FINAL TECHNICAL REPORT

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"MULTIDISCIPLINARY RESEARCH IN THE SPACE SCIENCES"

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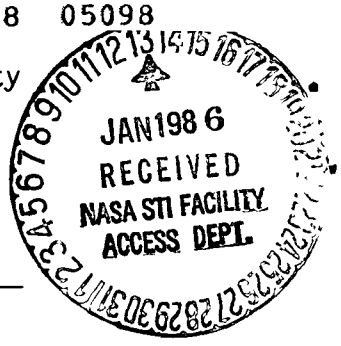

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NOTE: The only purpose for terminating this cooperative agreement was to afford more efficient management of the funds. The work is being continued under new cooperative agreements NCC 5-28 and NCC 5-29.

TASK I: ASTROPHYSICS

Receivers for Millimeter & Submillimeter Wavelength Astronomy

A. Superconducting Mixers

An ultra-low-noise 115 GHz receiver based upon a superconducting tunnel diode mixer has been designed and constructed. The first laboratory tests have yielded spectacular results: a single-sideband noise temperature of 75 K considerably more sensitive than any other receiver at this frequency. When laboratory tests are complete, the receiver will replace that currently in use on the Columbia-GISS CO Sky Survey telescope, resulting in a factor of ~25 improvement in observing efficiency on that instrument.

The mixer uses superconductor-insulator-superconductor (SIS) tunnel junction diodes, which are being developed by the computer industry as Josephson-effect logic elements. In the SIS mixer, however, the Josephson current is suppressed or ignored. The junction is then simply resistive, with a nonlinearity so strong that the mixer behaves quantum-mechanically rather than classically. The quantum mixer theory developed by Tucker predicts that the SIS mixer should have several major advantages over classical (e.g. Schottky diode) mixers: (i) gain, potentially unlimited, as opposed to loss in a classical mixer; (ii) a sensitivity approaching the ultimate quantum noise limit; and (iii) a very small ($\lesssim 1\mu W$) local oscillator power requirement. We have previously verified all the qualitative predictions of Tucker's theory, and now have provided the first convincing quantitative verification of the theory. This important step justifies using the quantum theory to design for optimum mixer performance.

The receiver was designed by combining a theoretical analysis of the SIS junction behavior with extensive low-frequency scale model simulations of the mixer mount. The mixer mount permitted a far wider tuning range than is conventional. Nevertheless, the mixer's performance is still far from optimum. The major remaining problem is the difficulty of tuning out the relatively large capacitance of our SIS junctions. We have begun to design a new mixer mount which will incorporate the first-order tuning directly onto the printed circuit of the SIS junctions. In this way we expect to improve upon our already unprecedented results.

Our receiver's superconducting junctions were supplied by a group at Princeton University (which has access to the NBS-Boulder facility for SIS junction fabrication), under D. Wilkinson. In return, we assisted them in constructing a copy of our receiver, scaled to lower frequency, which is intended for above-atmosphere measurements of the 3 K cosmic black-body radiation. Their receiver's preliminary single-sideband noise temperature is 50 K at 46 GHz. This is by far the best result ever achieved at that frequency (except for masers, which are too unwieldy for many applications). In addition, we have continued our cooperation with groups at IBM, the Sperry Research Center, and the University of Virginia. All have agreed to supply SIS junction chips to our specifications for integration into our experimental mixer structures.

B. Schottky Diode Mixers

A liquid nitrogen cooled receiver for 115 GHz has been built and is currently being used in Chile by the Columbia University Southern Sky Survey project. This receiver has a noise temperature of 390 K. Comparable receivers at room temperature or cooled to 15 K would have noise temperatures of ~900 K and ~200 K. Thus liquid nitrogen cooling is the best compromise for

use at a remote site. As part of the support for the Chile receiver an extensive mixer diode testing program is being carried out with diodes supplied by R.J. Mattauch of the University of Virginia. A doubly-tuned mixer mount has been built to use in diode testing. The two degrees of freedom in tuning permit diodes with widely different parameters to be tested under nearly optimal conditions. To a great extent this allows diode noise to be measured independently of the specific mixer design.

We have completed a theoretical analysis of the channel waveguide transformer, which was previously developed at GISS. This type of transformer is particularly well suited for millimeter wavelength applications. The theoretical analysis has resulted in a set of general design curves, which will enable the transformer to be adapted for widespread use.

