# EARTH, ATMOSPHERIC, OCEAN AND PLANETARY SCIENCES
PAPER II

1.   Draw a flow chart to find the square root of a positive number X correct to three decimal places by the method of bisection given that the square root lies between x_1 and x_2 ($x_2 < x_1$).

(20 marks)

2.   Palaeomagnetic pole positions of rocks of Plio-Pleistocene are plotted in the following figure. The position of the present day geomagnetic pole is also shown.


● Plio-Pleistocene to Recent paleomagnetic poles
(younger than 5 Ma)

★ Present-day geomagnetic pole
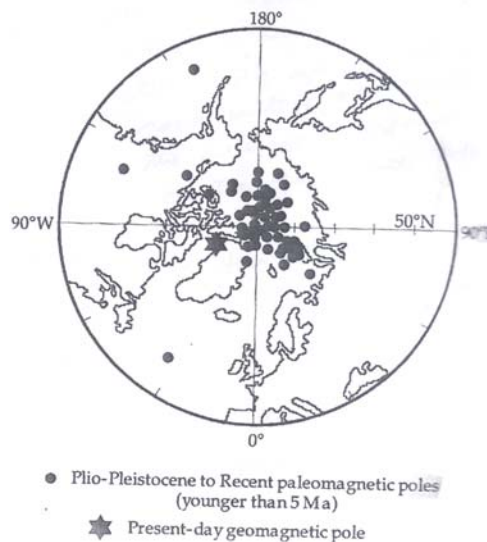
(a)   How does a palaeomagnetic pole differ from a virtual geomagnetic pole?

(5 marks)

(b)   Why does the palaeomagnetic pole clustered in the figure around the geographic pole rather than the geomagnetic pole?

(5 marks)

(c)   How do you locate the virtual geometric pole position from the Natural Remanent Magnetization of rocks?

(10 marks)

3.   Seismic waves inside the earth travel along curved paths. P and S waves disappear beyond an epicenter distance of 103°, but a phase of P wave gets recorded at 143° and thereafter.

(a)   Why do seismic waves travel along curved paths inside the earth?

(5 marks)

(b)   Sketch and name the different phases of earthquake waves that can travel inside a homogeneous and isotropic earth.

(5 marks)

(c)   Identify the phase of P wave that gets recorded from 143° onwards and
        explain its path of travel.

(5 marks)

(d)   Sketch and name the phases of the S wave that can be recorded in the
        shadow zone.

(5 marks)

4.   Vertical electrical sounding is carried out by passing current through two
        electrodes placed at A and B of a square array ABCD of side a, and
        measuring the potential difference developed in the ground between the
        electrodes C and D.

(a)   Derive the relationship between the apparent resistivity and the
        measured resistance.

(10 marks)

(b)   How does this array compare with the Werner's array in regard to
        accuracy of the apparent resistivity calculated?

(6 marks)

(c)   If the Werner's array measures a resistance of 3.414 ohms for a
        particular electrode separation, what will be the resistance
        measured in the square array for the same electrode separation?

(4 marks)

5.   The travel times of a seismic wave reflected at a velocity interface are 810
        ms and 821ms respectively at the extreme geophones of a
        symmetrical spread of length 400m. Travel time at the shot is 800ms.

(a)   What is the dip moveout? In what direction the reflector is dipping? How
        is the dip moveout connected to the dip of the reflector?

(4 marks)

(b)   What is the normal moveout? What is its utility in the analysis of seismic
        records?

(3 marks)

(c)   Assuming that the velocity V of the medium and travel time t are
        connected by the equation $V^2 t^2 = x^2 + 4h^2 + 4hx \sin \theta$,
        where x, h and θ are the geophone distance, depth to the interface and its
        dip respectively, calculate V and h.

(10 marks)

(d)   Use the relation in (a) to calculate the dip of the interface.

(3 marks)

6.   (a)   What is the general pattern of magnetic anomalies across mid-ocean ridge
                system. How do you explain them?

(8 marks)

(b)   How do you infer oceanic fracture zones from magnetic anomalies?

(4 marks)

(c) Explain the other geophysical signatures associated with mid-ocean ridge system?

