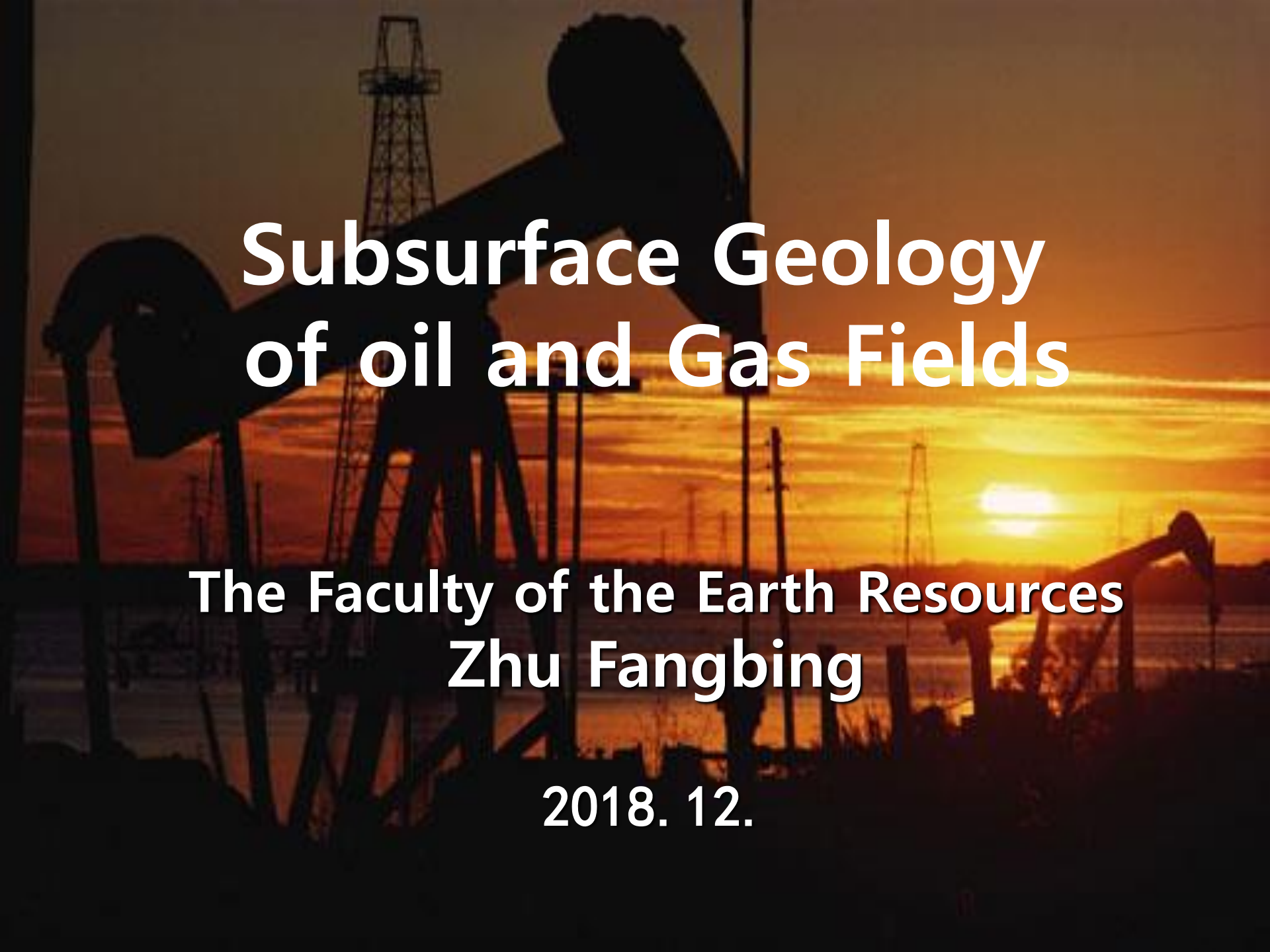

Subsurface Geology of oil and Gas Fields

The Faculty of the Earth Resources
Zhu Fangbing

2018. 12.

Subsurface Geology of Oil and Gas Fields

Chapter 4 Subsurface Structure Research

Subsurface Structure Research

- Exploration arrangement
- Reserves calculation
- Development design
- Dynamic analysis

Research Contents

Section 1 Subsurface Structure Overview

Section 2 Fault Research

Section 3 Geology Section Mapping

Section 4 Structure Map of Oil and Gas Fields

Section 5 Palaeostructure Research Method

Chapter 4 Subsurface Structure Research

Section 1 Subsurface Structure Overview

Contents
Methods

I. Subsurface Structure Research Contents

The basic features of subsurface structure

Fold:

bedding fluctuation

Fault:

bedding offset

Chapter 4 Subsurface Structure Research

Section 1 Subsurface Structure Overview

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Methods

Exploration Phase

Research Range：

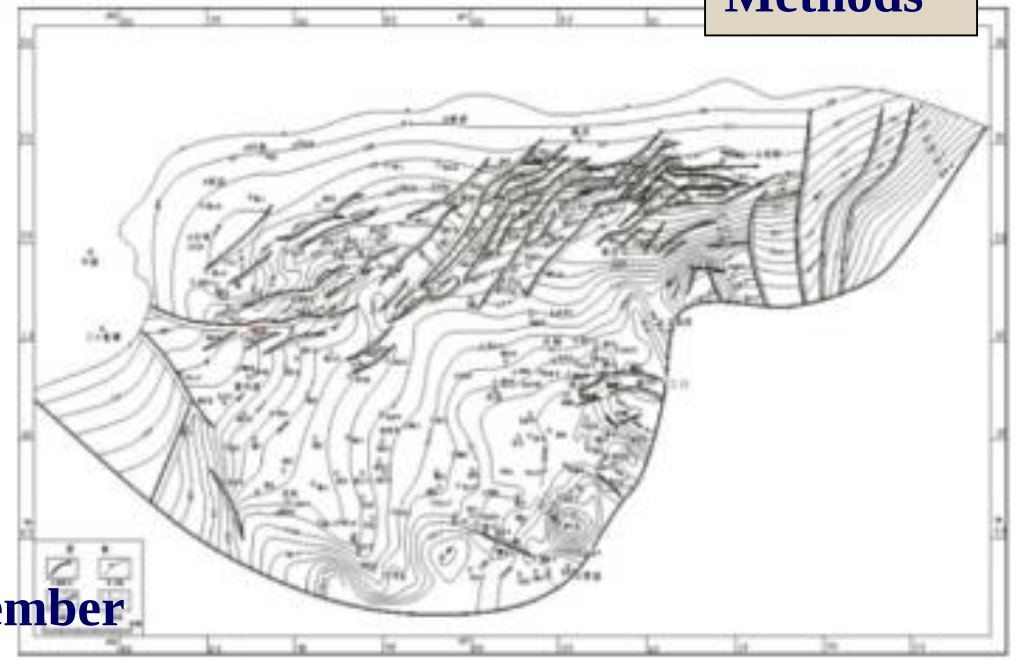
Basin, Depression
Structural zone

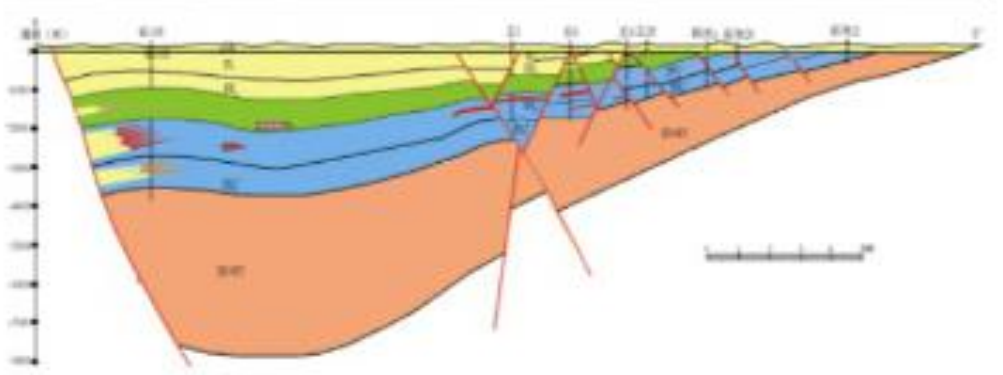
Mapping unit

Rock-stratigraphic unit:
System, series, formation, member

Contents

Structural distribution，
Structural evolution,
Trap description





Large range, thick ---- seismic data

Chapter 4 Subsurface Structure Research

Section 1 Subsurface Structure Overview

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Development Phase

Research Range：

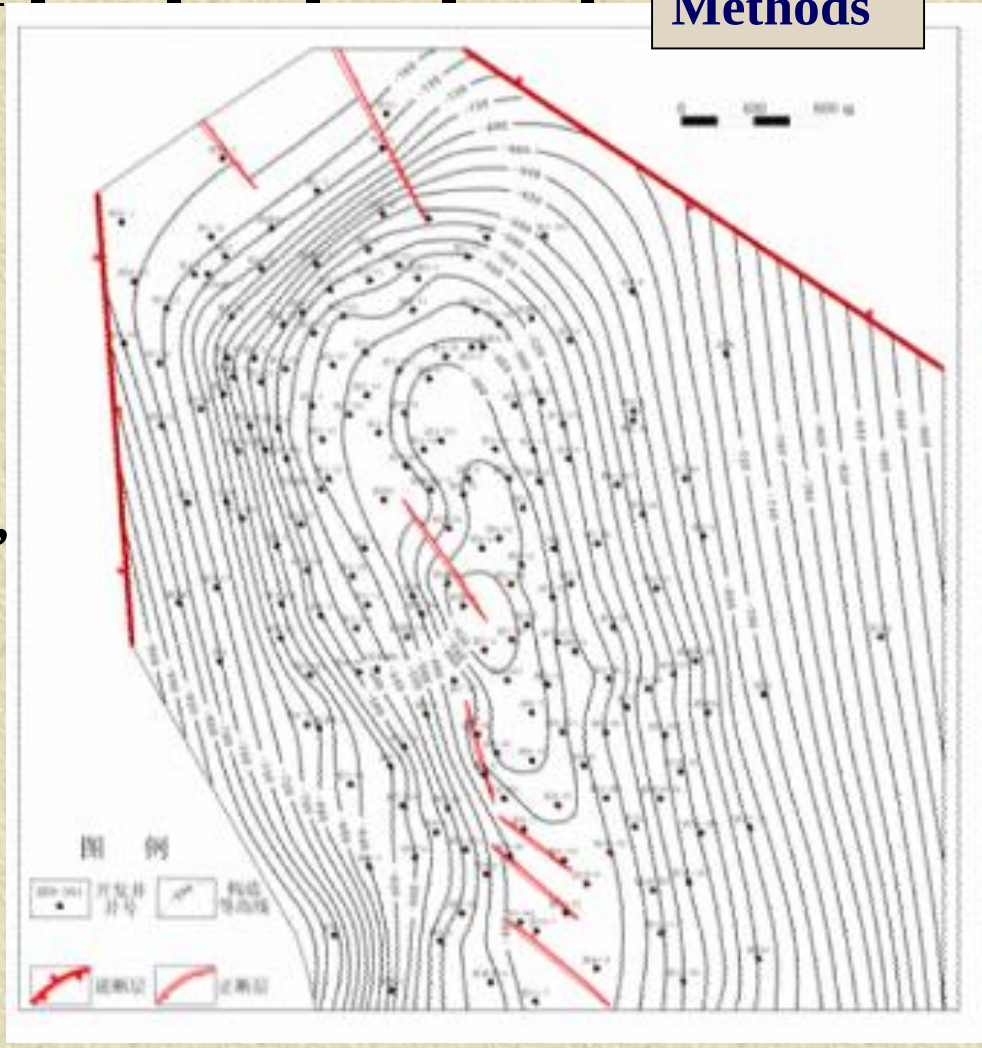
oil-gas field

Mapping unit

oil beds unit----
reservoir group, sand group,
single sand bed

Contents

Trap fine description



Chapter 4 Subsurface Structure Research

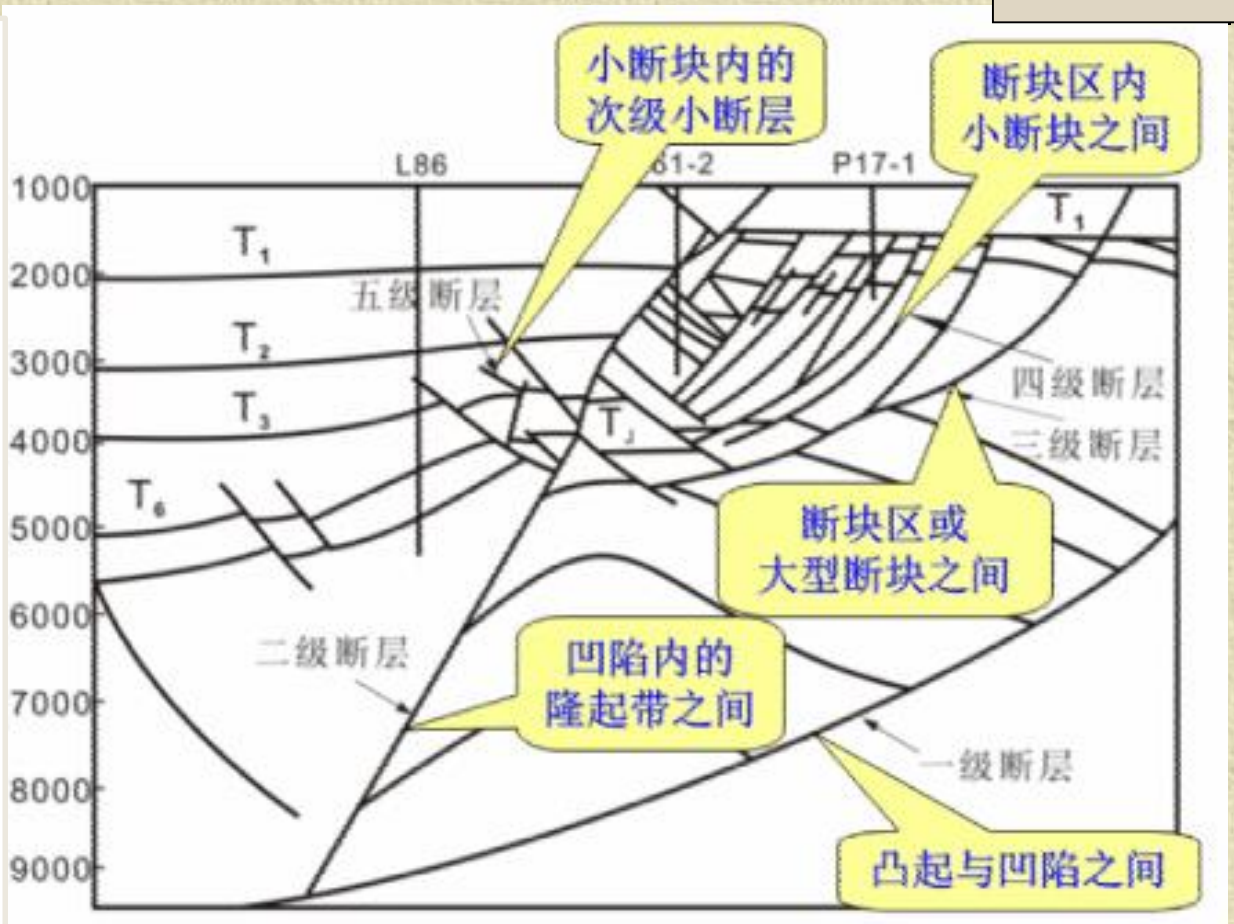
Section 1 Subsurface Structure Overview

Contents
Methods

Fault

Fault scale

- Regional Fault
- First Grade Fault
- Second Grade Fault
- Third Grade Fault
- Fourth Grade Fault
- Fifth Grade Fault



Low Grade Fault

（**Fault displacement**：**Tens of meters to several meters**；
Extension: **Thousands of meters to Hundreds of meters**）

Chapter 4 Subsurface Structure Research

Section 1 Subsurface Structure Overview

Contents
Methods

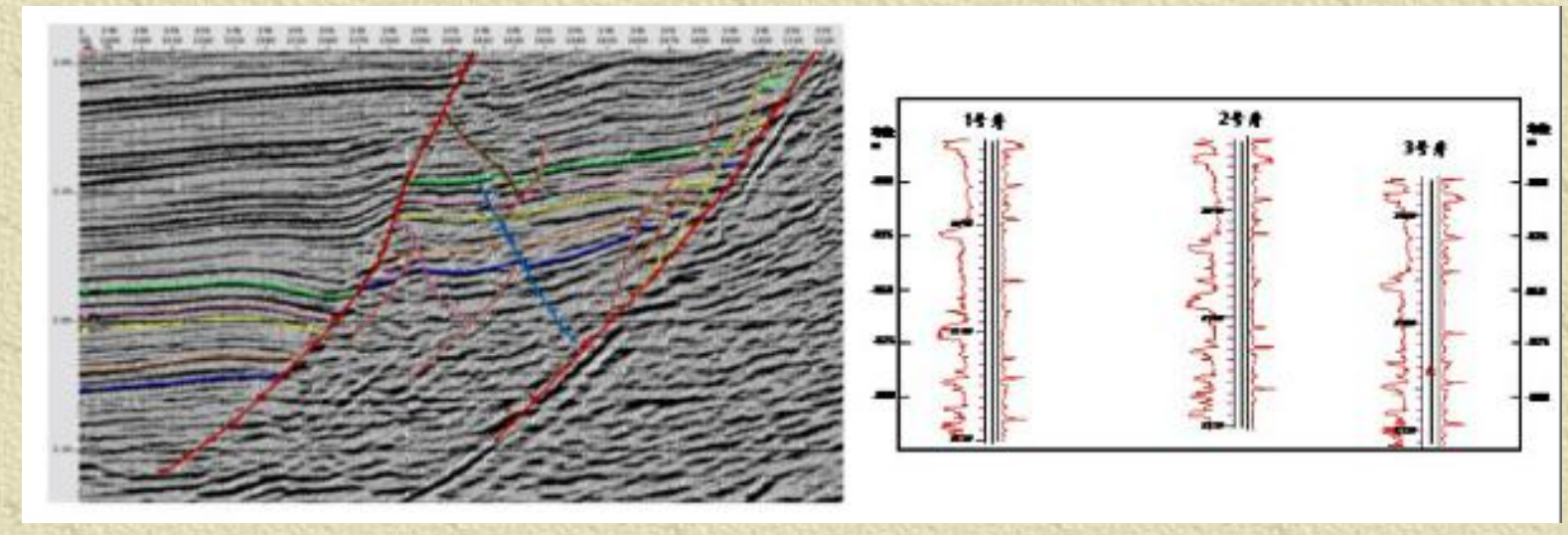
II. Subsurface structure research methods