The general mixer analysis program, developed as an earlier part of this project, has been successfully used by a number of other research groups, leading to an improved understanding of Schottky diode mixers.

Galactic Carbon Monoxide Survey in the First Quadrant

Over the past few years the 1.2 meter millimeter-wave telescope at Columbia University has been used to complete two large-scale surveys of molecular matter in the part of the inner galaxy which is visible from the Northern hemisphere (the first galactic quadrant); one of the distant inner galaxy and one of the solar neighborhood. The bulk of this matter, molecular hydrogen, is not generally detectable because it does not emit radiation at radio frequencies, so instead we observe radiation from carbon monoxide at 115 GHz. Although CO represents less than 0.1% of the molecular mass, it is easily detected and is known to be a reliable tracer of molecular gas.

The inner-galaxy survey has been used to determine the locations and physical properties of the largest molecular complexes in the inner galaxy. Within the range of our survey 19 complexes were detected with masses greater than 5×10^5 $M_\odot$, and we have deduced that roughly 100 such complexes exist throughout the inner galaxy. These 100 or so complexes are perhaps the most fundamental population - I objects in the galaxy.

These large complexes were found to be excellent spiral-arm tracers. The Sagittarius spiral arm in particular is traced with unprecedented clarity. A total of 15 large complexes are distributed quite uniformly along a 15 kpc stretch of the arm with a spacing which is comparable to that of the regular strings of H II regions observed in external galaxies. Most of the complexes interior to the Sagittarius arm were found to lie in the near side of the inner galaxy, suggesting that a significant assymmetry may exist in the distribution of molecular clouds in the inner galaxy.

Our CO survey of molecular gas in the solar neighborhood, which covers roughly 15° of galactic latitude in the first galactic quadrant, has been compared with a similar high-energy gamma-ray survey which has been produced

by the COS-B satellite. By using existing 21-cm surveys to trace the atomic gas distribution, our CO survey to trace the molecular distribution, and the gamma-ray survey to yield information on the total gas and cosmic ray distributions, such problems as the possible existence of a cosmic ray gradient in the galaxy, the contribution of point sources (such as pulsars) to the gamma-ray flux, and the molecular gas content of the galaxy have been investigated. We have found that a simple model, in which uniformly distributed cosmic rays interact with the interstellar gas, can account for almost all the observed gamma rays. If the contribution from point sources to the gamma-ray flux is significant, these sources must have a galactic distribution similar to CO. Our analysis has also provided a calibration of the ratio between molecular-hydrogen column-density and integrated CO line intensity.

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Galactic Carbon Monoxide Survey in the Second Quadrant

During the 1982-83 observing season we completed work on a large scale, low resolution survey of the second quadrant of the galaxy. The survey extends from galactic longitude $\ell = 98$ to $\ell = 180$ degrees, and latitude $b = -4$ to 10 degrees, excluding only the region $145 < \ell < 180$ and $6.5 < b < 10$. The survey has a resolution of .5 degrees, and is fully sampled over the entire region observed (about 1000 square degrees).

Survey of the Perseus Arm Extension

The discovery of several Perseus-arm molecular clouds in the first quadrant suggests that the Perseus arm is extended down to $\ell = 80°$ as the HI survey (Weaver and Williams 1973) shows. In order to see the full extent of these distant clouds, a full-resolution CO survey in the vicinity of the clouds will be achieved in the next season.

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Studies of Gas and Dust in the First Galactic Quadrant

Earlier studies of the molecular gas in the plane, based on undersampled observations, had to rely on statistical models of idealized clouds to estimate the numbers, sizes, and masses of clouds. Further, they did not have the benefit of the extensive surveys of giant molecular cloud markers that are now available in the radio continuum, H_2O maser line, submillimeter, and near infrared. We have concentrated on the giant clouds which are indicated by these surveys, and have measured the properties of associated CO emission wherever possible. We have found approximately 50 giant molecular clouds with typical masses in the range, 10^5 to 10^6 $M_\odot$.

We have found approximately 60 coincidences in angular position between far infrared sources and radio continuum sources which are H II regions. The H 109α recombination line velocity of each H II region has been used to associate the H II region with one of the 50 giant molecular clouds seen in CO.

