NASA GEODETIC APPLICATIONS OF THE MARK III VLBI SYSTEM

Robert Coates

NASA Goddard Space Flight Center

ABSTRACT

For the past 5 years, NASA has been developing the Mark III Very Long Baseline Interferometer (VLBI) System for very high accuracy geodetic applications, such as measurements of the contemporary tectonic plate motions, large-scale plate stabilities, regional fault motions, Earth rotation changes, and polar motion. Initial deployments at fixed observatories in United States have established an initial reference grid for determinations of stability of the North American Plate and for measurements of polar motion and UT1. Cooperating stations with new Mark III systems at Onsala, Sweden, and Effelsberg, Germany, observing with the U.S. stations, are to measure the relative plate motion between the North American and the Eurasian Plates. NASA plans to involve additional cooperating institutions throughout the world to develop a global VLBI network for plate motion determinations. NASA is developing mobile VLBI systems utilizing the Mark III for measurements of regional fault motions and crustal distortions. Initial deployments will be in the fault regions in western United States. Discussions have been initiated with foreign organizations regarding cooperative programs for measurement of fault motions in other active regions of the world.

INTRODUCTION

In the 1960's, NASA started supporting the development of the two space techniques, very long baseline interferometry (VLBI) and space laser ranging, for geodetic applications. NASA's interest was in the development of space technology that would permit the measurement of the dynamic motions of the Earth's crust that are believed to be the causes of earthquakes. The global distribution of large earthquakes shows that the earthquakes are most prevalent along the edges of the major tectonic plates. The relative motions between these plates causes severe distortions of the boundaries between the plates. This results in earthquakes. Thus, it is felt that the measurement of the relative plate motions and the crustal distortions along the boundaries of the plates will contribute significantly to a much better understanding of the processes which lead to earthquakes. NASA has concentrated on the development of the VLBI and space laser ranging because these two space techniques offer the potential for making measurements over very long distances with accuracies of better than a part in 10^8. The measurements with these techniques can be made over water and rough terrain. Thus, they seem to be ideal techniques for the measurement of plate motion, regional deformation, and other dynamic motions of the earth.

CRUSTAL DYNAMICS PROJECT

A coordinated federal program for the application of this space technology to crustal dynamics and earthquake research has been formulated.* The participating agencies are the National Aeronautics and Space Administration (NASA), National Ocean and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), the National Science Foundation, and the Department of Defense (DOD). All of these agencies have a role in earth dynamics and are interested in applying VLBI and lasers to their particular area of activity. NASA has been leading the technology development, and is the focal point for the initial phase of implementation of the VLBI and lasers for crustal dynamics. The NOAA National Geodetic Survey (NGS) is initiating a program to implement an operational VLBI system for polar motion and UT1 measurements. In addition, they plan to implement mobile VLBI for very high accuracy geodetic surveys in North America. The United States Geological Survey and the National Science Foundation have prime responsibility for earthquake research investigations. Their interest in utilizing VLBI is to obtain new and significant measurements and interpretations of the earthquake phenomena. The Department of Defense has a responsibility for high accuracy geodetic survey and mapping, as well as operational UT and polar motion determination.

The success of the NASA developments of VLBI and space laser ranging has prompted NASA to establish a Crustal Dynamics Project for the application of these space techniques to the study of the earth-dynamics motions as related to earthquakes. Both the Goddard Space Flight Center and the Jet Propulsion Laboratory are involved in the project. Goddard is responsible for the management

*National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, U.S. Geological Survey, National Science Foundation, and Defense Mapping Agency, "The Coordinated Federal Program for the Application of Space Technology to Crustal Dynamics and Earthquake Research," November 1978.

of the project, the science coordination and management, the VLBI technology developments, the implementation and operations of fixed VLBI observatory stations, and the laser ranging development and operation. The Jet Propulsion Laboratory is responsible for the mobile VLBI development and operations, plus related Deep Space Network (DSN) activities. In addition to NASA, the Crustal Dynamics Project involves many close cooperative efforts from many other institutions. As an example, the development of the Mark III VLBI for geodetic applications has had the participation of the Haystack Observatory, the Massachusetts Institute of Technology, the National Radio Astronomy Observatory, the Smithsonian Astrophysical Observatory (SAO), the National Geodetic Survey, the Owens Valley Radio Observatory, The Harvard College Observatory, and the Chalmers Institute.