(8 marks)

7. a) In the mantle, heat flow occurs on long time scales through convective motion as illustrated below.
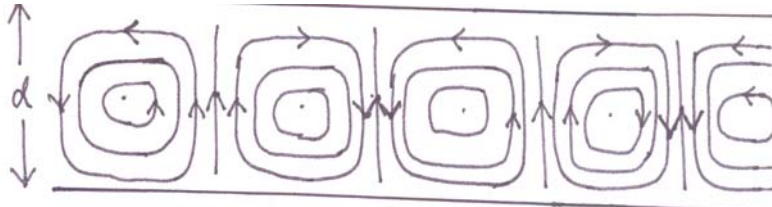
Extrapolate what would happen to the convection if the thickness of layer (d) and the kinematic viscosity (ν) of the mantle were increased.

(10 marks)

b) Geophysical observations show that the isotherms are distorted across two subduction zones , say A and B. The subduction rate in A is much higher than that in B. What can be the difference in the geotherm geometry at A and B?

(10 marks)

8.   The Global Positioning System (GPS) is used to precisely measure the position of points on the surface of the earth.

a) How can it be used to measure the velocities of different points on the Indian plate?

(4 marks)

b) Would you expect the positions of points determined using GPS to be readily plottable on Survey of India toposheets? Explain.

(5 marks)

c) Assuming that the following velocities were measured on the Indian plate:

Location	North Velocity (mm/yr)	East Velocity (mm/yr)
Colombo	45	25
Bangalore	40	23
Delhi	35	25
Almora	35	23
Leh	15	35

Why does the North Velocity drop from south to north in the Indian sub-continent?

(4 marks)

What is indicated by the velocity measured at Leh? Can you suggest a reason for it?
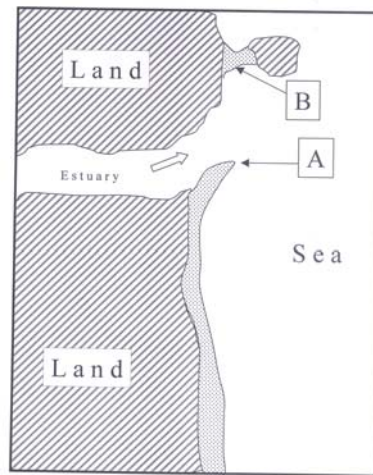
(5 marks)

Where would you expect maximum strain to accumulate in the Indian sub-continent?

(2 marks)

9.   a)   Define hardpan and mention the four main types of hardpans.

(6 marks)

b)   Mention the characteristics of hardpans in humid and arid climates.

(10 marks)

c)   What is the effect of hardpans on runoff generation?

(4 marks)

10.   a)   Explain diagrammatically a region that erodes into mountains and deep valleys and has undergone isostatic readjustment.

(10 marks)

b)   With reference to isostasy, what happens to the parts of the lithosphere when the densities are varying and when densities are approximately the same but have different thickness?

(10 marks)

11.   a)   With reference to remote sensing, define the term relief displacement.

(4 marks)

b)   Radar imageries and photographic images have opposite displacement. Why?

(10 marks)

c)   Though displacement is a limitation, it provides some useful information. What type of information could be obtained?

(6 marks)

12.   a)   With reference to bedload transport, describe the terms traction and saltation.

(6 marks)

b)   Although vast quantities of sediment are transported in suspension, why is suspended load less effective in terms of bed erosion?

(10 marks)

c)   What is the type of channel pattern displayed by a stream heavily loaded with bedload sediment.

(4 marks)

13. a) List five best geomorphic markers of tectonic uplift in an area.

(6 marks)

b) Assuming that the sea-level has not changed, how terraces could be used to determine the rate of tectonic uplift along a coast?

(7 marks)

c) In what geomorphic form would the effect of normal and thrust faulting across a river be manifested?

(7 marks)

14. a) Give the primary factors responsible for the hot and cold seasons as well as wet and dry seasons on the Earth.

(8 marks)

b) Why is diurnal range of temperature greater at higher elevations?

(6 marks)

c) What is the primary cause of daily range of temperature?

(6 marks)

15.

a) Identify the two features in the above diagram, marked as A and B.

(4 marks)

b) Describe the process responsible for these two features.

(12 marks)

c) Comment on the direction of the wave front vis-à-vis the shoreline.

