

U. S. DEPARTMENT OF THE INTERIOR  
U. S. GEOLOGICAL SURVEY

**CASCADIA:  
REGIONAL LITHOSPHERIC STUDIES  
OF THE PACIFIC NORTHWEST**

A FIVE YEAR SCIENCE PLAN  
SUBMITTED TO THE  
DEEP CONTINENTAL STUDIES PROGRAM  
OF THE U. S. GEOLOGICAL SURVEY

from  
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## SUMMARY

### WHAT IS CASCADIA?

CASCADIA is a six-year investigation by the USGS Deep Continental Studies Program, in close cooperation with other USGS Programs and the National Science Foundation (NSF), to study fundamental processes of continental growth and evolution along the active Pacific Northwest convergent margin, also known as Cascadia.

### WHY STUDY CASCADIA?

Cascadia presents a compact and accessible field laboratory for the study of subduction, continental accretion, and arc volcanism. In Cascadia, we can address nearly all of the major scientific goals identified in *A National Program for Research in Continental Dynamics* (Phinney and others, 1993):

- The origin and evolution of the continents
- The nature of earthquakes and plate boundary interactions
- The origin and dynamics of magmas in the continental crust
- The nature of deformation and mobility in the continental lithosphere
- The origin and evolution of sedimentary basins
- The nature of subcontinental mantle and its role in continental evolution

Although Cascadia contains most of the elements typical of convergent margins, it is a unique end member of the subduction zone continuum. The small plates of Cascadia are caught in the dextral shear couple between the encroaching Pacific plate and North America, and Cascadia appears to be tectonically segmenting as the subducting plate and the magmatic arc break up into rotating blocks. Three major convergent margin segments can be recognized:

- 1) the seismically active subduction zone and transpressive arc of Washington;
- 2) the aseismic subduction zone and extensional arc of central Oregon; and
- 3) the rapidly deforming triple junction region and seismically active arc--Basin and Range transition of northern California.

The compact size of Cascadia allows us to treat the entire plate margin as a *system* in which fundamental relationships between earthquakes and volcanoes can be explored. CASCADIA can thus provide the "whole-plate" framework essential to address major hazards and earth-resource issues, including active volcanism and the potential for great subduction zone earthquakes adjacent to the fast-growing Northwest urban corridor.

### WHAT IS THE PLAN?

CASCADIA investigations are focused in three research corridors, each one centered on a convergent margin segment. Major seismic, electromagnetic, and potential field experiments will be staged in each corridor over a six year span. The results will be integrated with supporting geological and petrological investigations to compare and contrast lithospheric processes in the three different tectonic regimes. When combined with the results of the Canadian LITHOPROBE program and recent NSF-funded studies of the margin, the three corridors will provide an unparalleled, three dimensional view of convergent margin structure and the processes responsible for continental growth and evolution. Our results will be summarized in synoptic map series that covers the entire plate boundary. An integrated crustal model of the Cascadia plate system will provide a solid foundation for resource and hazards based programs in the region.

## CONCISE RATIONALE

CASCADIA is a six-year investigation by the USGS Deep Continental Studies Program (DCS), in close cooperation with other USGS Programs and NSF, to study fundamental processes of continental growth and evolution along the convergent margin of the Pacific Northwest. This region, commonly known as Cascadia, is dominated by the Cascade Range, the active volcanic arc forming the backbone of Washington, Oregon, and northern California (fig. 1).

Cascadia presents a compact, accessible field laboratory for the study of subduction, continental accretion, and arc volcanism. In Cascadia we can address six of the eight major scientific goals identified in *A National Program for Research in Continental Dynamics* (Phinney and others, 1993):

- The origin and evolution of the continents
- The nature of earthquakes and plate boundary interactions
- The origin and dynamics of magmas in the continental crust
- The nature of deformation and mobility in the continental lithosphere
- The origin and evolution of sedimentary basins
- The nature of subcontinental mantle and its role in continental evolution

Most of these goals can be addressed in the context of Cascadia's classical convergent margin structure, which includes a subducting slab, accretionary complex, and an active volcanic arc and backarc. On the other hand, Cascadia also presents a unique scientific opportunity. As one of the last remnants of a convergent margin that once extended the length of the Cordillera, Cascadia is now undergoing a major tectonic reorganization. Cascadia is caught in the dextral shear couple between the encroaching Pacific plate and North America, and in response, appears to be tectonically segmenting as the remnant subducting plate and the magmatic arc both break up into rotating blocks. The processes of plate breakup, rotation and plate boundary jumps by which subduction ceases and the transform plate boundary grows have clearly played a major role in the late Cenozoic evolution of the continental margin south of the Mendocino triple junction.

Because Cascadia is undergoing a tectonic transition, it presents several important questions relevant to its unique situation: 1) Is Cascadia still capable of great subduction zone earthquakes? If so, where are they likely to occur? 2) Why are volcanoes and earthquakes distributed in such a non-random fashion along the margin? 3) How does the arc and forearc accommodate the tectonic transition? 4) Why is the present margin so discordant with the arcuate Mesozoic orogen that forms the Columbia embayment? Is it the result of continental accretion, rifting and dextral shear of the old continental margin, or some combination of both?

A very important question for those living in the Northwest urban corridor is whether great thrust earthquakes occur on the Cascadia subduction zone. Paleoseismologists who have examined evidence of rapid, episodic subsidence of coastal estuaries argue that great subduction zone earthquakes have occurred every 500 years or so during late Holocene time (eg. Atwater, 1987). Recent geodetic evidence indicates that interseismic strain is accumulating in the Washington forearc and is consistent with the occurrence of subduction zone earthquakes (Savage and Lisowski, 1991). Paradoxically, there is no historic or instrumentally recorded evidence for even small earthquakes on the megathrust. As a result, we do not know exactly where the plate interface is located or the extent of the locked zone. A solution to this problem will require a large scale, integrated geophysical experiment across the convergent margin.

Also anomalous is the nature of upper plate seismicity, which shows no apparent relationship to plate convergence; instead it is consistent with N-S compression in the fore arc and is commonly very deep, generally between 10 and 30 km (Ludwin and others, 1991). A major