The scientific objectives of the Crustal Dyanmics Project are to improve our knowledge and understanding of:

- The regional deformation and strain accumulation related to large earthquakes in the plate boundary region of the western United States.
- Contemporary relative plate tectonic motions of the North American, Pacific, South American, Eurasian, and Australian Plates.
- The internal deformation of continental and oceanic lithospheric plates with particular emphasis on North America and the Pacific.
- The rotational dynamics of the Earth and their possible correlation to earthquakes, plate motions, and other geophysical phenomena.
- Motions and deformation occurring in regions of high earthquake activity.

In order to achieve these objectives, a rather extensive measurement program utilizing both the VLBI and space laser ranging will be required. Frequent high accuracy measurements of baselines between many stations in active areas near the plate boundaries are required for the determination of the regional deformation and strain accumulation in these active regions. Regular measurements of baselines between a global set of stations on the different plates are required for the determination of the relative tectonic plate motions. Repeated measurements of baselines between several stations on the same plate are needed for the measurement of the internal deformation of the plates. The determination of polar motion and Earth-rotation variations requires daily measurement of PM and UT1 with a global set of stations in stable locations.

An integral part of the Crustal Dynamics Project is the test and validation of the capabilities of the space systems for making high accuracy geodetic measurements. As an example, one of the test experiments to be conducted later on this year is a five-station intercomparison between the VLBI and space laser ranging. Figure 1 shows the location of the five VLBI stations and the five laser stations. The systems are co-located at Westford, Massachusetts; Ft. Davis, Texas; Owens Valley, California; and Goldstone, California. In this intercomparison both the Mark III VLBI systems* and

*T. A. Clark, "Mark III System Overview," Proceedings of Radio Interferometry Techniques for Geodesy Conference, June 1979, NASA CP 2115, 1980.