Research information

Seismic

Drilling

Geological logging,
Well Logging,
Dynamic information



Chapter 4 Subsurface Structure Research

Section 1 Subsurface Structure Overview

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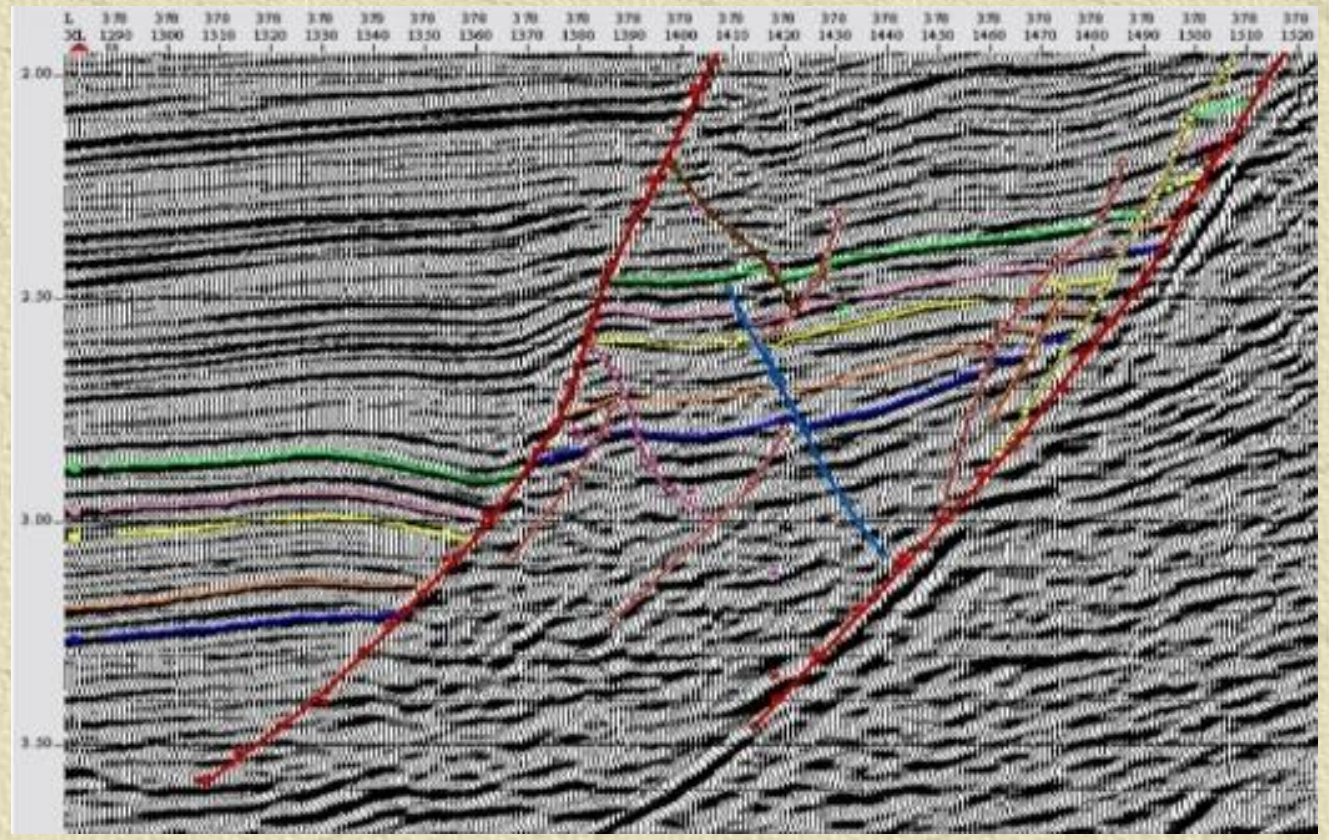
Methods

Seismic interpretation



Chapter 4 Subsurface Structure Research

Section 1 Subsurface Structure Overview

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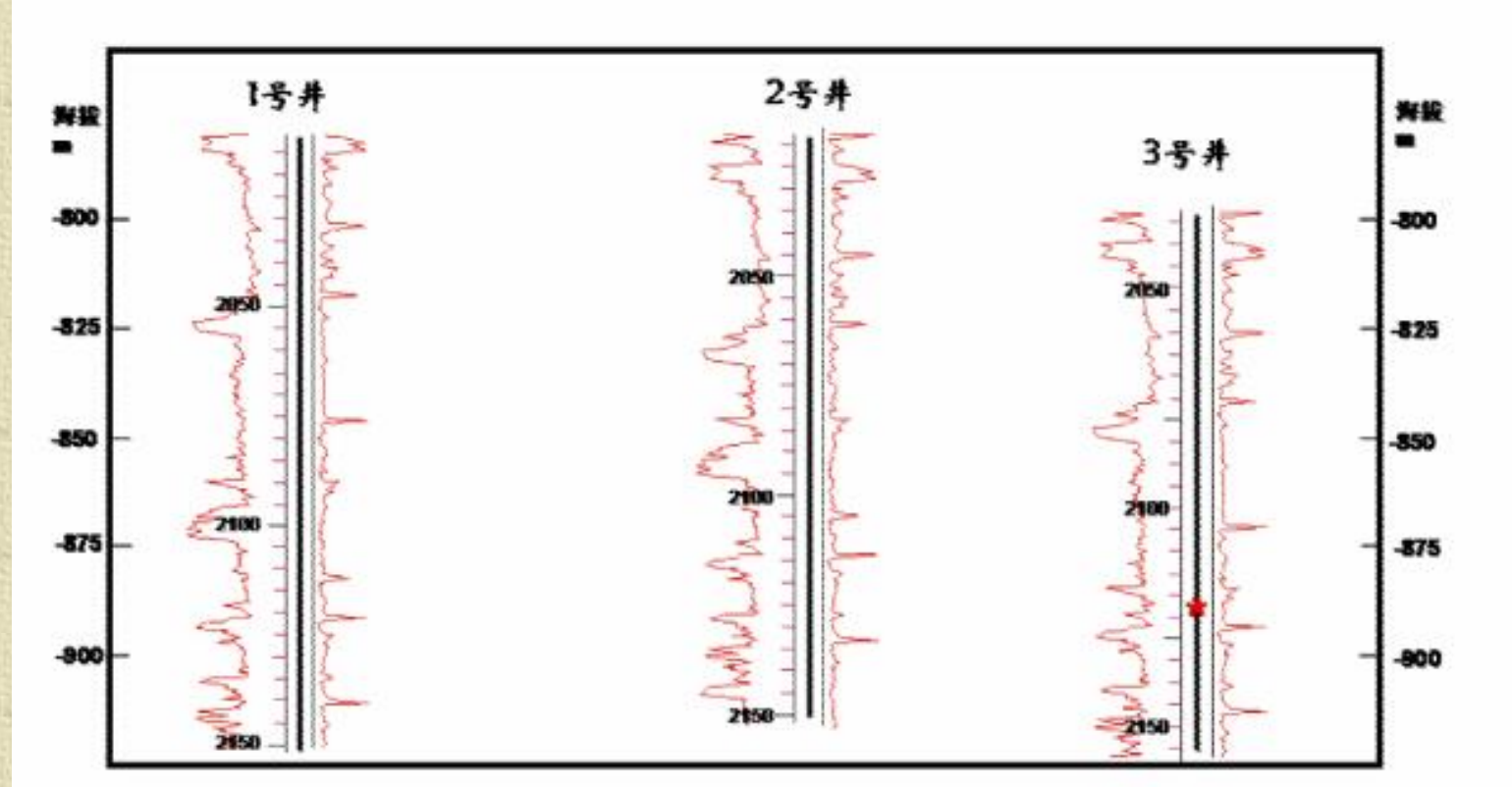
Methods

Multiwell structure research

Borehole fault research
Structure map



Chapter 4 Subsurface Structure Research

Section 1 Subsurface Structure Overview

Section 2 Fault Research

Section 3 Geology Profile, Geology Section

Section 4 Structure Map of Oil and Gas Fields

Section 5 Palaeostructure Research Method

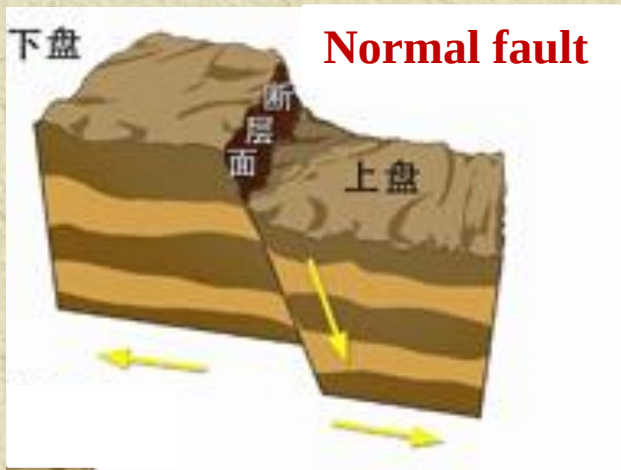
Section 2 Fault Research

I. Fault Identification

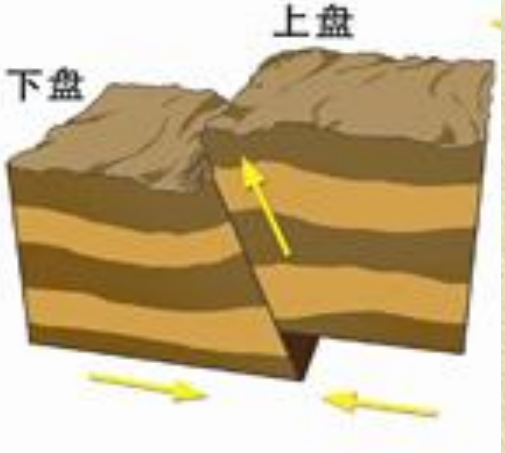
II. Fault Line

III. Contemporaneous Fault Research

IV. Fault Seal Analysis



Normal fault



Reversed fault

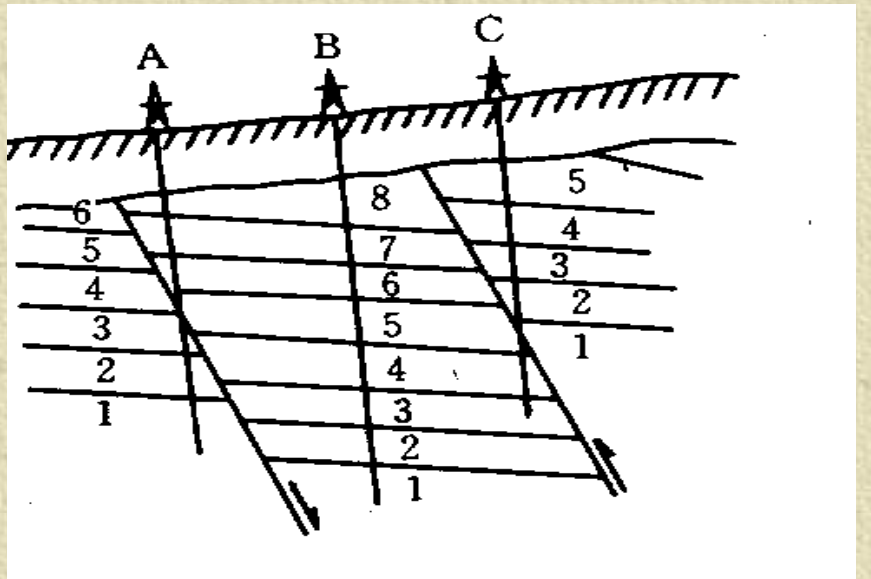
Section 2 Fault Research

I. Fault identification

1. Stratigraphic sequence abnormal on the drilling section ----stratigraphic repetition and stratigraphic break

Stratigraphic dip < Fault dip

Well A: 8765321
Well B: 87654321
Well C: 54321543



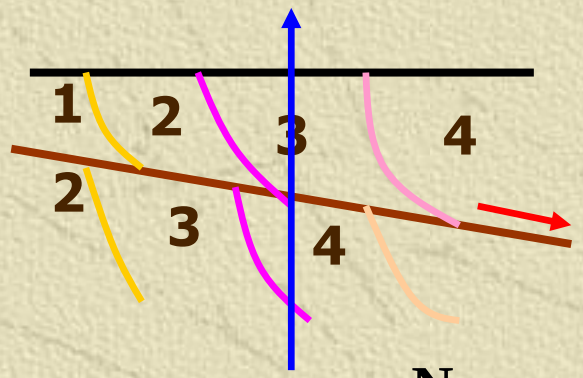
Schematic drawing of stratigraphic repetition and stratigraphic break

Section 2 Fault Research

I. Fault identification

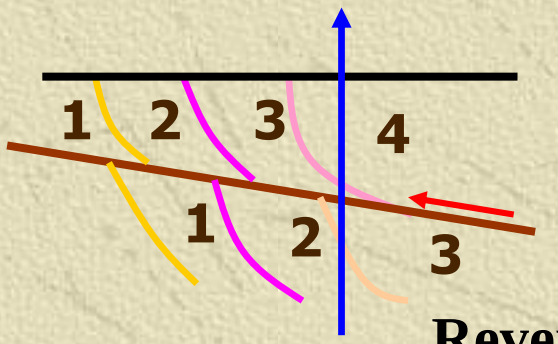
1. Stratigraphic sequence abnormal on the drilling section ----stratigraphic repetition and stratigraphic break

Stratigraphic dip >fault dip



343

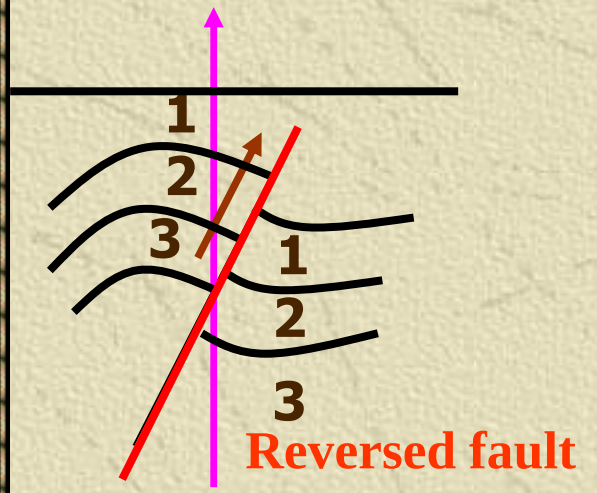
Normal fault



432

Reversed fault

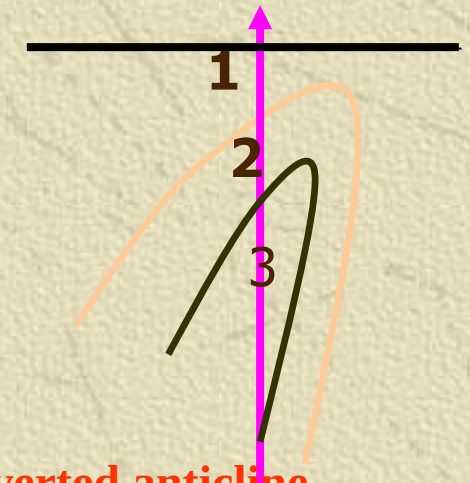
Section 2 Fault Research



Reversed fault

12323

Positive sequence repetition



Inverted anticline

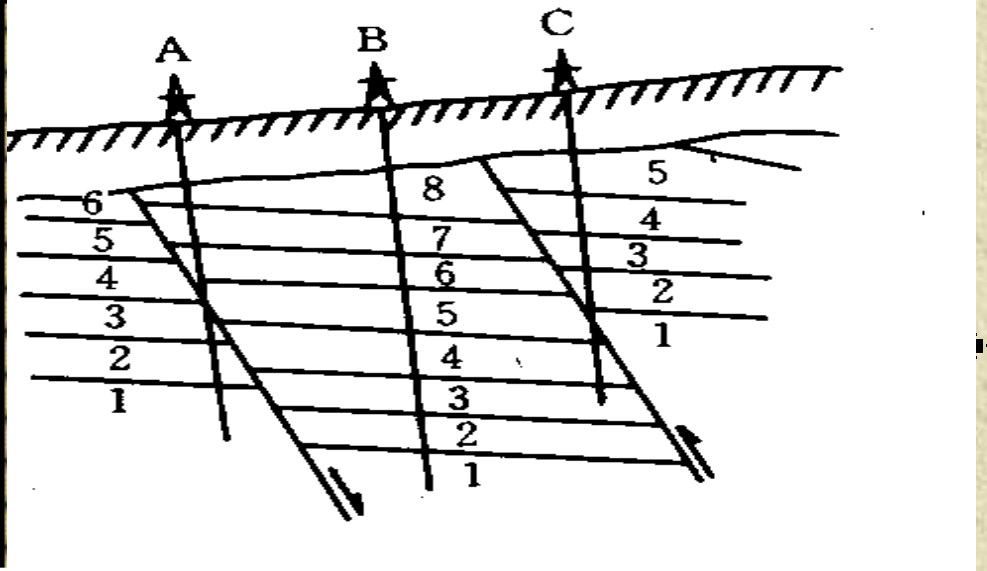
12321

Reversed order repetition

Section 2 Fault Research

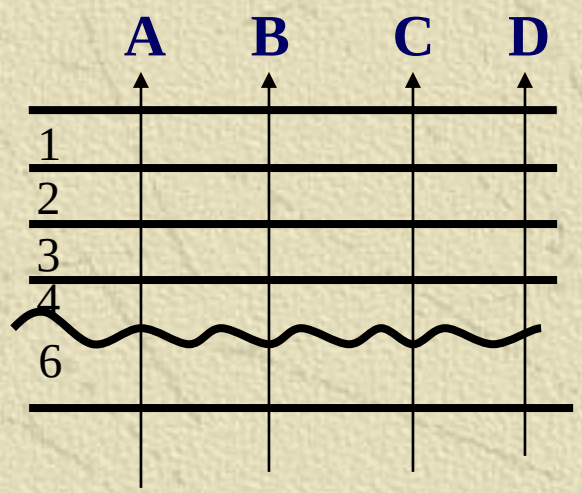
If correlation is "lost", that is if no similarity exists any more between the log shapes of two wells this could be for a number of reasons:

- **faulting**: the well has intersected a fault and part of the sequence is missing. Faulting can also cause a duplication of sequences!
- **unconformity**: parts of the sequence have been eroded



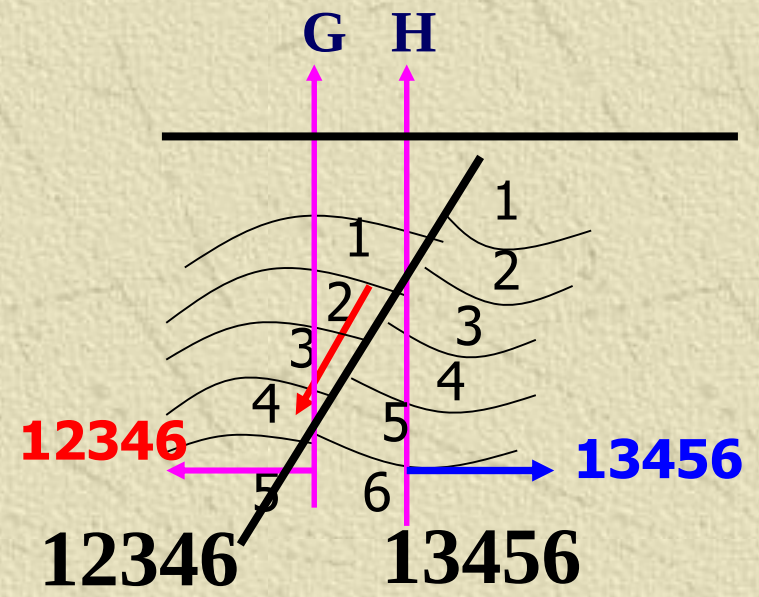
faulting

Well A: 8765321
Well B: 87654321
Well C: 54321543



12346 disappearance 5

unconformity

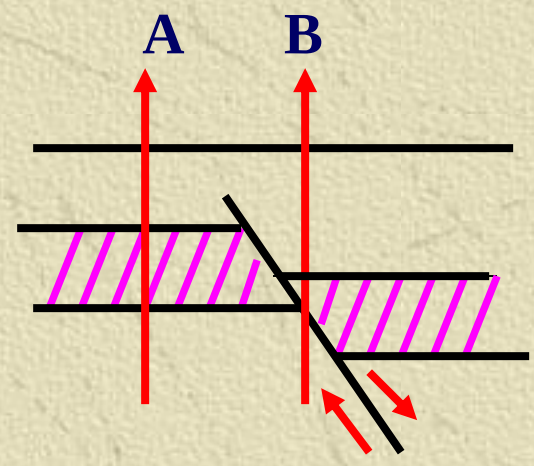


12346 **13456**

disappearance 5 **disappearance 2**

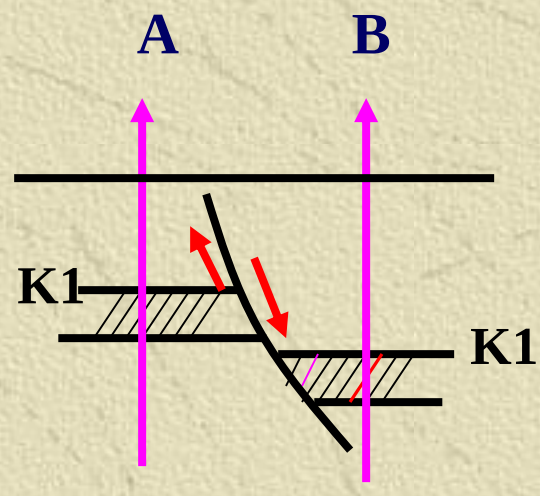
Section 2 Fault Research

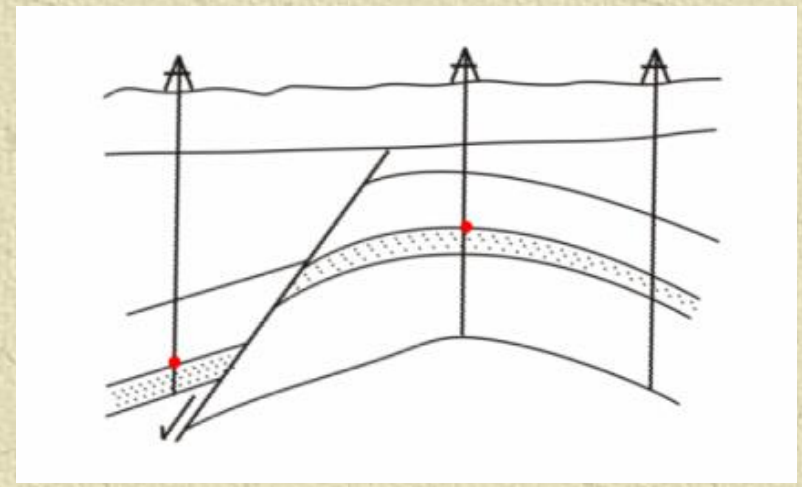
2. Near-range same layer thickness mutation



Section 2 Fault Research

3. near-range marker true vertical subsea great disparity





Downhole fault recognition assistant mark

Section 2 Fault Research

4.Abnormal subsurface contour

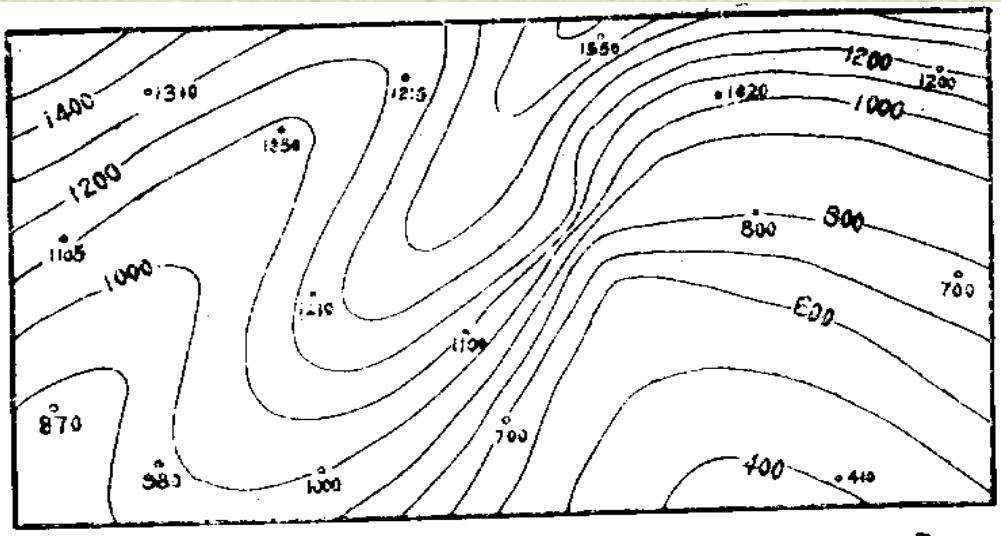


图6-2　由构造图的不协调现象中发现断层

Section 2 Fault Research

5.Drilling information

Core data

dip mutation,

coring crush,

fault breccia,

hole deviation mutation

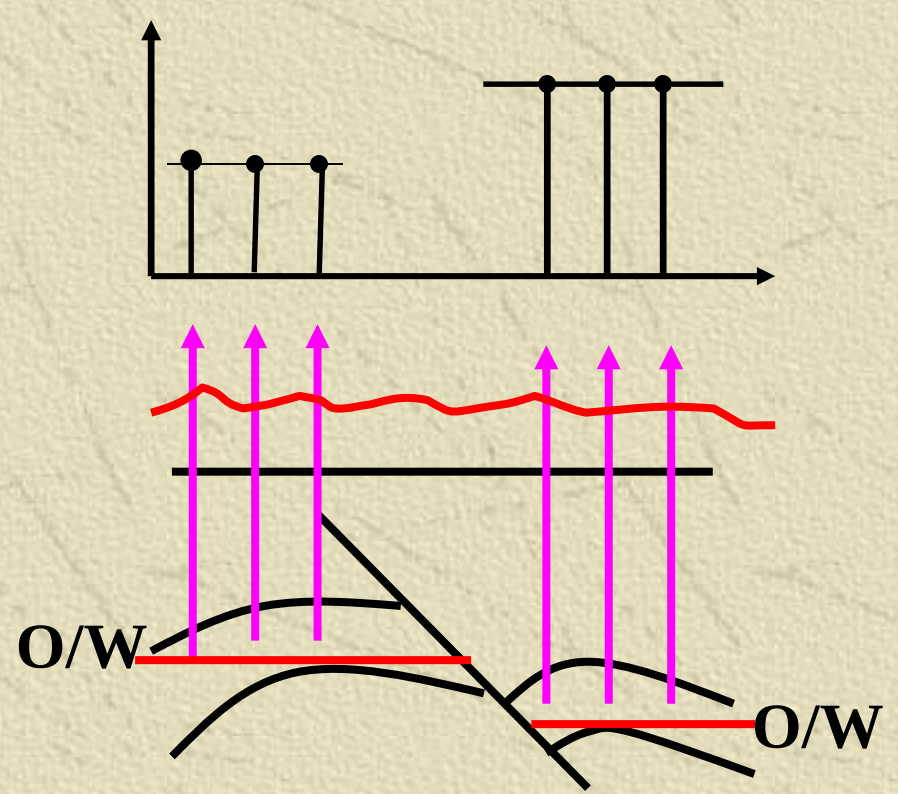
Section 2 Fault Research

6. Fluid property

Downhole fault recognition assistant mark

Fault block	Well number	Specific gravity	viscosity	Set point (℃)	Wax content (%)	Oil – water contact (m)
42 block	Well 42	0.8977	24.33	-28	5.46	-2050
7 block	Well 7	0.8468	6.54	24	15.07	-2300

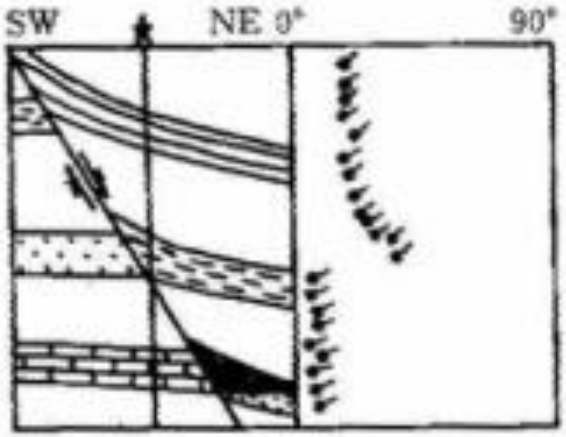
7.Reduced pressure and oil-water interface



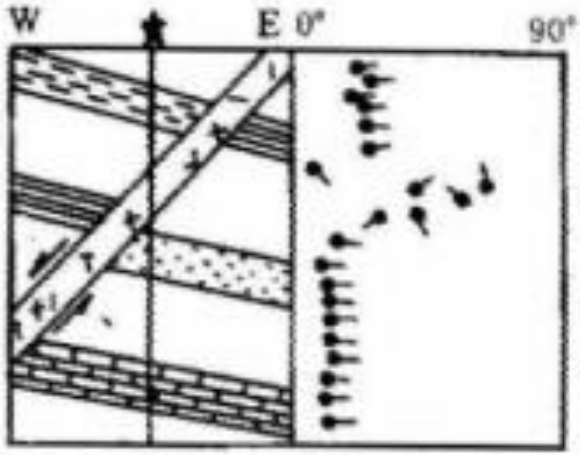
8.Dipmeter log

Diameter log vector diagram

Downhole fault recognition assistant mark



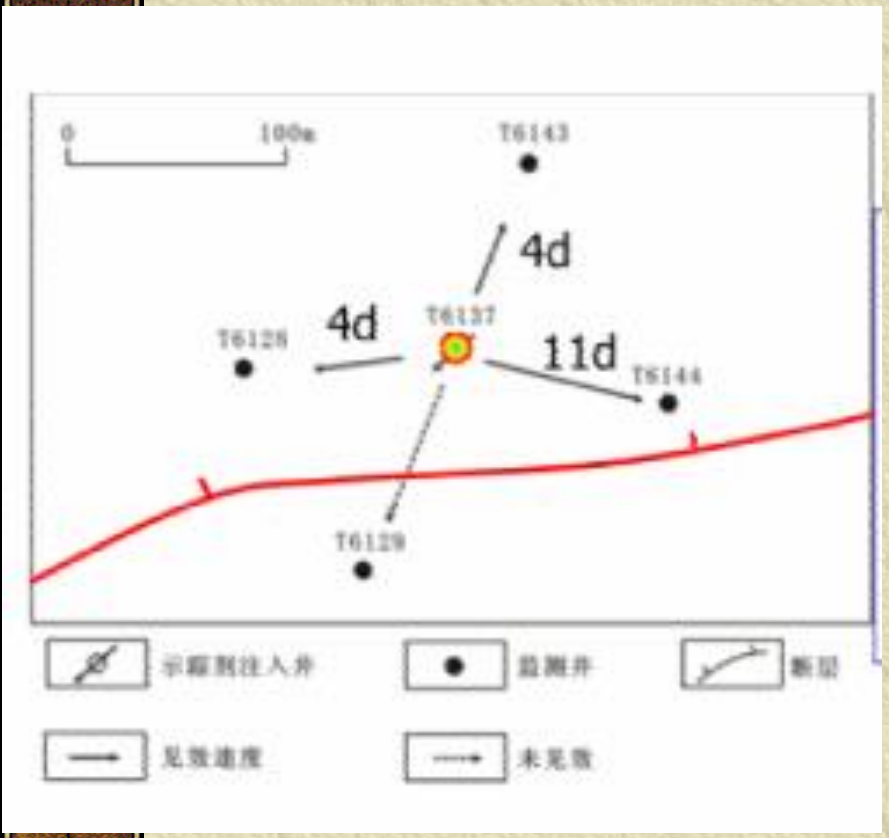
Two sides of the fault
attitude of stratum variation



Formed crushed zone
near the fault plane

Chapter 4 Subsurface Structure Research

Well-to-well dynamic check



Downhole fault recognition mark

(1)The thickness difference: stratigraphic repetition and stratigraphic break

(2)Elevation differences

(3)Fluids differences

(4)Diameter log vector diagram

(5)Well-to-well dynamic check: no response

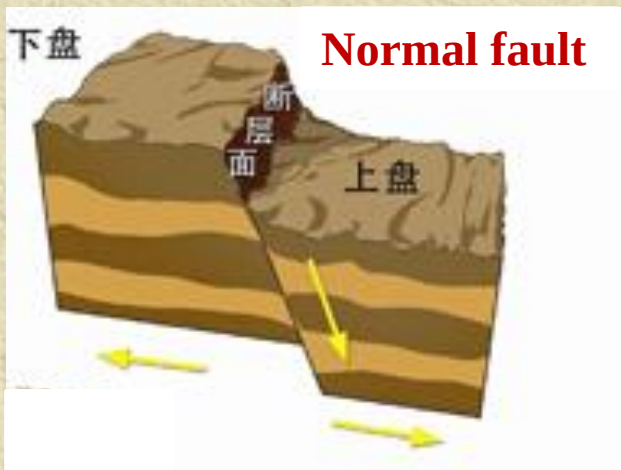
Section 2 Fault Research

I. Fault Identification

II. Fault Line

III. Contemporaneous Fault Research

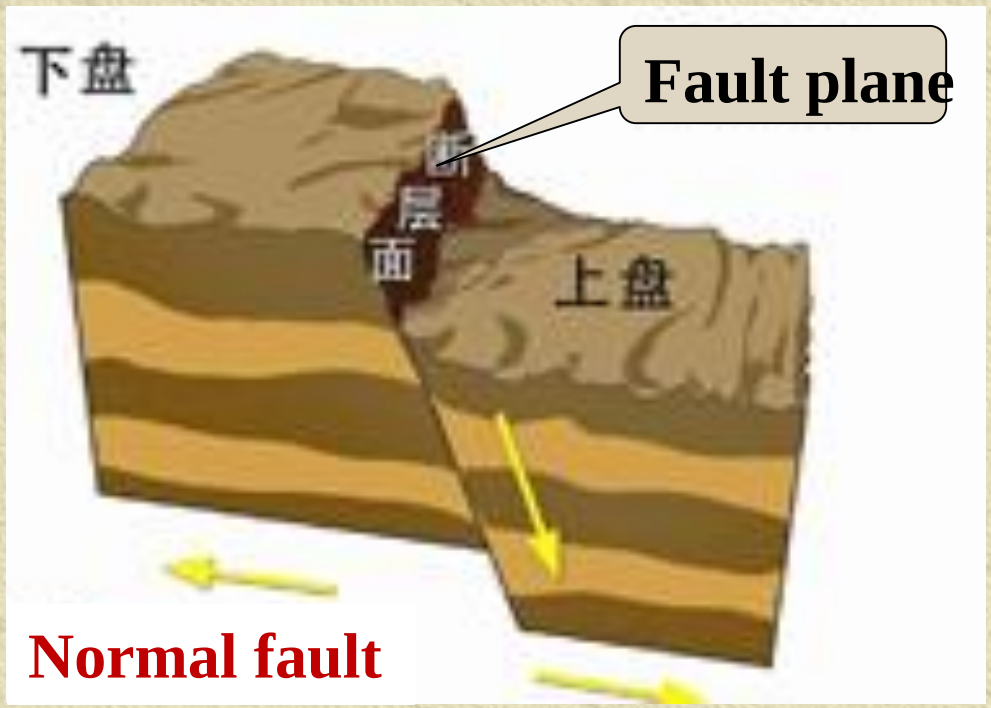
IV. Fault Seal Analysis



Normal fault

Reversed fault

II. Fault Line



II. Fault Line

1. To plot contour map of fault plane sea level elevation

The contour map which is expressed fault plane shape.