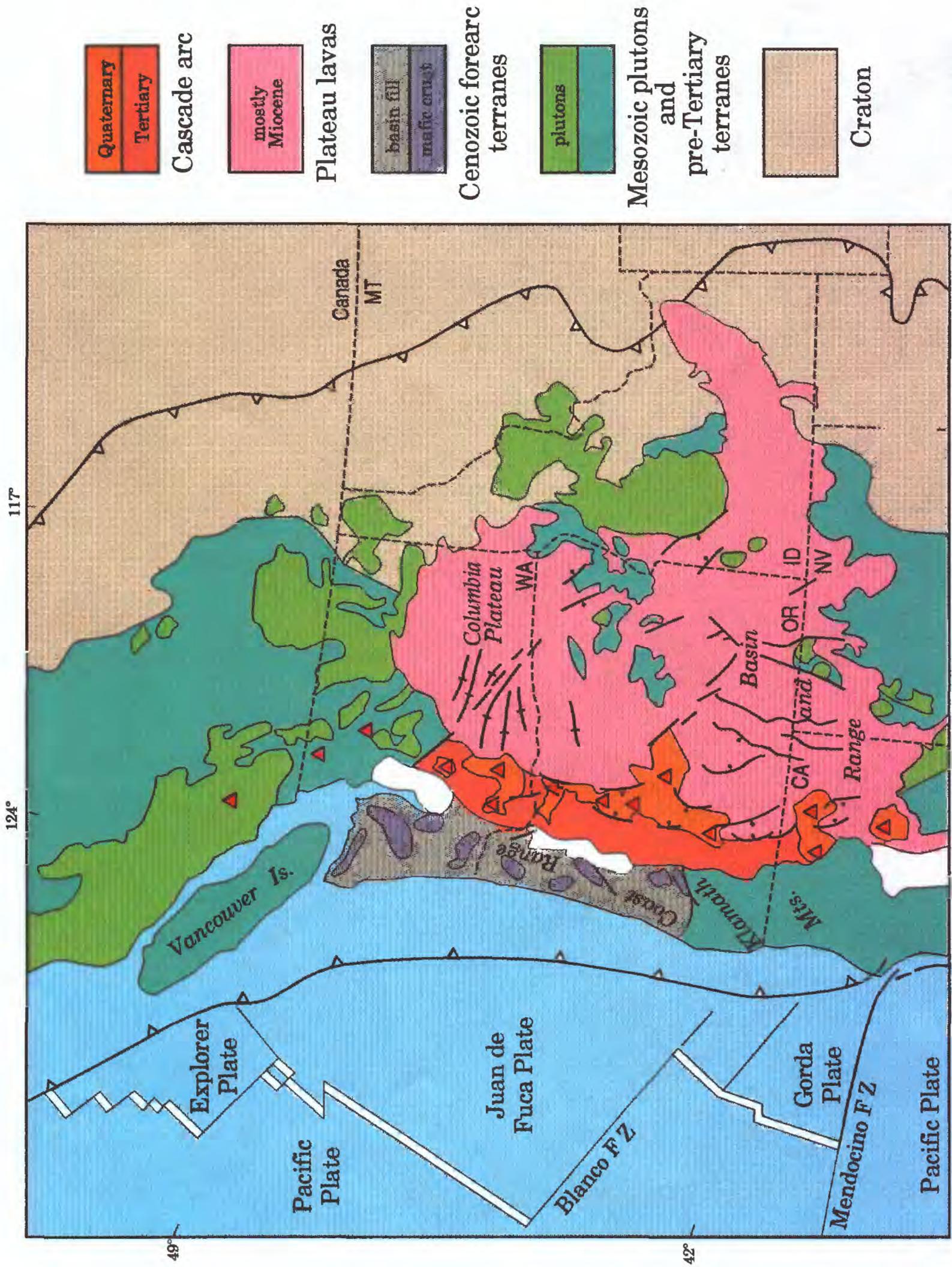


Figure 1. Tectonic setting of the Cascadia convergent margin. Triangles are major Cascade volcanoes; thrust faults have teeth on upper plate, normal faults have ball on downthrown block.

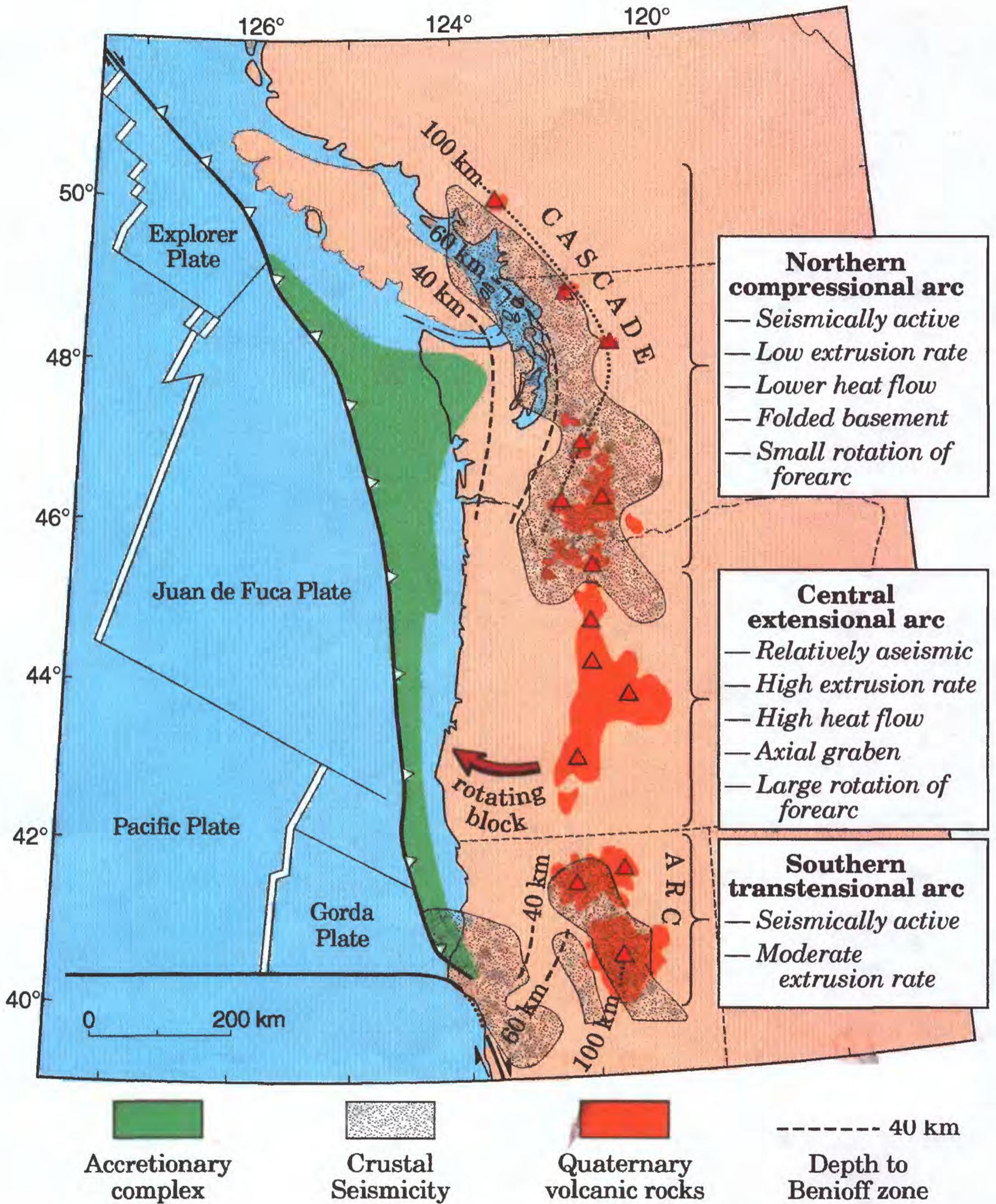


Figure 2. Major tectonic segments of the Cascadia convergent margin.

