THE OCEAN MICRO COSM

AS SEEN THROUGH THE ELECTRON MICROSCOPE
ELECTRON MICROSCOPES

2 TYPES

1) **TRANSMISSION** - TWO DIMENSIONAL IMAGE WHERE THE ELECTRON BEAM IS TRANSMITTED THROUGH A THIN SLICE OF TISSUE AND ONE OBSERVES THE CELLULAR ULTRASTRUCTURE
ELECTRON MICROSCOPES

2) **SCANNING** - LOOKS AT THE SURFACE OF SAMPLES AT HIGH RESOLUTION AND GREAT DEPTH OF FIELD;

- THREE DIMENSIONAL IMAGE
ELECTRON MICROSCOPES

• 3 MAJOR ADVANTAGES

1) **RESOLUTION** - THE ABILITY TO DISTINGUISH FINE DETAIL

2) **MAGNIFICATION** - CAN MAGNIFY OBJECTS THOUSANDS OF TIMES

3) **DEPTH OF FIELD** - MUCH GREATER THAN A LIGHT MICROSCOPE
SCANNING ELECTRON MICROSCOPE
SCANNING ELECTRON MICROSCOPE

- Electron gun
- Scan coils
- Scan generator
- Electron lenses
- Sample
- Backscattered electrons
- Secondary electrons
- Electron collector
- Mag = D/d
- TV
- Signal amplifiers

Equation: \[ \text{Mag} = \frac{D}{d} \]
SCANNING ELECTRON MICROSCOPE

ELECTRON GUN

ANODE

CONCENTRATOR

LENS

SCAN COILS

OBJECTIVE LENS

SAMPLE

SECONDARY ELECTRON DETECTOR

SCAN GENERATOR

COMPUTER

DISPLAY MONITOR
TRANSMISSION ELECTRON MICROSCOPE
LIGHT

TEM

LIGHT

ELECTRONS

APERTURE

CONDENSER

SPECIMEN

OBJECTIVE

INTERMEDIATE

PROJECTOR

OCULAR

EYE

SCREEN
SPECIMEN PREPARATION

• HYDRATED BIOLOGICAL SAMPLES MUST BE TREATED WITH A FIXATIVE SUCH AS GLUTARALDEHYDE AND/OR OsO₄ AND THEN DEHYDRATED

• FOR SEM ANALYSIS THE SAMPLE WOULD BE DRIED, MOUNTED ON AN Al STUB AND COATED WITH A THIN LAYER OF AuPd

• FOR TEM, THE SAMPLE IS DEHYDRATED THEN EMBEDDED IN PLASTIC AND ULTRATHIN SECTIONS ARE CUT AND PLACED ON A COPPER GRID AND THEN STAINED WITH URANYL ACETATE AND Pb
MARINE BACTERIUM
SHARK SKIN; DERMAL DENTICLES
DIATOMS

2 BASIC GROUPS
1) CENTRIC – STRUCTURAL CENTER IS A POINT
2) PENNATE – STRUCTURAL CENTER IS A LINE (BILATERAL SYMMETRY)

- COMMERCIAL IMPORTANCE IS IN THE DIATOMIC OOZE FROM SEDIMENTS; USED AS A FILTERING AGENT IN SWIMMING POOL AS AN INSULATING MATERIAL AND ADSORBANT
CALCAREOUS NANNOPLAKTON

- MINUTE GOLDEN BROWN ALGAE
- 15-100 um IN DIAMETER
- SECRETE PLATLETS OF CaCO$_3$ (CALCITE) CALLED COCCOLITHS
- COCCOLITHS INTERLOCK TO FORM AN EXTERNAL SPHERICAL CALLED A COCCOSPHERE
- ABUNDANT IN MARINE SEDIMENTS
- ROUTINELY USED IN STUDIES OF PALEOCLIMATOLOGY AND BIOSTRATIGRAPHY;
COCCOLITHOPHORE BLOOM

Barents Sea north off Norway on August 1, 2007. The bright aquamarine hues suggest that this is likely a coccolithophore bloom. A coccolithophore is a tiny, surface-dwelling ocean plant that is coated with microscopic limestone (calcite) scales. This white coating makes the plant highly reflective. It reflects nearly all of the light that hits it, and it is this reflected light that gives the ocean the radiant blue color seen in this image.
WHITE CLIFFS OF DOVER
PTEROPODS