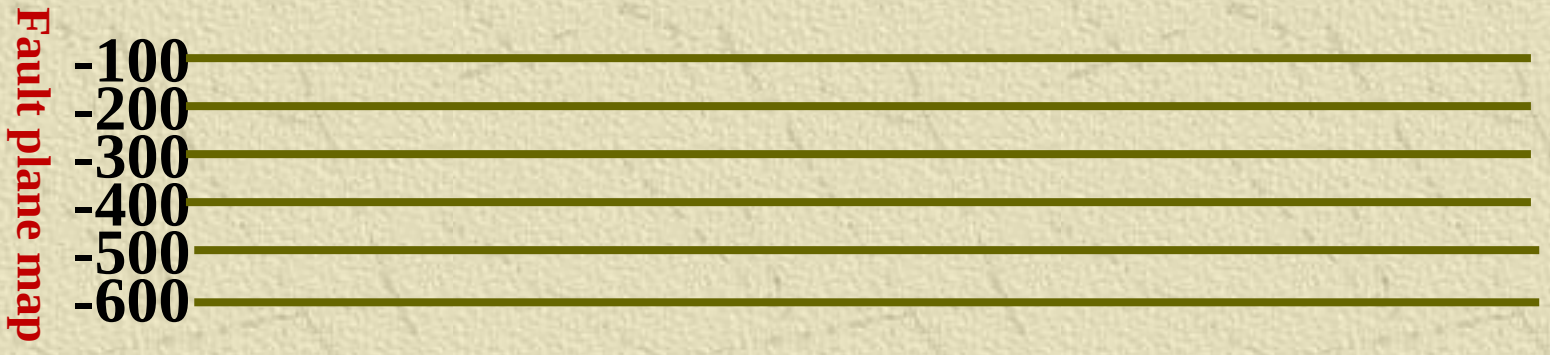
(direction of dip, Fault dip, strike and distribution range)

- **Same fault:** fault plane contour distribution regularly
- **Difference fault:** fault plane contour distribution difference tendency

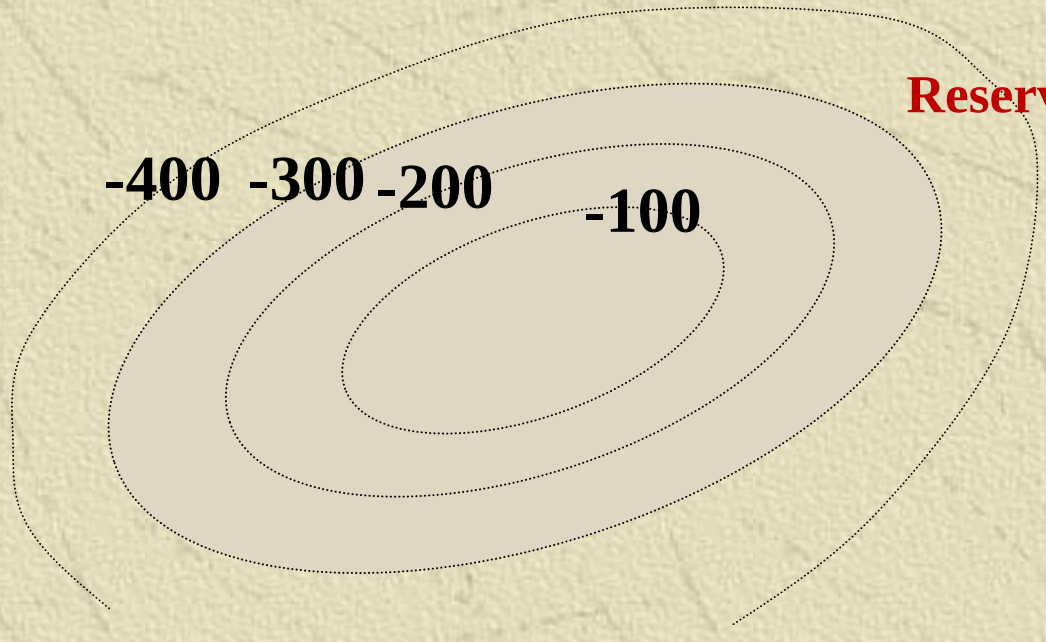
2. To plot reservoir contour map

3. Overlap fault plane map and reservoir contour, define the intersection point which has the same level, and connect the intersection points----Fault line

II. Fault Line

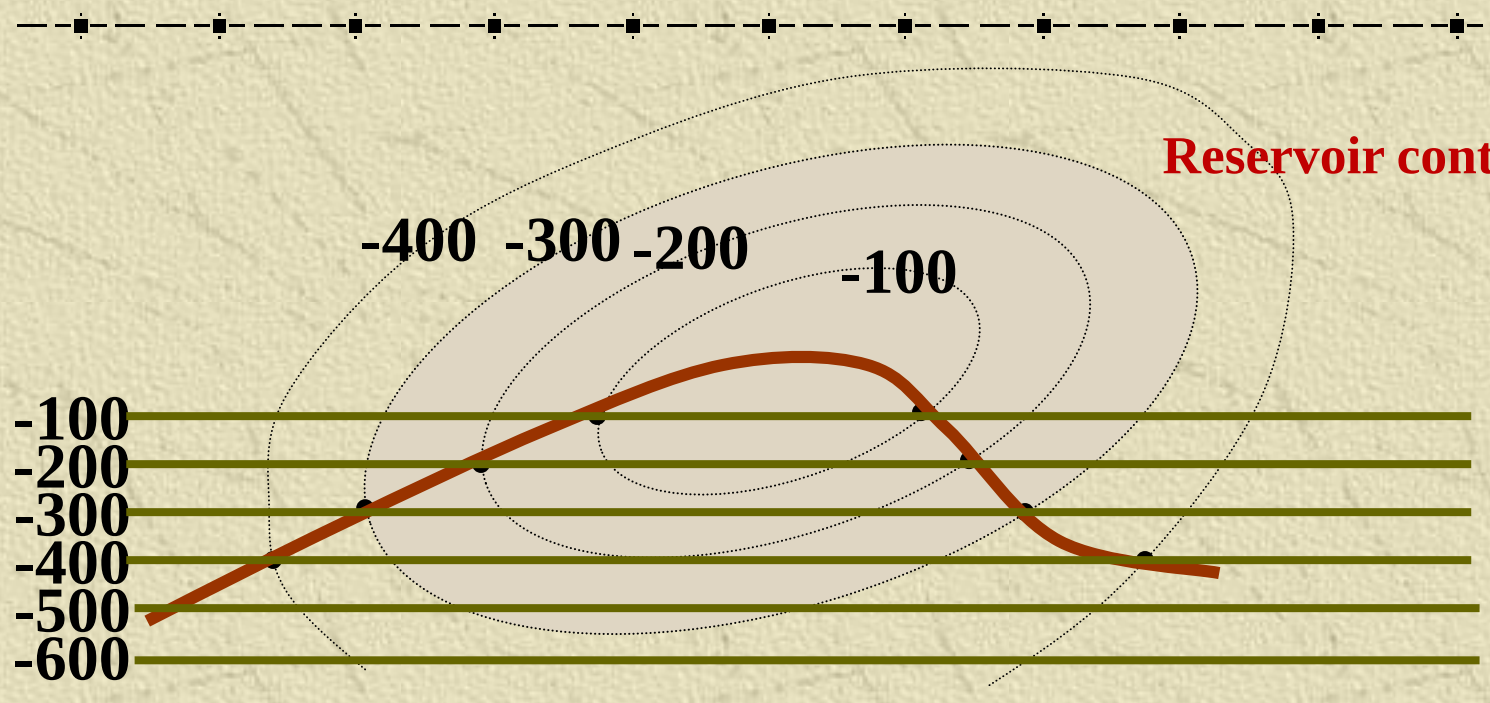


II. Fault Line



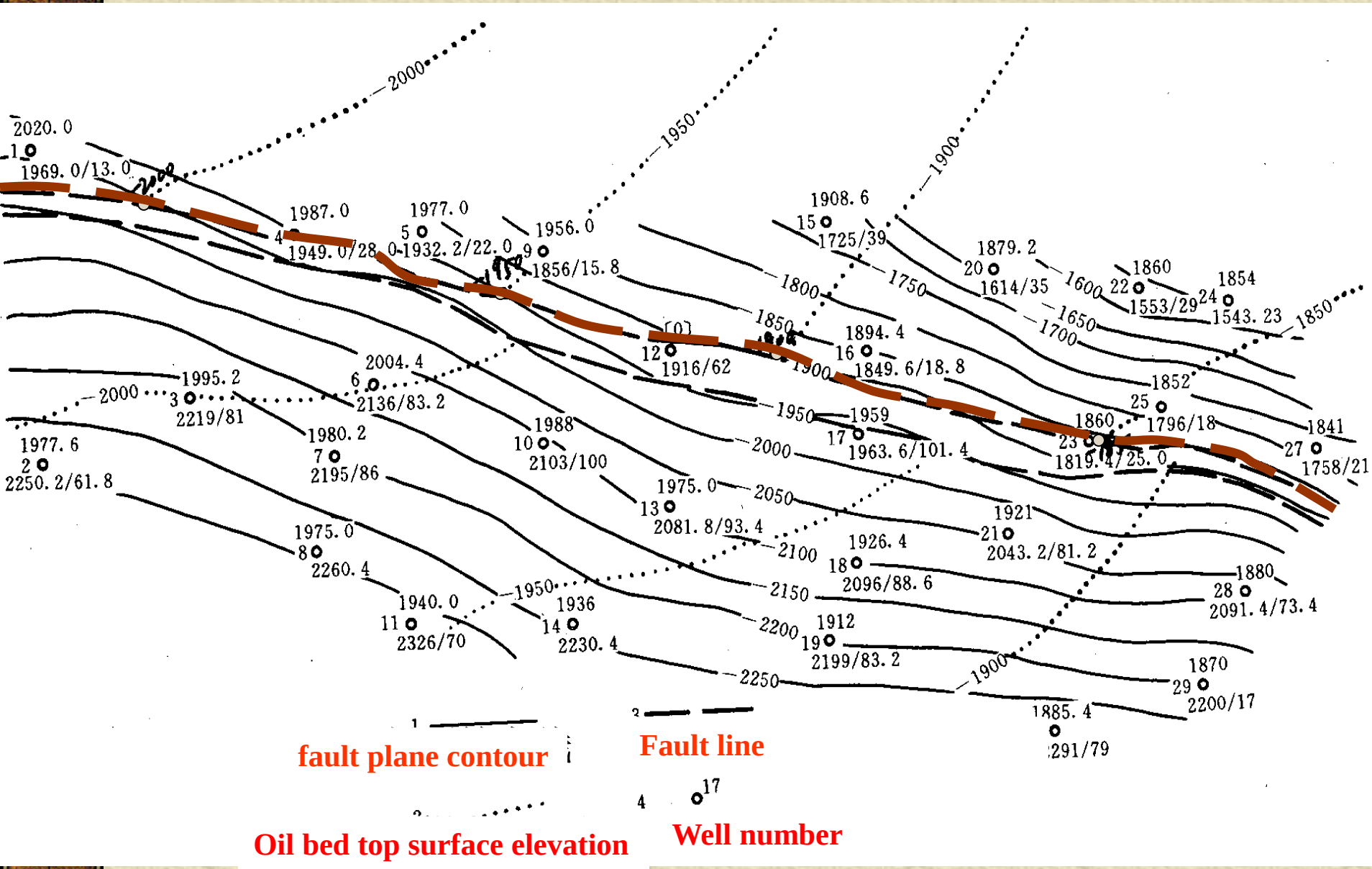
Reservoir contour map

II. Fault Line



Overlap fault plane map and reservoir contour, define the intersection point which has the same level, and connect the intersection points----Fault line

II. Fault Line



Section 2 Fault Research

I. Fault Identification

II. Fault Line

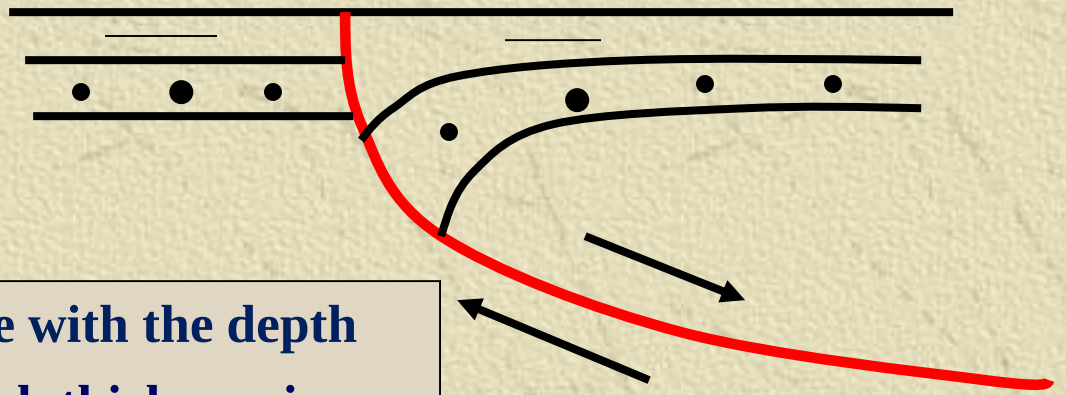
III. Contemporaneous Fault Research

IV. Fault Seal Analysis

Normal fault

Reversed fault

III.Contemporaneous Fault Research



(1)Fault throw increase with the depth

(2)The downthrow block thickness is much thicker than upthrow side thickness

(3)Horizontal slip increase with the depth

(4)The section bending，up steep and bottom gentle

III.Contemporaneous Fault Research

Growth Index ---- GI

The ratio of downthrow block thickness to upthrow side thickness

GI= downthrow block thickness/ upthrow side thickness

GI=1
GI>1, Active

upthrow block and downthrow block thickness contrast table (same layer thickness)

Formation	downthrow block thickness m	upthrow block thickness m	Difference m	Growth index
10	200	200	0	1.00
9	215	200	15	1.08
8	595	545	50	1.09
7	540	435	105	1.24
6	610	510	100	1.20
5	675	535	140	1.26
4	300	228	72	1.31
3	562	312	250	1.80
2	1234	1025	209	1.20
1	400	400	0	1.00

941m

Section 2 Fault Research

I. Fault Identification

II. Fault Line

III. Contemporaneous Fault Research

IV. Fault Seal Analysis

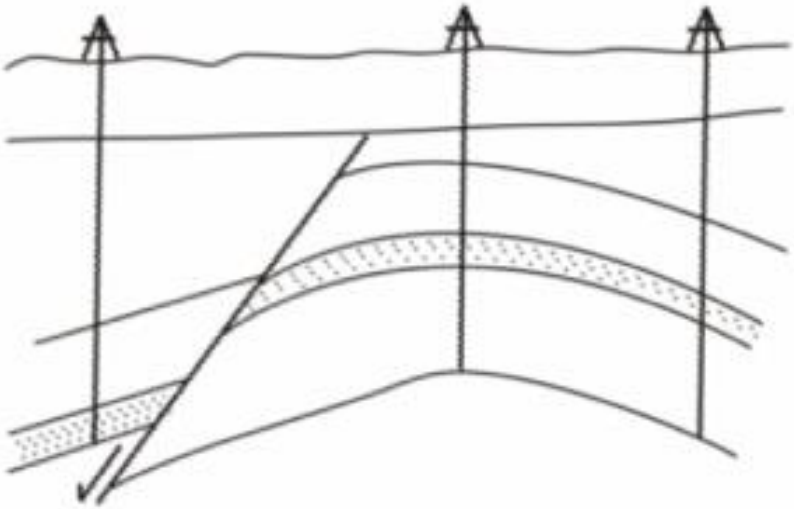
Normal fault

Reversed fault

Chapter 4 Subsurface Structure Research

IV . Fault Seal Research Methods

The fault sealing ability to fluid



Sealing or open?