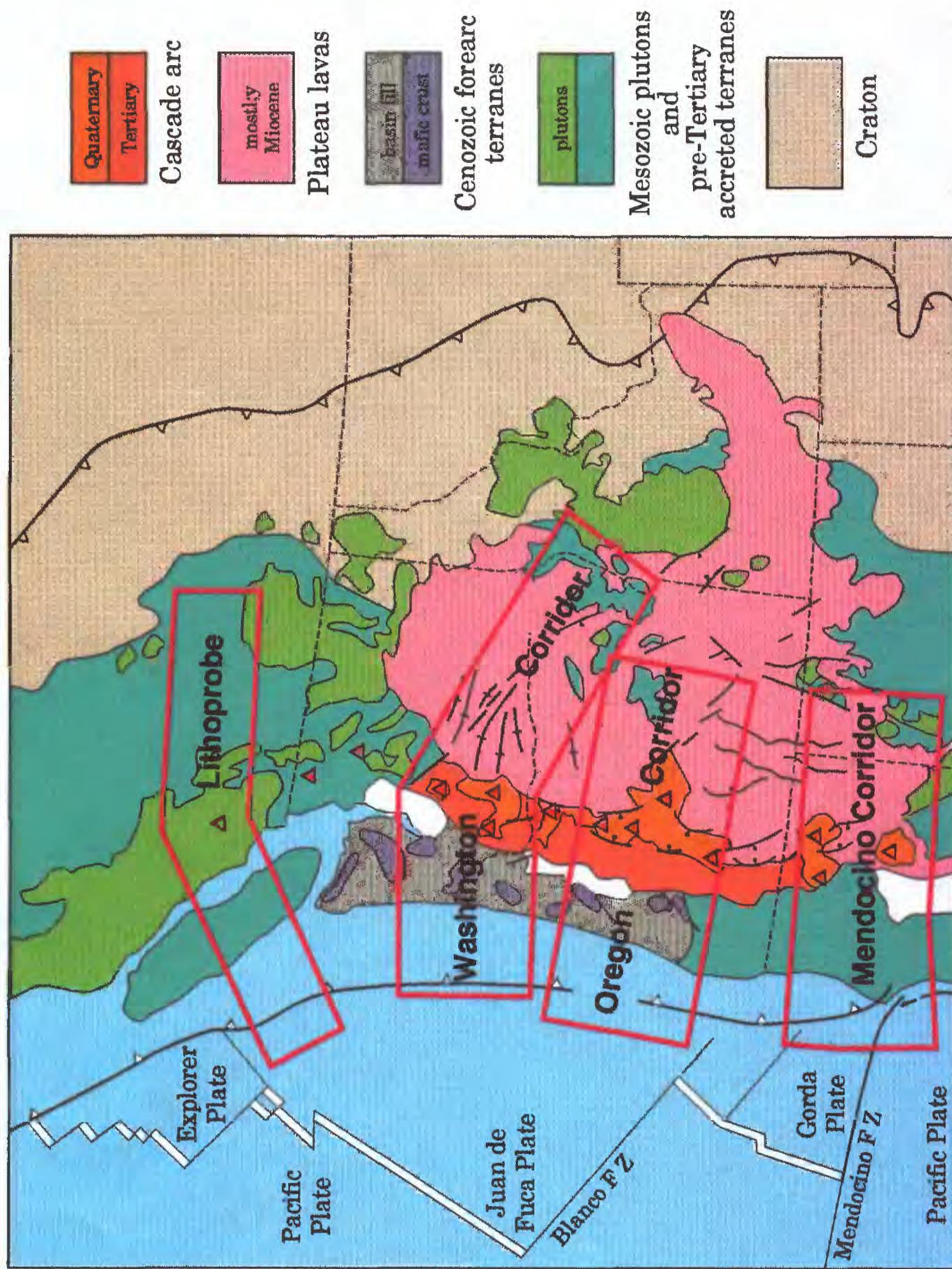


Figure 3. Regional lithospheric study corridors in Cascadia

crustal fault beneath Seattle was apparently the source of a large earthquake about 1100 years ago (Bucknam and others, 1992), and similar faults may lie beneath Portland (Blakely and others, 1993). The recent March 1993 M 5.7 quake south of Portland, may have occurred on a similar WNW striking thrust at about 15 km depth (Madin and others, 1993). This structure is not well understood by earth scientists; clearly there are major elements of the crustal framework that still elude us beneath Cascadia's lush vegetation.

Finally, the inverse correlation between distribution of present day seismicity (Shedlock and Weaver, 1991) and the distribution of Quaternary volcanic vents and production rate along the arc (Guffanti and Weaver, 1988; Sherrod and Smith, 1990) appears to be a fundamental characteristic of Cascadia (Fig. 2). We can divide the margin into three segments based on the distribution of earthquakes and volcanoes: i) a northern, seismically active transpressional margin with a degenerate volcanic arc (Washington and adjacent B.C.); ii) a central aseismic margin with a very robust extensional volcanic arc (central Oregon); and iii) a seismically active southern margin with a well developed transtensional arc (N. California).

This threefold segmentation also holds for late Cenozoic geological elements of the convergent margin, including: variations in the width of the accretionary wedge offshore (Snively, 1987; Clarke, 1992); the block structure and rotation of the forearc (Wells, 1990); the nature of deformation and volcanism in the arc (Smith, 1993; Sherrod and Smith, 1989); variations in arc basement along strike (Hamilton and Myers, 1966); and finally, the major differences in elevation, magmatic history, and style of deformation in the backarc (Christiansen and McKee, 1978).

Because tectonic segmentation appears to be a primary and long-lived feature of this margin, we have defined three research corridors across the convergent margin in which to compare and contrast convergent margin evolution (Fig. 3):

- The Washington Corridor- addresses the deep structure and evolution of the northern, seismically active segment of the subduction zone, the adjacent transpressive arc, and the flood basalt-filled Columbia basin in the backarc. It is characterized by a broad accretionary prism which underplates the northward translating and rotating basalt basement blocks of the forearc. The seismically active arc is undergoing dextral shear and is folded and uplifted, with isolated stratovolcanoes resting on the deformed arc platform. Although selected regions of the arc have been examined by magnetotelluric and seismic reflection (e. g. Stanley and others, 1992), the Washington corridor still lacks critical seismic, geologic, and potential field data in the arc, forearc and offshore subduction zone.

- The Central Oregon Corridor- addresses the deep structure and evolution of the aseismic part of the subduction zone, the adjacent extensional arc, and Basin and Range in the backarc. The corridor is characterized by a relatively narrow accretionary prism and a monolithic forearc block of Coast Range basalt, which is rotating and translating northwestward in front of the volcanically robust extensional arc segment. Pre-Tertiary crust may be missing in this segment, which lies within the Columbia embayment. Recent and ongoing seismic and electromagnetic studies in the northern part of this corridor (eg., Snively and others, 1980; Wannamaker and others, 1989; Catchings and Mooney, 1988a; Trehu and others, 1992; Luetgert and others, 1992) confirm an unusually thick mafic crust in the forearc, possibly in contact with the subducting slab. This large crustal block appears to be an important element of the convergent margin; its deep crustal boundaries with the Cascade arc and the Klamath Mountains must be explored.

- The Mendocino Corridor- addresses the evolution of continental lithosphere in the rapidly deforming triple junction region and in the seismically active arc--Basin and Range transition to the east. In this segment the narrow accretionary prism comes onshore, and the uplifted pre-Tertiary orogenic belt of the Klamath Mountains forms the forearc. This corridor builds on an

active offshore-onshore research program in the triple junction region which includes: young deformation studies (Clarke, 1992; Clarke and Carver, 1992; McLaughlin and others, in press); deep seismic refraction and magnetotelluric profiles across the arc-Basin and Range transition (Fuis and others, 1987; Stanley and others, 1990); and a nearly completed geologic mapping transect from the triple junction to the Basin and Range (D. S. Harwood and others, in prep.). The USGS and the NSF-funded Mendocino Working Group are cooperating on an experiment to study the deep structure and evolution of the Mendocino triple junction in 1993-94.

Our multiple corridors will allow us to approach Cascadia as a tectonic *system* in which we can investigate fundamental relationships between seismicity, volcanism, and crustal structure. Our corridors complement the LITHOPROBE transect in the adjacent Canadian Cordillera to the north (Clowes and others, 1987) and will extend our knowledge of the active margin across the transition to the San Andreas transform in the south. This broad synoptic view will force us to coordinate between disciplines and to produce well-constrained solutions for the structure and geodynamics of Cascadia.

### FY 1993 ACCOMPLISHMENTS

Efforts in FY 93 are focused on the Mendocino Corridor, in cooperation with the Mendocino Working Group, funded by NSF (principal coinvestigators-- A. Trehu-Oregon State University; S. Klemperer/B. Beaudoin-Stanford; A. Levander-Rice; A. Meltzer-Lehigh). The USGS (Luetgert/Mooney, BSeis) and NSF group cooperated on a series of three refraction-wide angle reflection profiles to study continental crust and upper mantle structure before and after passage of the triple junction. Preliminary results include strong reflections from the subducted Gorda plate north of the triple junction and strong lower crust/ upper mantle reflections north of the Clear Lake volcanic field south of the triple junction (Beaudoin and others, 1993). We are presently analyzing offshore industry seismic reflection data in preparation for FY 94 offshore MCS experiments, also in cooperation with the Mendocino Working Group (Clarke, BPMG).

Other experiments underway include an aeromagnetic survey of the triple junction (Jachens and Griscom, BGP) and a magnetotelluric survey (Stanley, BGP) across the northernmost part of the transform boundary just south of the triple junction. Digital compilation of the western part of the NORCAL geologic transect in the triple junction region also has been completed (Harwood/McLaughlin, BWRG). Field and petrologic investigations in the eastern part of the geologic transect (Guffanti/Smith, BVGP; Sawlan, BWMR) are focused on the southern end of the Cascade arc and address the kinematic and petrologic transition at the arc-basin and range tectonic boundary, which has been migrating westward through Quaternary time.

Geological and petrologic investigations also have begun in the Washington Corridor in preparation for major geophysical experiments in FY 1995-96. Detailed mapping is underway in a transect across the Eocene, Oligocene and Miocene Cascade arc in Southern Washington (Swanson/Moore, BVGP; Ashley/Evarts, BWMR), and digital compilation of geology has begun by Washington Division of Geology and Earth Resources. Special emphasis has been given to important crustal boundaries delineated by seismicity, potential fields, and earlier magnetotelluric studies. Analysis continues of seismic refraction data collected in the foothills of the Cascade Range in FY 91. In coordination with the Earthquake Hazards Reduction and Energy Resources Programs (NEHRP and ERSP), we have purchased several hundred km of industry seismic reflection data in western Washington, including Puget Sound. These data are providing critical constraints on crustal structure in the forearc and the nature of post Miocene crustal strain (Johnson and others, in press). They also provide a foundation for the 1995 refraction experiment (Potter, BSP).