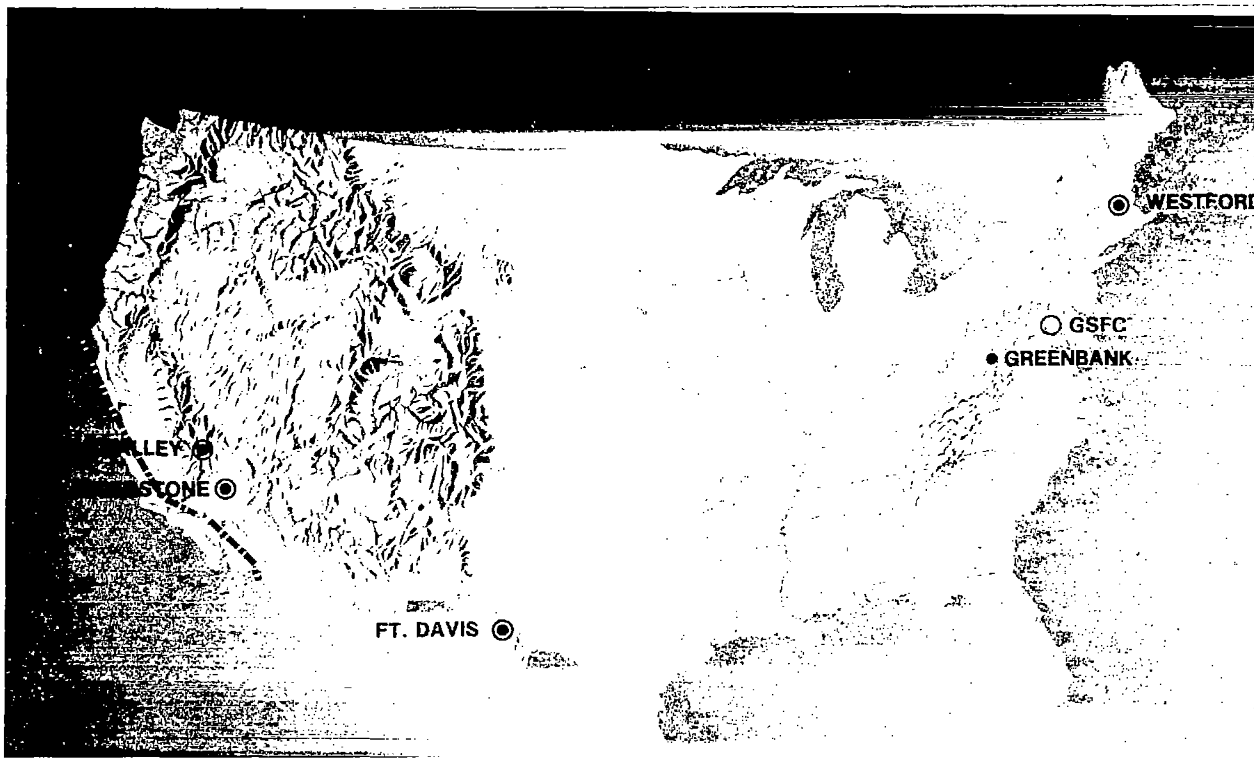

Figure 1. Map of the station locations for the 1979 intercomparison of satellite laser ranging and VLBI geodetic measurements.

the space laser systems will make a series of measurements for the determination of the baselines between the stations. The VLBI and laser results will then be intercompared in order to determine if there are any systematic effects apparent from these measurements. These baselines are expected to intercompare at the 5 centimeter level.

These intercomparison stations are planned to be used continuously by one technique or the other throughout the life of the project in the role of permanent base stations to be used in the determination of regional crustal deformation, internal deformation of the North American plate, and tectonic plate motions relative to the North American plate. It should be noted that the Westford site, the Ft. Davis site, and a new site in Richmond, Florida, make up the NGS Polar-motion Analysis by Radio Interferometric Surveying (Polaris) network* for operational polar motion and UT1 determination.

Figure 2 is a map of the different tectonic regions of the United States and locations of recommended sites for VLBI and laser measurements for the determination of the regional deformation in

*W. E. Carter, "Project POLARIS," Proceedings of Radio Interferometry Techniques for Geodesy Conference, June 1979, NASA CP 2115, 1980.