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Studies of Galactic Clusters

A new theory for the origin of bound galactic clusters was developed. This theory postulates that new stars appear at random times in a cloud core, and that the stellar masses are distributed according to some initial mass function. The primary result is an explanation for the differences between bound galactic clusters and expanding OB associations: bound clusters are the occasional result of star formation in low mass cloud cores ($M < 10^3$-10^4 $M_\odot$), and OB associations are the usual result of star formation in high mass cloud cores ($M > 10^4$ $M_\odot$). Star formation is assumed to proceed in a cloud until the luminosity of the embedded cluster exceeds a critical value proportional to the total cloud mass. Then the cloud core disrupts. If the efficiency for star formation at this time of disruption is small, as will be the case for high mass cloud cores, then the cluster will be unbound after the gas leaves. If the efficiency is large, then a bound cluster can remain. The masses, stellar densities, and radii of galactic clusters can be derived using only the observed initial mass function and mass-luminosity law for stars, and the characteristic gas densities of star-forming regions. We predict that high mass stars will form in the most massive clouds, that these stars will not generally appear until long after the first low mass stars form, and that some bound clusters will have a large spread in stellar ages.

Molecular Clouds Associated with Open Star Clusters

Soon after observations were begun, it was discovered that considerably more time would be required to complete our survey than had been anticipated. Three factors contributed to this: (a) it was necessary to share the telescope with as many as three other observers, (b) the weather during 1982-83 was exceptionally unfavorable, and (c) insufficient time was allowed for telescope system malfunctions and other minor problems which often resulted in significant loss of observing time.

The clusters in our sample were prioritized so that those with highest priority could be observed first. As of now, nine clusters have been completely sampled in ^{12}CO ($J = 1 \rightarrow 0$) and five more are in the process of being mapped in this transition. The supply of "high-priority" clusters in the third quadrant of galactic longitude has now been exhausted, but no mapping has been done in the second quadrant.

Our early results are very encouraging. We discover a tendency for there to be a "hole" in the molecular gas distribution in the immediate vicinity of intermediate-age clusters (~5-25 Myr) whereas younger clusters have gas even toward their centers and older ones seem to have none within ~5 cluster diameters. The hole size seems to grow with increasing cluster age, implying either expulsion or destruction of associated molecular clouds. Better statistics, as would be provided by mapping at least all of our high-priority clusters (of which there are roughly 25) are required to make a strong case for this behavior. However, if the new millimeter-wave receiver is as good in practice as it is in early lab tests, we should have no trouble completing our entire survey of 128 clusters during the next observing season.

Depending upon availability of IRAS data, priority may be given to

analyzing the infrared data. This will not significantly deter completion of the mapping as it can be done during the summer months which are unfavorable for millimeter observations.

A poster has been presented to the American Astronomical Society at the 161st meeting in Boston in which our early results were displayed. The abstract will appear in the next BAAS (Bulletin).

The Molecular Complex in Orion

During the current observing season, we have investigated the following areas of our galaxy for CO emission:

1. from $\ell = 180°$ to $\ell = 220°$, $b = -25°$ to $b = -20°$,
2. along the galactic plane from $\ell = 210°$ to $\ell = 220°$, $b = -5°$ to $b = 2°$,
3. in the region associated with the λ Ori HII region from RA = 5h 12m to 5h 56m, DEC = 9° to 16°.

For each of these regions, we have avoided areas which have been surveyed previously by the Columbia telescope.

The first of these areas revealed numerous high latitude molecular clumps which may be remnants of the molecular clouds which formed the nearby Ori OB I Association. For the second of these areas (i.e., along the galactic plane) a new, giant ($3 \times 10^5 M_\odot$), molecular cloud was found which possesses the unique property of having both low temperatures and wide line widths. This cloud, located at $\ell \sim 215$, $b \sim -2$, is probably part of the local arm of our galaxy at a distance of 2 kpc from the sun. The third area which surrounds λ Ori was found to have a good deal of strong CO emission with most of it lying in a shell like structure centered on λ Ori itself.

In addition to these observations, we have also been involved in determining masses for the clouds already surveyed in Orion/Monoceros, and investigating the kinematics of various clouds (especially the two molecular filaments) in that region.

Laboratory Spacetroscopy of Reactive Species

During the past year we studied the C_4H and C_3N spectra [1] and did some inital work on the CCN and CCD radicals. Previously gaseous C_4H and C_3N had only been observed in the outer envelope of the carbon star IRC+10216,[2,3] and until now had defied detection in the laboratory. Our laboratory measurements of C_3N and C_4H eliminate ambiguities in Doppler velocities and provide accurate values for the rotation, centrifigual distortion, and spin-rotation constants. The laboratory detections also serve to confirm the identifications of these radicals by astronomers. As part of the C_3N and C_4H studies we demonstrated that combined Zeeman and frequency modulation almost completely eliminates baseline distortion due to standing waves, and the spectra are free of lines from closed shell molecules present either as contaminants or produced in the discharge.

