I. Introduction
The Cenozoic is the final era of geologic time. The continents and their landscapes acquired their present form and many of the animals and plants of the present world have been shaped and modified by Cenozoic events.

A. Time - Era is separated into a Tertiary and a Quaternary Period
1. European geologists prefer a time table that divides the era into Paleogene and Neogene periods which represents a more equal division of the epochs.
2. Major unconformity representing a marine regression serves as a boundary between the Paleogene and Neogene systems.

B. Plate Tectonics
1. A time of considerable tectonic plate motion and sea floor spreading
   a. Approximately 50% of the present ocean floor has been renewed along midocean ridges during the past 66 million years
   b. Emplaced in the expanding Atlantic and Indian oceans
   c. San Andreas fault system
2. Orogenic and volcanic activity
   a. Closure of the Isthmus of Panama, that links North and South America
   b. North Atlantic rift extended itself to the north separating Greenland from Scandinavia destroying the land connection between Europe and North America
   c. Australia separated from Antarctica
   d. Indian Ocean rift split Arabia away from Africa - created the Gulf of Aden and the Red Sea
3. Collisions of Africa and India with Europe
   a. Transformed the Tethys seaway into the Alps and Himalayas

C. Climatic zones were more sharply defined than in earlier eras. A cooling trend clearly indicated by paleobotanical studies culminate in the Pleistocene Ice Age

C. Basin and Range Province
1. A large-scale physiographic feature that is the result of late Tertiary faulting Nevada, Arizona, New Mexico, and southern California folded and overthrust during the Mesozoic
2. Exists as a structural arch during the early Tertiary
   a. Arch subsided between great normal faults that developed on both the west and the east sides
   b. Similar faults with general north-south alignment developed in the interior of the region formed linear mountain ranges
3. Cause of the large-scale tensional faulting is still being debated by geologists
   a. Normal faulting in the Basin and Range is simply due to the way the crust adjusted to the change along the California coast when oblique shearing of the edge of the continent replaced the earlier subduction zone - This change coincided with the change from subduction to strike-slip on the North American and Pacific boundary
   b. Alternative theories
      1. Subducted Spreading Center
         a. Uparching and faulting occurred when westward-moving North America overrode part of the oceanic plate
         b. Spreading center was subducted and reached the region beneath eastern Nevada and western Utah
         c. Caused uplift and stretching of the crust in east and west directions
      2. Extension and uplift of the crust from the remnants of an oceanic plate that had been carried beneath the Basin and Range by an earlier episode of subduction
      3. Subduction ceased
         a. Oceanic slab may have formed a partially molten buoyant mass
         b. Pressed upward against the overlying crust and caused tensional faulting
Crustal extension and tensional faulting is related to convectional movements beneath the continental plate.

D. **Colorado Plateau**
1. Block of crust that remained undeformed during the Mesozoic orogenies; Paleozoic and Mesozoic rocks are relatively flat-lying.
2. Repeatedly raised during early to middle Pliocene time
   a. steep faults developed
   b. provided avenues for the upward escape of volcanic materials
   c. Best-known feature resulting from the linked processes of uplift and erosion - **Grand Canyon of the Colorado River**
      1. 2600 m deep
      2. river has penetrated through Phanerozoic strata into crystalline Precambrian basement rocks

E. **Columbia Plateau and Cascades**
1. **Built by volcanic activity** during Late Tertiary and Quaternary time
   a. basaltic lavas erupted along deep fissures in the region
   b. 500,000 km²
   c. flowed 170 km from their source
   d. combined thickness exceeds 2800 m
2. **Cascades** are west of the Columbia Plateau
   a. Surface manifestations of an ongoing collision between the **American plate and the small Juan de Fuca** plate of the eastern Pacific
   b. moves eastward on a collision course toward the coasts of Oregon and Washington plunges beneath the coastline
   c. volcanism began about 4 million years ago
   d. **Eruption of Mount St. Helens on May 18, 1980**
      1. exploded with a force equivalent to 50 million tons of TNT
      2. heard over 300 km away
   e. Mount Lassen erupted in 1914. nuee ardente (fiery cloud)
   f. Other well-known Cascade peaks
      1. Mount Baker
      2. Mount Hood
      3. Mount Rainier- last major eruption about 2000 years ago
      4. Crater Lake - formed when the top of a volcanic cone (Mount Mazama) collapsed into its subsiding lava column to form a caldera. This event occurred ~7000 years ago