Vertical sealing

Lateral sealing

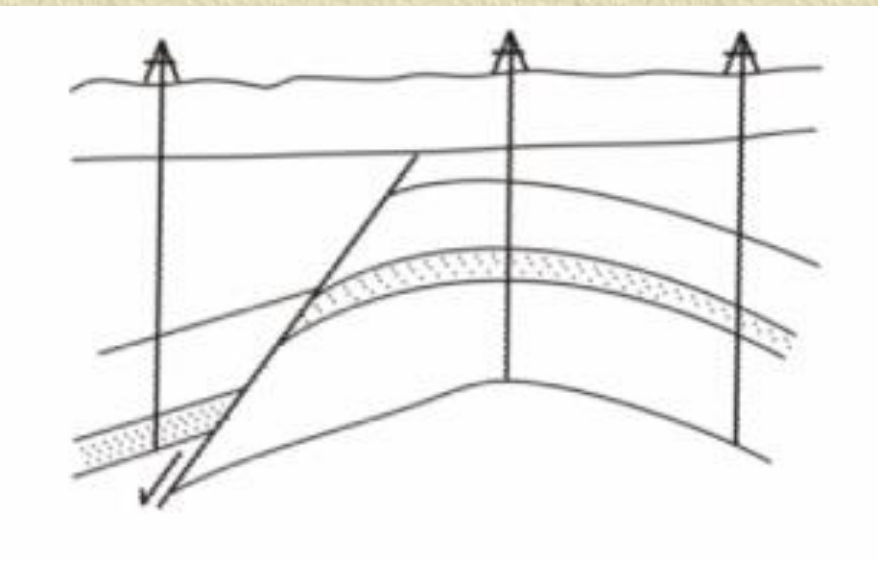
Chapter 4 Subsurface Structure Research

IV . Fault Seal Research Methods

1. The lithology of upthrow block and downthrow block

Formation contact on both sides of the fault

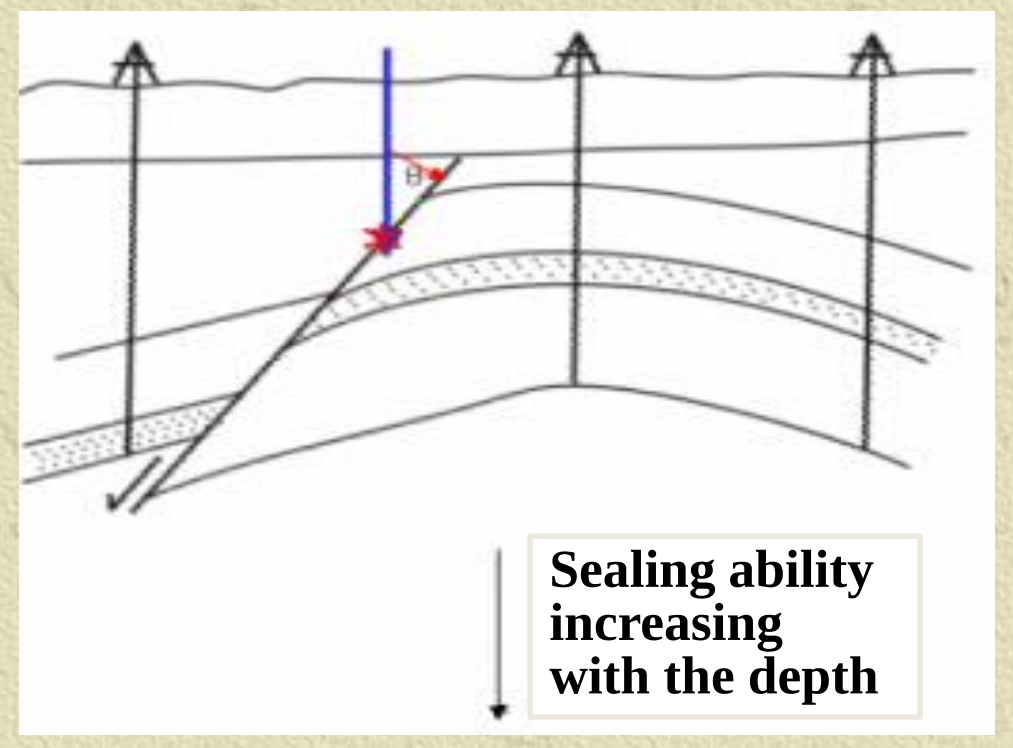
Notice: Variation of lithology and contact on both sides of the fault along fault strike



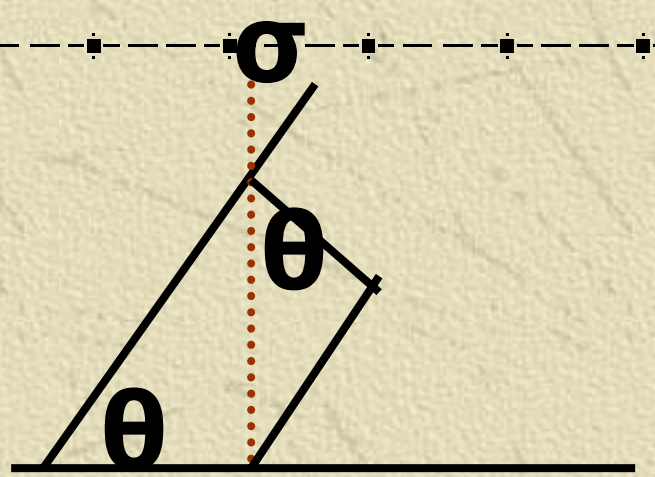
Chapter 4 Subsurface Structure Research

IV . Fault Seal Research Methods

2. Fault Mechanics Analysis



IV . Fault seal research methods



Fault Mechanics Analysis

$$S=P+\sigma \qquad (1)$$

S----Overburden Pressure

P---- Formation Pressure

σ---- Frame stress

$$\sigma = S-P=(\rho_r-\rho_w)*H/10 \qquad (2)$$

$$\sigma_{\perp} = (\rho_r-\rho_w)*H*\cos\theta /10 \qquad (3)$$

H----fault point depth, m

θ ---- fault plane dip

$$\sigma_{\perp} = (\rho_r - \rho_w) * H * \cos\theta / 10$$

$\rho_r = 2.25 g/cm^3$ $\rho_w = 1.03 g/cm^3$

$\theta = 60\text{-}45^o$

$H = 1000m$, $\sigma_{\perp} = 61\text{-}85.4 kg/cm^2$

$H = 2000m$, $\sigma_{\perp} = 121\text{-}170.8 kg/cm^2$

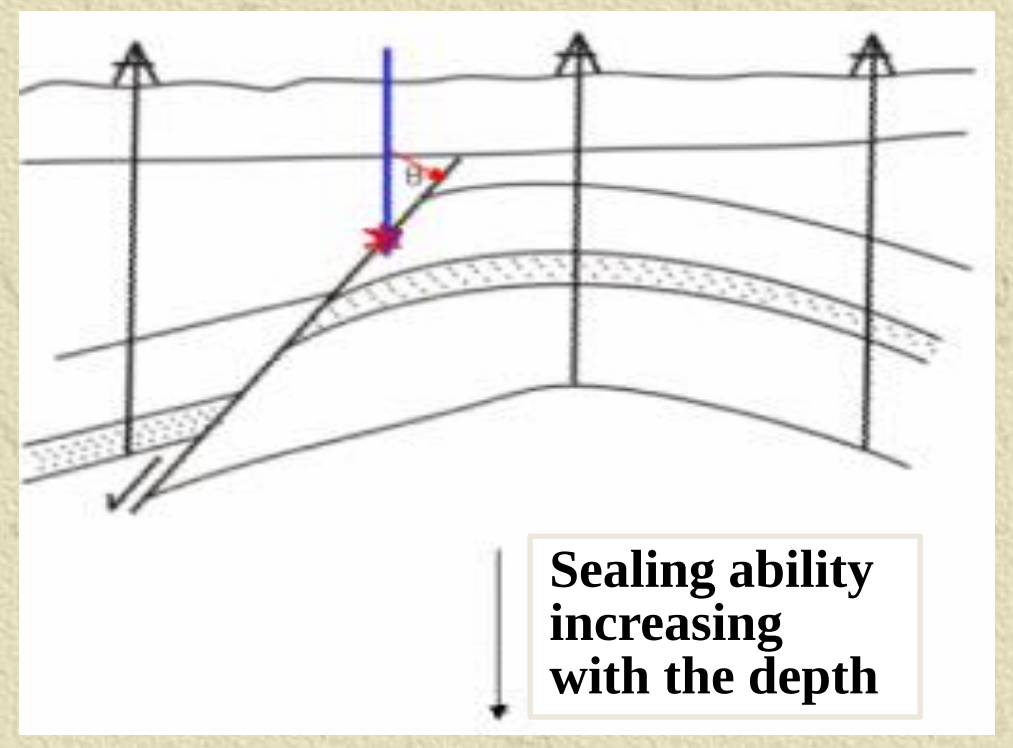
The compression strength

Sand:60-70kg/cm^2, Mud:20kg/cm^2

Chapter 4 Subsurface Structure Research

IV . Fault Seal Research Methods

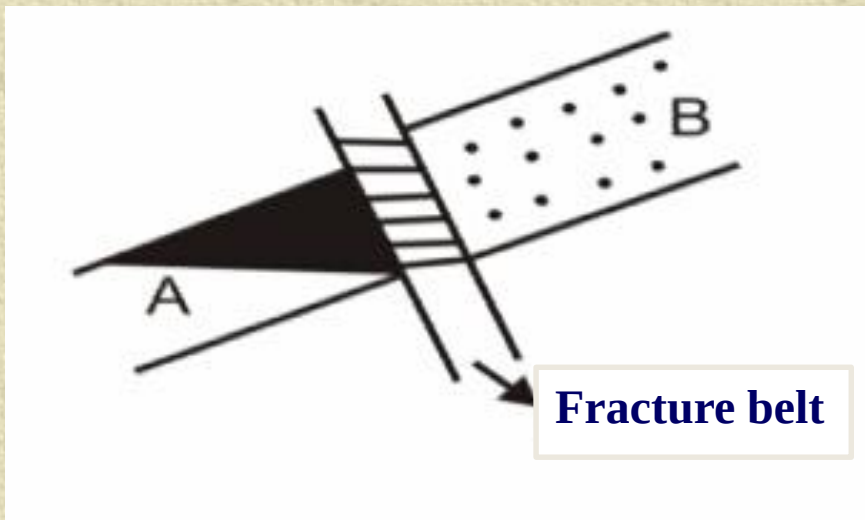
2. Fault Mechanics Analysis



Chapter 4 Subsurface Structure Research

IV . Fault Seal Research Methods

3. Filling materials in the fault zone



Fault plane seal

- Lithological analysis
- Diagenism and petrophysical property analysis (Φ, K)

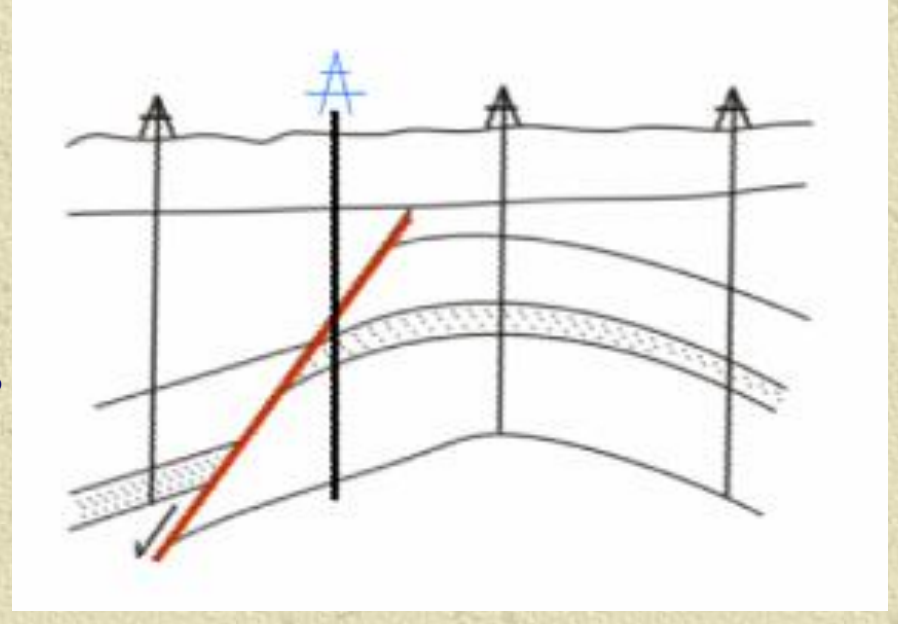
Chapter 4 Subsurface Structure Research

IV . Fault Seal Research Methods

4. Fault shows during drilling

▲**unsealing fault**

- Drilling fluid loss, well kicking, oil and gas shows
- Fault breccias
- Secondary mineral in the cuttings
- Drilling time decreasing



Chapter 4 Subsurface Structure Research

5. Well logging curve features

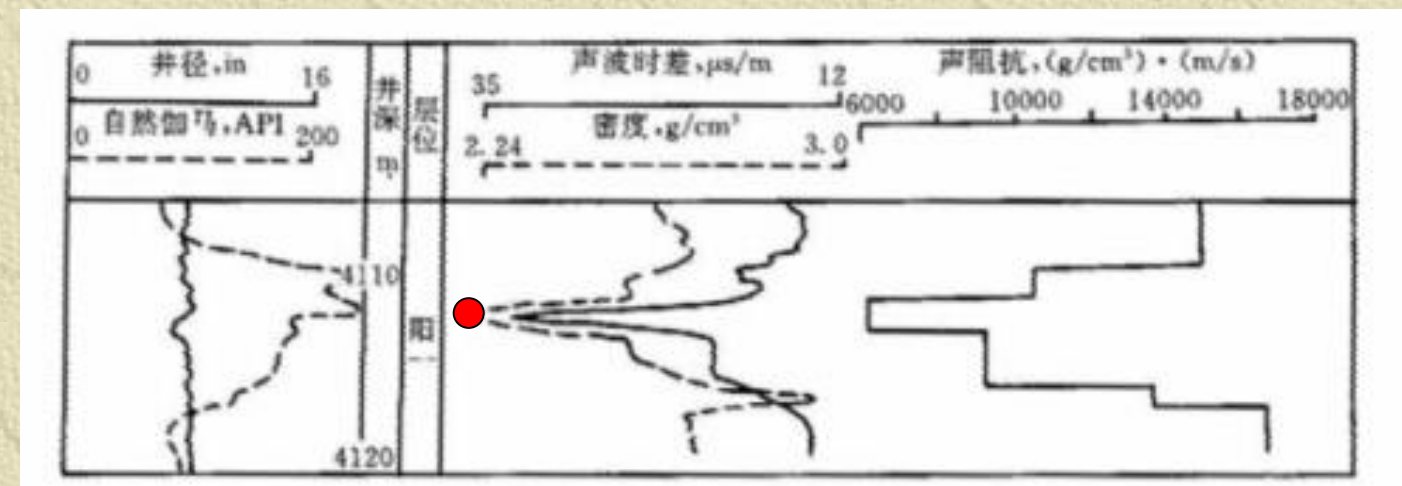
Sealed fault：

fault plane without permeability

Open fault

fault and fracture zone with permeability

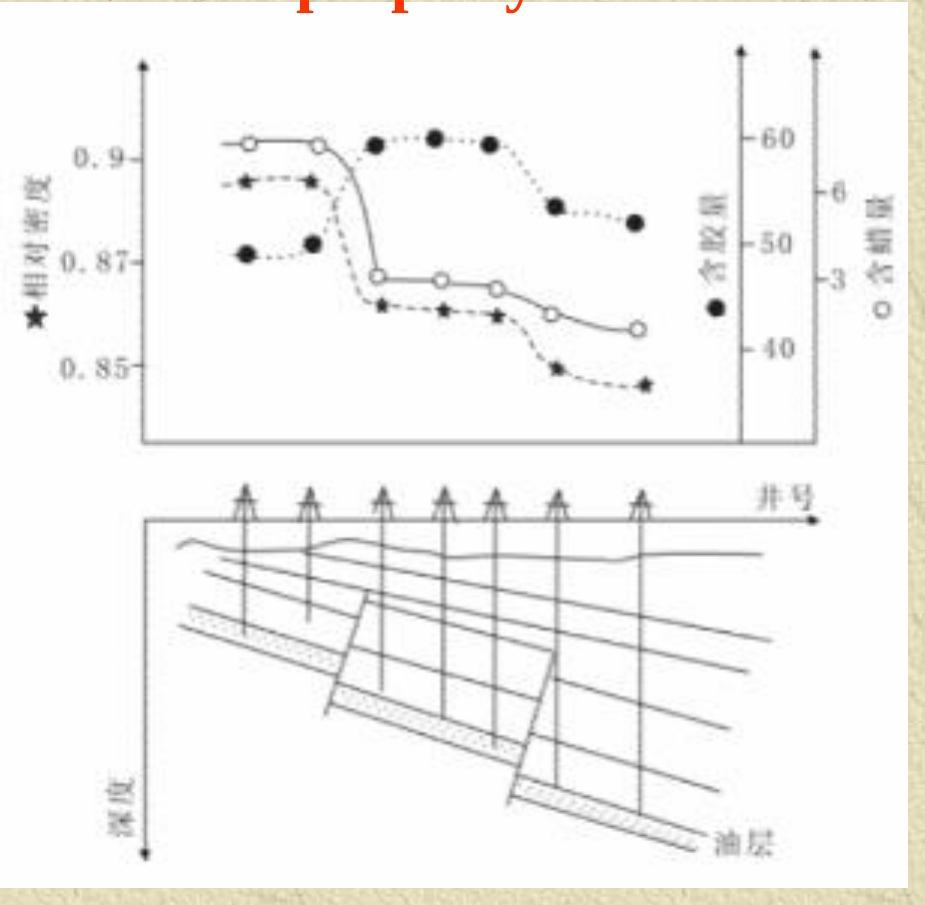
Δt increase, Density and Resistivity decrease， Hole enlargement



Chapter 4 Subsurface Structure Research

IV . Fault Seal Research Methods

6. Fluid property and distribution



- Fluids property differences between fault blocks two sides
- The height of Oil-Water interface difference