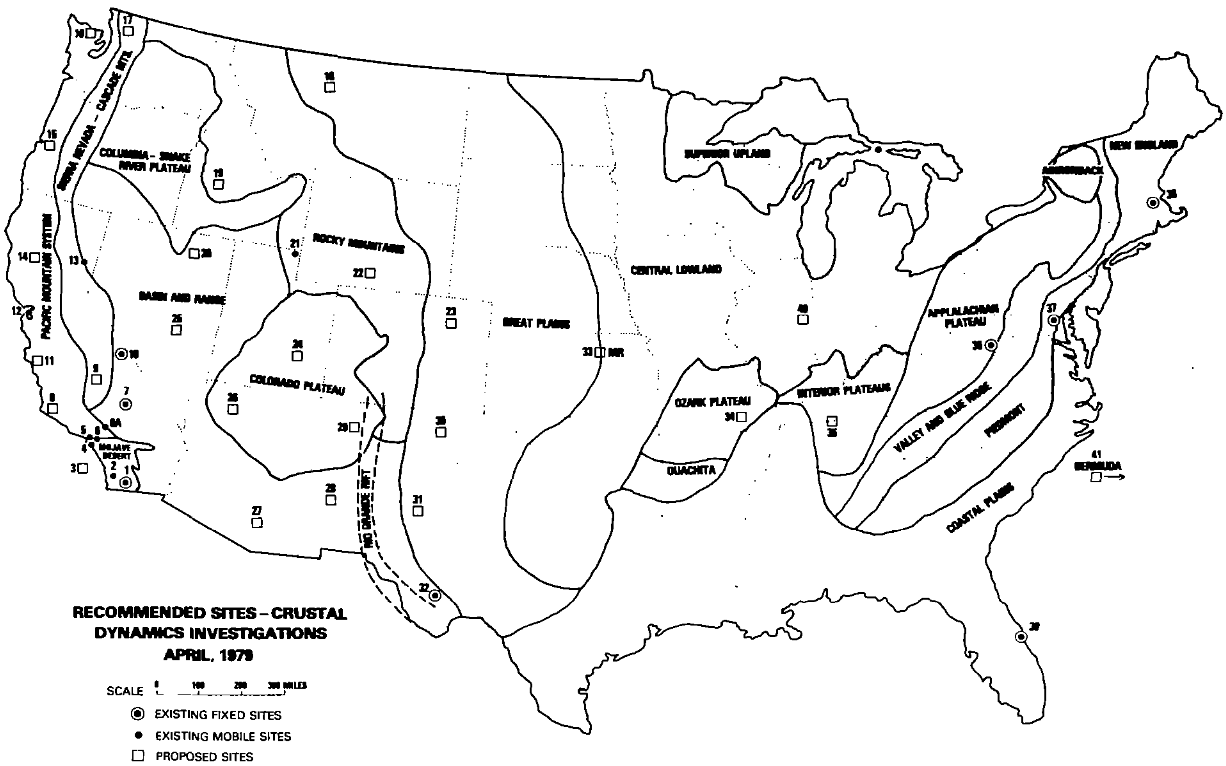

Figure 2. Possible locations of sites for measurements of the regional crustal deformation in the western United States and the internal deformation of the North American plate.

the western United States and the internal deformation of the North American plate. At the present time, this recommendation is a "strawman" proposal by a group of NASA scientists. It is expected that sites similar to these will be firmed up in the next few months through discussions with the scientific community and other government agencies. The final deployment will probably be similar to figure 2. This map shows several fixed and mobile sites that are already in operation, plus many new locations to be established for mobile systems or transportable systems. A total of 41 locations are identified, with the majority of locations in the seismically active western half of the United States.

Figure 3 shows the present deployment of space laser ranging stations around the globe. This includes NASA stations, SAO stations, European Range Observations to Satellites (EROS) stations, and lunar laser ranging stations. This distribution provides several stations on the North American plate, South American plate, the Pacific plate, the Australian plate, and the Eurasian plate for measurements of global plate motions and polar motion/UT1.

