Earth Science Final Exam

Weather: Short term state of the atmosphere with respect to temperature, moisture, wind velocity and barometric pressure
Climate: Average long-term weather conditions for a region, including things like average temperature and precipitation

- Both have energy supplied by Sun

Greenhouse Effect: controls warmth of bodies of water and climate, degree of reflecting infrared radiation back to Earth – Carbon Dioxide, Methane

- Presence of CO2 on Venus suggests climate was once the same

Energy from impacts – Earth is impacted by 100-1000 tonnes of dust every day

- Meteoroid impacts cause massive energy releases, even if small

Chapter 10: The Physics and Chemistry of Water and Air

Atmosphere
Consists of 4 layers:

1. **Troposphere** – surface level to 12km (80% of atmosphere thickest at equator, thinnest at poles), main layer of atmospheric circulation
   (Tropopause) – equal pressure marked by jet streams
2. **Stratosphere** – up to 50km – zone above weather, ozone enriched
3. **Mesosphere** – up to 80km – asteroids begin to burn, lack of ozone
4. **Thermosphere** – up to 500-700km (ionosphere) – air thin and responsive to solar radiation, dramatic temp. Changes

Mars, Earth, Venus originally had almost identical atmosphere compositions

- Venus – CO2 filled atmosphere, greenhouse very strong, equilibrium reached at very high temperature 737 K
- Mars – smaller planet cooled more quickly, less internal heat, surface dropped, from the water the hydrogen escaped (mars low escape velocity) and oxygen combined in surface soils (red colour) think atmosphere today, surface temps fluctuate

Dynamics of the Atmosphere

- When a compound changes state, energy is either absorbed (ice to liquid) or released (liquid to ice) in the process
  - Amount of energy released or absorbed per gram of matter during a change of state is known as **latent heat** (2260Joules/gram or 540 calories/gram)
- Air moves in **convection cells** in troposphere in response to:
  - **Temperature gradients**
  - **Density gradients**
  - **Pressure gradients**
- Density = Mass/Volume – density of air decreases when heated, density increased when increasing pressure
  - Density at lowest: at high elevation, hot day, low pressure
  - Density at highest – low elevation, low temperature, high pressure
- Adiabatic processes – occur without addition or subtraction of heat from any external source
- Parcels of air heated near earth's surface, air pocket expands when heated, becomes less dense and rises to a point of lower pressure at high altitude. The rising parcel of air then cools and its density will slowly increase to match surrounding air and stops rising – no water in this air
- Humid air is lighter/less dense than dry air – so evaporation adding water to the air causes a decrease in air density, which can rise to higher elevations. Here the humid air also is heated, rises, expands, and once it cools condensation begins – which releases latent heat

Convection and Rotation

- Earth's surface heated unevenly – more of suns heat is received per unit of land surface near equator than near the poles – uneven heating gives rise to convection currents
- Coriolis Effect – effects of rotation on atmosphere
    - Breaks up the flow of air between the equator and the poles into belts
    - Hadley cells, ferrel cells, polar cells
    - Air movement associated with boundaries lead to formation of **polar jet stream/subtropical jet stream**
        - Aid in development and direction of storms
        - Jet stream winds must exceed 57Km/h

Wind – movement of air from high-pressure zone to a lower pressure zone

- Wind is effected by the Coriolis force – deflected to right in northern hemisphere and left in southern hemisphere)
- Winds around low pressure centre develop inward spiral motion
- Winds around high pressure centre develop outward spiral motion
- Isobars – show how strong/weak wind is – the more and closer together the stronger the winds
    - Very close isobars signify spiral patterns of cyclones and anticyclones
    - Cyclones – strong spiral patterns around low pressure cells
        - Inward spiral flow leads to upward flow of air at centre, moist air flows upward to produce clouds and rain
    - Anticyclones - strong spiral patterns around high pressure cells
        - Outward spiral flow is called divergence, air flows out at base, cold air drawn downward compressed and heated adiabatically leading to clear skies

Oceans

2 circulation systems in oceans – wind driven (surface circulation) and density driven (deep water)

Ocean Current Flow – expressed in million of cubic meters per second

Salinity – density of seawater – grams of dissolved solids per kilogram of seawater

- What's really measured is the water's electrical conductivity, which is directly proportional to the amount of dissolved solids in water

North Atlantic warmest and most saline – mean potential temp of 5.08C and 35.09 salinity

77% of worlds oceans colder than 4 C, surface 26% colder than 4 C

- Cold water sinks

Surface Waters

- Most of surface circulation is driven by winds – results in huge **gyres** of water at subtropical altitudes
    - Gyres – 5 worldwide, wind driven
- Blowing wind interacts with upper layer of ocean and sets it in motion in same direction as the wind (surface flow to right in n.hemisphere and left in s.hemisphere)
- Top layer of water pushed/drags the layers below, which are deflected a littler further right or left than the surface layer and are slowed by friction – this process continues down into the water column to depth of 100m, creating downward spiral of water gradually deflecting further and further the right/left
- Winds blowing toward southwest push waters northwest, mid latitude winds blowing northeast push surface waters southeast
- Together these two winds drive the uppermost layer of water into the centres of the subtropical gyres and pile up a lens of warm water
- Seawater in the centre of the lens sits 2 meters higher than the rest of the ocean, water flowing away from the lens is turned to the right by the Coriolis effect, creating a huge subtropical gyre spinning in a clockwise direction (counterclockwise in southern hemisphere)
- This is transportation toward the equator, cold water from poles moving to equator

- In Northern Atlantic transport toward poles occurs in Gulf Stream, warm salty water headed north
- Warm northward moving conveyor belt transfers lots of heat to the atmosphere – transfer of warm North Atlantic water to the cold overlying air is about equal to the amount of solar radiation received in the same region

Deep ocean circulation – density driven

Thermocline – zone of rapid temperature change between warm upper layers and cold water filling the deeper ocean basins (El Nino)

1. Deeper permanent portion maintained throughout year
2. Shallower portion that changes as a result of seasonal heating

Poleward flow of warm water occurs above the thermocline – called thermohaline flow (halite meaning salt)

Waters form and sink because they are denser than the underlying water

- Sea water 3.5% more dense than freshwater
- Density can be increased at low latitudes when atmosphere evaporates water, leaving the remaining water saltier (i.e. more dense) and by formation of sea ice that stores freshwater and leaves salt behind
- Density also increased if ocean is cooled – salt loses weight and gains density when cooled by the atmosphere

Deep water formation in North Atlantic Deep Water region and Antarctic Bottom Water – all this water is sinking because it is dense – water must then come back toward surface through process called 'upwelling', aided by surface winds and the Coriolis effect.