IV. Fault seal research methods

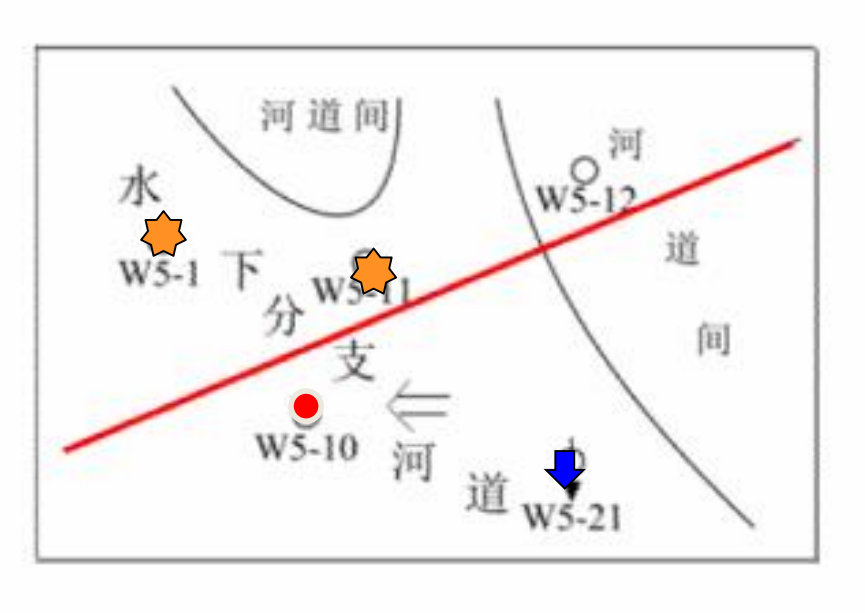
6. Fluid property and distribution

Oil property and Oil/Water height of adjacent two fault blocks

Fault block	Well number	Specific gravity	viscosity	Set point (℃)	Wax content (%)	Oil – water contact (m)
42 block	Well 42	0.8977	24.33	-28	5.46	-2050
7 block	Well 7	0.8468	6.54	24	15.07	-2300

Chapter 4 Subsurface Structure Research

7. Well-to-well testing



- Well interference test
- Tracer test
- Waterflood behavior

Section 2 Fault Research

I. Fault Identification

II. Fault Line

III. Contemporaneous Fault Research

IV. Fault Seal Analysis

Chapter 4 Subsurface Structure Research

Section 1 Subsurface Structure Overview

Section 2 Fault Research

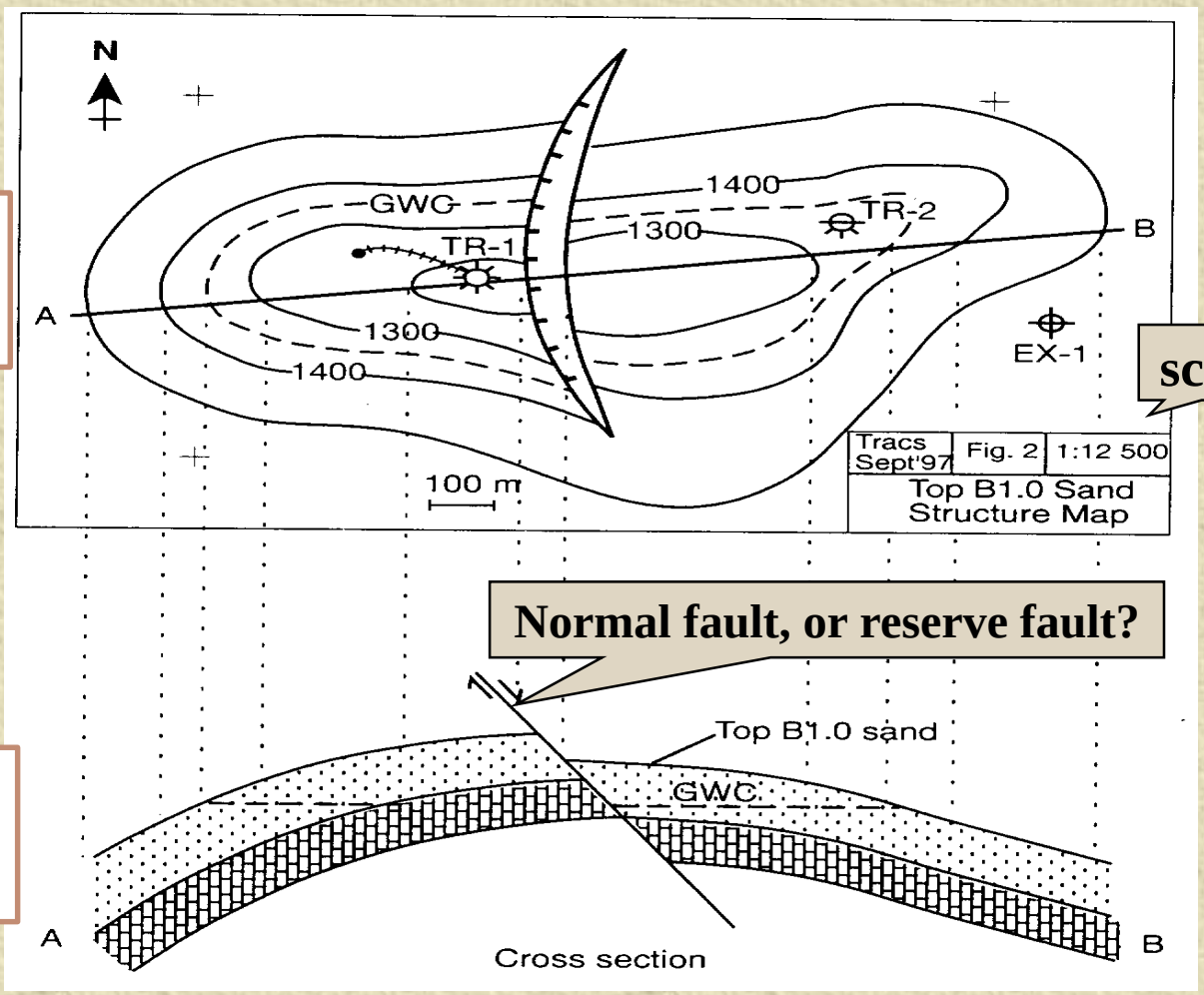
Section 3 Geology Section Mapping

Section 4 Structure Map of Oil and Gas Fields

Section 5 Palaeostructure Research Method

Structure contour map

Structure section map



Structure map

Structure contour map displays the shape and extend of the hydrocarbon accumulation, indicates the OWC and display the location of wells and fault.

Structure section map shows structure feature, fault and anticline.

Section 3 Geology Profile Mapping

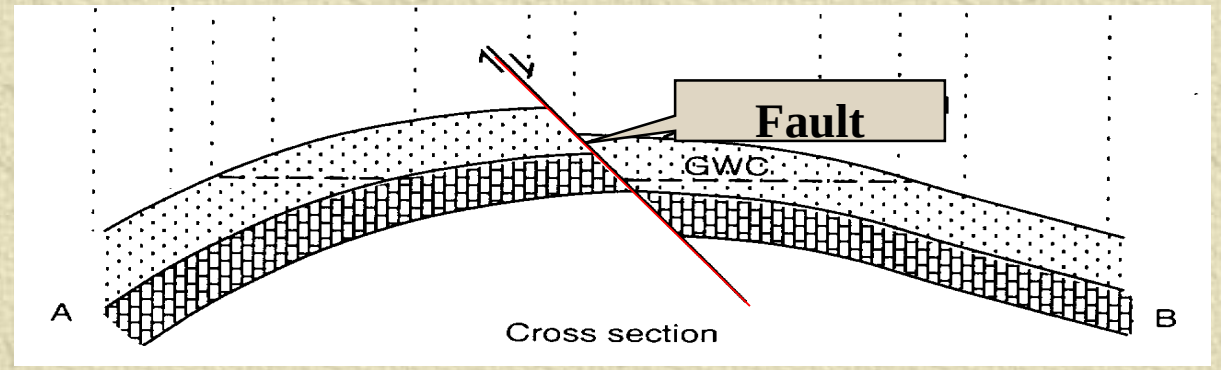
Geology profile of oil and gas field is the vertical section along some directions

Cross profile, cross section:

---------Vertical to construction axial direction

Profile section, elevation section:

--------Parallel to the construct axis



Section 3 Geology Profile Mapping

Cross profile
Longitudinal diagram

Cross profile :

To display the shape and extent of a hydrocarbon accumulation

To indicate the dip and strike of the structure.

To display the location of faults, wells and the fluid contacts

Section 3 Geology Profile Mapping

I.Section lines selection and well site adjustment

II.Well straightening

III.Geologic section mapping

Section 3 Geology Profile Mapping

I.Section lines selection and well site adjustment

1. Section lines selection

① To select the direction which indicates the features of structure and sedimentary

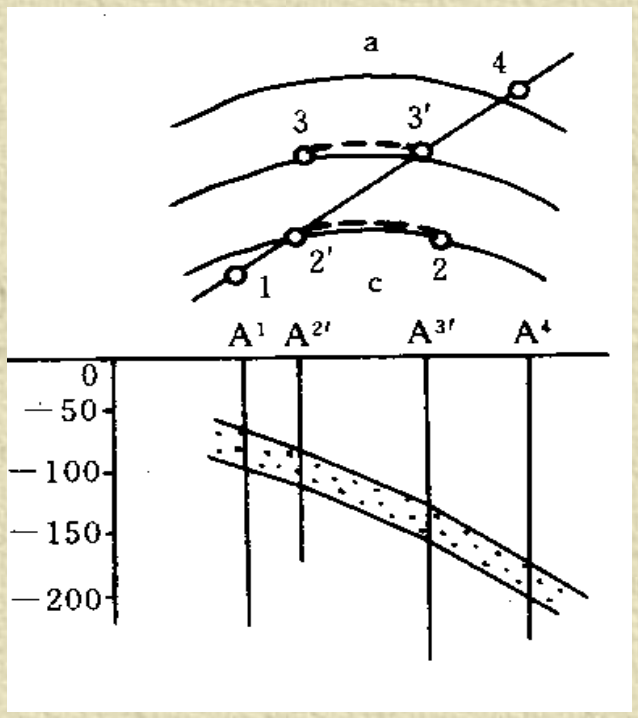
Vertical to construction axial direction

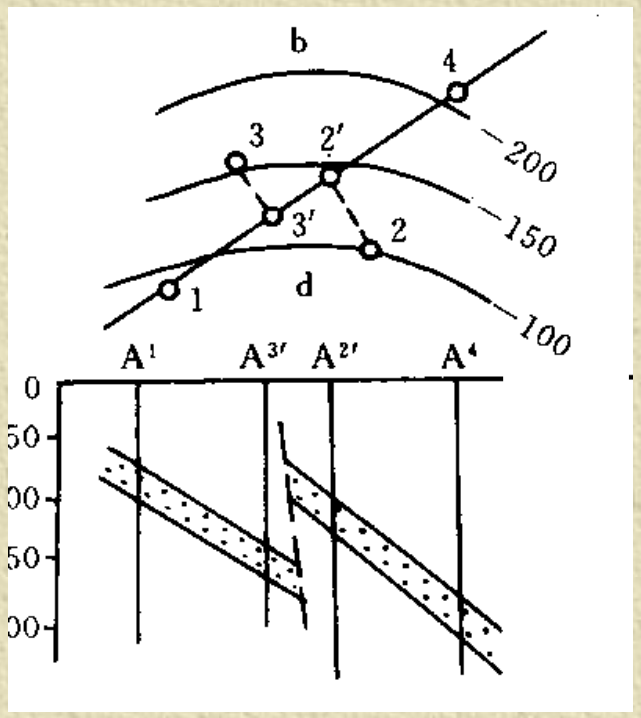
②To select the section which includes wells mostly

I. Section lines selection and well site adjustment

2. Well site correction

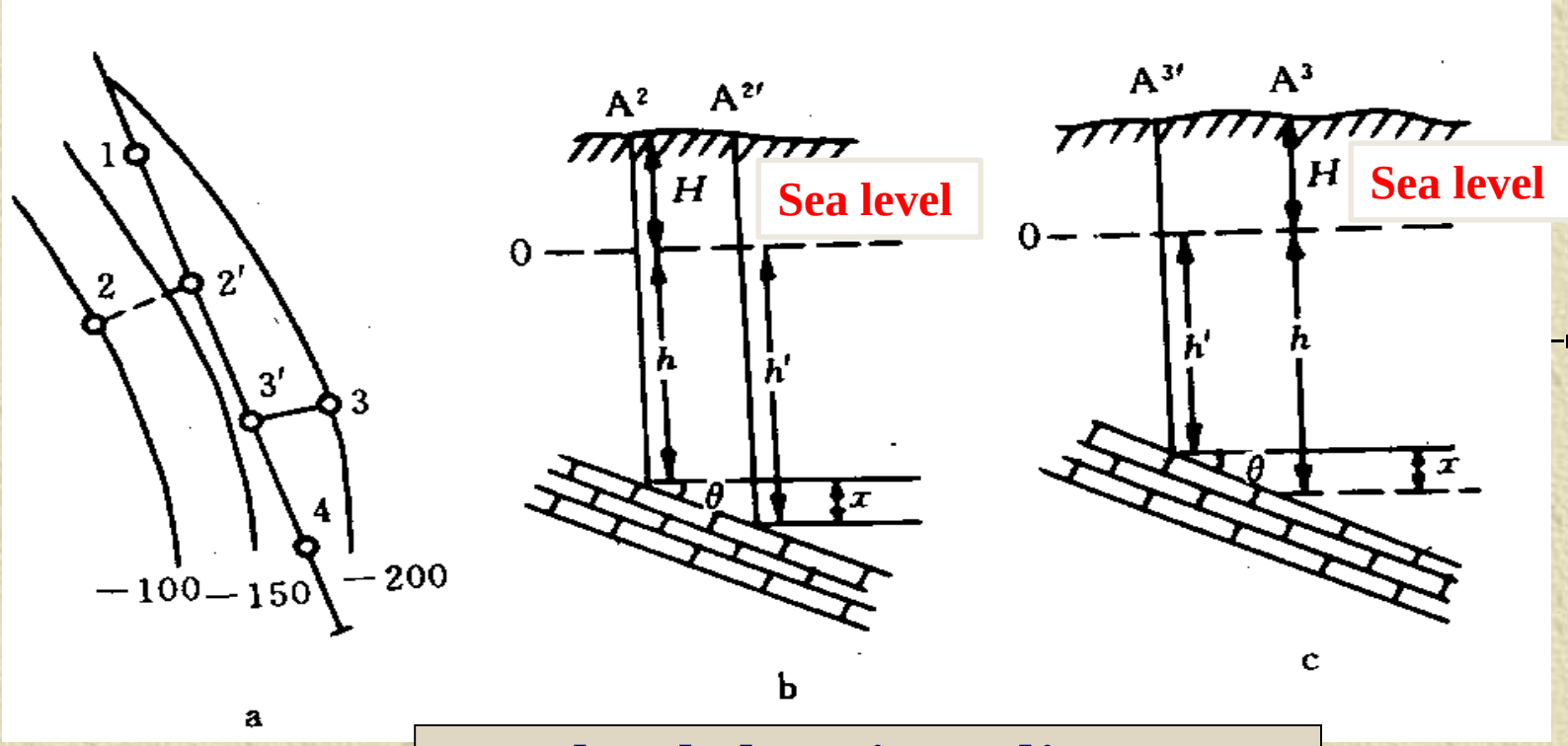
① When the selected profile vertical or oblique to formation strike, the projection along the formation strike





I. Section lines selection and well site adjustment

②When the selected profile parallel to the formation strike, draw the vertical line to the profile----depth correction



Sea level elevation adjustment schematic drawing

Depth correction $X=\pm L\mathrm{tg}\theta$ (1)

L: distance between well to profile
θ: true dip angle

Well 2': $-h'=-(h+x)$ Well 3'#: $-h'=-(h-x)$

$$X=\pm L\mathrm{tg}\theta/\cos\beta \quad (2)$$

θ:apparent dip
β:Angle of profile and dip direction

Section 3 Geology Profile Mapping

I.Section lines selection and well site adjustment

II. Well bore correction

III.Geologic section mapping

II. Well bore correction

Making the well bore of deflecting well and crooked hole project the profile along the formation strike