In the Oregon Corridor, we have begun cooperative studies of major, trace element and isotopic variations in a transect across a well-mapped segment of the Cascade arc east of Roseburg (Sherrod, BVGP; Gunn, BIG; Leeman, Rice U.). This systematic work will define petrologic evolution of the extensional arc segment and will provide a baseline for comparison to the largely transpressive arc of Washington. In the Portland area, we cooperated with National Geologic Mapping Program (NGM) and NEHRP in funding a high resolution aeromagnetic survey of the Portland Metropolitan area (Blakely, BGP; Wells, BWRG; Beeson, Portland State U.; Madin, DOGAMI). This survey was highly successful and delineated a number of potentially active faults beneath downtown Portland. The hazard implications were spectacularly confirmed just three weeks after the press conference by one of Oregon's largest historic earthquakes, a M=5.7 temblor just 30 miles south of Portland. A unique industry reflection profile up the Columbia River provides an opportunity to examine forearc deformation and the structure of the Cascade arc-forearc boundary in this transitional region between the Washington and central Oregon segments (Snively, BPMG; Niem, Oregon State University). This work will provide an essential interpretation of upper crustal structure and geology in preparation for a unique deep crustal experiment up the Columbia River into the arc in FY 1997. Analysis is continuing of refraction data collected on the east flank of the Coast Range in FY 91 (Luetgert/Mooney, BSeis).

A major effort was made during FY 93 to coordinate the work of DCS, NEHRP and Pacific Marine Geology (PMG), all of which are interested in the deep structure, evolution, and seismic potential of the Cascadia subduction zone. In a series of mini-workshops and coordination meetings, we defined the major deep crustal issues, critical equipment needs, a schedule of possible marine geophysical experiments, and possible sources of funding. We also discussed the value of a new USGS marine geophysical ship as a resource to be shared with the academic community. We expect the ship to be operational for deep seismic in FY 95 or 96 and have scheduled experiments accordingly. In the future, we hope to expand our cooperation with several NSF programs, in particular Continental Dynamics, Structure and Tectonics, and Geochemistry. CASCADIA can provide an important link between NSF and other mission-oriented hazards and resource programs of the USGS in the Pacific Northwest.

## RESEARCH PRIORITIES AND FIVE YEAR PLAN

We have initiated studies in three research corridors that cross the Cascadia convergent margin in northern California (Mendocino), Washington, and Oregon (Figs. 4, 5, and 6). North-south tie lines cross important tectonic boundaries between segments and connect the corridors to the Lithoprobe transect in northernmost Cascadia. Our plan is to stage the major geophysical experiments in sequential two-year windows, one for each corridor over the six-year span of the project. Supporting geoscience investigations have already begun in advance of the major geophysical experiments, which are scheduled in the Mendocino Corridor for FY 93-94, in the Washington Corridor in FY 95-96, and in Oregon in FY97-98 (see Fig. 7 for summary schedule). Major tasks in each corridor, along with a brief description, are listed by fiscal year in the following section, and a list of individual projects for FY 94 is in the appendix. Supporting geoscience investigations will continue in each corridor following the major deployments in order to support multidisciplinary analysis of results. In addition to the scientific reports and maps generated for each corridor, we plan a series of synoptic geophysical and tectonic maps of the Cascadia plate system to provide a broad perspective on plate boundary processes.

## Mendocino Research Corridor

Experiments in the Mendocino Corridor address the evolution of continental lithosphere in the rapidly deforming triple junction region, the Klamath Mountains, and in the seismically active arc-Basin and Range transition to the east. The Mendocino triple junction lies at the southern edge of Cascadia, and it marks the transition from subduction to transform tectonics, from doubled lithosphere to slab-window, from young, buoyant Gorda plate to old, dense Pacific plate, and from a zone of convergence along the Mendocino fault to one of free movement as the Gorda plate passes east of the corner of the Pacific plate. Because it is a transform-transform-trench triple junction, it is inherently unstable, and its history has been punctuated by "jumps" which have resulted in reorganizations of the plate boundaries that have profoundly affected all three plates (Griscom and Jachens, 1989).

Our primary goal in the Mendocino corridor is to investigate the evolution of the continental plate boundary as it changes from convergent to transform margin during passage of the triple junction; in particular we want to examine:

- the effect of the encroaching triple junction on the deformation history and seismic potential of the S. Cascadia subduction zone;
- the crustal structure and thermal evolution of thinned continental lithosphere along the new transform margin in the wake of the triple junction; and
- the petrologic evolution of the southern Cascade arc and the implications for changes in crustal structure during termination of subduction and encroachment of the Basin and Range.

In 1993-94, CASCADIA will cooperate with the Mendocino academic consortium funded by NSF to study the deep structure and evolution of the Mendocino triple junction. An opportunity exists in 1994 to use the *R/V Ewing* to extend the marine refraction and wide-angle reflection study to the Cape Blanco fracture zone region, which approximately marks the transition to the presently aseismic subduction zone of the central Oregon corridor.

### FY 94

**Task 94.1—Marine Seismic Reflection Survey, triple junction and southern Cascadia subduction zone:** (Clarke; DCS/NEHRP/PMG) (*A cooperative effort with the NSF Mendocino consortium*)

Offshore multichannel seismic reflection surveys can provide detailed control on the structural evolution of the Mendocino triple junction (MTJ) and its effect on the accretionary wedge and Cascadia subduction zone to the north. This element would augment proposed NSF data collection in the MTJ region and address important subduction zone issues. The additional USGS MCS lines would give a 3-dimensional view of plate geometry at depth and of MTJ-related deformation. They would also address important questions concerning the landward extent of the structural boundary between decoupled and coupled parts of the North American accretionary prism, and the offshore location of the pre-Neogene suture between the Franciscan Central and Coastal belts. These questions are not addressed in the proposed NSF coverage. In addition, because the Eocene to Holocene Cascadia accretionary wedge comes onshore just north of the MTJ, the imbricated and folded structures mapped offshore with high resolution seismic methods can also be mapped onshore (Clarke, 1992; Clarke and Carver, 1992). This geometry allows convergent margin structures and basins to be dated and correlated with triple junction migration.

**Task 94.2--Analysis of FY 93 seismic refraction and wide angle reflection data:** (Luetgert/Mooney; DCS/NEHRP) (*A cooperative effort with the NSF Mendocino consortium*)

High resolution seismic refraction /wide-angle reflection data collected in 1993 will help define the deep structure of the Mendocino triple junction. Knowledge of the crustal and upper