Measurements of the C_3N and C_4H spectra were aided by a powerful new laboratory mini computer system we installed last summer. The new computer system allows us to store thousands of spectra, analyze spectra while experiments are in progress, and to display and make copies of the spectra.

The C_3N was generated in a DC discharge of N_2 and HC_3N and the C_4H in a He and C_2H_2 discharge under nearly the same conditions in which CCH was observed. Interestingly the C_4H and CCH[4] concentrations are nearly the same suggesting that longer carbon chain molecules such as C_6H are produced in detectable concentrations.

We plan to continue to search for reactive species that are generated in DC discharges. There is strong evidence both from our work and from mass spectrometer studies[5] that numerous reactive species are simultaneously generated in discharges of simple gases such as C_2H_2, CH_4, C_2H_4, etc. and that spectroscopy of discharges will continue to be a very fruitful area of research.

During the next few months we will continue to search for new species with the present spectrometer. In addition a parallel effort will be undertaken to significantly improve the instrumental sensitivity by replacing the single pass absorption cell with a Fabry-Perot cell whose effective millimeter wave path length will be approximately 100 times greater than the present instrument. Our goal is to build a sensitive instrument that is able to track automatically a frequency range of 1 GHz an in hour, and whose sensitivity (minimum detectable absorption coefficient) is the same as can now be achieved in a 20 MHz frequency range with one hour total integration time. If we are successful we will be able to search for astrophysically important species for which no prior spectroscopic data exists and whose rotational frequencies are only known from ab initio calculations.

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TASK II: CLIMATE AND ATMOSPHERIC MODELING STUDIES

Climate Model Development and Applications

The research conducted during the past year in the climate and atmospheric modeling programs has been focused on the development of appropriate atmospheric and upper ocean models, and preliminary applications of these models. Principal models are a one-dimensional radiative-convective model, a three-dimensional global climate model, and an upper ocean model. Principal applications have been the study of the impact of CO_2, aerosols and the solar 'constant' on climate.

Model II of the 3-D climate model has now been completed. Model development and model sensitivity studies are summarized in a paper in Monthly Weather Review (Hansen et al., 1983). The 3-D model has been applied to study the climate sensitivity, obtaining approximately a 4°C warming for either a 2% increase in solar irradiance or doubled CO_2 in the atmosphere. To understand the contributions of the various feedback mechanisms to the resulting climate change, the 3-D model results have been analyzed with the aid of the 1-D radiative convective model. The analysis shows that the principal feedback processes in the model are changes in atmospheric water vapor, clouds and sea ice. The 3-D model has also been used to study the influence of vegetation and ground moisture conditions on the hydrologic cycle and climate (Rind, 1982, 1983). These experiments demonstrate that the processes that affect the global distribution of sea ice and of clouds, and the treatment of ground hydrology play a critical role in climate change in the model.

Progress has been made in the 3-D model development towards physically realistic treatment of these processes. In particular, a map of soil classifications on 1° x 1° resolution has now been digitized, and soil

properties have been assigned to each soil type. This improved treatment of soil hydrology, together with the seasonally varying vegetation cover, will provide a more realistic study of the role of the terrestrial biota in climate change.

A mixed layer-diffusive thermocline ocean model has been incorporated into the 3-D climate model to allow the study of the effect of ocean thermal inertia on the timing of the greenhouse warming due to slowly increasing levels of CO_2 and other trace gases in the atmosphere. In this model, the geographically dependent thermocline diffusion coefficients are obtained from an empirical relationship that relates the stability at the base of the mixed layer and the diffusion rate of bowl-produced tritium observed in the GEOSECS program.

The tracer model developed at GISS has been used to investigate the sources and sinks of atmospheric CO_2. In a study of atmospheric response to seasonal exchange of CO_2 with the terrestrial biosphere, Fung et al. (1983) have demonstrated that a 3-D approach is necessary to extract source/sink information from the isolated station data. The tracer model has now been coupled to an upper ocean model which includes temperature and salinity dependent carbonate chemistry. The improved model will be used to study the ocean's contribution to the seasonal and interannual variations of atmospheric CO_2.

