U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: EVIDENCE FOR PAST CLIMATE CONDITIONS

PRESENTER: DR. JOHN S. STUCKLESS

PRESENTER'S TITLE AND ORGANIZATION: CHIEF, GEOLOGIC STUDIES PROGRAM
U.S. GEOLOGICAL SURVEY
DENVER, COLORADO

PRESENTER'S TELEPHONE NUMBER: (303) 236-7387

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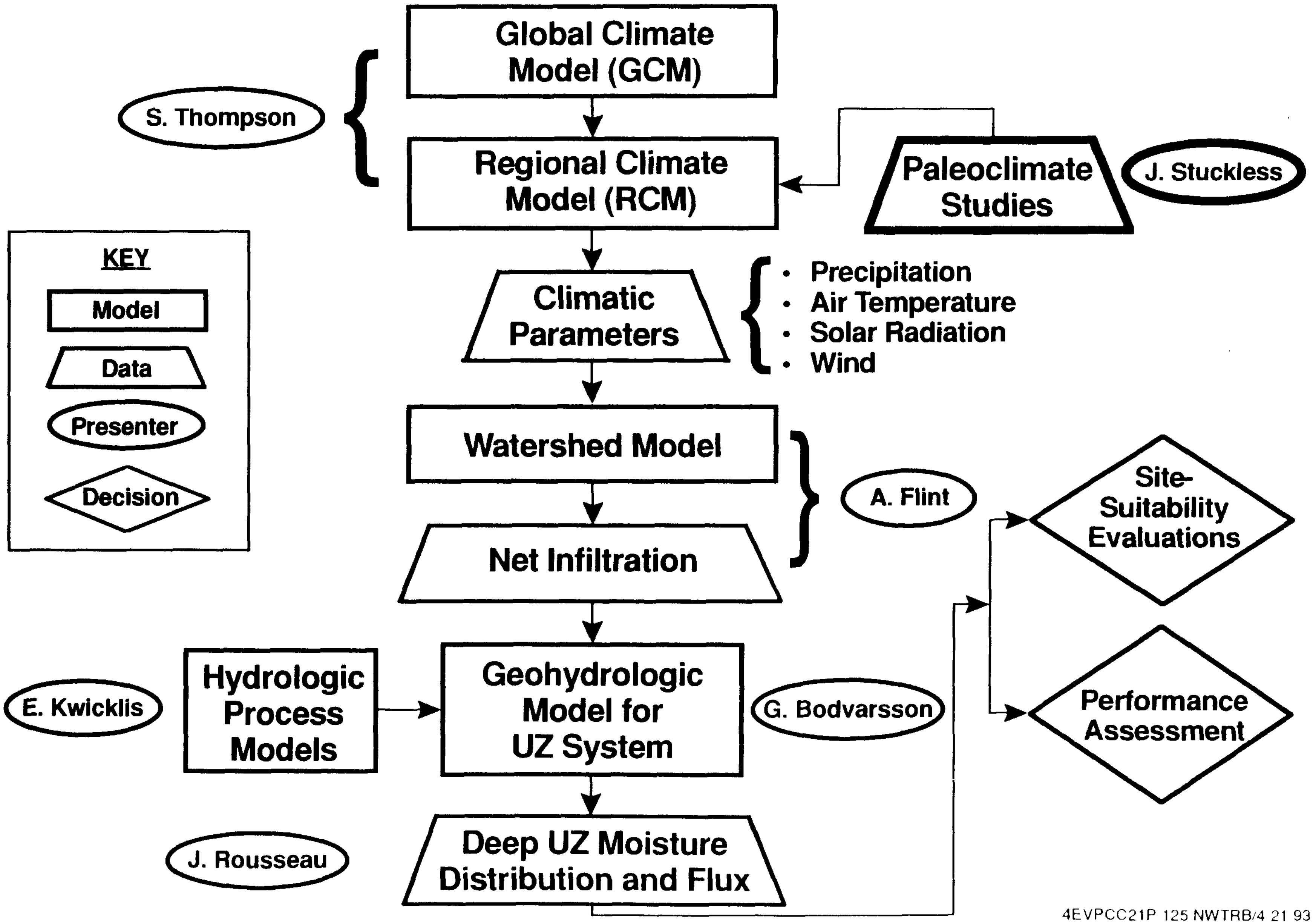
Example Model Hierarchy