# STAGE I — MENDOCINO RESEARCH CORRIDOR

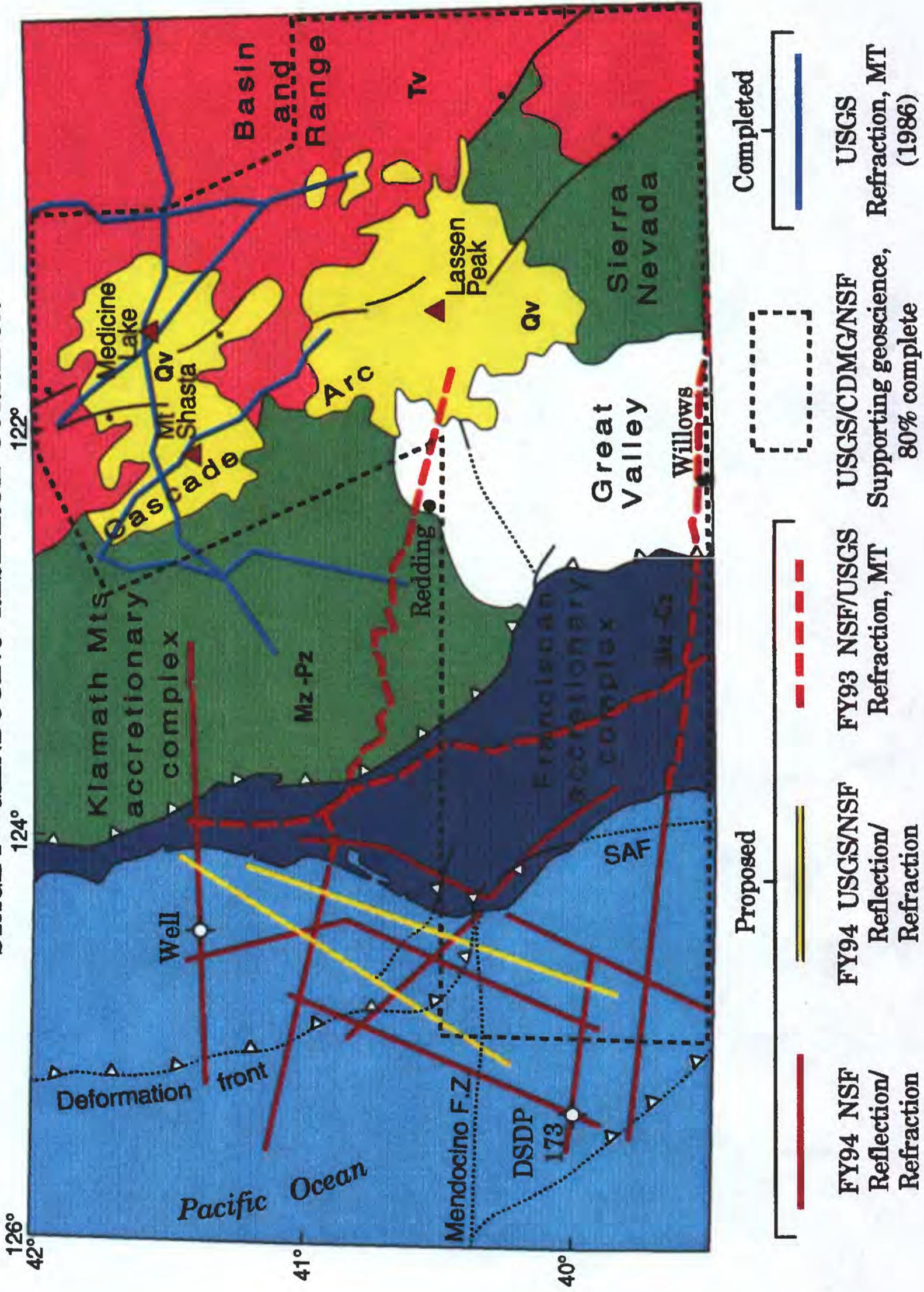


Figure 4. Existing and proposed geophysical surveys, Mendocino Research Corridor.

mantle velocity structure will allow us to quantify the effects of possible magmatic underplating south of the triple junction, deformation of the Gorda plate and its location at depth, and large-scale tectonic underplating north of the triple junction.

**Task 94.3--Magnetotelluric surveys and analysis of the triple junction region (Stanley; DCS/VGP)**

Four MT profiles will bracket the MTJ region to examine regional conductivity structure both in front of and behind the northward moving triple junction. The southernmost will be subparallel to seismic refraction line L1 of the NSF/USGS experiment; it will cross a major low-velocity anomaly in the crust mapped by Benz and others (1992) and extend into the Lassen Peak area. The northernmost will cross the Klamath Mountains and connect with earlier seismic and MT profiles. The profiles are designed to test: 1) whether low velocity zones mapped by teleseismic methods south of the MTJ are upwelling asthenosphere ("slab window") or possibly underplated Franciscan rocks similar to those underthrust beneath the Klamath Mountains to the north; and 2) whether conductivity characteristics of the southern end of the active Cascades arc near Lassen Peak indicate a difference in mid-crustal level fluid content because of the proximity to the margin of the Gorda plate, and thus determine the southern extent of the Cascades arc.

**Task 94.4--Potential field surveys and analysis (Jachens and Griscom; DCS/OMR)**

Critical elements of the three interacting plates at the Mendocino triple junction, particularly the south edge of the Gorda plate, are well defined by their gravity and magnetic anomalies. New aeromagnetic data, spanning both the onshore and offshore regions of Cape Mendocino, could help define the nature of this important boundary and provide continuity among the results of other investigations such as the Mendocino seismic experiment, onshore geologic mapping, seismicity, and neotectonic studies. We will also examine Mendocino triple junction instability over time and its relationship to regional patterns of seismicity and total deformation.

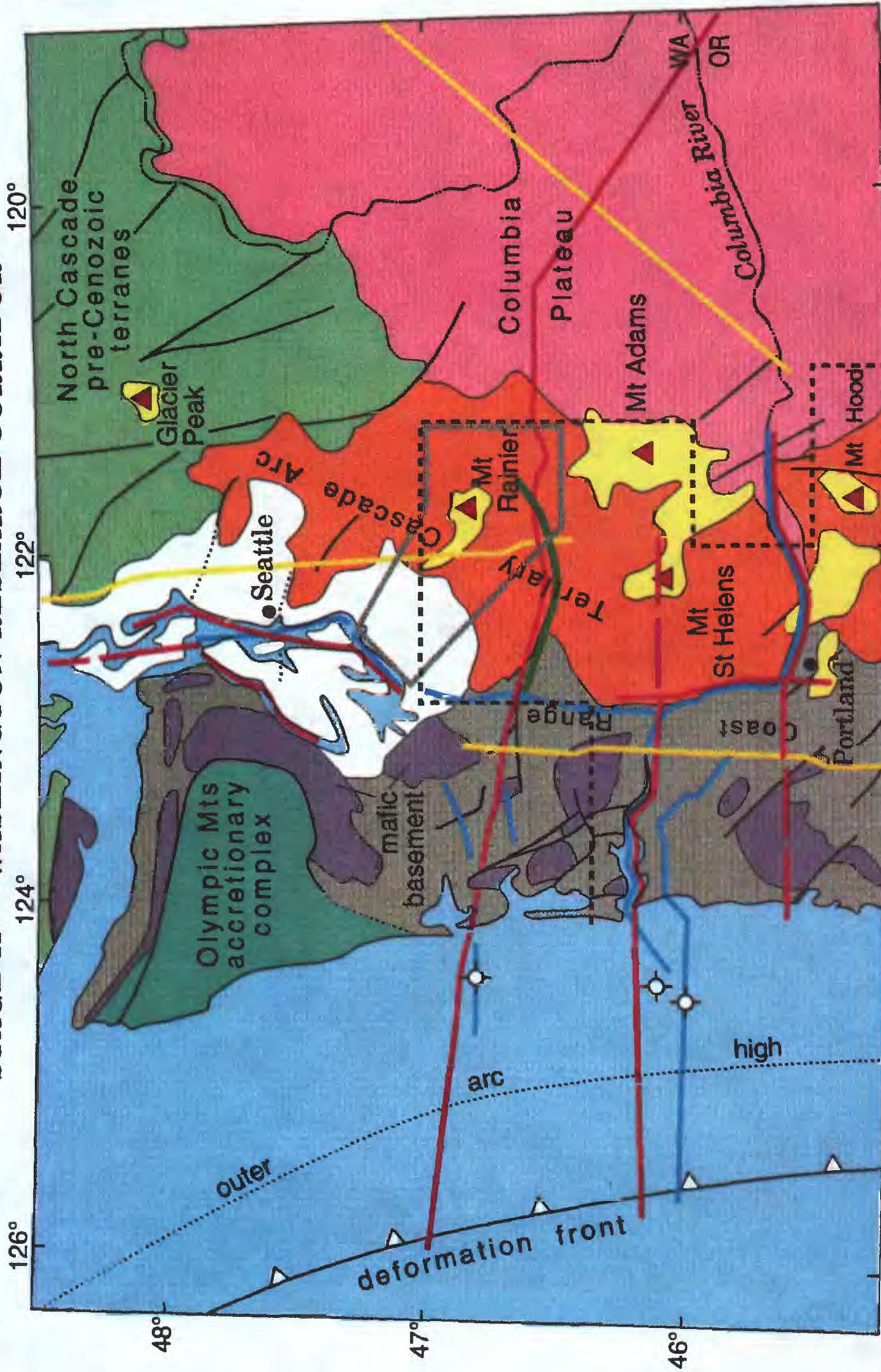
**Task 94.5--Supporting Geoscience (Harwood/Smith/Sawlan/Guffanti and others; NGM/VGP/DCS)**

A coordinated series of geologic mapping projects, largely funded by other programs have nearly completed a major transect across the continental margin at the latitude of Cape Mendocino. The nine 1:100,000 scale geologic maps of the NORCAL transect span the region from the Mendocino triple junction to the Cascade arc and Basin and Range, including the Franciscan complex, Klamath Mountains overthrust, and the northern Great Valley and Sierra Nevada. In the Sierran foothills, this transect provides a view into the roots of an earlier accretionary complex intruded by granites, potentially a very useful analogue to the late Cenozoic magmatism intruding the Franciscan in the wake of the Mendocino triple junction. Additional detailed geologic and petrologic investigations are underway in the Shasta, Medicine Lake and Lassen volcanic complexes and surrounding areas to examine the evolution of the arc, the spatial and temporal distribution of vents in the southern Cascades, and the interactions with the encroaching Basin and Range province. We expect these projects to continue over the next couple of fiscal years.