Chapter 11 – Cyclonic Storms

Thunderstorms

3 requirements:

1. Moisture – supplied by large bodies of water
2. Atmospheric instability – unstable air mass has warm moist air near surface below cold dry air above it – if a parcel is forced upward it will continue to rise on its own
3. A lifting mechanism – needs something to initiate upward motion
    - Differentiation – warmest air above surface, thermals, tend to rise
    - Cold fronts – boundary b/w two air masses of different temperatures, fronts lift moist air, lifting cold air the most abruptly, if air is moist and unstable, thunderstorms will form along the cold front
    - Mountains/terrain – air forced up the slope of rocks, upslope thunderstorms in Rocky Mountains in summer are common

Lifespan

- Thunderstorm cell has a distinct lifespan that lasts about 30 mins

1. Towering cumulus stage – cumulus cloud grows vertically, possibly 6km, air within cloud dominated by updraft, some turbulent eddies around edges
2. Mature stage – 12 to 18km, updrafts/downdrafts coexist – most dangerous stage as updrafts can be very strong
3. Dissipation stage – downdraft cuts off updraft, no more supply of warm moist air to maintain itself so it dissipates. Light rain and weak outflow winds may remain before leaving behind an anvil-shaped top

Types of Thunderstorms

- Single cell – very rare
- Multi-cell – most storms form in clusters – cells merge together, can last for several hours producing hail, damaging winds, floods, tornadoes
- Squall Lines – storm formed in line and extends laterally for many miles, most extreme are called "derecho"
- Supercells – cells unite producing one massive rotating thunderstorm, responsible for most tornadoes and major hailstorms, sometimes cause wall clouds that extend down to start tornado
    - Thunderstorms cause lightening, hail, strong winds

Tornadoes

Tornadoes are the smallest most violent weather disturbances on Earth, defined as a rotating column of air (counterclockwise in N. hemisphere) descending from a thunderstorm and in contact with the ground – usually brief but can sometimes last over an hour and travel several kilometers causing considerable damage

- 1000 tornadoes in US per year, peak season is April-June
- Most tornadoes come from supercell thunderstorms
- Vertical tube rotating rapidly (walls are moisture), established internal vacuum
- Descending funnel surrounded by water droplets that give it shape, picks up debris and gets wider
- In the centre the vortex is open and air is clear (similar to hurricane)
- Canada 2nd to US in tornadoes, most in southern Ontario late spring early summer

Fujita Scale:

	Category (MPH)	Damage
F-0	Gale (40-72)	Signs, chimneys, branches broken
F-1	Moderate (73-112)	Roofs peeling, mobile homes pushed
F-2	Significant (113-157)	Roofs torn off, mobile homes demolished
F-3	Severe (158-206)	Roofs/walls torn off, trained overturned, trees uprooted
F-4	Devastating (207-260)	Houses leveled, cars thrown
F-5	Incredible (261-318)	Houses thrown, cars thrown hundreds of yards

Hurricanes

1. Severe tropical storm in North Atlantic Basin
2. Originates within the belt of tropical trade winds, roughly 5-20 degrees from equator
3. Rotates counterclockwise around an 'eye' with minimum speed of 119km/h
    - Formed in North Atlantic Ocean, Northeast Pacific, or South Pacific
    - Need warm tropical oceans, light winds above them
    - Can produce violent winds, waves, floods and rain

Different names:

Typhoon – Northwest Pacific Ocean west of dateline
Severe Tropical Cyclone
Severe Cyclonic storm
Tropical Cyclone

Atlantic Hurricane Season June 1-Nov 30, 6 per year
East Pacific hurricane season May 15-Nov 30, 9 per year
Storm Surge – heavy waves that can damage buildings, cars etc., very dangerous and the reason why you must stay away from the Ocean during a hurricane

- Governments allow too many people to live in risky areas near the coast

Tropical cyclones, hurricanes, typhoons

- Slowly advancing or stationary cold front develops a bulge, at the boundary where cool and warm air meet travelling in opposite directions
- As moving air deflects, the bulge grows, forming a warm rightward moving front on the right side, and a cool leftward moving front to the left side of the bulge
- Since cold air is denser, it moves faster than the slower warm front
- As the faster moving cold air catches up with the slower warm air, the cold air under-rides the warm air, lifting a cell upward
- This lift produces a low pressure area at the point where the two fronts interact, the lifted air expands, cools adiabatically and condenses over the low pressure zone
- When the cold has taken over the warm front, occlusion is formed
- Occluded front – lifted completely off the ground into the atmosphere
- Disturbance is now a fully developed cyclonic storm, with low pressure centre, moving generally with easterly winds

Origin of Hurricanes

- Hurricanes (northern hemisphere) begin with a disturbance in the westward-flowing air not far from the equator
- Sea surface temperature must be 26 or higher (implication of global warming)
- As water vapour rises, it condenses which releases a large amount of latent heat energy – release of latent heat in transformation from gas to liquid
- This is the main energy source of hurricanes
- Avg hurricane releases 8000x more latent heat than electrical power generated each day by the US
- Hurricanes are fueled by warm ocean water so it loses power as it crosses land, but can regenerate if it gets over the ocean again
    - First thing is a tropical wave, disorganized and characterized by masses of thunderstorms
    - Next is a tropical storm and a name is given
- Difference b/w tropical storm and hurricane is just wind velocity

Structure

- Hurricanes have series of rain bands, spiral bands of torrential rain surrounding the eye travelling at **hurricane wind velocity**
- The entire storm is also moving at speed called **storm-centre velocity**
    - Slowest in tropical regions
- Destruction of hurricanes always greater on the right side

Effects on Ocean

- Sea swells – smooth long period waved that move out in all directions from the storm centre, can be 6-12 hours ahead of the eye
- When the hurricane moved to land, the mound of water gathering at the eye also moves inland causing most deaths and destruction from hurricanes in this surge

Hurricane Intensity

- Measured by numbered categories on the Saffir-Simpson Hurricane Scale
- Wind velocity, height of sea rise, and extent of destruction used in scale
- 2 does 4x damage of 1, 3 does 40x the damage, 4 120x, 5 240x the damage of a 1
- (Scale)
- Several category 1s occur many times yearly, while a category 5 occurs once in several years

<u>Example: Hurricane Andrew (1992</u>)

- Category 4 in Miami, almost went right through city
- Crossed Florida and lost power, but continued, caused $25 billion in damages, but only 50 deaths

- “Spin-up vortices” produce hurricanes most powerful winds but small area, can be double the speed of rotation of the main vortex

Katrina (2005)

- Costliest, one of deadliest hurricanes in American history
- Category 5, second of 2005, 6^{th} strongest Atlantic hurricane ever
- Locks were breached, flooded 80% of New Orleans
- $75 billion in damages, costliest in US history, killed over 1600

Storm Prediction

- No atmospheric conditions measurable that can predict where a hurricane will develop (thunderstorms can be predicted)
- But satellites can spot the development of hurricanes and can follow them
- Correlation between West African rainfall and hurricanes – the more rainfall produces more vegetation and enhanced evapotranspiration from plants (water added to air from plants) decreasing air density, thus more upward air convection over Western Africa. That interferes with the eastern airflow moving across Western Africa into the Atlantic, favouring hurricane development
- Wet/dry periods in Africa also correlate well with increases and decreases in US hurricane exposure
- Currently in dry period low exposure to hurricanes past 25 years so low hurricane awareness to people living on southeast coast, meaning if a wet period begins with increased frequency and intensity, likely to be enormous loss of life and property
- As atmosphere warms so does the surface of the ocean, leads to increase in evaporation rates and rapid convection leads to increased latent heat energy from condensation at the dew point elevation, and this latent heat energy is the driving force of storms, warmer oceans provide more energy to develop more frequent and intense hurricanes, and more northward storms

Names

- Once known by date and place
- 2 name lists developed for Pacific Basin and Atlantic Basin
- 6 separate sets of each basin, sets repeat every 6 years
- Very destructive storm names go to Hurricane hall of fame and are retired (Andrew 1992, Mitch 1998)
- Not enough names, assigned Greek letters

Stormfury - seeding

- US effort to seed hurricanes and measure resulting modifications because even a small decrease in a hurricanes energy would be worthwhile
- Adding silver iodide or dry ice to hurricane by means of an airplane
- Purpose is to produce ice crystals from the super-cooled water in the hurricane walls
- Believe that growth of ice from water would release some of the latent heat energy in the wall of the eye, if seeded properly it would widen the eye spreading energy out over more area, thus decreasing its velocity
- Hurricane Debbie seeded successfully in 1969
- Seeding ended, not legit

Frequency of Atlantic Basin Hurricanes

- Every year is different, 8 in 1999, but only 4 in 2002
- 15 in 2005, 4 of them at category-5
- Likely to occur again as earth and oceans warm

Chapter 12 – Climate: The Basics

Climate: Average long-term weather conditions for a region, including things like average temperature and precipitation
Climate of Earth has changed over time, 21,000 years ago ice covered Canada and Europe and sea levels were over 100m lower than today. 100 million years ago there was no ice and sea levels were very high

To consider substantive change, need to look at geologic time which has been around for hundred of millions of years.