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Outline

Climate program goal

Structure of data collection

Examples of climate change in the last Pluvial

Results and plans for Yucca Mountain

Conclusions

Climate Program

Participants

- US Geological Survey
- Desert Research Institute
- University of Arizona
- University of Utah
- Los Alamos National Laboratory

Climate Program
(Continued)

Evidence for climate data need (last 23 ka)

- Fossils of the Arctic Vole
- Fossils of the Columbian Mammoth
- Limber pine, white firs, willow are found in pack rat middens at elevations down to 1,200 meters
- All these suggest much wetter periods in the past and that now may be in an anomalously dry period

Climate Program
(Continued)

Purpose

- To provide the data needed to estimate the consequences of climate change on the Yucca Mountain unsaturated and saturated zones

Climate Program

(Continued)

Approach

- Reconstruct the climate for the past 1 million years with emphasis on the last 200,000 years using micro and macro fossils and isotopes from aquatic and terrestrial records

- Reconstruct Yucca Mountain unsaturated zone hydrology from U-series and Carbon-14 dates, fluid inclusions, mineralogy and isotopic data

- Reconstruct Yucca Mountain saturated zone hydrology from geochronologic, isotopic, geochemical, mineralogic, and paleontologic data for ground-water deposits such as fracture fillings in Yucca Mountain and tufa mounds and playa deposits in discharge areas

- Reconstruct atmospheric climatic conditions based on paleontologic and isotopic data

Climate Program

(Continued)

Goals

- Integrate hydrological model(s) with climate time series to forecast saturated and unsaturated zone response to future climate change

- Provide data needed to test climate modelling efforts

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Terrestrial Paleoecology

Pack rat middens and pollen

- Long-term climate response, as indicated by total terrestrial plant community
- Short-term climate response, as indicated by deuterium and carbon isotopes of cellulose

Vertebrate paleontology

- Climate response of vertebrate community with emphasis on mammals
- Carbon isotopes on enamel of mammal dentition

Lakes, Playas, and Marshes

Paleontology

- Climate and hydrological response of aquatic invertebrates with emphasis on ostracodes
- Shell trace-metal chemistry

Stable isotope geochemistry

- Oxygen and carbon isotopic composition of biogenic and inorganic carbonates

Tracer isotope geochemistry

- Strontium isotopic composition of biogenic and inorganic carbonates

Lakes, Playas, and Marshes

(Continued)

Sedimentology and Stratigraphy

- Sedimentological and stratigraphic analyses of outcrop and core materials

Data synthesis

- Reconstruction of past climate and hydrology

Calcite-Opaline Silica in Yucca Mountain

Uranium series (10ka to 400ka) and 14-C (< 50ka) dates

- Determine ages of fracture fillings
- Determine ages of discharge deposits

Fluid inclusion studies

- Determine composition and temperature of depositing fluids for calcite

Calcite-Opaline Silica in Yucca Mountain

(Continued)

Stable isotope and fluorescence analyses

- Characterize fracture filling minerals as saturated or unsaturated zone precipitated
- Determine temperature of precipitating fluids
- Determine isotopic composition of precipitating fluid and relate changes to climate changes

Tracer isotope analyses

- Characterize precipitating fluids (and thereby flow-paths)

Mineralogy

- Determine mineralogy of fracture filling and discharge minerals and relate it to conditions of precipitation