## **Washington Research Corridor**

The Washington Corridor examines the deep structure and evolution of the northern, seismically active segment of the subduction zone, its seismically active dextral transpressive arc, and the subsided Columbia basin in the back arc. The offshore is characterized by a broad accretionary prism which potentially underplates northward translating and rotating basalt

# STAGE II — WASHINGTON RESEARCH CORRIDOR



- |   |   |  |   |
|---|---|--|---|
| <b>Proposed</b>   |   | <b>Completed</b>   |   |
| <span style="color: blue;">—</span>   | FY92-95 Industry reflection (USGS, OSU, OR Dept Geol) | <span style="color: green;">—</span>   | DOE Reflection, USGS MT                 |
| <span style="color: red;">—</span>  | FY95-97 USGS Refraction/ wide angle reflection, MT    | <span style="border: 1px solid black; display: inline-block; width: 15px; height: 10px;"></span> | FY92-99 IAVCEI Decade Volcano project   |
| <span style="border: 1px dashed black; display: inline-block; width: 15px; height: 10px;"></span> |   | <span style="border: 1px solid black; display: inline-block; width: 15px; height: 10px;"></span> | USGS, UTEP Refraction, MT 1991, 1988    |
| <span style="border: 1px solid black; display: inline-block; width: 15px; height: 10px;"></span>  |   | <span style="border: 1px solid black; display: inline-block; width: 15px; height: 10px;"></span> | USGS, OSU, WA DNR supporting geoscience |

Figure 5. Existing and proposed geophysical surveys, Washington Research Corridor.

basement blocks of the forearc. The seismically active arc is undergoing dextral shear and is folded and uplifted, with isolated stratovolcanoes resting on the deformed arc platform.

Our major goal in this corridor is to examine the structure and evolution of the seismically active transpressive convergent margin segment of Cascadia, in particular:

- Precisely locate the subducting plate interface and attempt to image the possible locked zone by seismic methods.
- Determine the relative importance of tectonic underplating of accretionary wedge versus magmatic underplating in growth of the continental margin.
- Define the structures and mechanism responsible for coastwise transport and rotation of forearc crustal blocks, and the nature of the forearc-arc tectonic boundary.
- Determine the magmatic and structural evolution of the compressive arc and be prepared to contrast it with evolution of the extensional arc to the south in Oregon.

Other USGS Programs with current interests in this region include: National Earthquake Hazards Reduction, National Geologic Mapping, Evolution of Sedimentary Basins, Marine Geology, Volcano Hazards/Geothermal Research, and Mineral Resources Programs. In FY 93, we began a cooperative effort with NEHRP and ERSP to examine industry seismic reflection data in the Puget Sound area and in southwest Washington. A second cooperative effort was initiated with NGM, BWMR, and BVGP to provide a geological transect across the southern Washington Cascade arc.

#### **FY 94**

##### **Task 94.6--Industry Seismic Reflection analysis of the forearc (Potter/Johnson; ERSP/DCS/NEHRP)**

A network of industry seismic reflection data is available for Puget Sound, southwest Washington, and northwest Oregon. We are analyzing these data to determine upper crustal structural controls on forearc basin formation, evolution, and seismicity. Critical ties between surface geology and deep geophysical information are contained in industry seismic reflection lines collected in Puget Sound, the Puget lowland, and the southwest Washington - northwest Oregon Coast Range. These data demonstrate that the dominant late Eocene to late Miocene structures in and around the Grays Harbor basin, southwest Washington, record complex contractional deformation (thrust faulting, tectonic wedging, and folding) with a north-south to northeast-southwest shortening direction. Recurrent deformation near major crustal faults beneath Puget Sound also records N-NE-directed shortening. The seismic data will be integrated with well data and surface geology to produce a 3D grid of western Washington structure. This grid will provide essential upper-crustal resolution and structural constraints to define Cenozoic forearc basin geometries, the partitioning of strain between strike slip and contractional structures, and their role in clockwise rotation of Coast Range basement during oblique convergence. The data will also clarify the geometry of the Eocene Coast Range - Cascades boundary beneath the Puget lowland, its tectonic history, and its role in arc evolution.

##### **Task 94.7--Potential field studies of the forearc (Blakely/Finn; DCS/NEHRP)**

New aeromagnetic data will be acquired in southwestern Washington and northwestern Oregon in order to help constrain the geologic structure and tectonic boundaries between the arc and the northward moving and rotating forearc. This survey will adjoin the highly successful Portland basin survey which last year identified large, continuous, potentially active structures beneath the city (Blakely and others, 1993). Existing magnetic coverage is inadequate to address the complex structural boundary between the arc and forearc. New aeromagnetic surveys in the region spanning the Columbia River, Willamette Valley, and the western Cascades could help define the structure and lateral extent of Coast Range mafic rocks, their possible control of subduction geometry and arc structure, and their control of crustal

seismicity and volcanism. Block boundaries beneath Quaternary cover in the Puget-Willamette lowland are particularly amenable to potential field studies.

**Task 94.8--Supporting Geoscience (Ashley/Evarts/Moore/Swanson; NGM/ERSP/VGP/MRS WA DNR).**

Geologic mapping underway in the southwest Washington Cascade arc will provide a geological and petrological transect of the transpressive arc segment along the proposed seismic refraction line across the Cascades. The geology of this segment is not well known, although major gravity, aeromagnetic, seismic, and conductivity structures have been recognized in the arc and forearc for at least a decade. In order to constrain the geophysical and petrological models of arc structure and evolution, we must understand the basic stratigraphy and structure of this transpressive arc segment and determine whether major geophysical anomalies (e.g. southwest Washington conductor, St. Helens and Rainier seismic zones, Olympia gravity gradient, etc.) correlate with geological structures accommodating strike slip, crustal shortening and clockwise rotation; or petrologic boundaries in the Paleogene arc that separate Coast Range "oceanic" magmatic sources from arc magmatic sources. Understanding the volcanic evolution of the Tertiary compressive arc, including the style of volcanism, distribution and structural setting of source vents, and chemical variation over time will help constrain the geophysical interpretations. Work is also in progress by the Washington Division of Geology and Earth Resources to digitize several 100K quadrangles along the proposed geophysical transect.

**FY 95**

**Task 95.1--Seismic refraction and wide angle reflection survey of the Washington forearc and arc (DCS/NEHRP/PMG)**

A combined marine and land seismic survey could image the deep boundary between the accretionary wedge, the offshore extent of the continent and the detailed geometry of the slab. A high resolution land seismic refraction/wide-angle reflection profile could follow these deep structures across the Coast Range, Puget Sound Basin and Cascade arc. This is one of the major objectives of CASCADIA. Tracing the subducting oceanic plate eastward into the trench and beneath the convergent margin is necessary to be certain of the geometry of the subducting plate and the locus of the presumed locked zone. This tracking can be achieved by marine seismic profiling and onshore recording. Complementary high-resolution seismic refraction/wide-angle reflection profiling across the forearc could provide a model of the velocity structure of both the upper crust and the lower crust/upper mantle of the forearc and arc roots. Such a study could be coordinated with IRIS and local research groups to provide an opportunity for university piggy-back or add-on research. The resulting integrated crustal model based on the velocity structure, along with gravity, aeromagnetic, magnetotelluric, seismic reflection, and seismicity data is essential for the accurate evaluation of crustal earthquake mechanisms and could substantially improve our ability to locate earthquakes recorded by the existing seismic net. This experiment could also address the crustal thickness and composition of the presumably accreted Coast Range basalt basement, the extent of the Olympic Mountains subduction complex beneath the Coast Range basalt terrane, and the implications for source areas of great thrust earthquakes in western Washington. This profile will help define the nature of the eastern boundary of the Coast Range basement and its relation to the southwest Washington conductor (SWCC of Stanley and others, 1987; 1992), which appears to coincide with major Cascade volcanoes and seismic zones in southwest Washington. Finally, this experiment addresses in a fundamental way the role of tectonic underplating of oceanic crust and mantle in building the continental crust and the role of magmatic underplating in the arc and backarc. How much crust has been added by these processes, and how has the Moho evolved through time?

**Task 95.2--Electromagnetic studies in the Washington forearc (Stanley; ERSP/NEHRP/VGP)**

MT studies will be extended from well studied areas in the Cascades westward across the Coast Range to provide additional constraints on crustal structure of the forearc. Extensive MT, potential field and seismic reflection mapping of the southern Washington Cascades has defined a regional mid-crustal conductor which appears to localize seismicity and Cascade volcanism (Stanley and others, 1992). Regional north-south MT profiles have been completed along new refraction profiles (Luetgert and others, 1992) but are still being interpreted. Detailed MT surveys along the east-west refraction/wide angle seismic profile from Willapa Bay to White Pass in the Cascades could provide additional constraints on the seismic interpretation of the thickness of the Coast Range basalt crust and underplated sediments. The area of the southern Washington Cascades has been adequately covered, but the region west of the Cascades remains to be surveyed with detailed MT profiles. Ultimately, the east end of the profile could also be extended onto the Columbia Plateau to connect with deep oil wells and proprietary MT data in the area around Yakima to determine sub-basalt structure.