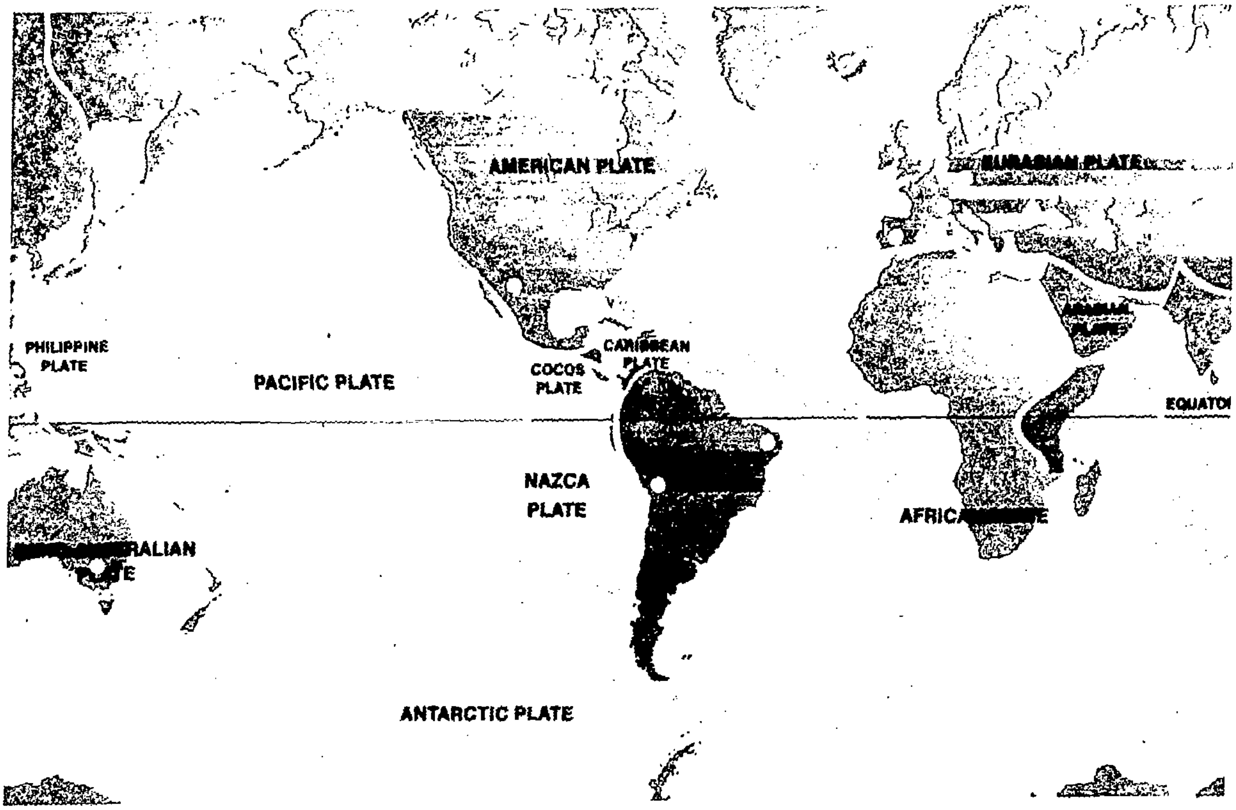

Figure 3. 1979 deployment locations of space laser ranging systems.

In figure 4, the solid dots are the locations of fixed VLBI stations in 1979 which will be used for geodetic measurements. This shows the five VLBI base stations in North America that were discussed above, the DSN stations in Australia and Spain, and the European stations at Onsala, Sweden, and Effelsberg, Germany. This initial deployment will begin the measurements of the plate motions between the three respective plates, the internal deformations of the North American and Eurasian plates, and polar motion/UT1.

The development of geodetic VLBI capability at the two European stations has been accomplished through cooperative joint efforts of several United States and European agencies and institutions. The host institutions are the Chalmers Institute of Technology for the Onsala station and the Max-Planck-Institut für Radioastronomie for the Effelsberg station. The Mark III VLBI systems are being assembled from subsystems funded by the NASA Crustal Dynamics Project, the host institutions the U.S. Geological Survey and the U.S. Air Force. The Crustal Dynamics Project VLBI team fro Goddard Space Flight Center, Haystack Observatory, and Massachusetts Institute of Technology responsible for the implementation of the Mark III unique equipment.