SAGE II

In accordance with our task to carry out modeling and interpretation of SAGE II data, we have been defining the version of the 3-D GCM to be used. The present plan is to emphasize the 8° x 10° (latitude x longitude) horizontal resolution, with 9 vertical levels and a top at 10mb for problems restricted to the troposphere and lower stratosphere. For problems which

involve the entire stratosphere, we use a 21-level version with a top at .01mb. With the 8° x 10° horizontal resolution the 9-level version requires 6 minutes of Amdahl 470/V6 CPU time per simulated day, while the 21-level version takes 15 minutes.

The 9-level troposphere-lower stratosphere model has been completed and its climatology determined from a five year run. Comparisons with observations indicate that the model produces a very realistic climatology. In particular, this model successfully reproduces the high latitude tropopause in contrast to the performance of an earlier version. The 21-level troposphere-stratosphere-lower mesosphere model has recently been completed, and will be tested fully in the coming months.

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TASK III: CLIMATE APPLICATIONS OF EARTH OBSERVATIONS & GEOLOGICAL STUDIES

CLOUD CLIMATOLOGY

During the past year this project has focused on development of 2-channel satellite analysis methods and radiative transfer studies in support of multichannel analysis techniques. Comparison of the 2-channel method we have developed over the past years to five other methods in preparation for the International Satellite Cloud Climatology Project has led to some additional improvements of our method as well as better error estimates. The final version of the method has been applied to four months of data covering one seasonal cycle. Analysis of this data, in addition to revealing the nature of global cloudiness variations over one year, will help evaluation of the errors and uncertainties in this type of analysis and will serve as a basis for development of new diagnostic methods. Publications are in preparation describing the complete technique, the surface albedo map derived by the analysis, and the seasonal variation of global cloudiness inferred from the analysis results.

Complete radiative transfer models for all of the AVHRR channels have been constructed. Sensitivity studies are being carried out to determine the optimum use of the channels in a multispectral cloud analysis method.

LONG-RANGE CLIMATE STUDIES

Land Cover Transformations and Albedo - Land cover transformations (both natural and man-made) may affect the climate in a number of ways. The most readily observable change following a land cover alteration is the change in the surface (and often the planetary) albedo, which has been investigated as a potential cause of climatic variation (Charney, 1975; Charney et al., 1977; Sagan et al., 1979, Potter et al., 1981). Clearing of natural vegetation for

agriculture and grazing, and desertification - or degradation of arid and semi-arid vegetation under the combined impact of drought and poor land-management practises - have been the major processes affecting the surface cover during the last century. Areal changes associated with these processes have been documented through a literature survey, and the main findings are described below.

The global pattern of clearing for agriculture has changed substantially during the past century. During the late 19th and early 20th centuries, the sparsely-settled grasslands and steppes of western North America, Asiatic U.S.S.R., Australia, Argentina and South Africa were brought under cultivation. Agricultural land also increased in India, China and southeast Asia. Between 1870 and 1920, an estimated 381.5 million ha were brought under cultivation, or a mean annual rate of increase of 1.1%/yr. However, although arable land continued to increase in the 20th century in some developed countries like Australia and the U.S.S.R., most of the recent changes in vegetation cover are occurring in the tropical forests and savannas of developing countries. Between 1920 and 1980, arable land has increased by 343.5 million ha to a present total of around 1.4 billion ha, or an annual increase of around 0.5%/yr. This figure only reflects addition of permanent cultivation, and thus underestimates recent clearing due to increases in shifting cultivation, grazing and collection of firewood. In recent years, expansion of the arable land in many of these countries is contributing to tropical deforestation. Some of the highest annual rates of deforestation occur in the Ivory Coast (7%), Nigeria (4.8%), Thailand (3.6%), Brazilian Amazon (1.55%) and the Philippines. The average rate of deforestation for the tropical zone (all forest land) is 11 million ha/yr or 0.6%/yr of forest area (Lanly, 1982).

Desertification involves a number of partly interrelated climatic, vegetational, edaphic and geomorphologic changes, which are difficult to quantify. Desertification is largely of anthropogenic origin, linked to the adverse consequences of human and animal population increase in a marginal ecosystem, and is only indirectly related to climate change. In the Sahel region of Africa, climatic data do not indicate a long-term deterioration, although at least three major periods of drought have occurred during the last century. UN estimates of the rate of desertification (5.4 million ha/yr) may be widely overestimated, since detrimental effects may be largely reversible when anthropogenic pressures or local weather conditions improve.