**FY 96-97**

**Task 96.1--Deep seismic experiment in Puget Sound (NEHRP/PMG/DCS)**

A deep crustal marine seismic reflection survey in Puget Sound recorded by onshore seismic stations could image the seismogenic middle crust and subducted Juan de Fuca plate. Airgun profiling along a series of lines in Puget Sound recorded onshore by temporary and permanent seismic stations could be used to obtain the first controlled-source tomographic images of deep crustal structure beneath this seismically active and densely populated portion of Cascadia.. The E-W trending Seattle fault, with 9-10 km of vertical displacement on Eocene basement, has been identified as having seven meters of dip slip motion in the past 1000 years (Bucknam and others, 1992) and thus constitutes a major hazard for Seattle. Puget Sound is characterized by some of largest potential field anomalies in the North America and contains the thickest sedimentary basins in Cascadia. Major questions need to be addressed, such as why are the earthquakes so deep in this region and how are the strains partitioned in this transpressional environment? The profiles will examine the deep seismogenic region of the Seattle fault and similar structures as far north as Georgia Strait. This study will be a cooperative effort with the Canadians, IRIS, and university research groups.

**Task 97.1--Columbia River seismic refraction/wide angle reflection study (DCS/NEHRP/PMG)**

A unique onshore-offshore seismic survey running up the Columbia River could image the deep boundary between the accretionary wedge, the offshore extent of the continent and the detailed geometry of the slab, which may be broken in this region. A high resolution seismic refraction/wide-angle reflection profile could follow these deep structures across the Coast Range, Willamette Basin and Cascade arc. The Columbia River represents a unique opportunity along Cascadia where a modern seismic vessel can transect the deformation front, the subduction trench, the continental slope and shelf, the Coast Ranges, and even the arc itself. The USGS already possesses industry seismic reflection data acquired up the Columbia River which images crustal structure down to 3 seconds. By deploying a large number of closely spaced recorders on the shores of the Columbia River, and steaming up the river with a large airgun array, we should be able to image the middle and lower crust as demonstrated for similar experiments in San Francisco Bay and in Prince William Sound (Brocher et al., 1993; Brocher and Moses, 1990). The experimental design will simultaneously provide low-fold seismic reflection coverage of the middle to lower crust as well as dense wide-angle recordings to provide a detailed seismic velocity model along the transect. Due to the sharp bend in the Columbia River, two parallel profiles can be obtained (Figure 5). The northern side will connect directly offshore to a marine line and be extended east of the bend via unreversed recorders. The southern transect, at the latitude of Portland, will consist of airgun shots recorded on a sparser array in the coast range as well as densely spaced recorders deployed along the Columbia River. Completion of this transect will fill the gap between the Grays

Harbor transect where the margin is transpressional and the central Oregon transect described by Trehu and others (1992), where the margin is transtensional.

#### **Task 97.2--Deep seismic experiment across the Olympic accretionary complex (NEHRP/PMG/DCS)**

A deep crustal marine seismic reflection survey seaward of the Olympic Peninsula recorded by onshore seismic stations could image the accretionary wedge complex and the subducted Juan de Fuca plate. Land seismic profiling could be used to examine the accretionary wedge complex in the only place where it comes ashore along the Cascadia margin. This onshore-offshore transect would complement the profiles obtained in Puget Sound and would focus on tracking the subducted Juan de Fuca plate to depth and determining the internal structure of the accretionary complex. According to some models, this accretionary complex deforms plastically while blocks of Coast Range basalt basement are fragmented into blocks during northward transport around the accretionary complex. This transect would focus on the locked portion of the subduction complex, which Hyndman and others, (1992) suggest is capable of generating large-magnitude earthquakes along the Cascadia margin.

### **Central Oregon Research Corridor**

The Central Oregon Corridor addresses the deep structure and evolution of the aseismic part of the subduction zone, the adjacent extensional arc, and the Basin and Range in the backarc. It is characterized by a well-developed accretionary prism and a large, thick forearc block of Coast Range basalt, which is rotating and translating northwestward in front of the volcanically robust extensional arc segment. Pre-Tertiary crust may be missing in this segment, which lies within the Columbia embayment. This embayment is a major re-entrant in the Cordilleran orogenic belt, presumably formed by continental rifting or collisional processes. The eastern part of the embayment is covered by Miocene flood basalts of the Columbia River Basalt Group, which erupted from dike swarms in the Blue Mountains.

Our major goal in this corridor is to investigate the structure and evolution of the aseismic, extensional arc segment of the Cascadia convergent margin; in particular:

- Precisely locate the plate interface and produce a seismic image of potential asperities; be prepared to compare with similar work off seismically active Washington
- Compare the relative importance of tectonic vs. magmatic contributions to crustal growth in Oregon vs Washington
- Determine the magmatic and structural evolution of the extensional volcanic arc and be prepared to contrast it with the compressional arc in Washington and the transtensional arc in California

Important lithospheric-scale seismic and electromagnetic studies have already begun in the extensional corridor (e.g., Wannamaker and others, 1989; Catchings and Mooney, 1988a; Trehu and others, 1992; Luetgert and others, 1992); however, basic questions remain regarding the structure of the subduction zone, its interaction with Coast Range basalt crust, and the peculiar aseismic nature of this margin segment. Further questions remain regarding mid-crustal fluids inferred from the conductivity structure and their role in seismogenesis (or lack thereof) and magmatism.

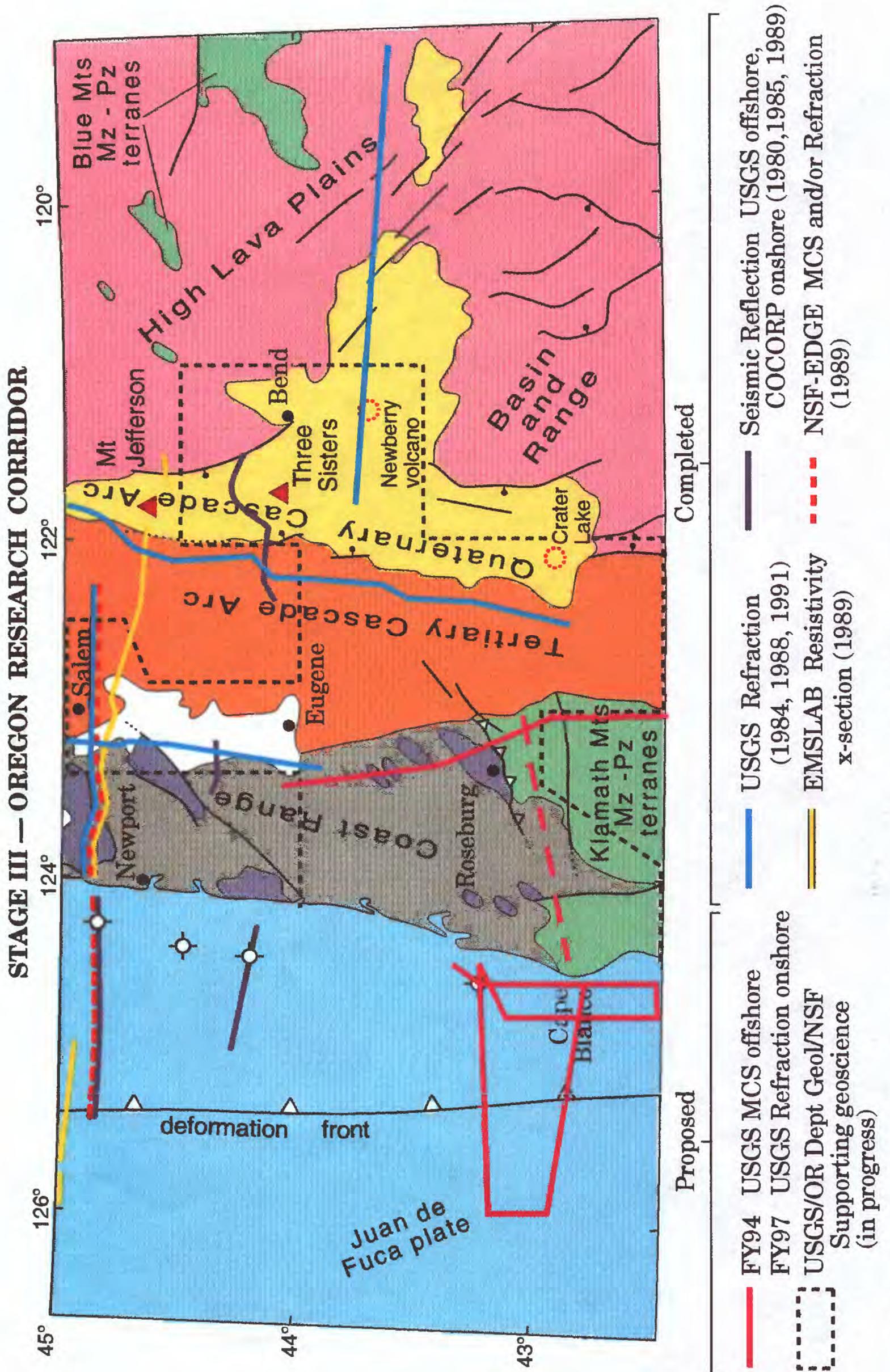


Figure 6. Existing and proposed geophysical surveys, Oregon Research Corridor.