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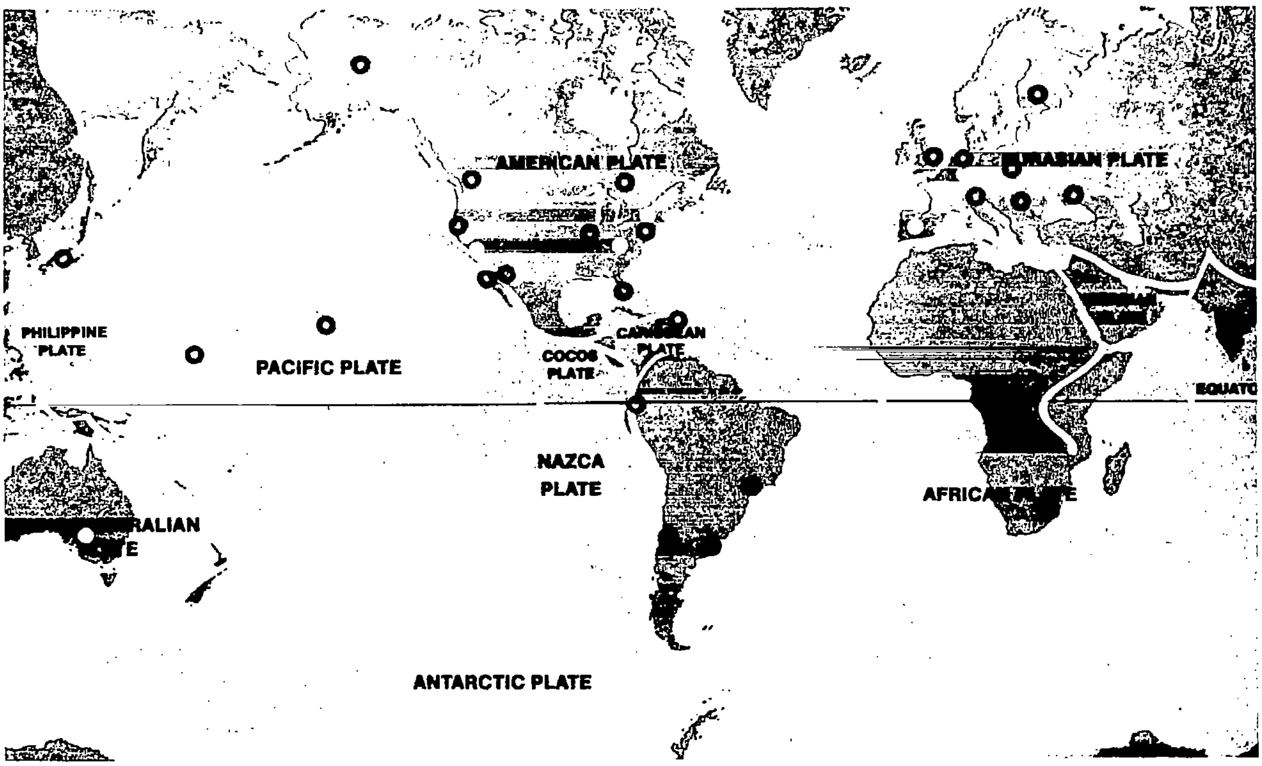

Figure 4. 1979 locations of VLBI fixed stations (solid dots), and locations of a few of the radio astronomy or space tracking antenna facilities (open circles) which could be considered for future geodetic VLBI applications.

motions, crustal motions, and polar motion/UT1. To illustrate the tremendous potential that exists for global VLBI participation, the open circles in figure 4 are a few of the existing radio astronomy or space tracking facilities which could be considered for geodetic VLBI applications. In the development of the Mark III VLBI system, NASA has designed the configuration to be self-contained so that it can be easily moved into an antenna facility for geodetic or astronomical observing sessions and then moved to another facility for other observations. This configuration provides the flexibility to make use of the many existing antenna facilities around the world.

Besides the seismically active region in the western United States discussed earlier, there are many other regions of high earthquake activity along plate boundaries throughout the world. Some of these tectonically important areas are indicated in figure 5. The deployment of mobile VLBI systems in these active regions in a manner similar to that illustrated in figure 2 will provide important information about the deformation in these regions. By monitoring these deformations and other seismic and geodetic measurements, geophysical models of the region can be developed that will provide insight into the reasons for the occurrence of earthquakes in the region. Through extensive cooperation with other organizations and countries, NASA would like to stimulate the development