Albedo changes associated with land transformations over the last 30 years have been estimated (including irrigation, salinization, dam-building, urbanization) revising Sagan et al. (1979). Albedo values were taken from Hansen et al. (1983) and other sources. The range of likely albedo changes was derived assuming a minimum albedo contrast between tropical forest and adjacent clearing (0.03), and a maximum contrast using the lower limit of tropical forest albedo and assuming conversion to savanna/grassland (0.09). Two rates of desertification were used: the UN estimate cited above and 1/2 that value, allowing for reversibility under favorable environmental conditions; and two estimates of albedo contrast: assuming a change from semi-arid shrub/scrub to sandy soil (0.12), and that of a protected enclosure to sandy, unvegetated soil (0.05). The total albedo changes over the last 30 years for the various processes based on our best estimates has between 0.00042 and 0.00072, or roughly half of Sagan et al.'s (1979) estimate of 0.001. The differences from Sagan et al. are in the lower albedo contrast associated with tropical deforestation, more conservative estimates of permanently desertified land and a lower albedo change due to this process, a

significantly lower estimate of the effect of salinization and inclusion of arid-land irrigation and dam-building, both of which tend to reduce albedo. Desertification could be comparable to tropical deforestation in the magnitude of the resultant albedo change except under the more restrictive assumptions of desert areal change and albedo contrast. The results are very sensitive to the underlying assumptions, and the areal estimates, particularly for desertification, is uncertain by a factor of 2 or 3.

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Volcanic Eruptions and Climate - Preliminary studies were completed comparing the magnitude, volatile-element composition and climatic after effects of the eruptions of Tambora 1815, Krakatau 1883 and Agung 1963 (Rampino and Self, 1982). A detailed volcanological investigation of the Agung eruption has also been completed (Self and Rampino, 1983, submitted). Initial results suggest that decreases in Northern Hemisphere surface temperatures are positively correlated with our estimates of the minimum mass of sulfur released by the eruptions. The observed temperature decreases appear to vary linearly with the cube root of the estimated minimum sulfur yields (Devine et al., 1983).

A long-term record of eruptions and atmospheric after effects based on contemporary reports for the entire period 1500 B.C. to A.D. 1500 has been

compiled (Stothers and Rampino, 1983a, b). This chronology shows excellent correlation with the independent volcanic aerosol record preserved in *Greenland ice-core acidity layers.*

Publications - Task III

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8. Schiffer, R. A. and W. B. Rossow, 1983: The international satellite cloud climatology project (ISCCP): the first project of the World Climate Research Programme. Bull. Amer. Meteor. Soc. (in press).

9. Stothers, R. and M. Rampino, 1983: Volcanic eruptions in the Mediterranean before AD 630 from written and archaeological sources. J. Geophys. Res., (accepted).

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TASK IV: CHEMISTRY OF EARTH AND ENVIRONMENT

Kinetic Fractionation of $^{13}CO_2$ and $^{12}CO_2$ Across An Air-Water Interface

In the past year an experimental setup was made to determine the kinetic fractionation of $^{13}CO_2$ and $^{12}CO_2$ across an air-water interface. This fractionation could be important in using $^{13}CO_2$ as a tracer for ocean water movement and the fate of fossil fuel and biospheric CO_2 in the atmosphere.

The setup consisted of a large tank (25 liter) which was half filled with ocean water. Sample flasks were connected to the tank and the liquid and gas phase were circulated. The air phase was spiked with CO_2 so a net invasion of CO_2 into the water resulted. The rate of circulation was adjusted such that the boundary layer thickness was about 40 micron (which is the average film thickness of the ocean).

The first setup suffered from several flaws. Temperature control was absent, leakage occurred and sample sizes were so large that the system was perturbed significantly every time a sample was taken. A new system was built which is currently being tested.

Work with the old system proved useful. It was shown that film thicknesses in the range of ocean boundary layers could be produced. Extraction procedures for CO_2 for mass spectrographic analyses has given confidence that small samples can be run with great accuracy.

During the coming summer the project will be finished and the fractionation will be determined over an air-distilled water interface and an air-seawater boundary. Also the temperature effect of kinetic fractionation will be looked into.