(4 marks)

16. a) Give specific geomorphic situations where one would find Quaternary continental records.

(7 marks)

b) What for is amino acid analysis done and what is the type of material required for amino-acid dating?

(7 marks)

c) A complete paleoclimatic record can be erected using lacustrine sequences. Why?

(6 marks)

17. (a) If you were to determine the precise age of formation of the materials given in column (1) using a radiometric dating method given in column (2), which one would you choose and why?

Col. (1)		Col. (2)	
1.	Bundelkhand granite	1.	$^{147}Sm - {}^{143}Nd$
2.	Deccan Basalts	2.	U – Pb zircon
3.	Amphibolites from southern India	3.	$^{40}Ar - {}^{39}Ar$

(9 marks)

(b) For a rock sample, $\in_{Nd}$ with respect to Chondritic Uniform Reservoir (CHUR) is defined as $\left[\dfrac{(^{143}Nd / {}^{144}Nd)_{sample}}{(^{143}Nd / {}^{144}Nd)_{CHUR}} - 1 \right] \times 10^4$.

An igneous rock has a positive $\in_{Nd}$ value at the time of its formation. If so,

(i) What can we infer about the Sm / Nd ratio of its mantle source?

(ii) Is the source enriched or depleted in LREE with respect to CHUR?

(5 marks)

(c) A mantle source rock containing 70% olivine (Ol) and 30% clinopyroxene (cpx) and having 3.2 ppm of Ce undergoes partial melting. What will be the concentration of Ce in the melt produced by 30% batch melting?

Use the following information:

In batch melting $C_L / C_S = 1/[D + F (1-D)]$, where C_L and C_S are concentrations of Ce in melt and source, respectively, F = fraction of melting, D= bulk partition coefficients. The partition coefficient $K_{d\,(ol\text{-}melt)}$ = 0.01 and $K_{d\,(cpx - melt)}$ = 0.07
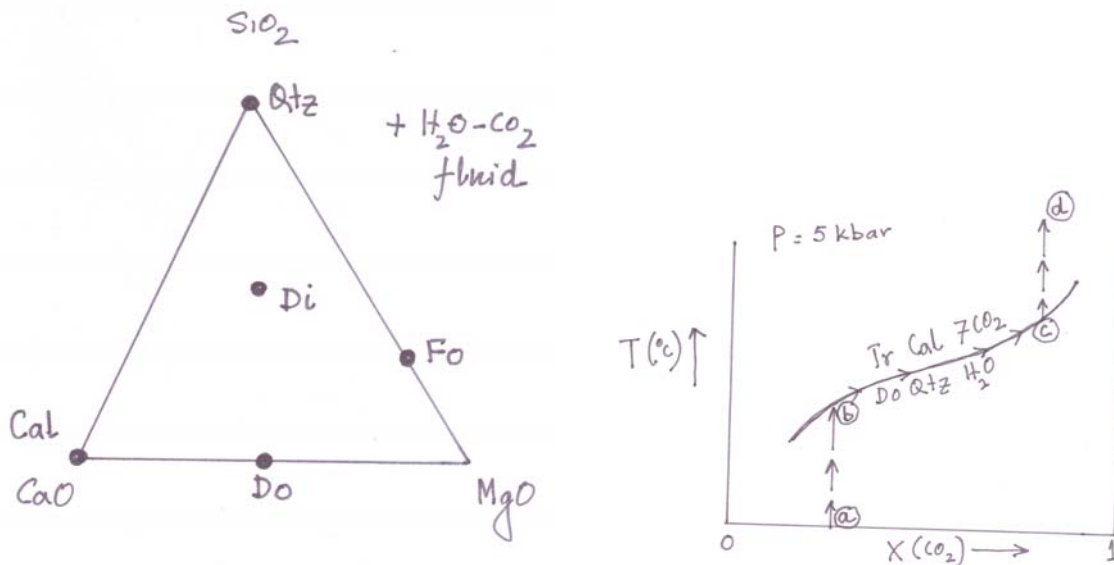
(6 marks)

