetry Factor** (T) [4].

$$T = D_a/D_d$$

where D_a is the distance from the midline of the drainage basin to the midline of the active meander belt, and D_d is the distance from the basin midline to the basin divide (Figure 2). For a perfectly symmetric basin, T = 0. As asymmetry increases, T increases and approaches a value of 1. Assuming that the dip of the bedrock can be shown to have negligible influence on the migration of stream channels, then the direction of regional migration is an indication of the ground tilting in that direction [4]. Thus, T is a vector with a bearing (direction) and magnitude from 0 to 1. Values of T are calculated for different segments of valleys (Figure 2) and indicate preferred migration of streams perpendicular to the drainage-basin axis. This analysis is most appropriate to dendritic drainage patterns, where evaluation of tributary valleys as well as the main or trunk valley allows for a larger range of T.

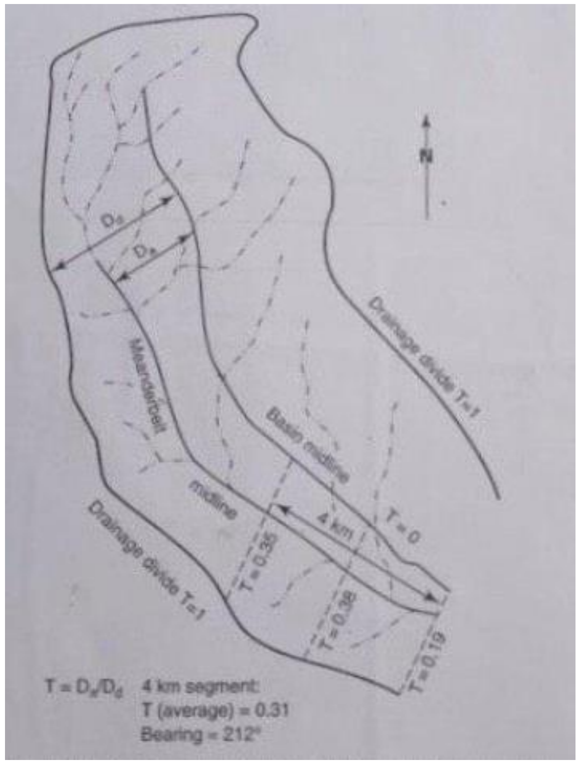


Figure 2 Diagram of a portion of a drainage basin showing how the transverse topographic asymmetry factor (T) is calculated for one stream segment within the basin. (After Cox, 1994 [4].)

Lecture Eight

HYPSOMETRIC CURVE AND HYPSOMETRIC INTEGRAL:

The hypsometric curve describes the distributions of elevations across an area of land, ranging in scale from one drainage basin to the entire planet. The curve is created by plotting the proportion of total basin height (h/H = relative height) against the proportion of total basin area (a/A =relative area) (figure 1) [2]. The total height (H) is the relief within the basin (the maximum elevation minus the minimum elevation).

The total surface area of the basin (A) is the sum of areas between each pair of adjacent contour lines. The area a is the surface area within the basin above a given line of elevation (h). The value of relative area (a/A) always varies from 1.0 at the lowest point in the basin (where h/H = 0.0) to 0.0 at the highest point in the basin (where h/H = 1.0).

A useful attribute of the hypsometric curve is that drainage basins of different sizes can be compared with each other because area and elevation are plotted as functions of total area and total elevation. That is, the hypsometric curve is independent of differences in basin size and relief, there should be no effect of different scales.