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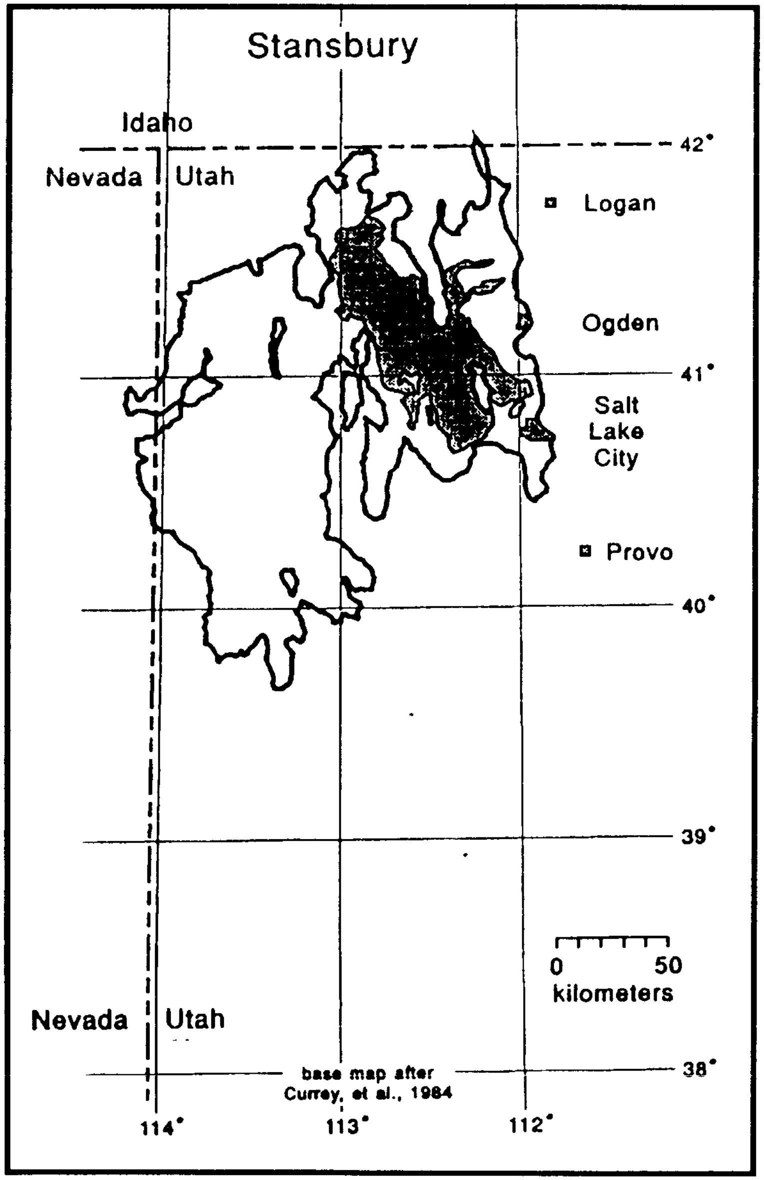
Probable Regional Climate History for a Pluvial Using the Last Pluvial as an Example

- Growth of the continental ice in Canada and U.S.A. focuses polar front into the northern great basin (about 25 - 26ka)
- Lakes throughout the intermountain west begin to expand
- Distribution of vegetation species drops in elevation by as much as 1280 m
- The Great Salt Lake provides a well documented example of a pluvial chronology