Methods: Calculation

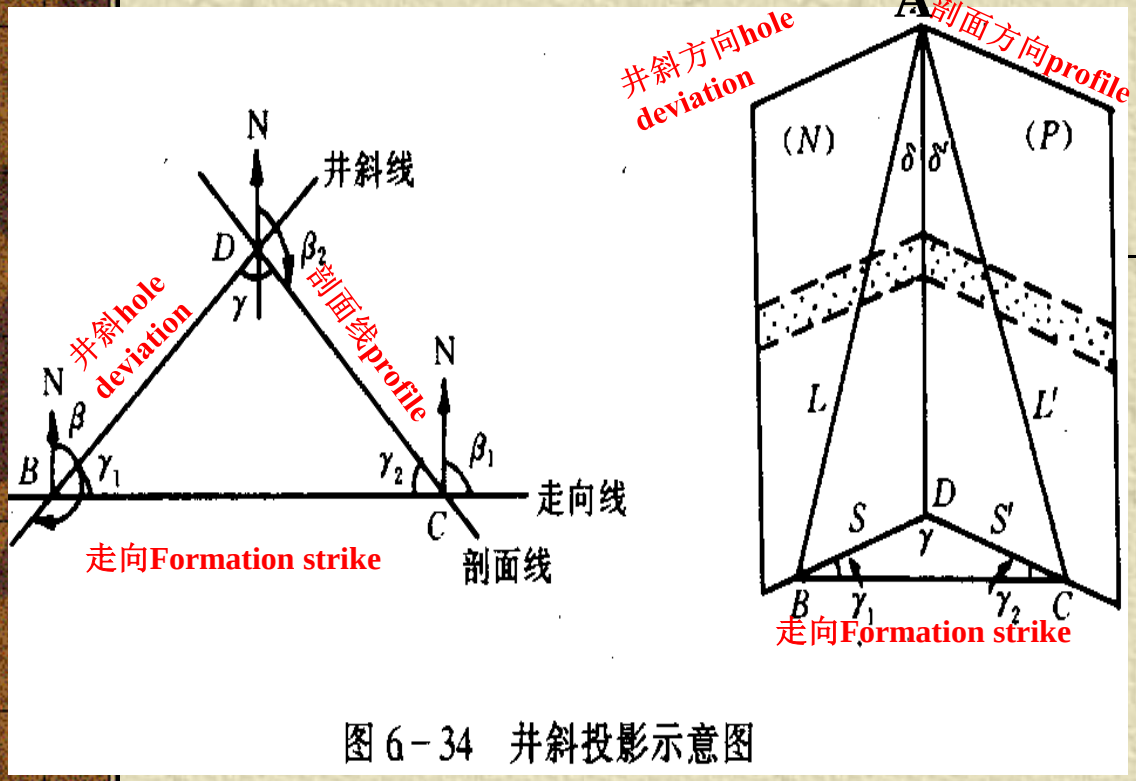


图 6-34 井斜投影示意图

L：The length of the hole deviation

L’ ：The length of the hole deviation which is corrected on the profile

Δ：deviation angle

δ’ ：deviation angle which is corrected on the profile

γ：the angle of profile and hole deviation

γ1：the angle of formation strike and hole deviation

γ2：the angle of formation strike and profile

BD=AD*tg δ　　CD=AD*tg δ’

BD/CD=Sin γ2/Sin γ1=tg δ/tg δ’

δ’ =arctg(tg δ*Sin γ1/Sin γ2)

AD=L*cos δ=L’ *cos δ’

L’ =L*cos δ/cos δ’

Section 3 Geology Profile Mapping

I.Section lines selection and well site adjustment

II. Well bore correction

III.Geologic section mapping

III. Geologic section mapping

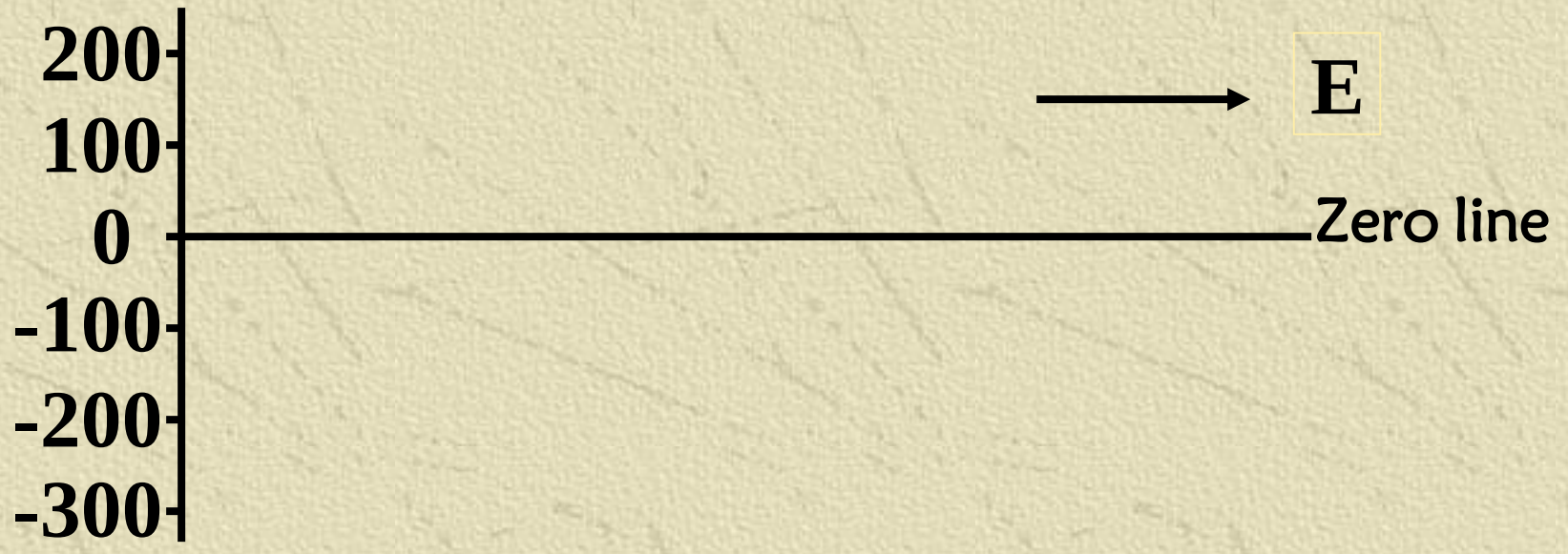
Structure section map could show general geologic feature on the section, such as structure feature, fault, unconformity, fold and facials changes. Some steps will be followed:

- **Use the results of correlation to determine depths of every well. If the well is a directional well, we should adjust the depth of deviation well.**
- **Select a line which stands for the structure feature of the study area and hang on every well on practice space in some scale.**
- **Mark results of correlation and fault point on well profile, and connect the same strata boundary with smooth line and fault line on the section.**

Section 3 Geology Profile Mapping

III. Geologic Section Mapping

1. Plotting selected section line according to scale

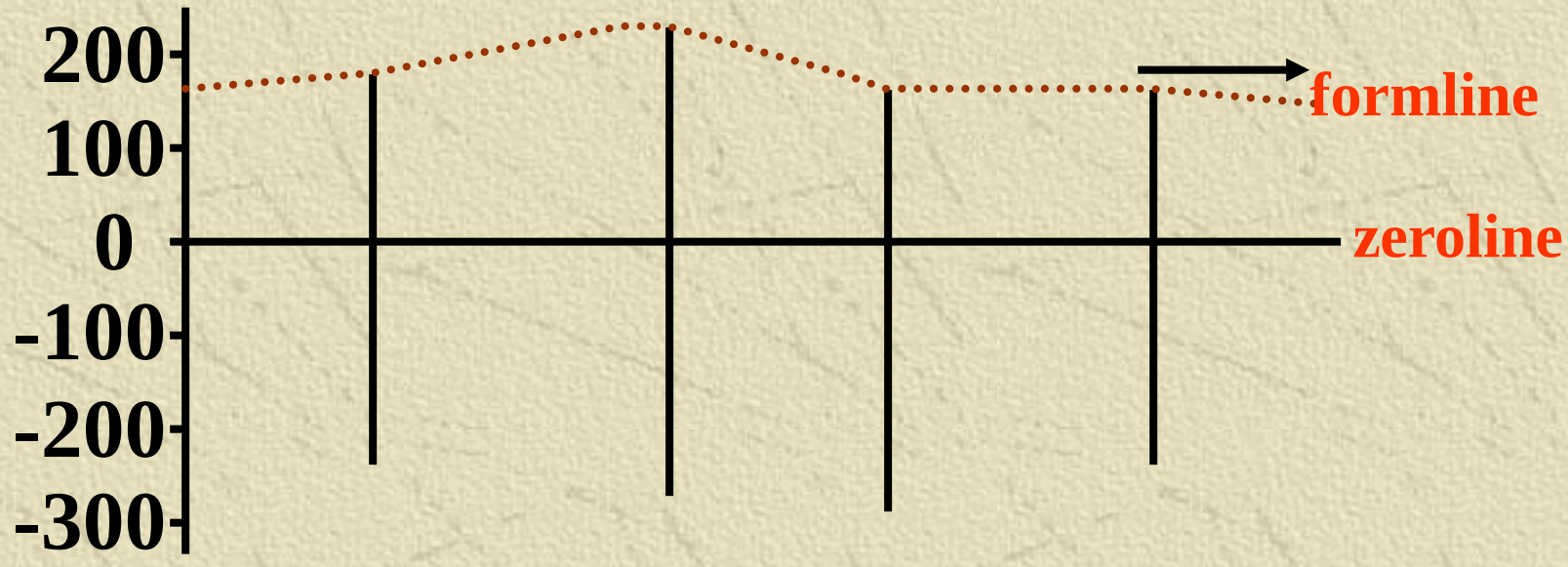


III. Geologic Section Mapping

2. Wells are marked on the section line

Plotting formline according to well head elevation

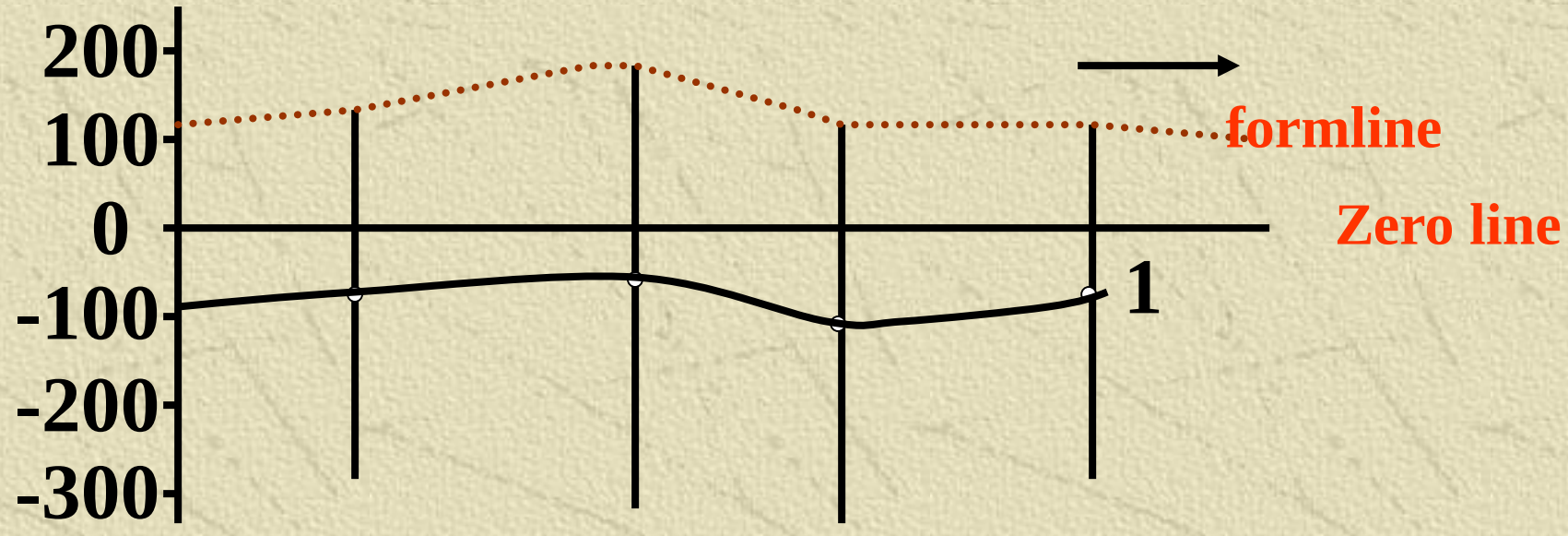
Well head elevation: The distance between ground level to sea level



III. Geologic Section Mapping

3. Mark results of correlation and fault point on well profile

To connect the same strata boundary with smooth line and fault line on the section.



III. Geologic Section Mapping

4. Legend and Table

Mapping unit	
Draftsman	
Mapping time	
Authorization	

5. Description

Chapter 4 Subsurface Structure Research

Section 1 Subsurface Structure Overview

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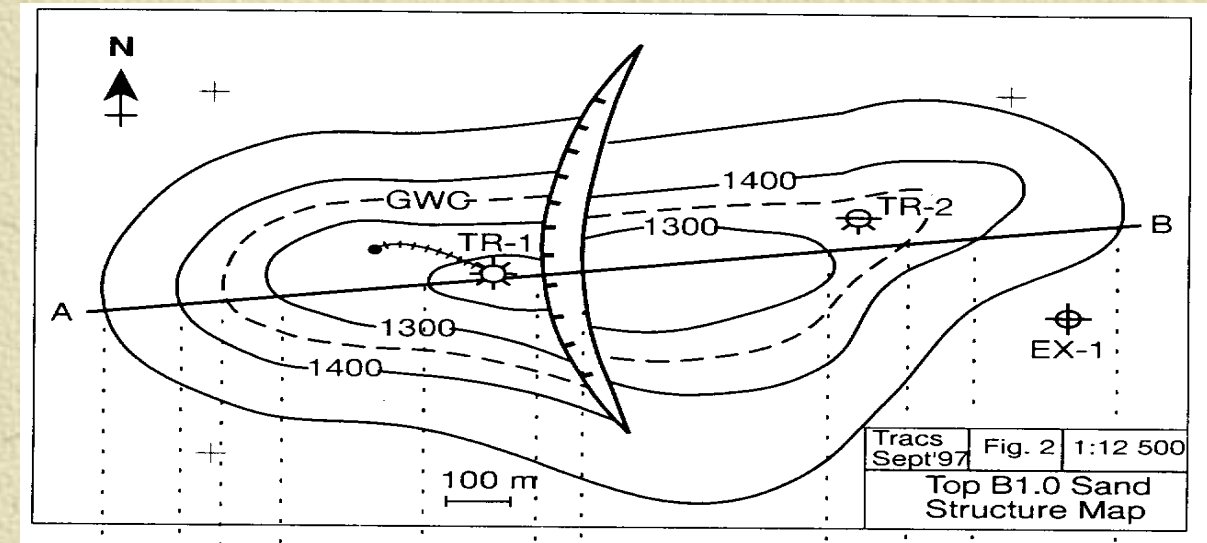
Section 4 Structure Map of Oil and Gas Fields

Section 5 Palaeostructure Research Method

Structural contour map

- **To display the top (and sometimes the base) of the reservoir surface below the datum level. The depth values are always true vertical sub sea.**
- **To display the shape and extent of a hydrocarbon accumulation and indicate the dip and strike of the structure.**



Section 4 Structure Map of Oil and Gas Fields

Structure map: The contour map which is expressed a bed plane shape.

Structure map of oil and gas field: The contour map which is expressed the shape of an oil bed or the marker nearby oil bed.

I. Preparing before mapping

II. Mapping method

Section 4 Structure Map of Oil and Gas Fields

I. Preparing before mapping

1. Mapping marker selection
2. Well sea level elevation calculation
3. Scale and contour interval selection

Section 4 Structure Map of Oil and Gas Fields

I. Preparing before mapping

1. Mapping marker selection

Mapping marker----The bed boundary which will be mapped

(1) To indicate structure features

(2) To represent the fluctuation of reservoir top and bottom surface

Section 4 Structure Map of Oil and Gas Fields

I. Preparing before mapping

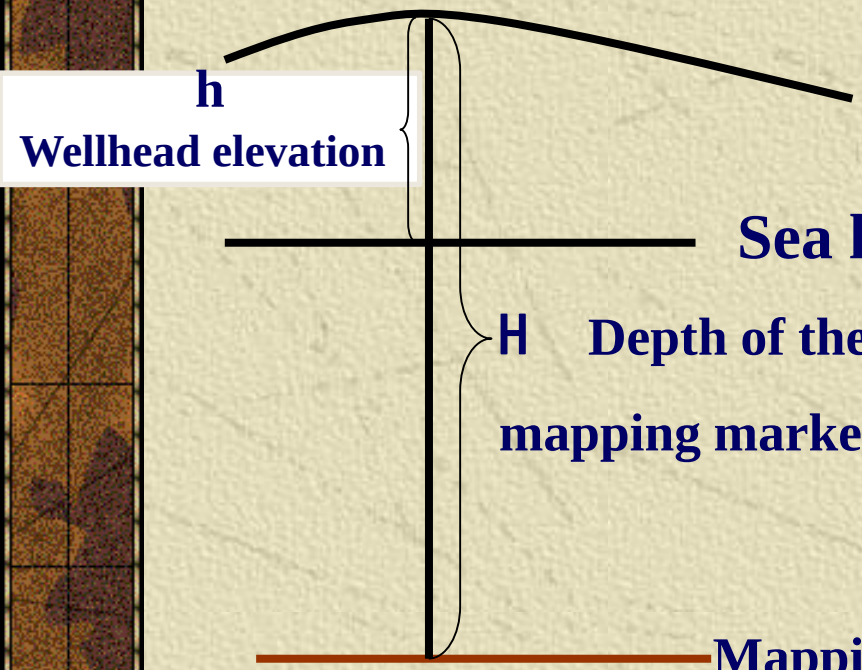
2. Well sea level elevation calculation

The distance between the mapping marker and sea level

Section 4 Structure Map of Oil and Gas Fields

I. Preparing before mapping

2. Well sea level elevation calculation



The distance between the mapping marker and sea level

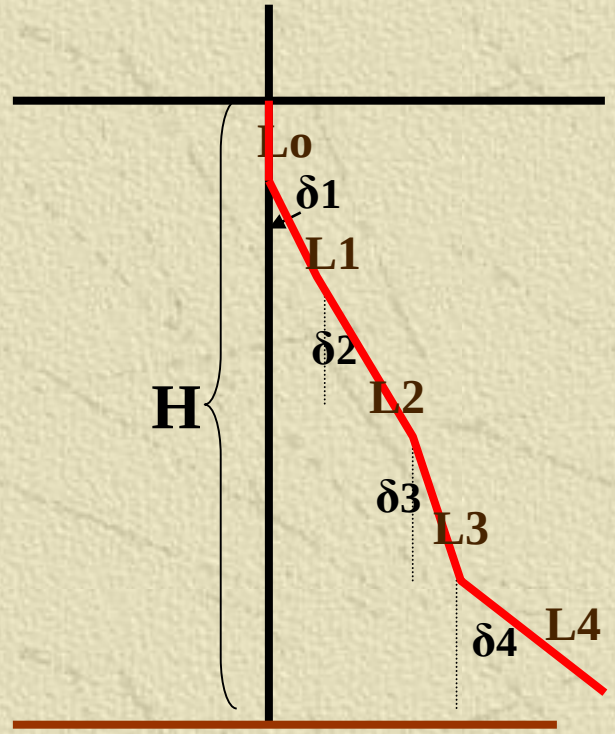
Mapping marker: h-H (Vertical well)