- MARINE GASTROPOD PODS
- SHELL IS COMPOSED OF ARAGONITE ($\text{CaCO}_3$)
- MORE SUSCEPTIBLE TO DISSOLUTION; PRESERVED IN THE FOSSIL RECORD
OCEAN ACIDIFICATION

- As CO$_2$ increases in the atmosphere, the acidity of the ocean increases; pH has dropped from ~ 8.2 in preindustrial times to ~ 8.1 today.
- Many marine plankton have calcium carbonate shells.
- Aragonite shell of pteropods is more susceptible to dissolution than the calcite shells of foraminifera and coccoliths.
OCEAN ACIDIFICATION

- UNCERTAIN WHETHER MARINE PLANKTON CAN ADAPT TO AN INCREASINGLY ACIDIC OCEAN
- LOWER pH MEANS LESS CARBONATE AVAILABLE MAKING IT MORE DIFFICULT TO FORM THEIR SHELLS
- ALTHOUGH SOME SPECIES OF COCCOLITHOPHORES SHOW INCREASED CALCIFICATION AND PHOTOSYNTHESIS AT LOWER pH, THE OVERALL EFFECT FOR THE MAJORITY OF CALCIFIYING ORGANISMS IS BELIEVED TO BE DETRIMENTAL
OCEAN ACIDIFICATION

- FORAMINIFERA, CORALS, ECHINODERMS, MOLLUSCS CAN ALSO BE AFFECTED.
- IF MARINE PLANKTON CANNOT MANUFACTURE THEIR $\text{CaCO}_3$ SHELLS, THE ENTIRE FOOD WEB COULD BE AFFECTED LEADING TO VAST SHORTAGES IN SEAFOOD.
RADIOLARIANS

• ZOOPLANKTON; MARINE PROTOZOANS WITH SILICA SHELL
• RANGE IN SIZE FROM 50-200 um
• THEIR SKELETAL MORPHOLOGY MAY HAVE A HYDRODYNAMIC OR FEEDING FUNCTION; ANOTHER MAY BE BALLAST
• USED IN PALEOCLIMATOLOGY AND PALEOCEANOGRAPHY
ACANTHARIANS

• Planktonic protozoans sometimes classified with the Radiolarians
• Shells are composed of strontium sulphate (Celestite)
• Morphology consists of 20 spines emanating from a central point inside the shell
• Not found in the fossil record because their shells dissolve quickly upon death
FORAMINIFERA

• Protozoans that secrete a shell or test made of calcite ($\text{CaCO}_3$)
• 2 major groups
  1) Planktonic - Free floating
  2) Benthic – Bottom dwelling
Skeletons have chambers separated by a septa or wall; foramen – opening through wall
• Continue to be the most important fossil group in both biostratigraphy and paleoenvironmental reconstructions
FORAMINIFERA

- SEM HAS BEEN USED TO DATE SEDIMENTS BY EXAMINING MARINE MICROFOSSILS SUCH AS FORAMINIFERA SO THAT OIL COMPANIES KNOW WHERE TO DRILL FOR OIL
DINOFLAGELLATES

• PRIMITIVE EUKARYOTES THAT HAVE BOTH ANIMAL AND PLANT LIKE CHARACTERISTICS
• SOME INGEST OTHERS FOR FOOD AND SOME ARE PHOTOSYNTHETIC
• PRIMARY PRODUCERS
• 2 FLAGELLA WITH CELLULOSIC PLATES THAT FIT TOGETHER TO FORM A THECA
Cathodoluminescence

Characteristic X-rays

Backscattered electrons

Secondary electrons

Auger electrons

Transmitted electrons

Sample \rightarrow heat

Absorbed current
X-RAY MICROANALYSIS

• IF WE COLLECT THE X-RAYS GIVEN OFF FROM THE SAMPLE USING AN X-RAY DETECTOR MOUNTED ON THE SIDE OF THE SEM SAMPLE CHAMBER WE CAN GENERATE AN X-RAY SPECTRUM WITH PEAKS CORRESPONDING TO THE ELEMENTS PRESENT IN THE SAMPLE
• NON-DESTRUCTIVE TECHNIQUE
• ABLE TO THE DETERMINE THAT THE COLONIAL RADIOLARIAN SHELL WAS SILICA AND THE GRANULES INSIDE, SrSO₄; CAN PLACE 1e⁻ ON AN EXACT SPOT
ENERGY DISPERSIVE SPECTROSCOPY