- Earth formed at 4.54 billion years ago
- Use linear and log scales

Climate System

- Forcing – factors what cause climate changes
- Response – variation in climate produced by forcing event

3 causes of climate change – forcing factors

1. Plate tectonics – internal heat engine, ocean circulation/currents based on arrangement of continents
2. Earth's orbit – **Milankovitch**'s 3 factors of orbital variation
    a. Orbit varies in periods lasting over 100,000 years, sometimes orbit is circular sometimes its more elliptical – can vary Earth's solar radiation by as much as 10% each period
    b. Tilt changes from 21.5 to 24.5 in pattern over 41,000 years, lower tilt gives less radiation in summer more in winter, smaller tilt means greater contrast between summer and winter
    c. Wobble of axis by gravitational pull of Sun and Moon changed equatorial bulge, changing direction of tilt, 26,000 year cycle
3. Sun's energy – strength of sun has increased slowly throughout history, and sunspots result in variations in radiation arriving to Earth

Climate system response

- Quick changes give little time for response, more gradual changes are responded by the climate system
- Equilibrium is difficult to achieve

1. Rate of response of the system is fastest when climate system is farthest from the equilibrium it seeks
2. The system has many components with different response times; each responds to the same forcing at its own tempo

Climate system feedbacks

- Positive feedback: Some factors already in climate system may amplify the forcing
    - Ex. If there were a decrease in Sun's energy to heat earth, it would result in more ice and snow cover on land. This snow would reflect sunlight decreasing the amount of heat received by Earth, further cooling the climate.
- Negative feedback: factors suppress the primary forcing
    - Ex. Reflection of energy on warming of the atmospheric greenhouse that increasing CO_2 content might be producing.

Amount of incoming sunlight and amounts reflected and absorbed radiation depends on latitude.
Albedo is the percentage of incoming radiation that is reflected rather than absorbed by a surface

- Snow and ice have high albedos ranging from 60-90%
- Albedo also vary depending on the angle the incoming solar radiation arrives
- Type of vegetation covering land can affect average albedo
- **Vegetation-albedo feedback** is when solar radiation is reflected leading to less absorbed heat and further cooling of the climate

Climate Data Archives

- Historical – thermometers and barometers to measure temperature and air pressure, over time have gained more info as temperatures are recorded, also now use balloons and satellites
- Pre-Historical - **Climate proxy records –** record of some natural event that is closely controlled by climate, ex. Wine harvest, price of wheat – most widely used proxy record is distribution of isotopes, particularly oxygen
    - Sediments/ice – sediments from thousands of years ago preserved in sedimentary rock layers that have not yet subducted and are also preserved in ice, but as Earth changes with plates moving sediments can be mixed, degrading the quality of climate related data it may contain
        - Deep Antarctic ice sheet layers that extend over 400,000 years
        - Greenland over 100,000 years, mountain glaciers 10,000 yrs
        - Fossils used to determine age through isotope dating
    - Oxygen isotopes – using oxygen to date things
        - ^{16}O forms 99.8% of all oxygen and ^{18}O accounts for the rest for about a 1/400 ratio and both are in all materials that have oxygen
        - Variation in isotopes in materials is called **fractionation,** occurs because of temperature – bonds are stronger in higher mass number
        - All materials in water have the same isotopic ratio between the material and the fluid, so we can figure out temperature of the ocean 1000 years ago if we can find a material that was in the ocean at that time.
        - Use oxygen isotope ratios as a geothermometer

Climate Models

1. Physical – emphasize things like atmosphere and ocean current variations
    - Simulate climate today, control case
2. Geochemical – track the movement of distinctive chemical tracers through the system
    - Used to follow mass movement of Earth's materials like sediments, dissolved ions

Past Glaciations

- Major cold periods "icehouses"
- Major extreme periods "greenhouses"
- In past 500 million years Earth has experienced 3 intervals of Icehouse conditions, lasting millions of years

Glaciers

- To form glaciers, need accumulations of snow and ice that exceed the rate of ablation
- As the snow ice buildup thickens, it reaches a point where the glacier or ice sheet moves due to slope and pressure of overlying ice, pressure of overlying ice can produce melting at the base that helps it slide
- From glacier to ice sheet need:
    - Cold climate for extensive period
    - Good supply of precipitation – warm ocean current to polar region
    - Stable platform upon which to build the structure – large stable continent that allows ice and snow buildup (Antarctica/Greenland)
- Sea levels around glaciers/ice sheets will be low as large volumes of water are sitting on the land

Chapter 13

Icehouse-Greenhouse

- Icehouse – times when ice sheets are present on continents
- Greenhouse – times when continental ice sheets are absent
- Faint Young Sun Paradox – Earth being warm enough in the past to have an abundance of liquid water, even though sun's strength was 25-30% less back then
    - There must have been something else that kept early Earth warm that made the planet habitable

Carbon in Rocks

- Present day carbon in atmosphere is 390 ppm (390 parts per million units of air)
- This carbon comes from human contribution, but mostly from volcanoes emitting 0.15 gigatons per year
- Mildly acidic rain (carbonic acid) will break down any rock with Calcium turning it into calcium carbonate, which removes carbon from the atmosphere, so this process could cool down climate by removing CO_2
- Plants add to decrease of CO_2 by taking it from air and adding it to soil
- Chemical weathering in rocks used as a thermostat, lower energy from sun compensated by greenhouse effect in past, now with stronger sun greenhouse effect is less as more CO_2 is taken out of the atmosphere.

Polar Position Hypothesis

- Ice sheets should appear on continents when they are located at or near polar positions
- No ice sheets should appear anywhere on earth if no continent exists anywhere near the poles
    - Gondwana, part of Pangaea, drifted over the south pole from 450-240 mya but didn't have ice – hypothesis not supported for this period
    - Antarctica has been over south pole since 125 mya but didn't have ice sheets until 25 mya – not supported again

Pangaea

- 350-250 mya: assembly
- 240-180 mya: stability
- 180 mya: breakup began
- Occupied 1/3 of area of Earth, and extended high to north and low to south latitudes, symmetrical at equator
- Put a bunch of info into a computer to try to figure out climate during Pangaea, things like sea level, elevation of continent, CO_2 level of 1650ppm
    - Results:
        - Interior of continent had little precipitation
        - In the interior seasonal temperatures were extreme, hot winters very cold summers – if glaciers formed they melted
    - This was climate modeling in its infancy, and applied conclusions to modern day

Tectonic Control of CO_2

BLAG Hypothesis – by **B**erner **L**asaga **a**nd **G**arrels

- When there is lots of active volcanoes and floor spreading, there's high atmospheric CO_2, and when there's less spreading and volcanism theses less CO_2 in the atmosphere (less activity less CO_2, more activity more CO_2)
- Can determine spreading rates by measuring rock band distances from the central ridge
- Good for testing rocks younger than 100 mya