F. **Sierra Nevada and California**
1. Lie south of the Cascades
2. Mountains were folded and intruded during the **Jurassic Nevadan orogeny**
3. Most of Tertiary time
   a. peaks were steadily reduced by erosion
   b. entire block raised along normal faults bounding its **eastern side in Pliocene** and continuing into the Pleistocene
   c. tilted westward
   d. eastern front was lifted 4000 m
   e. depressed western side formed the California trough
4. Region west of the Sierras was most directly affected by subduction tectonics
   a. underwent a change from subduction tectonics to strike-slip tectonics at about the beginning of
5. Miocene time - Complex fault movements created islands and intervening sedimentary basins
   a. fine-grained marine clastics, diatomites, and bedded cherts accumulated resulted in marine regressions in many areas
6. End of the Tertiary
   a. seas were restricted to a narrow tract along the western edge of California
G. The **Tethyan Realm**
1. Conversion of a major seaway separating Eurasia and Gondwanaland to a spectacular array of mountains and plateaus
2. considered one of the greatest events of the Cenozoic Era
3. Europe
   a. Eocene
      1. large-scale folding and thrust-faulting
      2. northward-moving African block first encountered the western underside of Europe
      3. crumpled the strata that now compose the *Pyrenees and Atlas* mountains
      4. Alpine region began to be squeezed
      5. marine conditions persisted
   b. Oligocene
      1. compression caused enormous recumbent folds to rise as mountains
      2. thrust faults
      3. north of the mountains, topographic depression
      4. received the piedmont deposits eroded from the mountains
      5. Terrestrial clastics - molasse
   c. Pliocene
      1. further thrust from the south carried the older folded belts northward over the molasse deposits
      2. crumpled the Jura folds
      3. form the northern front of the *Alps*
      4. followed by spasmodic regional uplifts
4. East of the Alps
   a. volcanism, folding, thrusting, and emplacement of massive granitic intrusions
   b. began early in the era and increased during the Miocene
   c. great elongate tracts of the former sea floor were squeezed into folds
   d. thrust southward
   e. occurred at or near sea level
5. **India**
   a. a broad, subsiding trough formed along the northern edge
   b. >5000 m of continental sediments were deposited
   c. contain an important fossil record of Cenozoic mammals and plants
6. Two final epochs of the era
   a. regional uplifts brought the plateaus and ranges to lofty elevation, caused the retreat of those in seas that still remained
   b. the transformation of the Tethys
7. **Mountain ranges formed** - *Alps, Atlas, Apennines, Carpathians, Caucasus, Pamirs, and Himalayas*
8. **Surviving parts of the Tethys** - *Mediterranean, Black, and Caspian* seas
9. One event in the history of the Tethys not directly related to orogeny in the region
   a. **drying of the Mediterranean**
   b. occurred about 5.5 million years ago
   c. **Messinian event**
   d. final stage of the Miocene in Italy
   e. an indirect result of a sudden but temporary expansion of the Antarctic ice sheet
   f. loss in volume of ocean water lowered mean global sea level by as much as 50 m
   g. left the Mediterranean isolated from other oceans
   h. extensive evaporate bed formation

H. North of the Tethys
1. lavas were extruded in Scotland, Ireland, Spitzbergen, Greenland, and Baffin Island - **Thulean event**
2. **Ireland - Giant's Causeway**
   a. accompanied the separation of Greenland and Europe
b. Northeastern Europe - a record of repeated marine incursions during the Paleocene, Eocene, and Oligocene

II. Cenozoic Climates
A. Worldwide cooling began during the early Cenozoic and culminated in the great Ice Age.
   1. Decrease in temperatures was not entirely uniform
   2. Cooling resumed during the Oligocene
      a. pulse of warmer conditions occurred during the Miocene
      b. after which climates grew steadily cooler
   3. Glacial Periods
      a. Large-scale glaciations during Pleistocene
      b. Although the most extensive glaciations of the Cenozoic were those of the Pleistocene, glaciation occurred on a more limited scale at other times during the Cenozoic.
      c. the accumulation of Miocene glacial ice and resulting lowering of sea level contributed to the drying up of the Mediterranean Sea
   4. Evidence for Pliocene glaciation - recognized in the Sierra Nevada, Iceland, South America, and the Soviet Union
B. Effects of Pleistocene Glaciations
   1. Over 40 million km$^3$ of ice and snow lay upon the continents
   2. Estimated that sea level may have dropped at least 120 m during maximum ice coverage continental shelves became dry land, covered with forests and grasslands British Isles were joined to Europe a land bridge stretched from Siberia to Alaska during interglacial stages, marine waters returned to the low coastal areas Direct impact on the erosion of lands relation of glacial land forms
   3. depressed the crust 200-300 m below the preglacial position
      a. removal of the last ice sheet downwarped areas gradually began to return to their former positions
      b. dramatically apparent in parts of the Baltic, the Arctic, and the Great Lakes region
      c. obliterated old drainage channels and caused streams to erode new channels
   4. Formation of lakes
      a. Great Lakes
      b. between Lake Erie and Lake Ontario
      c. came into existence when the retreating ice of the Wisconsin stage uncovered an escarpment formed by a southwardly tilted resistant strata
      d. weak shales beneath the limestone are continually undermined
   6. large system of ice-dammed lakes
      a. covered a vast area of North Dakota, Minnesota, Manitoba, and Saskatchewan largest of these lakes was Lake Agassiz
   7. Pluvial lakes
      a. particularly numerous in the northern part of the Basin and Range Province faulting produced >140 closed basins
      b. Lake Bonneville in Utah
C. Causes of Glaciation
   1. Widely accepted theory was developed by Milutin Milankovitch (1879-1958)
   2. proposed that irregularities in the Earth's movements and their influence on the amount of solar radiation received by the Earth could account for glacial, and interglacial stages
      a. Calculation based on 3 variables
         1. Earth's axial tilt
            a. tilt of the Earth's axis varies between about 22' and 24' over a period of 41,000 years
            b. results in a corresponding variation in the seasonal length of days and in the amount of solar radiation received at higher latitudes
         2. precession - refers to the way the axis of rotation moves slowly in a circle that is completed about every 26,000 years
         3. orbital eccentricity - Earth's orbital path around the sun
            a. varies about 2% over an interval of about 100,000 years
b. results in the Earth being at times closer or farther away from the sun
   c. Combination of the variables periodically results in less solar radiation received at the top of the Earth's

3. Milankovitch cycles correspond rather well to episodes of glaciation over the past 2,000,000 years
4. Other factors must also be involved
   a. a variation in the amount of solar energy reflected from the Earth back into space rather than being absorbed - albedo, 33% at the present time
   b. only a 1% lessening of retained solar energy could lead to as much as an 8° drop in average surface temperatures
   c. absorption of solar energy hindered by cloud cover, volcanic ash, and dust in the atmosphere
   d. fluctuations in carbon dioxide