1e-

x-ray

N
KLM
EDS SENSITIVITY IS LIMITED TO ~ 1000 ppm
X-RAY MAPS
ADIOS
ASIAN DUST INPUT TO THE OCEANIC SYSTEM
DUST STORM-CHINA
DUST STORM-CHINA
OVERGRAZING, DEFORESTATION, URBAN SPRAWL, SPARSE RAINFALL HAVE EXPANDED THE DESERTS EASTWARD
WHY STUDY DUST PARTICLES?

- DUST PARTICLES CAN PROVIDE NEEDED NUTRIENTS FOR MARINE PHYTOPLANKTON LIKE IRON LEADING TO ALGAL BLOOMS

- STUDIES AT THE USGS FOUND THAT BACTERIA AND FUNGI WILL HITCHHIKE ON TO SAHARAN DUST AND CAUSE ALL SORTS OF RESPIRATORY PROBLEMS WHEN INHALED
WHY STUDY DUST PARTICLES

• IN LIGHT OF THE CHERNOBYL ACCIDENT IN 1986, AND THE RECENT JAPANESE NUCLEAR CATASTROPHE, SCIENTISTS ARE VERY INTERESTED IN WHAT HAPPENS TO ATMOSPHERIC DUST

• HOW FAR DOES IT TRAVEL?

• DOES IT FALL HARMLESSLY TO THE OCEAN FLOOR OR IS IT INGESTED BY MARINE ORGANISMS ENDING UP IN THE FOOD CHAIN WHICH IF RADIOACTIVE IS CONCENTRATED BY THE TOP END FEEDERS
PARTICLE COLLECTION

- SEDIMENT TRAPS WERE DEPLOYED AT DEPTHS OF 37,127,400, 900, 2200 AND 3500 METERS
- IN ADDITION, ATMOSPHERIC SAMPLES WERE COLLECTED AT THE TOP OF A 20 METER TOWER ON THE SHIP
- THE FOLLOWING SLIDES ARE QUARTZ PARTICLES COLLECTED FROM THE 37 METER TRAPS
PARTICLE SIZING

PARTICLES WERE SIZED ON THE FILTER PAD AND AN X-RAY SPECTRUM WAS COLLECTED FROM EACH INDIVIDUAL PARTICLE FOR 5 SECONDS; PARTICLES WERE SORTED BY SIZE AND CHEMISTRY.
ADIOS PROJECT

• LARGE SILICA PARTICLES ( >75UM ) WERE TRANSPORTED THOUSANDS OF MILES FROM THEIR SOURCE IN THE GOBI DESERT AND DEPOSITED INTO THE NORTH PACIFIC OCEAN SHOWING UP SIMULTANEOUSLY IN THE ATMOSPHERIC AND SEDIMENT TRAP SAMPLES AS DEEP AS 3500 METERS

• SMALLER CALCIUM AND INCREASED AMOUNTS OF CLAY AND IRON RICH PARTICLES WERE ALSO FOUND IN THE SHALLOW 37 METER TRAPS
ADIOS PROJECT

- SOME OF THESE PARTICLES WERE BEING INGESTED BY MARINE ORGANISMS

- WE WERE ABLE TO TRACK THE DUST BACK TO ITS SOURCE BY ANALYZING SOIL SAMPLES FROM THE GOBI DESERT AND MATCHING IT TO THE DUST WE FOUND IN OUR TRAPS
ADIOS PROJECT

• IT is extremely difficult to account for the transportation of these giant dust particles, over 10,000 km. from their source.
• Some had diameters exceeding 200 μm.
• What is even more puzzling was the fact that in contrast to our data, surface sediments sampled near the ADIOS collection site showed no quartz particles > 55 μm.
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AFRICAN DUST STUDY

• JUST COMPLETED COLLECTING DATA ON AFRICAN DUST SAMPLES FROM JOE PROSPERO AT UM FROM 1979-1995

• NO EVIDENCE OF THE GIANT DUST PARTICLES WE FOUND IN THE ADIOS PROJECT

• INSTEAD, PARTICLES AVERAGED ~2 um IN DIAMETER (ONLY ANALYZED > 1 um)