Uplift Weathering Hypothesis

- Chemical weather viewed as active driver of climate change, not a thermostat
- The more surface area, the greater erosion, and the fresher the rock surface the more rapid weathering will take place
- Continental collisions correlate with times of ice sheet glaciations for the past 325 million years
- When current period of "fossil fuel warming" is over, global climate likely to drop rapidly

Ocean Heat Transport Hypothesis

- Processes that can change ocean volumes:

1. Changes in volume of ocean floor ridges – higher the ridge the higher the sea level
2. Collision of continents – when continents collide, sea level reduced
3. Construction of volcanic plateaus on ocean floors – basalt spills increase sea levels
4. Water storage in ice sheets – Antarctica melts would cause seas to rise 66m
5. Thermal expansion of water – water expands when heated

- Hypothesis states that sea levels can control long term icehouse-greenhouse climates: high water levels cause warmer climates, low water levels cause cooler climates
    - Criticism of the hypothesis:
        - Low sea levels should lead to more extreme warm/cold periods and if glaciers grew during winter they would be melted in hot summer
        - High sea levels should lead to moderate climates, but this does not happen in wet maritime areas as they promote ice growth in winter, growth of ice sheets at high latitudes

Snowball Earth

- Good geological evidence there was ice on continents near the equator several hundred million years ago – meaning the whole of Earth's surface was at or close to freezing point
- To address this controversy, must be able to age date rocks containing the glacial evidence and determine latitude positions of the land masses containing the ice
- Problem is reliability of latitude data
- Consensus is that ice sheet bearing continents were just barely in the tropical area and near tropics it wasn't frozen maybe slush – "Slushball Earth" model
- Back to snowball Earth, it would have heated again though spreading and volcanism putting CO_2 into the oceans, once oceans saturated in CO_2 it find its way out to the atmosphere leading to a stronger greenhouse effect so Earth heats and melts the snow
- Thermostat always there, when earth is cool it will heat, when it is too hot it will cool

Paleocene-Eocene Thermal Maximum (PETM)

- Eocene Optimum a 6 million year period when earth was warm until temps dropped significantly and ice sheets forming 35 million years ago
- On the Eocene Optimum big spike in temperatures – PETM – lasting for about 20,000 years where ocean temps raised by 6 degrees initiated by an event that only took 1000 years
- Some event released 2000 gigatons of carbon into the atmosphere (same amount as co2 emissions today)
- Waters at this time circulated in ways that prevented the formation of ice sheets

Effects

- Global temps increased 6 degrees, seas 22 degrees in arctic summer
- Sea levels rose from thermal expansion of water
- Circulation was different, water flowed south to north warming the deep ocean basins dramatically, opposite today
- Extinction of close to 50% of deep ocean formanifera, but land mammals in abundance

Possible Causes

- Volcanic activity degassing mantle
- Comet rich in carbon impacted earth
- Burning of large volume of peat (early coal) – not possible
- Orbital anomaly repeated over and over – no
- Release to the atmosphere of large volumes of **methane** (CH_4)
    - Methane comes from decay of marine life, escapes to atmosphere as CO_2 and water
    - On cold ocean floors methane combines with water to form methane clathrate
    - As ocean floor temperature rises or pressure decreases, methane clathrate breaks down, releasing CO_2 into the atmosphere, raising temperatures
    - This release of methane is responsible for the PETM and lasted for about 1000 years

Current Icehouse

- Currently go back and forth between glacial and interglacial periods
- Clearly the big cycles of glaciations correspond with the 100,000 year cycles Milankovitch was talking about, also the 41,000 year cycle, and on a smaller scale would see the 23,000 year cycle as well
- Past 35 million years CO_2 has been decreasing (not including human industrial capacity)

- Most recent glacial period began 110,000 years ago and was over by 12,500 years ago

Younger Dryas Event

- Dramatic cooling event well documented in pollen records from Arctic plant called Dryas in Europe – 13,000-11,700 years ago in North Atlantic
- Freshwater lakes formed in depressions of glaciers, overflowed and spilled onto the denser salt water
- Cold surface melt water reduced evaporation, pushed cold air across Europe

Little Ice Age

- 1000-1300 Medieval Climatic Optimum warm climate
- In 1400 when climates got colder shipping in North Atlantic stopped.
- Only about 1 degree colder than now, but much harsher conditions esp. in winter
- Getting cooler and cooler

Millennial Oscillations

- Events as short as 1000 years in duration, first was the Young Dryas Event
- Events that appear to not be explained by Milankovitch orbital factors
- 3 hypotheses
    - Natural oscillations inherent in the internal behaviour of northern ice sheet
    - Result of internal interactions among several parts of the climate system
    - Response to solar variations external to the climate system
- Origin of millennium oscillations unknown, but may be correlated with periods of frequent ice rafting

El Nino

- Name given to an ocean circulation pattern in Pacific Ocean that recurs every 2 to 7 years
- During El Niño years effects on sea life and humans on South American coast is devastating as strong winds fail to blow in eastern and tropical Pacific, upwelling doesn't occur, and surface waters near coast are warm, large amounts of moisture lead to floods and natural disasters

Sunspots

- Appear as dark spots on sun's surface
- Appear on roughly 11 year cycle, being monitored for about 400 years
- Tracks pattern of disturbance of magnetic field orientation
- Unlikely it had any effect on the Little Ice Age

Humans and Climate Change

- CO_2 concentration in atmosphere at 280ppm and remained for thousands of years
- Around 1800 CO_2 values began gradually increasing and accelerating
- Land clearing and burning of fossil fuels the primary processes
    - Burning wood directly produces CO_2, less vegetation leads carbon levels to sink
        - Biosphere capable of removing great quantities of atmospheric CO_2
        - Biosphere cannot remove as much CO_2 as is being added annually
- Methane is also increased in today's atmosphere
    - Released as natural gas in coal mining and oil drilling
- "Door to hell" – 35 years ago drilling for natural gas in Uzbekistan, drill collapsed the roof of an underground cavern
    - Crew set the gas on fire, worried it was poisonous, has burned steadily contributing to atmospheric gas ever since
- 3 reasons as to amount of CO_2 in atmosphere today
    1. Warming trend solely due to greenhouse effect induced by human activity
    2. Has been a slow natural climatic trend, small human contribution to greenhouse effect

3. Has been a slow natural climatic cooling trend, so human contribution to greenhouse is very large
    - Reality lies between 1 and 3, 2 has no evidence
- Climatic scientists try to solve the problem by first looking at natural trends then looking at volumes of gasses evolved from human activity and assessing their effect as greenhouse contributors
- Consensus is that to date added CO_2 should account for 2.5 degrees Celsius of global warming, at most 4.5 at least 1.5
    - 1800-1870: 13.6 C
    - 2009: 14.5 C

Next 100-1000 years
- CO_2 levels will continue to rise and global climate will continue to warm
- Over the next millennium orbital variations (Milankovitch factors) will produce cooling but maximum effect will be decrease temp of .2 degrees, insignificant in the face of a strengthened greenhouse
- 2xCO_2 and 4xCO_2 scenarios, times the amount of CO_2 from pre-industrial levels
- These models project that human technology exists and is being applied to control emissions
- Use the 4x curve – emissions would not decline until after 2130 and CO_2 levels would be back to today by about 2300
- If this occurred there would be no ice sheets at poles, sea levels would rise dramatically
- Since 1970 there has been 2 big jerks in climate, 1976 and 1998 – both relate to species extinctions
- Global changes in climate tend to occur in jerks during which climate conditions jump from one more-or-less stable state to another. At least one climatologist calls these leaps "**magic gates**"
    - Northern animals and sea life will be devastated through loss of habitat, lack of food supply, disease
    - Winters shortened by a month on each end
    - Species extinctions will accelerate globally
    - With no control on population, and loss of land due to flooding Earth will be unable to provide basic accommodation and food for everyone (can lead to famine, war, etc.)