Advection And Diffusion In Interstitial Waters

Interpretation of profiles of nutrients and products of redox reactions in interstitial waters is often complicated by spurious peaks and inadequate definition of biological influences in a system. Soluble radiotracers offer a means to determine the rates and distribution of interstitial water transport and thus provide parameters useful for interpretation of biologically and chemically active constituents. In many situations movement of interstitial waters occurs in conjunction with movement of the solid phase also; particulate radiotracers offer a means to measure this component of transport. Radioisotopes from bomb fallout are present throughout most of the natural water systems and in recent sediments. Soluble tracers from bombs are well mixed on the time and space scales of interest for most estuarine work so a tracer spike experiment was designed to accompany pore water measurements in an estuarine system.

Bell jars were placed on a muddy sediment surface in Quartermaster Harbor, Puget Sound (15 m of water) and injected with tritiated water. Cores were taken by divers after 24, 48 and 72 hours, sectioned, pore waters separated by centrifugation, and analyzed for ^{3}H, Mn^{++}, Fe^{++}, $NH^{4}+$, and dissolved silica. Nearby boxcores provided additional nutrient data, biota counts, and particulate samples. One boxcore and one diver core were analyzed for ^{222}Rn deficit.

A well mixed pore water region was established within 24 hours of ^{3}H injection and penetration to depths greater than 25 cm occurred during the experiment. Some loss of ^{3}H resulted from lateral transport. The speed and patchiness of ^{3}H penetration together with observations of biota throughout the cores indicate active biological pumping of water to depth.

The interstitial waters best fit a 3-layer model. These layers are:

1) a well mixed layer extending from 0-11 cm; 2) a diffusive layer from 11-18 cm; and 3) an irrigated layer from 18 cm to bottom (about 40 cm). The ^{222}Rn deficit and nutrient data also show downcore peaks indicative of advection from above (pumping) and substantiate these demarcations.

Particulate isotopes from bomb fallout are available in estuarine sediments in concentrations sufficient to be of use as tracers. The halflife and input functions of ^{134}Cs, ^{210}Pb, and ^{238}Th make them a particularly useful suite to assess the rate and extent of sedimentation and particle mixing in a shallow system. Samplers were taken from boxcores to complement the pore water studies but analysis is as yet incomplete. Preliminary results indicate that there is active particle bioturbation to depths of at least 10 cm in this region. Water associated with these particles will be advected and such contribution will add to the effect of pumping seen by the tritium spike experiment.

Analysis of particle and water movement will then allow a more realistic interpretation of any pore water constituants than is possible if transport is assumed to be purely diffusional. In the case of Quartermaster Harbor, this study has shown that advection is quite significant.

Isotopic Tracer Studies of Crustal and Mantle Processes

During the past year we have used Nd, Sr, and Pb isotopes to study a wide range of earth science problems. The foci of the investigations undertaken are: (I) petrogenetic studies of igneous rocks from the Aleutian volcanic arc, (II) provenance studies of terrestrial and marine sediments, and (III) problems relating to the geochemistry of the mantle and mantle-crust evolution. All of these studies are presently in progress, and require continued support in order that they may be completed. Interim results are summarized below.

(I) The investigation of isotopic systematics of Aleutian igneous rocks is undertaken in collaboration with Alan Zindler, Charles Langmuir, and Hubert Staudigel and Scott Weaver of Lamont-Doherty Geological Observatory, Emil Jagoutz of the Max Planck Institut fur Chemie, and Robert W. Kay of Cornell University. The scope of the investigation comprises both a general regional investigation of Aleutian volcanics and an intensive study of Okmok Volcano, Umnak Island. For the regional study, Nd and Sr isotopes have been measured in samples which have been previously analyzed for Pb and Sr isotopes, and major and trace elements. These represent perhaps the most complete data set for a volcanic arc to date, and the only arc suite with Nd, Sr, and Pb isotopes measured on the same samples. In addition, sediments proximal to the Aleutian trench and lavas from the Pribilof Islands have been analyzed for Nd and Sr isotopes. Results have shown that the Aleutians have the lowest $^{87}Sr/^{86}Sr$ ratios of any arc studied to date. On a plot of $^{143}Nd/^{144}Nd$ vs. $^{87}Sr/^{86}Sr$, all data lie within the field defined by mid-ocean ridge (MORB) and ocean island basalts. Variations seem to be independent of differentiation trend (tholeitic or calc-alkaline) and the presence or absence of continental crust. The three isotopic systems vary systematically and enable some constraints to be placed on the source regions of Aleutian magmas. For example, a major component must be derived from a source similar to the source of MORBs, and any sediment component must be minor (less than 10%) and carbonate free. In detail, simple modeling schemes are inconsistent with combinations of the isotopic and trace element data. More complex modeling schemes become non-unique. The purpose of the detailed study of Okmok volcano is to examine the degree to which regional variations can be considered to truly possess regional significance, as well as to study aspects of the evolution of a single volcano. A suite of samples representing the stratigraphic section of