18. (a)   In the phase diagram given below a melt of composition I starts to crystallize in equilibrium along I – a – b. What would be the proportions of A, B and melt (L) at b?
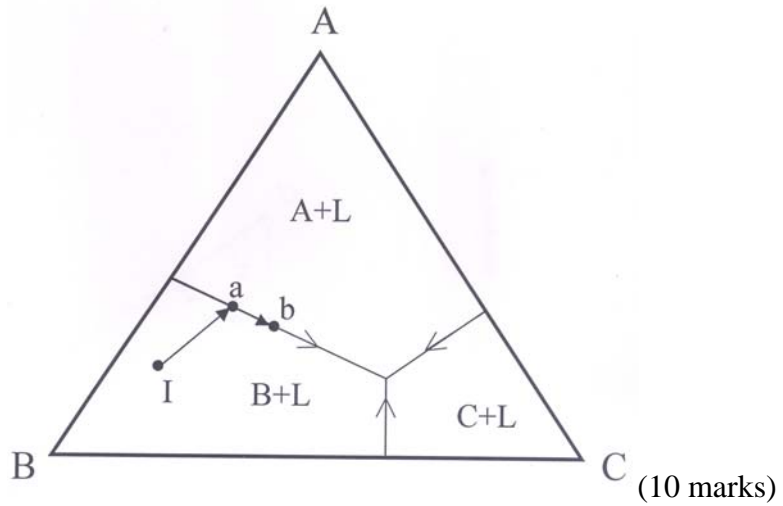
(10 marks)

(b)   For each of the following trace elements found in the silicate minerals, name a major element that the trace element commonly replaces in silicate structures.

(i) Rb	(iii) Ga	(v) Li	(vii) Ge	(ix) Pb
(ii) Sr	(iv) Ti	(vi) Mn	(viii) Rare earths	(x) Ni

(10 marks)

19.
(a)   In Fig (i), identify all possible relations involving the phases quartz (qtz), diopside (Di), forsterite (Fo), Calcite (Cal) and dolomite (DO)

(5 marks)

(b)   Explain the term "variance" or "degree of freedom"

(5 marks)

(c)   In fig. (ii), what is the variance along b – c (Tr stands for tremolite)

(5 marks)

(d)   a – b – c – d is the T – X (CO$_2$) bath for fluid evolution in Fig. (ii). For what possible conditions, will the fluid will evolve along c – d (from b – c)?

(5 marks)

20   (a)   How can the stable isotopic composition of foraminiferal tests be used to infer changing ice volume in the geological past?

(10 marks)

(b)   A marine sedimentary succession contains radiolarian ooze at the bottom followed by foraminiferal ooze and pteropod ooze at the top. Infer the basin history.

(10 marks)

21.   (a)   The figure indicates the Fe content of pore water in a sediment profile. What does the iron distribution show in terms of redox potential of pore water in zone A, B and C?
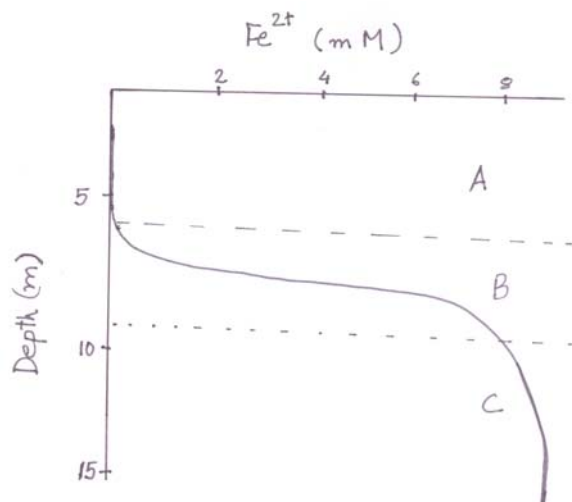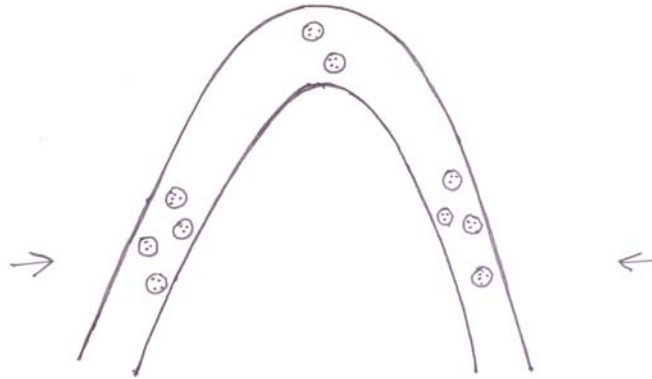

(12 marks)

(b)   Explain, with help of a diagram, the variation in the solubility of aluminium as a function of water pH. What pH range favors the formation of Bauxite ore and why?