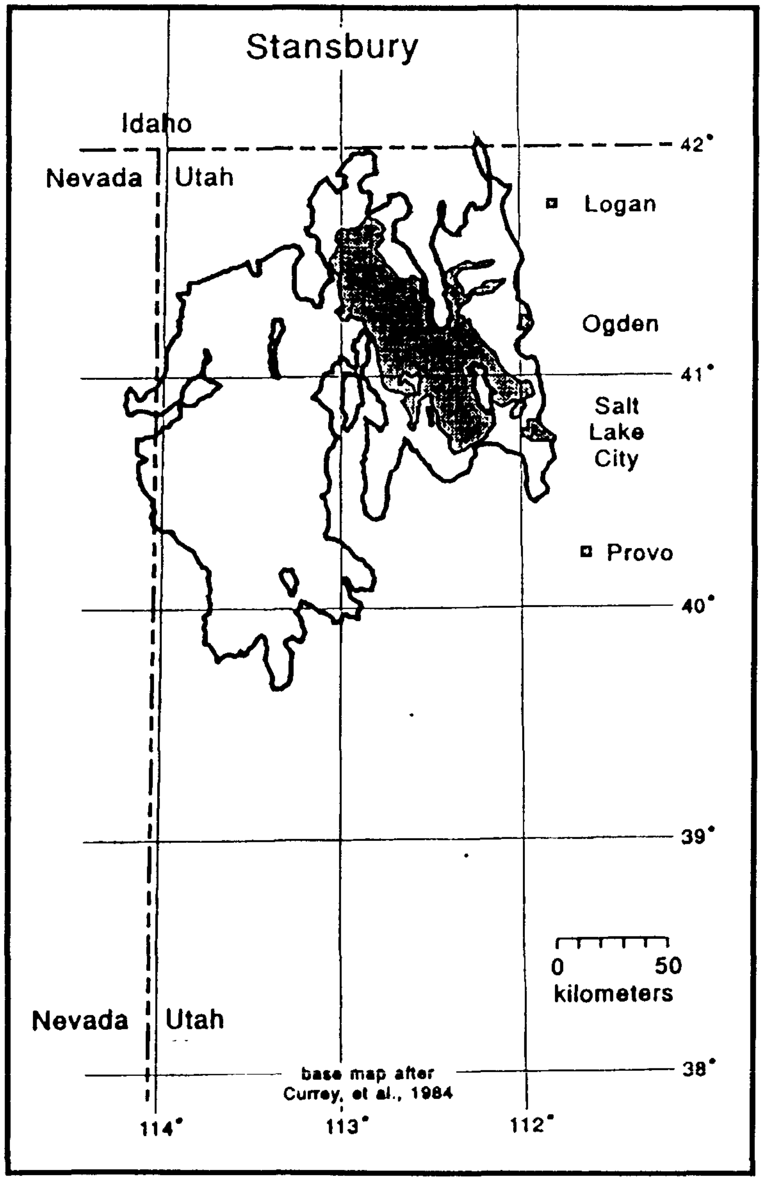
22 to 25 ka



- Great Salt Lake rises about 100 m to Stansbury shoreline by 22k
- Polar front moves seasonally or periodically from northern Great Basin to southern Great Basin
- Water table is at playa surface in Kawich playa (just northeast of Nevada Test Site)
- White fir found as low as 1,500 m elevation in pahranagat range

Shaded area is the modern Great Salt Lake
Heavy line shows maximum extent of Stansbury shoreline