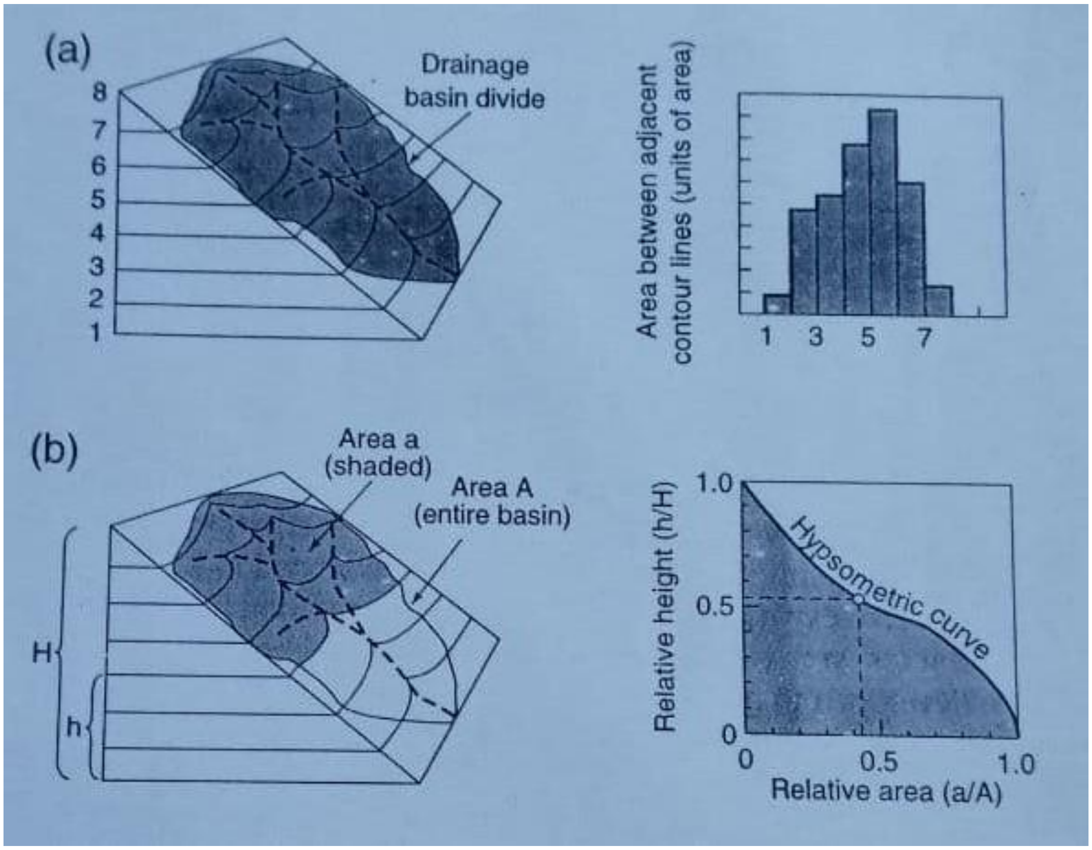


Figure 1 Hypothetical drainage basin showing how one point on the hypsometric curve is derived. Plotting several other values (for different contours) of a/A and h/H allows the curve to be constructed. (After Strahler, 1952 [2] and Mayer, 1990 [9].)

A simple way to characterize the shape of hypsometric curve for a given drainage basin is to calculate it's hypsometric integral (H_i). The integral is defined as the area under the hypsometric curve. One way to calculate the integral for a given curve is as follows [8, 9]:

$$H_I = \frac{\text{mean elevation} - \text{minimum elevation}}{\text{maximum elevation} - \text{minimum elevation}}$$

Thus only three values, two of them easily obtained from topographic map, are necessary to calculate the integral. Maximum and minimum elevations are read directly from the map. Mean elevation can be obtained by point sampling (on a grid) of at least 50 values of elevation in the basin and calculating the mean [8], or by analysis of Digital Elevation Models (DEMs). High values of the hypsometric integral indicate that most of the topography is high relative to the mean, such as smooth upland surface cut by deeply incised streams. Intermediate to low values of the integral are associated with more evenly dissected drainage basins.

The relationship between the hypsometric integral and degree of dissection permits its use as an indicator of a landscape's stage in the Cycle of Erosion. The Cycle of Erosion describes the theoretical evolution of landscape through several stages: a "youthful" stage characterized by deep incision and rugged relief, a "mature" stage where many geomorphic processes operate in approximate equilibrium, and an "old age" stage characterized by a landscape near base level with very subdued relief. A high hypsometric integral indicates a youthful topography (figure 2a). An intermediate value of the hypsometric integral and a sigmoidal-shaped hypsometric curve indicate a mature stage of development (figure 2b). Further development to the old-age stage will not change the value of the integral, unless high-standing erosional remnants are preserved (figure 2c).

In summary, hypsometric analysis remains a powerful tool for differentiating tectonically active from inactive regions.

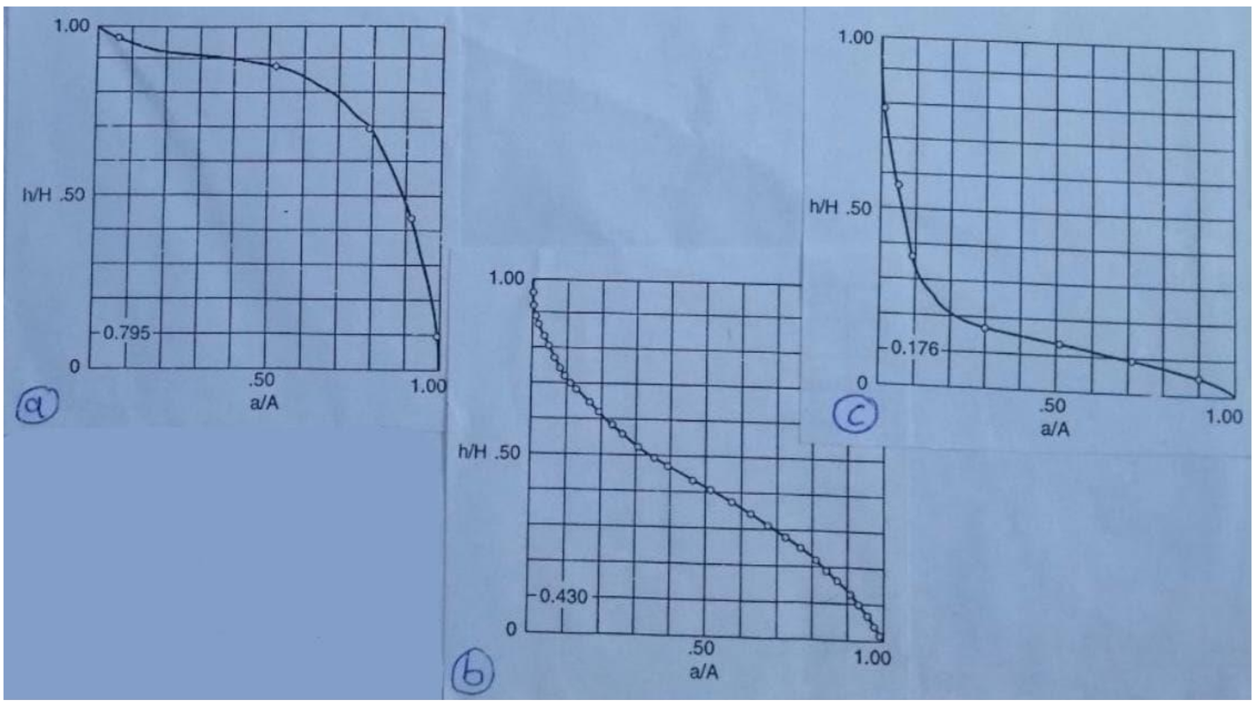


Figure 2 Three examples of different values of hypsometric integral.