(8 marks)

22.   (a)   A metamorphic layer containing garnet porphyroblasts has been buckled to develop a fold, as shown in the following figure. Explain the rotational motion of porphyroblasts on the two limbs and the hinge of the fold.

(10 marks)

(b)   Define a structural horse. How is it different from a structural horst? In what type(s) of deformation setting(s) can they be formed?

(2+2+2 marks)

(c)   Name two major types of fault-related folds in compressive tectonic settings. Footwall synclines are typically associated with which one of the two folds?

(2+2 marks)

23.   (a)   What are Continental Flood Basalts (CFB) ? What are the current models of their origin? Give at least three examples of CFBs. Are continental flood basalts a recent phenomenon in Earth history, or do they extend back into Precambrian time?

(10 marks)

(b)   Deccan lavas erupted between 69 to 64 Ma at a rate of 1 km^3 per 5000 years spreading over 1000 km^2, and covered a total area of 5 x 10^5 km^2. Calculate the total volume of the Deccan basalts.

(6 marks)

(c)   What are carbonatites? Where do they usually occur, and what kind of igneous rocks are generally associated with them? Give two major evidences for their mantle origin.
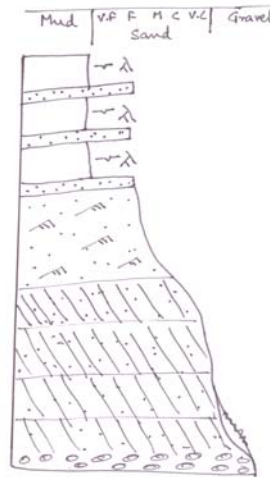
(4 marks)

24.   (a)
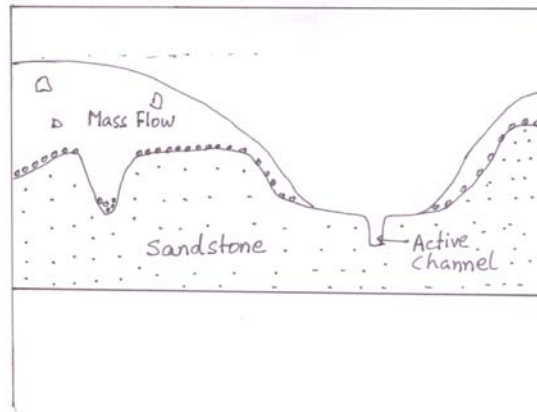
Refer to the above diagram and explain the sequence of events that might have occurred in this region.

(8 marks)

(b)   Examine the stratigraphic column in the given figure and answer the following.

(12 marks)

(i)   What general depositional sedimentary environment does this column represent? Give reason for your answer.

(ii)   Divide the column into parts representing sub-environments and label each part.

25.   (a)   The following wind data were received from 20 km to the east, north, west and south of a station, respectively: 90°, $10ms^{-1}$; 120°, $4ms^{-1}$; 90°, $8ms^{-1}$; 60°, $4ms^{-1}$. Calculate the approximate horizontal divergence at the station.

(7 marks)

(b)   Suppose the wind speeds given above are each in error by $\pm10\%$, What would be the percentage error in the calculated horizontal divergence in the worst case?

(c)   Match the following:

(i)	Bowen ratio	(a)	Ratio of buoyancy to shear terms in the turbulent kinetic energy equation
(ii)	Richardson number	(b)	Ratio of meanflow speed to the shallow water gravity wave speed
(iii)	Rossby number	(c)	Ratio of sensible to latent heat flux
(iv)	Froude number	(d)	Ratio of acceleration to Coriolis force

26.   (a)   What is the Brunt-Vaisala period of an air parcel displaced in an isothermal environment of 300 K?