the volcano, including samples from superimposed lava flows, was collected during the fieldwork in the summer of 1980 with the aid of William Devlin of Lamont and Walter Haydel of the University of Maryland. The work has been presented at the American Geophysical Union (Goldstein et. al. 1981) and at the 1981 IAVCEI meeting in Japan (Langmuir and Goldstein 1981).

(II) Studies of marine and terrestrial sediments are undertaken with Keith O'Nion of Cambridge University. The provenances of particulates from major world rivers, and pelagic clays and atmospheric dusts from the world's oceans, have been investigated through measurement of $^{143}Nd/^{144}Nd$ ratios, and Sm and Nd abundances. Results from different geographical areas are remarkably similar, with a variation of $^{143}Nd/^{144}Nd$ smaller than found previoulsy for Fe-Mn deposits and pelagic clays (Goldstein and O'Nions 1981). Fine fractions of sediments from the Amazon, Mississippi, Congo, Yellow, Ganges, and Mekong rivers, and atmospheric dust samples from the eastern Atlantic and western Pacific have overall Nd isotopic variations which are similar to those of Atlantic Fe-Mn deposits and pelagic clays. $^{143}Nd/^{144}Nd$ ratios in Pacific dust and river samples are similar to those of western Pacific pelagic clays, however, they are lower that Pacific Fe-Mn deposits and seawater.

Although continental sources can account for marine Nd isotopic variations in the Atlantic, additional components with higher $^{143}Nd/^{44}Nd$ ratios are required in the Pacific. Mantle derived material may be such a source of Pacific Nd through seawater circulation at mid-ocean ridges, and reactions with volcanic ash. The importance of these components in the Pacific may reflect the comparatively large rate of Pacific volcanism. In addition, the "mean crustal ages" of materials transported to oceans by winds and large rivers are about 1 to 1.5 b.y. These represent the average age of the continental crust. This work will be presented at the American Geophysical

Union (Goldstein and O'Nions 1982).

(III) Problems relating to the geochemistry of the mantle and crustal evolution have been investigated through collaboration with Alan Zindler, Robert Endres, and Hubert Staudigel of Lamont, Stan Hart of MIT, and Emil Jagoutz of the Max Planck Institute. The scope of these investigations have comprised both a detailed geochemical study of the Ronda massif (an alpine ultramafic body in Sourthern Spain), and a new re-evaluation of available Pb, Sr, and Nd isotopic data for oceanic basalts. The Ronda investigation is an attempt to study the scale of mantle heterogeneity. Fieldwork during the fall of 1981 concentrated on both large scale (with respect to the size of the massif) and small scale collection of samples of peridotite, and "mafic layers" of basaltic composition. In addition five consecutive acid leaching experiments were performed on a single whole rock sample of a mafic layer. The sample had $^{87}Sr/^{86}Sr$ ratios significantly higher, even after the strongest (Hf) leach, than a plagioclase separate. This shows that the whole rock leached residue still contained crustal contaminant. In addition, a Sm-Nd age of 21.6 ± 1.7 m.y. was determined by an internal isochron, with an initial $^{143}Nd/^{144}Nd$ ratio which has only been observed in present day normal mid-ocean ridge basalts. The age determined is identical to independent determinations of the emplacement age of the massif. This work is to be presented at the American Geophysical Union (Zindler et. al., 1982a).

A multi-dimensional evaluation of the Pb, Sr, and Nd isotopes in MORBs and individual oceanic islands or island groups shows that the define a plane in five dimensions. This new observation demonstrates the coherence of the isotopic systematics for all three elements in the present-day mantle, and that the sub-oceanic mantle is composed of three chemically independent components. These systematics obviate mass balance arguments which have been

used to support convective isolation of the lower mantle (and consequently chemical stratification of the mantle), and the need to call on special processes which only affect Pb (such as extraction to the core over geologic time). A model which treats mantle-crust evolution quantitatively using these systematics for all three isotope systems has been developed. A portion of the work is in press (Zindler et. al., 1982b) and will be presented at the American Geophysical Union (Zindler et. al., 1982c, Goldstein et. al. 1982).

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