Chapter 14 – Impacts from Space

We know that Earth gets its energy from impact of asteroids, decay of radioactive elements, and gravitational contraction
- 1 million years ago was the most recent big impact, occurring at Zhamanshin, Kazakhstan
    - 1-km diameter object expected to impact with Earth every 1 million years

Terms to remember:

Ablation – removal of material by heating and vaporization as a space object passes through earth's atmosphere
Accretion – gradual accumulation of material through the collision of particles
Achondrite – class of stony meteorite formed by igneous processes, they lack chondrules
Amor asteroid – asteroid whose perihelion distance lies just outside of the earth's orbit but inside the orbit of Mars
Apollo asteroid – asteroid that passes inside earth's orbit
Asteroid – rocky or metallic orbiting body of 100m or greater in diameter
Astronomical unit – mean distance between Earth and Sun
Carbonaceous chondrite – primitive class of chondrite that contains highly oxidized minerals and carbon or organic compounds
Chondrite – common stony meteorite containing spherical bodies called chondrules
Chondrules – spherical mm-sized bodies formed by melting of material in the solar nebula
Fall – an observed fall of a meteorite that is subsequently discovered
Find – a meteorite that was found by not observed to fall
Meteor – the light produced when a meteoroid enters earth's atmosphere and burns due to friction
Meteorite – a meteoroid or asteroid fragment that passes through earth's atmosphere and arrives safely on Earth
Meteoroid – a rocky or metallic space object that is less than 100m in diameter

Asteroids and the Asteroid belt

- Meteorites coming from the asteroid belt (between mars and Jupiter) are chondrite meteorites (have chondrules)
- Differentiate meteorites based on composition that tells us when the rock cooled

Near Earth Objects (NEOs) – asteroids and comets whose orbits intersect Earth's orbit or comes very close – have been kicked out of asteroid belt by collisions

- Ones that actually intersect Earth's orbit called Apollos
- Those that intersect orbit of Mars are called Amors

If Earth were struck by a comet 5km in diameter atmosphere would be temporarily destroyed

- Largest crater we see preserved on land is in Sudbury Ontario – 200km diameter 1.085 billion years ago
- Nest is Chicxulub Mexico, could be as wide as 300km
- To date about 172 impact craters have been discovered on Earth

Comets come from the Oort cloud

- Most famous is Halley's comet, named after Edmund Halley – orbits every 74 to 79 years so should go by round 2061
- Hale Bopp went through solar system in 1997 nucleus 40km in diameter

Classification of Meteorites (best discoveries in Antarctica)

- Aerolites (stones) 92.8%
  - Primitive chondrites – contain chondrules, made mostly of carbon
  - Differentiated chondrites (achondrites) – more silicate materials
- Siderolites (stony-irons) 1.5%--> Roughly 50/50 composition of metals/silicates – pallasites
- Siderites (irons) 5.7%-->Primarily composed of metals, represent metallic core of differentiated asteroid
- More primitive carbonaceous chondrites increasing in abundance further from the sun

Chondrules

- Small spherical objects 1mm in diameter and appear to have crystallized rapidly from molten or at least partly molten drops
- Most primitive matter in the solar nebula

Crater Morphology

- Kinetic Energy = ½ mass x velocity^2
- Hypervelocity impact means velocity is not really effected because its so large, and therefore velocity is very high
- When rocks strike Earth nearly all its kinetic energy is transferred to heat
- Craters typically 15-20x the size of the impactor
- Once impacted with Earth, hot gasses expand in the crater and are hurled out producing an ejecta blanket
- Shock waves from the impact travel outward and subject rocks to sudden stress, making rocks at the rim of the crater turn up
- The bigger the size of the impact, the more effects on the rocks around it
- Breccia floor with material, ejecta blanket around site, uplifted rim
- Manicouagan crater in Quebec 210 mya, complex crater

Impact identifiers

- Shatter cone – shock waves travel through rocks at different speeds based on their composition, when waves overlap they fracture rock, waves are in a cone shape
- Deformation twins in materials – waves of energy can deform atomic scale structural arrangements in minerals
  - Quartz (SiO_2) changes in high pressure to coesite and stishovite
  - Common in walls of impact craters
- Tektites – minerals coming from the impact object as its melted and splashes into the atmosphere, the material forms spherules and falls back to the surface
- Ir – iridium, strong depletion in Earth's crust, high Ir anomalies a strong impact identifier
- Soot – would be leftover from burning vegetation around the site

Killer Asteroids

- Near Earth Objects are objects that cross Earth's orbit or come close
  - Majority are asteroids/meteoroids, some are comets
- Some of these are Potentially Hazardous Asteroids (PHA)
  - Object at least 150m diameter and pass within 0.05AU of Earth
- 8084 NEAs discovered, 828 1km or larger, 1244 are PHAs
- Estimated that impact of body of 1km would wipe out 25% world pop.

Torino Scale

- Hazard scale for asteroids
- Greater risk given higher number (8,9,10) and red, 1 being least risk
- Two are a 1 today, 2011 AG5 and 2007 VK184
- Apophis asteroid number changes between 0 and 1 as its monitored

Earth's early impact history

- Earth wouldn't exist without impacts, it formed through accretion, the collision of bodies and sticking together
- Existence of moon due to mars-sized object impacting Earth making both bodies molten and differentiated
- Late Heavy Bombardment Period lots of impacts up until 3.8 bya
- Amino acids almost certainly came from carbonaceous chondrites in the latter stages of bombardment
- Earth received 100-1000 tons of debris daily

4179 Toutatis

- Orbits on plane differing 3 degrees from Earths orbit, crosses every 4 years
- 2004 within 4 lunar diameters to Earth, could be seen with binoculars
- "Doomsday asteroid" its impact would wipe out 75% of Earth
- Not expected to impact in next 500 years
- If an object is on the way can try to destroy or deflect it

Chapter 15 – Impact Case Studies

Meteor crater (Barringer Crater)

- In Arizona desert not far from Flagstaff
- Canon Diablo meteorite 100kg
- Most studied crater in world, 1km across almost perfect circle
- Rim rises 45m above surrounding flat desert, floor 185m below
- Sediments 265m thick
- Impactor
  - Pieces found as far as 7-10km away, irons
  - Quartz, shatter cones, tektites all there
- Meteoroid impactor would have been 30m diameter, 300,000 tonnes velocity of 15km/second
- 100 million tonnes of rock heated and made into dust
- Life around it would have been destroyed
- Took place between 26,000-50,000 years ago, most likely 49,000 years ago

Chesapeake Bay Crater

- No typical signs of crater or impact
- Tektites on US East coast, no other suggestion it came from Chesapeake Bay area
- Drilled in late 1980s and found ejecta, quartz, etc
- Peak rim structure found buried beneath the Bay
- 3 other craters found that are exactly the same age – 35.5 mya, result of a comet shower impacting Earth

Tunguska Event

- Largest impact event recorded in history - occurred in Siberia 1908
- Shock waves felt around world, noise heard 1000km away, gasses reached heights of 20km
- Originally thought to be a comet because no material found
- Likely a stony meteoroid 50m diameter, exploded 8km above surface
- Events like this occur once every 3000 years

Exploding objects

- Fireball exploded over Yukon-BC border in 2000, Tagish Lake meteorite on display in UWO
- Blown apart by the shock of encountering Earth's atmosphere
- Can result in simple or complex craters