• MOST COMMON CLASS WAS AlSiFe and VARIATIONS OF THAT e.g. AlSiFeK, AlSiFeMg, AlSiTi, AlSiMgFe; Ti AND Fe
CENTER FOR OCEAN TECHNOLOGY

• USING AN AUTOMATED PARTICLE SAMPLER TO COLLECT PARTICLES ON SMALL MILLIPORE FILTERS IN THE OCEAN

• ANALYZING PARTICULATES IN THE LAB USING THE SEM AND X-RAY MICROANALYSIS SYSTEM INCLUDING SIZING AND CHEMICAL CLASSIFICATION

• GOAL IS TO PROGRAM THE SAMPLER TO COLLECT OCEAN PARTICULATES AT A SPECIFIC LOCATION AND TIME AND DEPTH
AUTONOMOUS MICROBIAL GENOSENSOR

FIRST DESIGNED AS A DEVICE TO DETECT RED TIDES USING SAMPLE COLLECTION, FILTRATION, CELL LYSIS, RNA EXTRACTION, PURIFICATION, CONCENTRATION, GENE AMPLIFICATION; DATA IS TRANSMITTED TO SHORE. SYSTEM CAN BE PROGRAMMED TO COLLECT MARINE PARTICULATES ON TO FILTER PADS; CAN BE DEPLOYED FOR 3 DAYS.
EDS SYSTEMS

• THERE ARE EDS SYSTEMS THAT OPERATE INDEPENDENTLY OF AN SEM
• THEY HAVE THEIR OWN X-RAY SOURCE TO IRRADIATE THE SAMPLE LOCATED IN A SAMPLE CHAMBER
• CAN BE USED BY MUSEUMS TO DETECT FORGERIES
• HAS BEEN USED TO ANALYZE THE SHROUD OF TOURIN
SEM APPLICATIONS

• SEM HAS BEEN USED TO DATE SEDIMENTS BY EXAMINING MARINE MICROFOSSILS SUCH AS FORAMINIFERA SO THAT OIL COMPANIES KNOW WHERE TO DRILL FOR OIL

• CRITICAL DECISION WHERE TO DRILL BECAUSE OF THE TREMENDOUS COSTS INVOLVED
ENVIRONMENTAL SEM’S

• NORMALLY A SAMPLE IN A STANDARD SEM MUST BE COMPLETELY DRY SINCE IT IS IN A HIGH VACUUM ENVIRONMENT

• THE MOST ADVANCED SEM’S CALLED ENVIRONMENTAL SEM’S ALLOW HYDRATED SAMPLES TO BE EXAMINED IN THEIR NATURAL STATE

• ALLOWS DYNAMIC IMAGING TO BE DONE SUCH AS WATCHING CEMENT DRY OR WATER DROPLETS FREEZE
APPLICATIONS OF ENVIRONMENTAL SEM’S

- BIOLOGY – EXAMINATION OF LIVE PLANT SEEDLINGS, POLLEN GRAINS IN SITU, AND LIVE INSECTS
- CEMENT SCIENCE – STUDY HOW WATER REACTS WITH CEMENTS TO PRODUCE BULK PROPERTIES SUCH AS STRENGTH, STIFFNESS AND PERMEABILITY AND THE EFFECTS OF ADDITIVES ON THE CEMENTING PROCESS
APPLICATIONS OF ENVIRONMENTAL SEM’S

• ART MUSEUM – INVESTIGATE THE DEGRADATION PROCESS OF ENVIRONMENTAL POLLUTANTS ON MATERIAL USED BY PAINTERS, SCULPTORS AND ARCHITECTS

• OTHER FIELDS – SOIL SCIENCE, POLYMERS, CERAMICS, FOOD TECHNOLOGY, DENTISTRY, PAPER COATING CHEMICALS, FORENSICS
SUMMARY

ELECTRON MICROSCOPES ARE POWERFUL INSTRUMENTS FOR STUDYING THE OCEAN WITH ADVANTAGES OF:

1) HIGH RESOLUTION
2) HIGH MAGNIFICATION
3) LARGE DEPTH OF FIELD

* CHEMICAL COMPOSITION
* PARTICLE SIZING