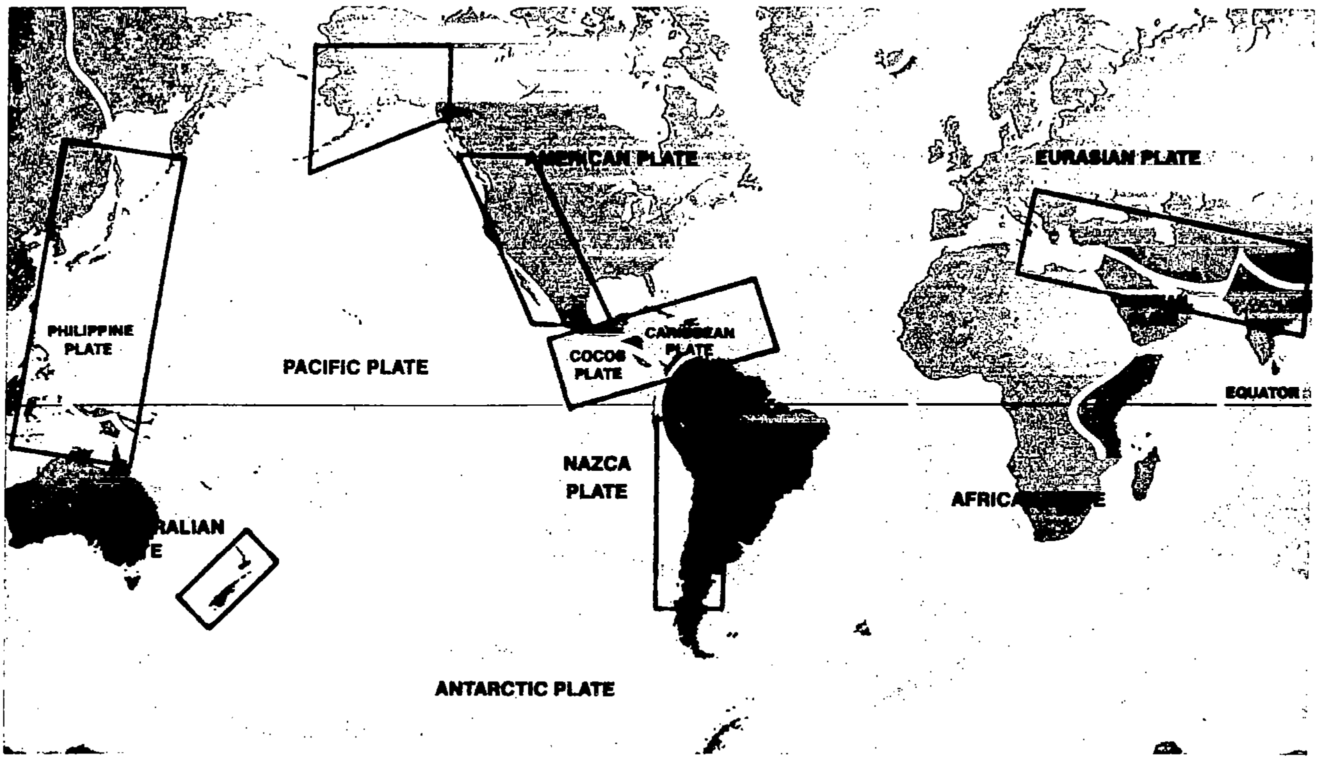

Figure 5. Tectonically important areas of high earthquake activity.

of regional measurement plans with mobile systems in these seismically active areas. This will enhance the scientific understanding of earthquake processes as related to the dynamics of the Earth.

SUMMARY

The NASA Crustal Dynamics Project is an effort to develop and demonstrate the capabilities of the VLBI and laser ranging techniques for unique high accuracy geodetic measurements which have the potential for significant scientific measurements of the dynamics of the Earth. The thrust of the project is to implement minimal networks to demonstrate the capability and to work with user organizations all over the world to encourage them to build up their own capabilities for carrying on these very significant measurements.

REFERENCES

Carter, W. E., "Project POLARIS," Proceedings of Radio Interferometry Techniques for Geodesy Conference, June 1979, NASA CP 2115, 1980.

Clark, T. A., "Mark-III System Overview," Proceedings of Radio Interferometry Techniques for Geodesy Conference, June 1979, NASA CP 2115, 1980.

National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, U.S. Geological Survey, National Science Foundation, and Defense Mapping Agency, "The Coordinated Federal Program for the Application of Space Technology to Crustal Dynamics and Earthquake Research," November 1978.