Unit 4 Introduction: Geologic Time Sale and Extinction Events

Precambrian time/super-eon: 4540-542 mya

- Ended with Precambrian extinction event 542 mya
- Mid-Precambrian (oxygen catastrophe) 2500 mya

Phanerozoic Eon: from 542 mya to today

- Paleozoic Era: 542-251 mya
- Mesozoic Era: 251-65.5 mya
- Cenozoic Era: 65.5-today

Definitions:

Species – group of organism interbreeding to produce fertile offspring and separated from other such groups with which interbreeding does not normally occur

Biodiversity – the variation of life forms within a given ecosystem or even the entire Earth – rapid changes to environment likely promote species extinction

Extinction – end of an organism or group

- Background extinctions – extinctions caused by moderate environmental changes or normal biological interactions
  - New species appear through mutation, change in DNA in response to a biological process called speciation
- Mass extinctions – rare and occasional extinctions that result in total elimination of large numbers of existing species, all followig criteria must be met to be classified as a mass extinction
  - Event must be global
  - All ecologies (land/water) must be involved
  - Time of event must be short (less than 1 million years)
  - 30% or more of the species must become extinct
- (For events, see page 3 of unit 4 intro)

Mass Extinction causes (not including human action)

- Flood basalts
  - These large volcanic events could put lots of dust and aerosols into atmosphere, stopping photosynthesis and collapsing the food chain
  - Would cause persistent warming from increased CO_2
- Sea level falls
  - Usually tied to large glacial periods, can occur due to sinking mid ocean ridge
  - Some sea level fall associated with 5 of the big mass extinction events
- Impact events

- Asteroid/comet impact could destroy food chains due to fires, falling rock fragments, or energy of huge object would destroy Earth's atmosphere
- Sustained climate change
    - Severs cooling or warming would cause most species to become extinct, probably to blame for Holocene extinction occurring now
- Methane clathrates
    - Methane caged inside water molecules, breaks down into CO_2 in atmosphere, strengthening greenhouse effect, catastrophic
- Anoxic ocean water
    - Lacking oxygen, marine life become extinct, caused by evaporation causing high saline concentration to sink down bringing strongly anoxic water up toward surface
    - Amplified in global warming period with more evaporation

Extinction periodicity and correlations

- Harold Urey suggested there was a periodicity to impacts of Earth by large objects
- Two groups on causes of mass extinctions
    1. Those who seek a single explanation for all mass extinctions
    2. Those who believe each event had its own unique cause(s)
- Periodicity hypothesis claims events have occurred at regularly spaced intervals throughout geologic time
- Raup/Sepkoski study gets a lot of press but is probably unwarranted since its so badly out of date
    - Claim 26 million year periodicity in extinction patterns of past 250 million years, astronomical factor and make 3 suggestions:
        - Eccentric orbit of sister star of Sun dubbed Nemesis
        - Tilting of the galactic plane
        - Effects of a mysterious planet X which lies beyond Pluto on the edges of the Solar System
    - Not right but must be something common to land and sea as the cause of mass extinction events

33 million year Rampino and Stothers study worth reading but their correlation seem to be unrealistic

- Found correlations between continental flood basalts and extinctions
- Established periodicity in flood basalts, large impacts, magnetic field reversals, mass extinctions
- Say space objects impacted Earth leading to flood basalts, evidence of craters has been filled by lava
- Used 3 studied to build on their hypothesis – none really work
    - No evidence to build theory that correlate magnetic field reversals with impacts – Loper and McCartney 1991
    - Muller/Morris 1986 Claim an impact induced an ice age, but no reversals during ice ages so not a legit argument – Loper and McCartney
    - Burek and Wanke suggest impact would displace volume causing upward flow of magma, cause magnetic field reversal

Chapter 16: Precambrian Time Extinctions

Of all geological time, we know least about the **Precambrian** because the evidence is so poorly preserved. We know life developed in relatively early Precambrian, but because no hard parts/shells/skeletons were involved, history is hard to prove

- Oxygen Catastrophe (2500 mya, extinction at 2400 mya)
    - Prokaryotes, oxygen production, mass extinction
    - Prokaryotes produced oxygen as waste and combined with iron in water to form iron oxides, removing the oxygen from the environment
    - Prokaryokes/eukaryotes sources of methane which combined with the oxygen to produce water and carbon dioxide
    - Oxygen producing prokaryotes increased dramatically, and oxygen escaped to the atmosphere

        - Lots of oxygen returned to the oceans, leading to extinction of many species, possibly largest extinction event ever, but because the life was soft bodied, there is a lack of evidence
        - Some 2500 new oxygen containing minerals created during this period of oxygen appearance
    - Snowball Earth (850-630 mya)
        - Considerable controversy as to whether it ever existed, should be evidence but there is not
        - Snowball periods appear to have pumped evolution as they killed off predator species, promoted reproduction across species as means of survival, mixed genes would prompt development of new species with new traits different from the original
        - No mass extinction
    - End Precambrian Extinction (542 mya)
        - Evidence mixed among huge explosion of new life forms
        - Before this most organisms were single celled and organized in colonies, in Cambrian this all changed as new life forms emerged

2 theories possible

1. Great extinction of life at end of Neoproterozoic and new life developed in all the abandoned niches
2. Cambrian life developed from preexisting life and there was no mass extinction at all

Chapter 17: Phanerozoic Eon – A trip through time

The first subdivision of the **Phanerozoic Eon is the Paleozoic Era, and it includes the periods Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Permian**. The Paleozoic Era ends with "The Mother of all Catastrophes" at the end of Permian.

<u>Cambrian Period</u> (542-488 mya)

- Abundance of life forms in warm waters around Rodinia, evidence of fossils
- Perfect conditions for life as complex multi celled organisms were formed as suitable habitats formed with abundant nutrients in shallow warm seas

Extinctions

- 2 distinct periods of mass extinction, each responsible for extinction for about 40% of marine general, 2 hypothesis have been advanced

1. **Glacial cooling and lowering of sea levels** – Miller, species developed in warm water are intolerant of cold water, growth of glaciers would have decreased sea levels and produced barriers to adjacent bodies of water, eliminating many of the shallow seas where the species developed
2. Oxygen depletion – ocean water overturn bringing anoxic water to the surface killing species

<u>Ordovician Period</u> (488-444 mya)

- Godwana (part of Pangaea) originally near equator but moved to sit over south pole area
    - Originally lots of volcanoes and subduction, spewing out carbon dioxide strengthening the greenhouse and making marine waters warm
    - As it drifted to the south pole and glaciers grew, volcanism subsided, climate cooler, oceans cooled to levels of today – middle of the period
    - 2 other continental land masses moved toward each other causing lots of volcanic activity, strengthening greenhouse again and turning the planet into a hothouse
- Extinctions
    - 85% of all species killed off
    - Thick glaciers sucked up most of the world ocean water, bringing sea levels to dramatic lows
    - As glaciations ended and species moved into vacated niches, another glacial stage arrived and killed them off, then stopped to have sea levels rise and temps normalized
    - Extinctions here seem to be quite rapid

Silurian and Devonian Periods

Silurian (444-416 mya)

- Ice sheets less so more water in oceans, tectonically not much going on
- Mild climate, greenhouse, diversity of species, first time we see life move onto land as forests of moss developed near shore
- Very minor extinctions

Devonian (416-359 mya)

- All the land masses were coming together to form Pangaea
- High seas and flooding of edges of continents
- Temperate climate, period of cooling, then warmed again in late Devonian
- "Age of fish" enormous biodiversity life evolved during this time
  - Dunkeleosteus – largest most deadly fish to ever hunt in Earth seas
  - Some fish developed strong lungs and were able to crawl on land
- Plants developed seeds and spread wildly
- Lots of green and trees led to decrease in carbon dioxide