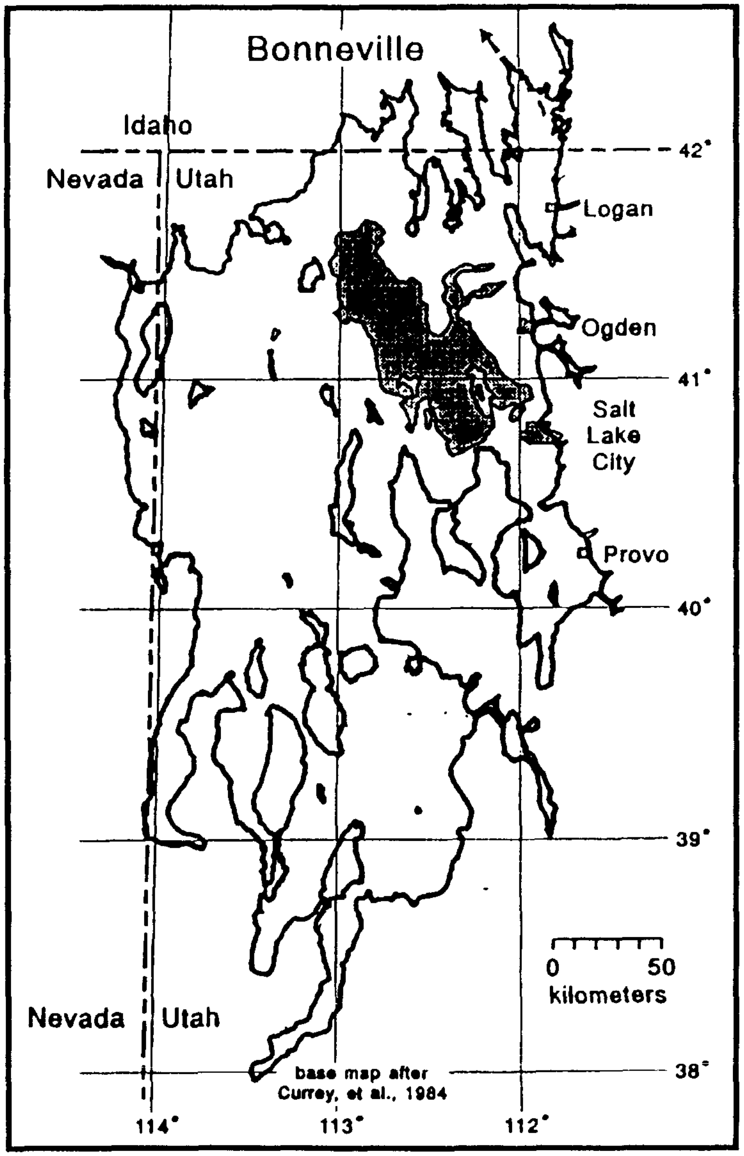
20 to 22ka



- Polar front, perhaps at times merged with subtropical front, resides year-round in southern Great Basin
- Stansbury Lake level falls, while pluvial lakes from Texas to SE California reach maximum levels
- Discharge from alluvial fans in southern Nevada probably reaches maximum
- Marsh lakes in southern Nevada probably permanent
- Water table still at surface in Kawich playa
- Browns Room at Devils Hole filled with water

Shaded area is the modern Great Salt Lake
Heavy line shows maximum extent of Stansbury shoreline

15 to 20 ka

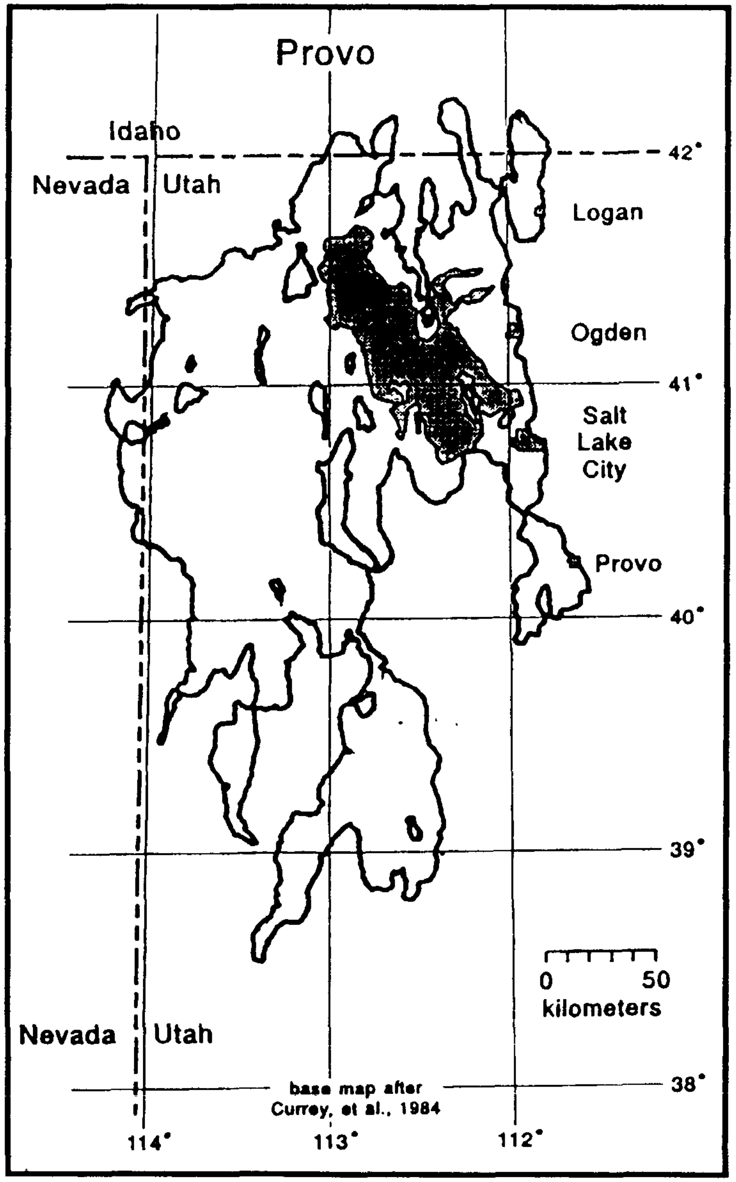


- Polar front resides in southern Great Basin seasonally or periodically
- Great Salt Lake rises to Bonneville level
- Most southern pluvial lake volumes show steady state to slow decline
- Discharge from alluvial fans in southern Nevada continues, but is locally seasonal
- Marsh lakes vary in volume seasonally, some ephemeral
- Water table below surface at Kawich playa
- Water level falls in Browns Room (Devils Hole)