(5 marks)

(b)   According to Stoke's law, the terminal velocity of a cloud droplet of radius R is $-(1.19 \times 10^8 \ m^{-1}s^{-1}) \ R^2$. The negative sign indicates that the droplets are falling to the ground. What updraft wind is required to keep a 10μm droplet from falling?

(5 marks)

(c)   The number density of cloud droplets greater than size R (radius) is given by $N = \dfrac{N_0}{\lambda} e^{-\lambda R}$ where λ and N_0 are constant. In case (i) N is plotted as a function of R and in case (ii) logarithm of N is plotted as a function of R. In which of these cases does the slope give an estimate of λ?

(5 marks)

(d)   Given $N_0 = 1.6 \times 10^{-7} \ m^{-4}$, $\lambda(m^{-1}) = 8200(RR)^{0.21}$ where RR is the rain rate in mm/h, find the number density of droplets greater than 10μm radius when the rain rate is 20mm/h.

(5 marks)

27.   (a)   An air parcel of initial temperature 25°C rises 3 km from the surface. What is the final temperature of the parcel? What happens to the water vapour in the parcel at 3 km altitude?

(4+1 marks)

(b)   Wind chill is the hypothetical air temperature in calm conditions ($v= 0$) that would cause the same heat flux from the skin as occurs for the true winds and true air-temperature:

$$T_{windchill} = T_{skin} - \left[\frac{v + v_0}{v_0} \right]^{0.21} (T_{skin} - T_{air})$$

Where $T_{skin} = 33°C$ and $v_o = 2$ m/s, $v=$ wind speed in m/s.

Calculate the wind chill temperature if $T_{air} = -5°C$, $v= 20$ m/s.

(5 marks)

(c)   Show that the scale height for an atmosphere composed of a gas of molecular weight M is given by $H = \dfrac{RT}{Mg}$ where R is the universal gas constant g = acceleration due to gravity and T, the absolute temperature. What is the scale height for an atmosphere with 50% each of oxygen and nitrogen? (T=290 K and g = 9.8 m/s.^{2})

(10 marks)

28.   The temperature and rainfall data for each month for a city are given below

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T(^{o}C)	21	22	25	28	30	35	40	38	32	28	25	23
rain(mm)	0	1	0	1	0	70	100	300	200	50	0	2

(a)   Which of the following best describes the location of this city? Why?
(i)   tropical   (ii) temperate   (iii)   Polar

(5 marks)

(b)   Is it possible to infer whether the city is located in the northern hemisphere or the southern hemisphere? If so, which and why? If not, why?

(5 marks)

(c)   What is the annual rainfall?

(3 marks)

(d)   What is the mean annual temperature?

(3 marks)

(e)   What is the mean summer temperature?

(4 marks)

29.   (a)   Explain the relationship of geostrophic wind to thermal wind and gradient wind.

(10 marks)

(b)   Match the following

(i)	Global warming	(a)	Fog
(ii)	Chloroflurocarbons	(b)	Tsunami
(iii)	Air pollutants	(c)	Ground water pollution
(iv)	Deforestation	(d)	Mass fish mortality
(v)	Earthquake	(e)	Ozone hole
(vi)	Eutrophication	(f)	Global cooling
(vii)	Use of fertilizers	(g)	Mortality of calcareous organisms
(viii)	Ocean acidification	(h)	Landslides
(ix)	Industrial activity	(i)	Sea level rise
(x)	Volcanism	(j)	Increase in green house gases

(10 marks)

30. (a) Define circulation and vorticity.

(6 marks)

(b) Write a mathematical expression for the rate of change of absolute vorticity following the motion. Also define all the terms in it.

(7 marks)

(c) Define the relationship between circulation and relative vorticity considering a rectangular element of area ($\delta x . \delta y$) in the x-y plane.

(7 marks)

31. (a) Describe Reynold's averaging

(10 marks)

(b) Why is data assimilation required in modeling processes?

(10 marks)

32. (a) Write at least three favourable conditions for rapid cyclogenesis

(6 marks)

(b) Calculate the average (standard) surface temperature for dry air, given standard pressure, P, 101.3 kPa, density, g, 1.225 kg.m^{-3} and R$_d$ 0.287 kPa K^{-1}m^3 kg$^{-1.}$

(7 marks)

(c) Given solar constant, S, 1368 W.m^{-2}, global albedo, A, 0.3 and Stefan – Boltzmann constant, σ, 5.67 x 10^{-8} W.m^{-2}.K^{-4}, find the relative equilibrium temperature of the earth-atmosphere system.