Extinction

- Late Devonian extinction of 80-85% marine species
- Extinctions took place over 10 million years – 370-360 mya
- 370 mya – evidence of asteroid impact (tektites, Ir, tsunami deposits)
- 360 mya – anoxic seas killed most marine species

Carboniferous Period (359-299 mya)

- Period of icehouse (glaciations), low sea levels, strong mountain building, production of large coal deposits
- Continental blocks in last stages of joining up to make Pangaea
- Started warm, got cool as Gondwana moved back over the south pole
- Cooling didn't effect tropical regions, still abundant trees in swampy lowlands – source of worlds greatest coal deposits
- Fish that developed lungs and ability to go on land evolved into amphibians and were abundant on land and in seas

Permian Period (299-251 mya)

- Pangaea fully assembled, extended from south pole to equator and into north polar regions
- Abundant life in seas, also on land
- Coniferous trees thrives in dry environment
- Fauna, lizard like creatures evolved, ancestors to dinosaurs, crocodiles and most reptiles developed in Permian, cockroaches developed in Permian and have continued to be successful through to today
- Massive extinction event ended this period, wiping out 96% marine life and 70% terrestrial life
- End of Paleozoic era, start of Mesozoic era at 251 mya

Triassic Period (251-201.6 mya)

- Pangaea started to rift apart, producing continental shelves of shallow waters where life was abundant
- Should have been lots of life but took a long time to recover from Permian extinction
- Hot enough that no glaciers were able to form, even at south pole

Extinction

- Lots of dinosaurs, reptiles on land sea and sky, start of small fury mammals
- Could have been an asteroid impact
- 80% marine organisms killed off, most land animals killed leaving dinosaurs to advance to abandoned niches
- 50% of all species died at 201.6 mya
- Lots of volcanism and spreading activity, CO_2 pushed from water into atmosphere, adding to greenhouse strength, warming everything – could have triggered release of methane from methane clathrates and ocean overturn – anoxic event most likely

Jurassic Period (201.6-145.5 mya)

- Only some mild background extinctions
- More rifting of Pangaea leading to lots of spreading volcanism, and thus lots of carbon dioxide to strengthen the greenhouse
- Warm climates, with no land over poles also no glaciers
- Golden age for dinosaurs – dominated land sea and air
- Dinosaurs fed off mammals

Cretaceous Period (145.5-65.5 mya) (from Latin word 'chalky')

- Last and longest period of Mesozoic era (80 my)
- Pangaea broken up and all continents visible
- Sea levels high, large shallow warm seas, perfect for growth of biodiversity
- Cretaceous – from Latin word for chalky, from large deposits of calcareous shells of organisms that are chalk today
- Petroleum deposits arose from breakdown of vast quantities of marine organisms
- Early large mammals like marsupials (kangaroos) appeared
- Dinosaurs ruled Earth for 150 million years (avg lifespan of a species is 4 million years)
- Massive extinction event at 65.5 mya

Cenozoic Era (65.5 mya-now)

Tertiary period (65.5-2.6 mya)

- Pangaea continued to spread, Antarctica to south pole and North and South American joined up
- Climate gradually cooled (except during PETM)
- 55 mya going into icehouse climate and 35mya continental ice sheets had grown- still in this icehouse
- Cretaceous-Tertiary mass extinction changed everything, reptiles replace by mammals as dominant vertebrates, and without dinosaurs mammals developed and evolved spectacularly
- In part because extinction event of 65.5 mya burned everything making good fertilizer making plants grow in abundance
- PETM event caused extinction of close to 50% marine organism called formanifera
- Only background extinctions in other species

Quaternary period (2.6 mya – now)

- Icehouse conditions dominate, glacial periods last about 100,000 years, interglacial 10-15,000 years
- Currently in the Holocene Epoch including 12,000 years ago to today
- Holocene marked human rise to top of dominance scale

Extinction

- Closely following dominance of humans comes beginning of Holocene mass extinction – chapter 20

Chapter 18 –End Permian mass extinction 251.4 mya

251.4 mya marked the most catastrophic mass extinction ever, as 96% of marine species and 70% of all terrestrial species died, in less than 1 million years, including insects

Dating the Extinction

- Originally lots of speculation as to exact date of event, but rocks found in China and Greenland has been productive and helped clear things up
- Zircon crystals contain uranium which radioactive decays so age can be dated accurately
- Found undisturbed rock sequence in China at Permian-Triassic boundary, dates the event at 251.4 +/- 0.3 million years ago – between .72 and 1.22 my
- Greenland evidence suggests animals died off over period of 10 to 60 thousand years, plant life took several hundreds of thousands of years to go through whole extinction process
- Old theories that there were up to 5 separate events are not supported

Extinction Hypotheses

- Asteroid impact
  - No direct evidence, but some indirect evidence such as fullerenes (dense form of carbon molecules from extraterrestrial sources), tektites and shocked mineral fragments in rocks at the 251 million year horizon, but no crater
  - Bedout crater (size of Chicxulub) 250.1 +/- 4.5 my
    - Breccia, tsunami debris, meteorite sediment
  - Wilkes Land (probable impact crater: at lest 2X Chicxulub)
    - Found by gravity survey 2.5km below ice in Antarctica
    - Hard to be sure, everything frozen under the ice
- Siberian Traps emissions
  - Sulfur bearing aerosols from eruptions and CO_2 emissions
  - Not enough warming to promote catastrophic extinction, but warm enough to interfere with ocean flow patterns
- Ocean flow pattern and anoxia
  - Today in Atlantic warm saline water flows north via Gulf Stream
  - Cools and sinks

    - Bottom waters eventually become anoxic, would not have been able to become anoxic enough to wipe out so many species
- Methane hydrate gasification
    - 2002 suggested that global and ocean warming sufficient for methane clathrates on ocean floor to be warmed enough to break down, releasing huge amounts of methane gas.
    - Waters would have become very anoxic and killed most marine life
    - Methane would break down into water and carbon dioxide in atmosphere increasing greenhouse and further increasing global warming and more gasification

Looking at purely terrestrial processes, for mass extinction to occur need all of:

1. Rapid global warming by release of CO2 from Siberian traps volcanism
2. Disruption of ocean flow circulation and beginning of deep water anoxia
3. Dissolution of methane hydrates, prompting severe water anoxia and high global temperatures

Chapter 19: End Cretaceous Mass Extinction 65.5 mya

Background

- Cretaceous life was one of the most prolific Earth ever experienced; both land and seas were filled with enormous biodiversity, but reptiles (dinosaurs) ruled
- Because Pangaea was still breaking up, sea levels were high and lots of in land warm seas, no ice sheets

K-T Extinction Boundary 65.5 mya

- Second worst mass extinction, behind end-Permian extinction
- Decline of small plants at bottom of food chain devastated entire chain
- Scientists (Alvarez) found clay layer in crust globally a few mm thick with high Ir concentration – first evidence of the extinction had to do with something extraterrestrial
    - Calculated the asteroid must have been 10km in diameter – released dust into atmosphere shutting off global photosynthesis for several years resulting in the collapse of the global food chain
    - But no impact site, and this time coincided with the Deccan Traps
    - But mixed in clay tektites, fragments of rock with shock features, and lots of carbon (from burned vegetation
    - Fireball layer mm thick with carbon rich debris, ejecta layer cms thick with tektites, coesite, stishovite, all things said to be produced by an impact