Limber pine, reflecting more continental conditions, becomes the dominant tree species down to 1,500m elevation throughout southern Nevada

Shaded area is the modern Great Salt Lake
Heavy line shows maximum extent of Bonneville shoreline

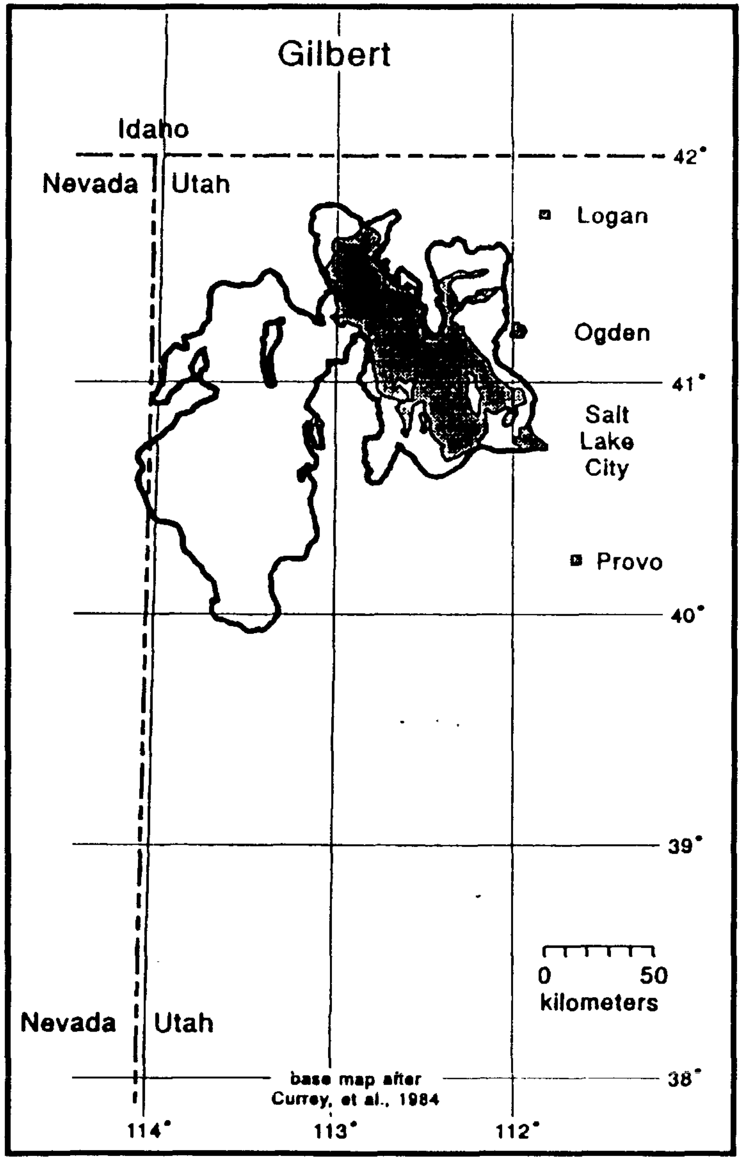
12 to 15 ka



- **Polar front less commonly fixed in southern Great Basin**
- **Great Salt Lake collapses to Provo level about 14.5k, due to Bonneville flood, then evaporates to low stand about 12k**
- **Southern pluvial lakes contract**
- **Alluvial fan discharge in southern Nevada is primarily seasonal**
- **Marsh lakes smaller and often ephemeral**
- **Juniper/pinyon woodland replaces retreating limber pine woodlands**

Shaded area is the modern Great Salt Lake
Heavy line shows maximum extent of Provo shoreline