(7 marks)

33. (a) Distinguish between warm core and cold core eddy.

(6 marks)

(b) What remote sensing tool can one use to identify warm and cold core eddies?

(8 marks)

(c)   Explain how Ekman theory can be used to describe presence of cold water in the core of a cold core eddy.

(6 marks)

34.   (a)   Gulf stream, Kuroshio and Somali currents are all examples of western boundary currents. Explain how Somali current is different from the rest.

(6 marks)

(b)   What will be the effect of global warming in the formation of bottom water and its movement across the globe.

(8 marks)

(c)   Why is El Nino considered as a coupled ocean-atmosphere response?

(6 marks)

35.   (a)   What triggers denitrification in the coastal waters?

(8 marks)

(b)   What is the intermediate species of nitrogen formed during nitrification as well as denitrification with green house effect? What are its properties?

(4 marks)

(c)   Distinguish between biochemical oxygen demand and chemical oxygen demand.

(8 marks)

36.   (a)   What are the different life zones in oceans? Describe their properties.

(10 marks)

(b)   How does overturn in water affect aquatic life?

(4 marks)

(c)   With respect to animal life in streams, distinguish between shadders, collectors, grazers and gougers?

(6 marks)

37.   A sediment core was recovered from off the west coast of India. Planktic forminifera where picked and radiocarbon dated. The calibrated calendar ages for various depth intervals of the core are given in the table below. Also given are the $\delta^{18}O$ values

Depth (cm)	0 – 2	9 – 11	19 – 21	29 – 31	39 – 41
Age (ka)	1.5	9.8	20.0	30.1	40.2
$\delta^{18}O$ ‰	–2.0	–2.5	–1.5	–1.9	–1.8

(a)   Calculate the average sedimentation rate

(5 marks)

(b)   Why is the age corresponding to the surface not zero?

(5 marks)

(c)   How will you interpret the $\delta^{18}O$ values at the top of the core and at 20 ka?

(5 marks)

(d)   How do the ages of ocean floor compare with the ages of continental rocks? What is the reason for the difference and why?

(5 marks)

38.   (a)   As a consequence of plate tectonics, what are the major surface ocean circulation changes in the world oceans, from Paleogene to Neogene? What was the major consequences of such a change?

(12 marks)

(b)   What are Pleistocene oxygen isotope stages? What is their significance?

(8 marks)

39.   (a)   Explain sodium balance in the ocean.

(3 marks)

(b)   Crustal rocks contain 2.4% of Na, 75% of which goes into solution during weathering to make a sea water concentration of 11.8 g/L of Na. Calculate the amount of rocks that must be weathered to get this concentration. From this derive the formula for percentage in solution.

(6 marks)

(c)   Ca composition in crustal rocks is 4.1% and the average seawater composition is 413 ppm. Using the formula derived in (b) above calculate the percentage in solution for Ca? Why is this value lower than that of Na?

(6 marks)

(d)   Explain the biological pump of the carbon cycle.

(5 marks)

40. Match the following

1.	Beach erosion	-	water vapour
2.	Upwelling	-	photosynthesis
3.	T-S diagram	-	fluoride
4.	Oxygen minimum zone	-	mixed layer
5.	Red tide	-	wave convergenced
6.	Mangrooves	-	Phytoplankton bloom
7.	Longshore current	-	barrier layer
8.	Excess precipitation over evaporation	-	normal to the shore
9.	Nutricline	-	parallel to the shore
10.	Ocean colour	-	denitrification
11.	Pycnocline	-	watermass
12.	Global warming	-	density gradient
13.	Wind mixing	-	sea WiFS
14.	Rip current	-	coastal protection
15.	Major ion	-	dispersant
16.	Greenhouse effect	-	ocean acidification
17.	Euphotic zone	-	trichodesmium
18.	Oil spill	-	nitrate gradient
19.	TBT (Tri butyl tin)	-	zooxanthallae
20.	Coral reef	-	port and harbour pollutant

(20 marks)