Chicxulub Crater

- Located on the Yucatan coast in Mexico
- Oil company Pemex wanted to look for oil there, found a 180km diameter crater but didn't tell people until after the drilled and collapsed most of it
- Still found lots of evidence of impact
- Found outer rings on the crater the furthest 300km diameter, perhaps due to gravitational collapse after impact
    - Largest undeformed impact crater proven to exist on Earth
- K/T extinctions occur on two timescales, first mass mortality reducing the standing crop of the oceans immediately follows impact, then the actual extinction took place over about 1000 years after impact and probably due to raised ocean and surface temperatures

Impact Event

- Sequence of events:

1. Asteroid collision in asteroid belt send carbonaceous chondrite into earth-crossing orbit, 65.5 mya their orbits intersected
2. Punched hole through Earth's atmosphere at 30km/second
3. Struck Yucatan Peninsula of Mexico within 5 seconds
4. 1/10th of second asteroid buried 3km deep where front stopped but back kept moving flattening it out into a disk shape release of energy in first minute 10^{25} joules or 300 million atomic bombs
5. Blew hole 15km deep, 180km wide, vaporized asteroid material and rock on surface
6. $5x10^2$ tons of dust released into atmosphere, fell back to earth as 10kg rock debris per square meter
7. Fragments reentered atmosphere and turned into fireballs from friction, global firestorm, producing distinct fireball layer evident at K-T boundary, occurred globally as the layer is uniform in thickness globally, produced global acidic precipitation
8. Led to high amounts of sulfur release into atmosphere, reflected light back to space stopping photosynthesis for at least 6 months, cold temps
9. Tsunami threw debris all over area
10. CO2 released into atmosphere from limestone breakdown and asteroid debris, greenhouse would have raised temps by over 15 degrees and lasted about 100 years, followed by short period of global freezing once dust fell back to Earth

T-Rex and Death Star

- Debate whether extinction of dinosaurs was sudden or gradual
- Some say it was immediate, others say it was gradual and that most land species died while most marine species survived
- No creature larger than a small dog survived the K-T extinction event in any environment
- Largest outpouring of basalt of Deccan Traps is during 500,000 years roughly 65 million years ago, Ir rich layer thought to come from impact shows through some of this basalt layer
- Deccan Traps occurred as India cruised over the Reunion plume
- Probably didn't contribute as much to extinction, but did release large amounts of CO_2 strengthening greenhouse and aiding global heating

Other impact craters

- Another crater 24km in diameter in Ukraine, and in North Sea
- 600x400 km basin/crater in India, central peak and raised rim 65-66 million years old – comet/asteroid 40km diameter
- Scientists think this impact created fissures though which the Deccan Traps flowed

Chapter 20: Holocene Mass Extinction

Background

- Holocene is the 6th mass extinction within the Phanerozoic eon, and estimates that ¼ of global species be extinct by 2125 and up to ¾ extinct by 2200
- Cause is almost entirely biological, due to humans and human practices that have led to destruction of habitat, over exploitation of resources, pollution, and climate change
  - Not only biological catastrophe but also a major political, economic and moral dilemma
- Most extinction events occur over period of 100,000 years or more, to compare estimates that total species expected to be extinct in 40,000 years
  - Total species lost is 27,000 per year, background extinction rate is one species per year
- PETM period of heating temps rose .025 C per 100 years, now is increasing 1-4 C per 100 years
- Rate of addition of gasses to atmosphere today is so fast that most life forms don't have a hope to survive, and will thus become extinct

Waves of extinction

- First wave: spread of modern humans 40,000 BP to 1800
  - Over half animals over 44kg died out
  - 11,000 BP megafauna terminated, mastodons saber-tooth tigers
  - Most extinctions from overkill of species
  - Global warming killed off species at extreme climates
  - Diseases also spread from humans to newly encountered animals
- Second wave: spread of Europeans 1500-1970
  - 869 extinctions over this period, 70x greater than background rate extinction of mammals
  - Most extinctions occurred on islands due to colonial expansion
  - Over exploitation, habitat destruction, introduction of invasive species from home
- Third wave: Globalization 1970-2100
  - Worldwide deterioration of species populations
  - Amphibians highest risk of becoming extinct
  - 40% world forest cover cut down since 1970, 15,000,000 hectares cut down annually
  - **Loss of habitat** primary source of extinctions in 3rd wave
  - Kill big animals that appear in our cities although its humans who moved and destroyed their habitat
  - **Over exploitation** increasing threat
    - 1990s cod fishing industry collapse
    - Tortoise used as pets and shell for art
    - Burning of sturgeon fish for steamships
  - **Invasion of alien species** occurs on isolated island species, as new species come in and destroy species already there
  - **Climate change** is the real killer, 15-37% of regionally endemic species will die by 2050 due to climate change, will skew food chain
  - **Pollution** effects all ecosystems, chemicals and toxic materials accumulate
    - 2nd largest threat to amphibians
    - Fertilizer run off effects marine ecosystems
    - BP oil spill killing species in Gulf and surrounding bodies

- **Disease** responsible for large pop declines, reduction of reproduction
    - Into of blight to North American killed off chestnut trees
    - European water mold has killed 26 tree species in Oregon/Cali

Biodiversity, Extinction, Human Species

- Atmospheric CO@ at 387ppm and rising by 2ppm annually
- Growth of human population (increase by 2.6 billion by 2050) together with climate change may initiate tipping points with catastrophic consequences

Solutions

- Education is the only solution, science is essential
    - Reduction of human population
    - Improvements to microbiology – altering plant species to make it resistance to changes in climate
    - Regulation of natural habitat preservation – alternatives to petroleum, biofuel causes less pollution but will lower food supply must find balance
        - Brazilian rainforests being destroyed for growth of biofuels
        - Essential habitat for innumerable species
    - Transformation of our attitude towards nature – need to make priorities in funding research and engage public in understanding value of biodiversity and affects of humans on environment

3 extinction scenarios for our time

1. Collapse of Gulf stream
    - Component of thrmohaline circulation system
    - Gulf stream brings warm water northward along with warm moist air
    - Europe would get really cold, famine would begin globally as global temps decreased – example of negative feedback
2. Collapse of Amazon rainforests
    - Massive and absorb lots of CO_2
    - Predications that CO_2 rise by 2100 will reduce rainfall from 5mm to 2mm per day
    - Will cause surface temperatures to heat causing plant growth to die out, soils will not be able to absorb CO_2 and positive feedback system strengthens greenhouse, killing off the animals in the rainforest, if correct will start to be visible in 2040
3. Methane release from seafloor
    - Same mechanism that produced the PETM
    - If pressure is relieved or temps increase on sea floor by even a little bit, icy solid methane hydrate will breakdown releasing massive amounts of methane into the atmosphere
    - Methane much stronger greenhouse gas than CO_2

2 modern extinction stories

- Golden Toad
    - “The Weather Makers” Tim Flannery
    - Golden toad along with other species died in 1987 in South American rainforests as there was no rain – 30/50 species of toad died
    - 1987 scientists observed mating in a small pool, males fighting for females, but with no rain the eggs dried and perished
    - 1988, one male frog and that’s it, no females to breed with
    - 1989 same male toad back, since then none have ever been seen again, abundance to complete extinction over 2-3 years
- Passenger Pigeon of North America
    - Most abundant birds in 19th century, extinct completely when last one dies in 1914 in a zoo
    - Causes were hunting for pigeon meat for human consumption and fed to pigs, and loss of habitat through deforestation
    - Travelled in large flocks making them easy to kill, killed in nesting sited by crushing their heads, lure flocks by making one bird call them
    - Hunters killed last flock, knowingly, 250,000 birds
    - After millions of years in existence, died in 20-30 years