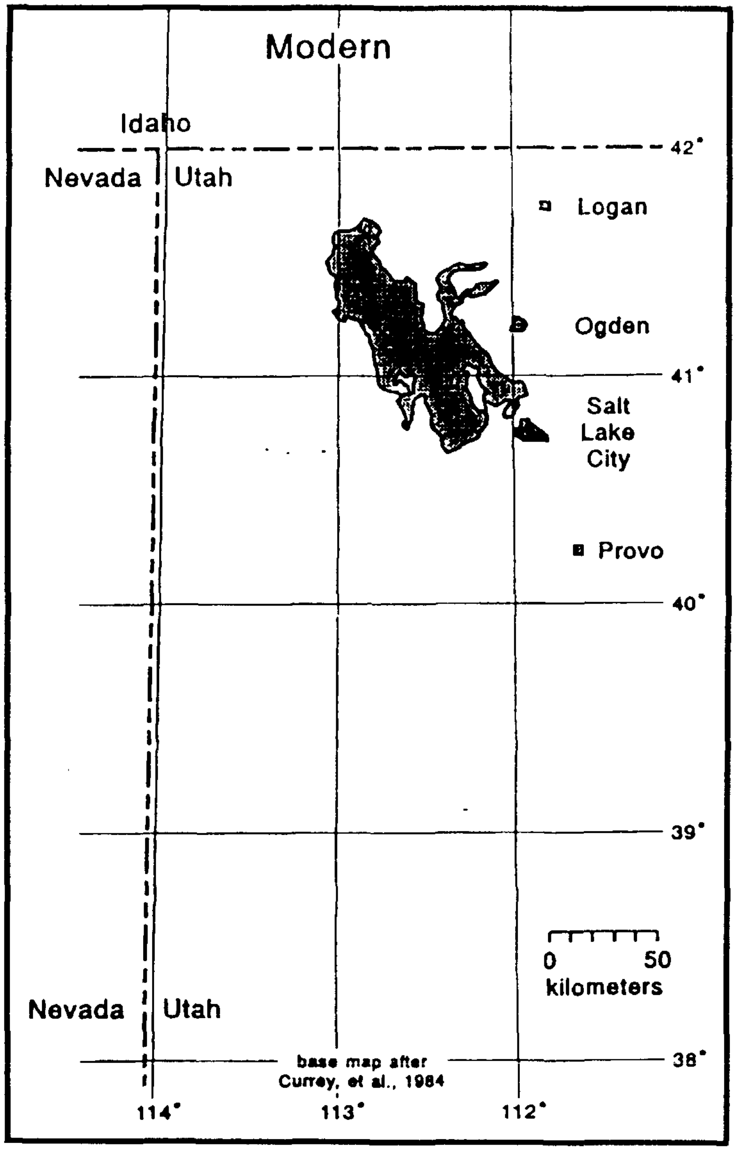
12 ka



- Polar front similar to modern position
- Great Salt Lake expands to Gilbert shoreline
- Southern pluvial lakes reach low stands or dry out
- Alluvial fan discharge in southern Nevada terminates or is seasonal
- Marsh lakes small, often only in valley centers

Shaded area is the modern Great Salt Lake
Heavy line shows maximum extent of Gilbert shoreline

Holocene (< 12 ka)



- Polar front and subtropical fronts similar to modern status, but show sustained activity in southern Nevada during some climate perturbations such as the current El Niño

  Great Salt Lake only expands periodically when mean annual temperature or mean annual precipitation trend towards lower or higher values, respectively, such as neoglacial, little Ice Age, or strong El Niños

- Some southern lakes, such as Silver and Soda, expand during these cooler or wetter events

- Alluvial fan discharge in southern Nevada is rare, marsh lakes are not in evidence, valley center wetlands may exist

Shaded area is the modern Great Salt Lake

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Climate History in the Yucca Mountain Area

- Modern ostracodes match those that live in areas with average rainfall of ~ 110 mm/yr and mean annual temperature of 9° C

- Ostracodes in a sample from a 15 ka deposit match those that live in areas with average rain fall of about 340 mm/yr and a mean annual temperature of 17° C