Section 4 Structure Map of Oil and Gas Fields

I. Preparing before mapping

2. Well sea level elevation calculation

The distance between the mapping marker and sea level



Crooked hole:

$$H=Lo+L1\cos\delta 1+L2\cos\delta 2$$

$$+\cdots+Ln\cos\delta n$$

Mapping marker: h−H

Section 4 Structure Map of Oil and Gas Fields

I. Preparing before mapping

3. Scale and contour interval selection

(1) Scale

Exploration 1:200000-1:100000
Development 1:10000

(2) Contour interval

A. The less scale, the larger contour interval
B. The bigger dip, the larger contour interval

Section 4 Structure Map of Oil and Gas Fields

I. Preparing before mapping

1. Mapping marker selection
2. Well sea level elevation calculation
3. Scale and contour interval selection

Section 4 Structure Map of Oil and Gas Fields

II. Mapping method

1. Interpolation method

2. Profile method

II. Mapping methods

1. Interpolation method

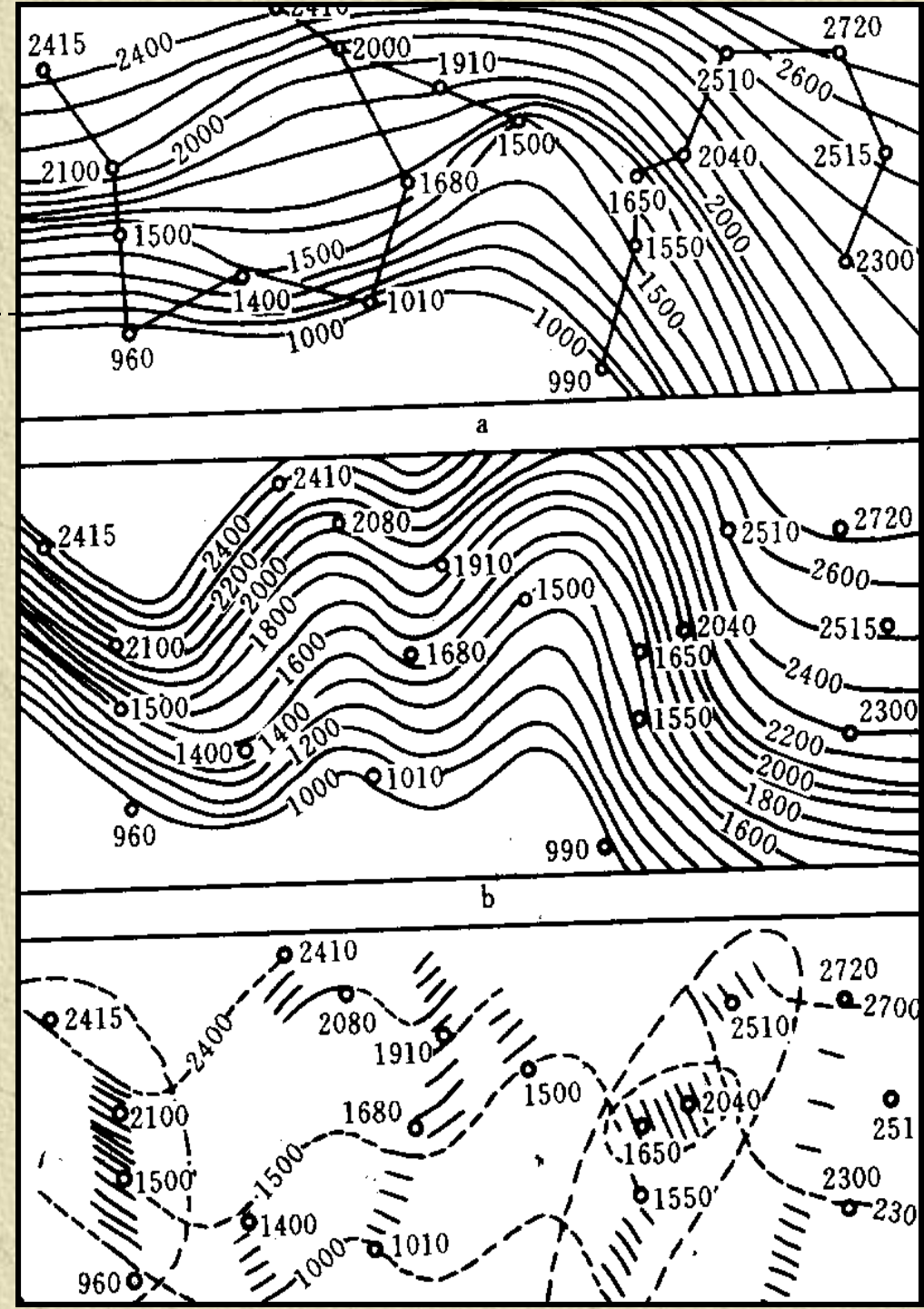
Condition:

Gentle structure

Occurrence change little

gentle strata and

simple structures.



II. Mapping methods

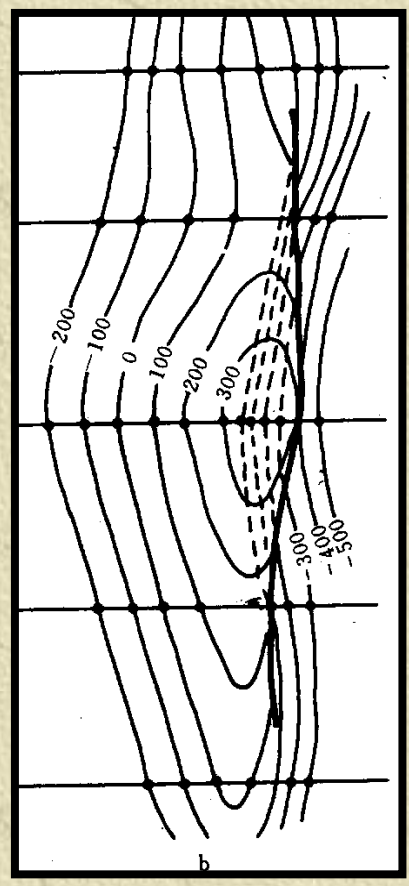
2. Profile method

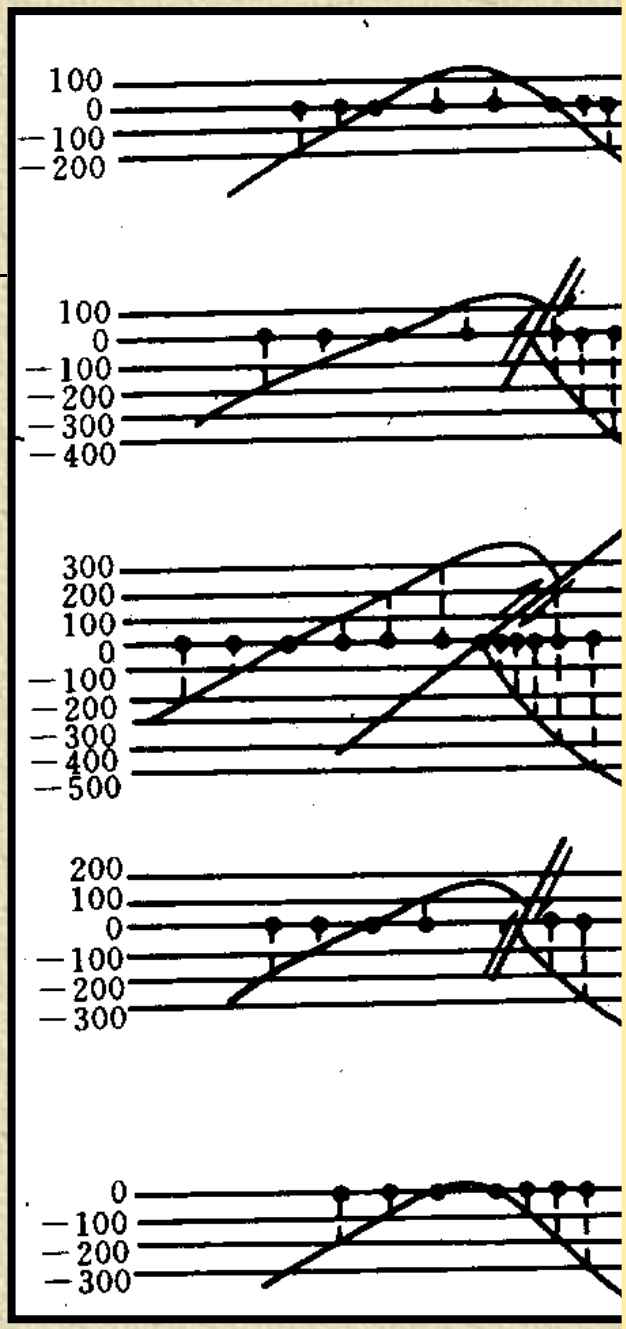
Condition:

① Long axis structure

② The structure with steep dip angle

③ The complicated structure with fault

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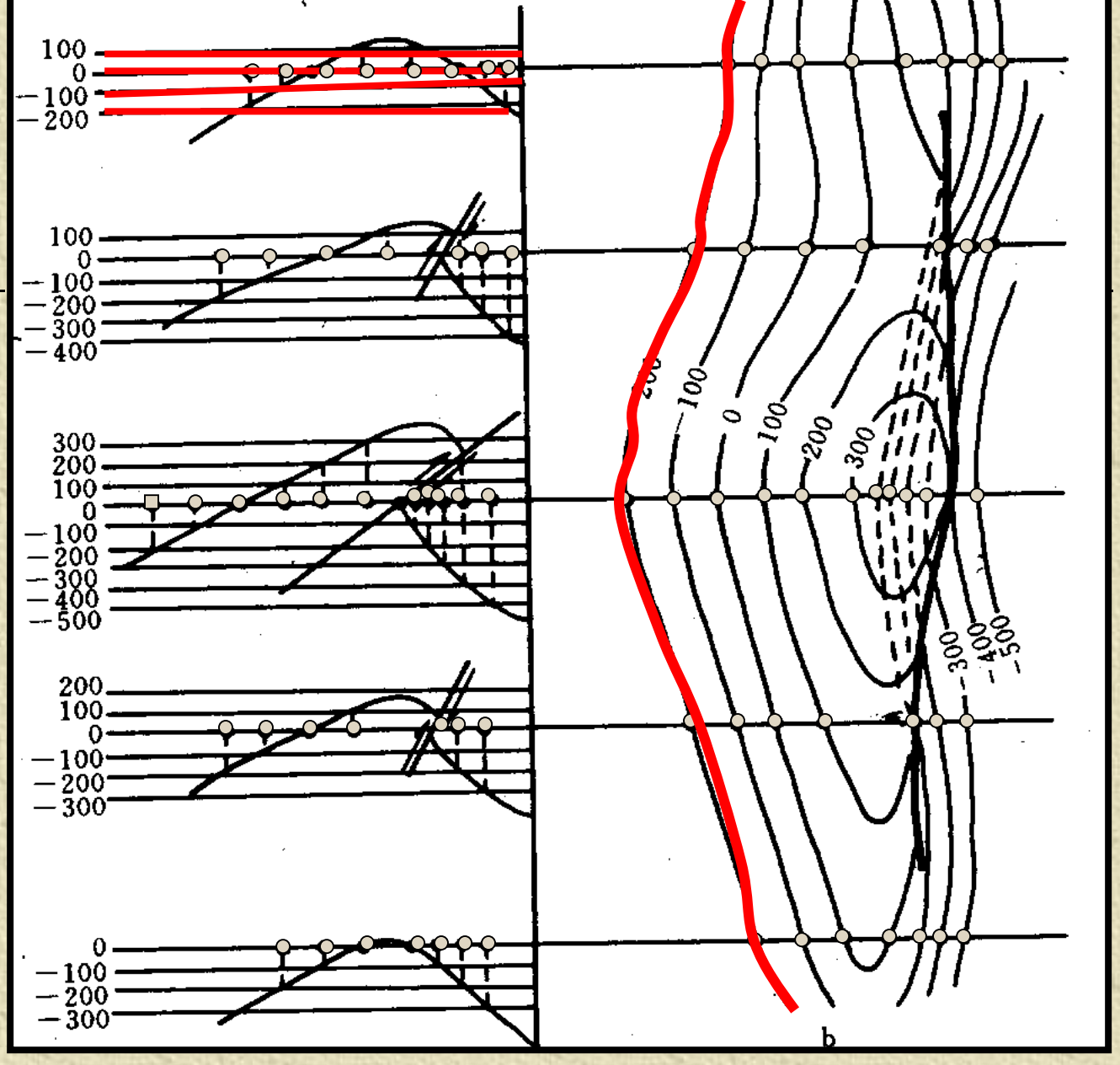

Profile method----structure map

profile map; b—structural map

How to plot structure map

(1)Using results of correlation to determine depth of datum which will be mapped.

(2)Plotting contour map

(3)Analyzing feature of region structure, and make structure map in line with the feature of region structure.

(4)Paying attention to position of fault, using seismic profile and correlation result to analyze position of fault.

Chapter 4 Subsurface Structure Research

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Section 5 Palaeostructure Research Method

Paleostructure: syndepositional structure, syndepositional anticline,

Paleostructure or syndepositional is formed during the sedimentation

I. Paleostructure Features

II. Paleostructure research methods

Section 5 Palaeostructure Research Method

I. Paleostructure Features

1. The sedimentary development: continuous
2. Thickness feature: thin top and thick flank
3. Lithology variation: coarse top and fine flank
4. Stratigraphic contact---- unconformity
5. Structure configuration

Section 5 Palaeostructure Research Method

II. Paleostructure research methods

1. Lithologic analysis
2. Sedimentary break analysis method
3. Structural configuration analysis
4. Thickness analysis

Section 5 Palaeostructure Research Method

II. Paleostructure research methods

1. Lithologic analysis

Sand-shale percentage map

Sand thickness contour map

Sand content percentage map

Lithologic qualitative analysis:

Based on same bed lithology and lithofacies variation in a plane

➡ indicate the location of palaeostructure

Section 5 Palaeostructure Research Method

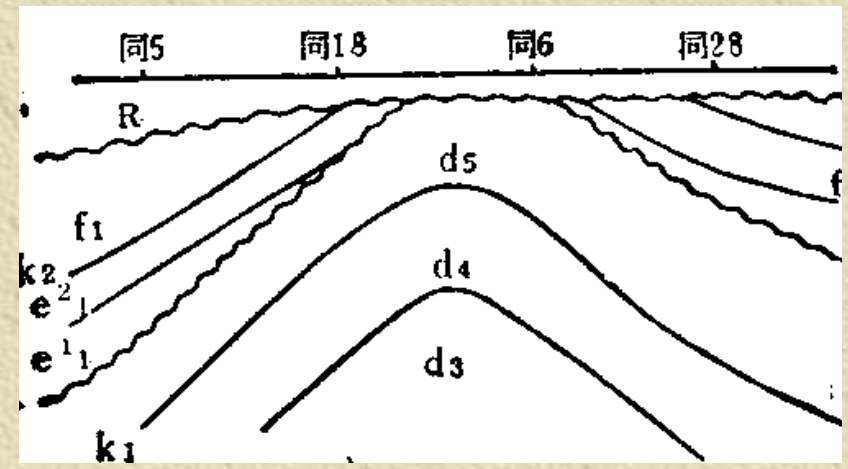
II. Paleostructure research methods

2. Sedimentary break analysis method

Stratigraphic contact relationship define the geological age

Based on: unconformity contact or erosion surface

➡ **structure formative stage**



Section 5 Palaeostructure Research Method

II. Paleostructure research methods

3. Structural configuration analysis

Structural configuration define palaeostructure evolution:

Based on ----(1) difference of structural layer(superstructure and infrastructure) and structural configuration;

(2) the variation of two side flank

Section 5 Palaeostructure Research Method

II. Paleostructure research methods

4. Thickness analysis:

Tracing the thickness variation in different geological history, analysis regional and local structure evolution of the basin

According to thickness variation of overlying rock define paleostructure rise quantitativly

Condition: Stable subsidence area ?

Principle: under the condition of sedimentary compensation, the thickness will indicate the earth crust subsidence magnitude quantitatively, infer the paleostructure magnitude

Sedimentary compensation: earth crust subsidence magnitude continuously is compensated sediment immediately

Sedimentation thickness is agree with the subsidence range

Chapter 4 Subsurface Structure Research

Section 1 Subsurface Structure Overview

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Section 5 Palaeostructure Research Method

Comprehensive Questions:

1. The significance of subsurface structure research.
2. What are the basic features of subsurface structure?
3. What are the research range and mapping units for the exploration phase subsurface structure research?
4. What are the research range and mapping units for the development phase structure research?
5. Summary the research information for an oil field subsurface structure.
6. How to identify fault with the stratigraphic sequence abnormal?
7. How to identify reversed fault and inverted anticline according to sequence repetition order?
8. What is the difference between the sequence missing from fault and unconformity erosion?
9. What information could be inferred fault during drilling?
10. How to plot fault line?
11. Summary the features of contemporaneous fault.
12. Explain growth index
13. Analyses fault seal research main methods
14. Section lines selection principle
15. Well site correction methods
16. Mapping marker selection principle
17. Mapping methods of structure contour map of oil and gas fields
18. Summary the paleostructure features
19. Paleostructure research methods
20. Sedimentary compensation