Photos of fracture fillings

Calcite/Opaline-Silica Results

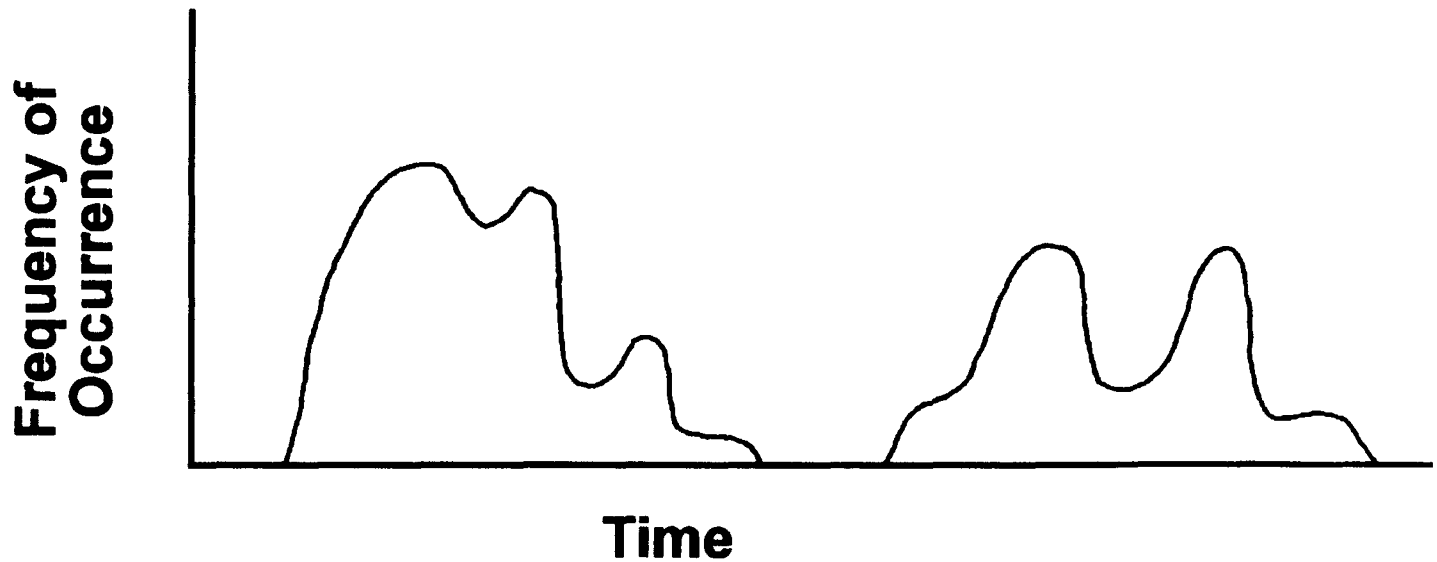
- Studies of fracture fillings show differences between calcites formed in the saturated and unsaturated zones

- Calcites formed in the saturated zone have been found up to 80m above the current water table suggesting only limited fluctuations over a period of time yet to be determined

- Mineralogic studies at Los Alamos suggest a similar amount of water-table fluctuation

- The existence of unsaturated zone calcites shows that at some time (yet unknown), water moved through the unsaturated zone (quantity unknown)

Hypothetical Frequency of Calcite Occurrences in Drill Core as a Function of Time



1) Do low frequencies of occurrence correspond to dry climates?

2) Do low frequencies of occurrence correspond to very wet climates and periods of fracture-filling dissolution?

3) Do high frequencies of occurrence correspond to wet or moderately wet periods of time?

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- Climate reconstructions provide the framework in which to understand the past hydrological behavior of the unsaturated and saturated zones within Yucca Mountain

- Carbonates and other minerals within Yucca Mountain show that during various times in the past, water moved through the unsaturated zone and that the saturated zone was at least 100m higher than today

- Preliminary data suggest the carbonates in the unsaturated zone may contain dissolution surfaces, which would imply downward movement of water, unsaturated with respect to calcite

Conclusions

(Continued)

- The various carbonate or other mineral records within Yucca Mountain provide the hydrological history of the mountain that, when dated, can be compared with the regional climate record to establish a cause-and-effect relationship
- Local and regional data demonstrate major climatic changes occurred during the last 25ka
- The relationships between past climate and Yucca Mountain hydrology, when established, will provide the criteria for both empirical and modeled estimates of the probability and nature of hydrological changes during the next ten thousand years and beyond