|    | FY93  | FY94   | FY95  | FY96                           | FY97   | FY98   |
|----|---|--|---|--------------------------------|--|--|
| WA |   | <p><b>MAJOR EXPERIMENTS</b></p> <p>Grays Harbor-Rainier refraction-marine seismic<br/>           arc-forearc transition aeromag. survey—magnetotellurics<br/>           industry reflection—analysis<br/> <b>SUPPORTING GEOSCIENCE</b></p> | <p><b>MAJOR EXPERIMENTS</b></p> <p>Puget Sound<br/>           marine seismic—analysis<br/> <b>SUPPORTING GEOSCIENCE</b></p> | <p>marine seismic—analysis</p> |  |  |
| OR | <p>Eocene-Oligocene Cascade arc evolution<br/>           Oligo-Miocene Cascade evolution—forearc-arc transition<br/>           forearc block tectonics</p>  |  | <p>Willamette Valley<br/>           aeromag. survey</p>   |                                | <p><b>MAJOR EXPERIMENTS</b></p> <p>Columbia R.<br/>           marine seismic—magnetotellurics<br/>           aeromag. survey<br/> <b>SUPPORTING GEOSCIENCE</b></p> | <p>Coast Range bdy.<br/>           seismic refraction</p>  |
| CA | <p>Portland<br/>           aeromag. survey<br/>           industry reflection<br/>           Coast Range-Klamath Mts. tectonic bdy.<br/>           Coast Range petrologic evolution<br/>           Cascade arc petrologic evolution</p>   | <p>Cape Blanco<br/>           marine seismic</p>   |   |                                | Cape Blanco geology  | <p><b>CASCADIA OVERVIEW</b><br/>           FY 95-98<br/>           seismic tomography<br/>           synoptic maps</p> |
|    | <p><b>MAJOR EXPERIMENTS</b></p> <p>MTJ<br/>           seismic refraction—marine seismic<br/>           industry reflection—magnetotellurics<br/>           aeromag. survey—analysis<br/> <b>SUPPORTING GEOSCIENCE</b></p> <p>triple jct. digital geology<br/>           Klamath-Cascade digital geology<br/>           arc-basin and range transition<br/>           volcanic framework</p> |  | <p>analysis</p>   |                                |  |  |

Figure 7. CASCADIA project plan, FY 93-98.

## FY 94

### **Task 94.9--Marine reflection and wide angle seismic refraction/reflection, Cape Blanco region (Clarke/Brocher; DCS/NEHRP/PMG)**

Land recordings of a marine seismic reflection survey in the vicinity of the Blanco fracture zone could help image the deep boundary between the accretionary wedge, the offshore extent of the continent and the detailed geometry of the slab in this transitional region. The Blanco fracture zone intersects Cascadia in the vicinity of the transition between the seismically active arc in northern California and the aseismic arc in central Oregon and represents the focus of many prominent latitudinal changes along Cascadia. The width of the accretionary prism, the age of the subducting oceanic crust, and the nature of the bedrock in the Coast Ranges all change dramatically north of the Blanco fracture zone. The proposed marine seismic reflection lines are designed to investigate the offshore extensions and connections of the Fulmar fault as well as a major suture zone between the Tertiary mafic rocks (equivalent to the Siletz River Volcanics) north of this region and the Mesozoic accreted terranes in the Klamath Mountains (with its Franciscan assemblage equivalents). The profiles would be located in the very center of the aseismic part of Cascadia and, in the absence of seismicity, are thus a direct means of determining the geometry of the subducted oceanic crust there. These profiles could be compared to an existing profile across the northern Oregon extensional arc and work in progress just north of the triple junction.(Trehu and others, 1992, 1993).

### **Task 94.10--Supporting Geoscience (Sherrod/Wells; NGM/VGP/DCS)**

Geologic mapping has defined a major tectonic boundary between the oceanic basalt of the Coast Range and the Klamath Mountains in southern Oregon which projects beneath the Cascade arc. The following topical studies will be undertaken to constrain interpretations of existing reconnaissance MT and proposed geophysical lines across this boundary: 1) Structural mapping along the only U.S. exposure of this major tectonic boundary between Coast Range basalt and pre-Tertiary continent to define the geometry, kinematics, and origin of the suture, either as a subduction zone or rift basin margin ; 2) a petrologic traverse across the extensional Cascade arc at the latitude of Roseburg to assess temporal changes in magma source and to compare to a traverse in progress across the compressional arc in Washington; 3) geologic and petrologic characterization of unusual tholeiitic and alkaline suites in the Oregon Coast Range to determine their tectonic significance (Wells and Snavely USGS; Duncan and Pyle, OSU). These compositions are unusual in a forearc setting and may reflect unusual tectonic circumstances. Petrologic modelling of their source zones could constrain lithospheric structure and tectonic history of the forearc; and 4) structural analysis of the forearc to test models of tectonic rotation and strain partitioning into pure and simple shear domains during oblique subduction.

## FY 97-98

### **Task 97.3--Electromagnetic and Potential field studies in Oregon (Stanley/Blakely; DCS)**

MT, aeromagnetic, and gravity studies in southwest Oregon could help define the geometry of the Columbia embayment, accretionary terrane boundaries, and possible segmentation of the Cascade volcanic arc. Some of the largest-amplitude magnetic anomalies in North America occur along a north-south band within the Western Cascades of Oregon, but near surface rocks in the area do not appear to be the source of the anomalies. They may reflect Eocene accreted Coast Range oceanic crust (Blakely, 1992), ultramafic rocks accreted during Eocene time (Johnson and others, 1990), or granodiorite intrusions of the Western Cascades (Finn, 1991). Understanding the causes of these enigmatic anomalies is critical to our understanding of the structural boundary between the forearc and arc. In southwest Oregon, this anomaly terminates at a major terrane boundary between the Oregon-Washington Coast Range and the Mesozoic terranes of the Klamath Mountains, which project northeastward toward the Blue Mountains beneath the Western Cascades. Gravity anomalies associated with the suture continue

northeastward on strike with a distinctive gravity gradient that parallels the Blue Mountains (Riddihough and others, 1986; Blakely and Jachens, 1990). Additional studies may show a connection between these two parts of the pre-Cenozoic orogenic belt and define the geometry of the Columbia embayment beneath the Cascade arc. New surveys could also define the structure of the suture zone between Paleogene oceanic terranes and pre-Tertiary continent, and its extent beneath the Western Cascades.

## **Synoptic Investigations**

### **FY 94**

#### **Task 94.11--Cascadia Plate Map Series (Haugerud and others; DCS/NGM/NEHRP)**

A series of synoptic maps of the Cascadia plate system will provide a holistic overview of the topography, geology, and geophysics of the entire convergent margin. We are using the Canadian Juan de Fuca plate map series of the late 1970's as our inspiration, but we are creating digital products from digital datasets. Our objective is to create a series of digital maps of Cascadia at a provisional scale of 1:2,000,000, including; topography, tectonic assemblage, gravity, aeromagnetic, crustal thickness, heat flow, isotopic provenance, volcanic vent distributions, and velocity structure, among others. These will be useful in analyses of convergent margin tectonic processes.

#### **Task 94.12--Isotopic systematics of the Cascade arc (Gunn and others; NGM/DCS)**

The systematic acquisition of Sr, Nd, and common Pb isotopic compositions of volcanic and plutonic rocks of the Cascade arc will provide constraints on the composition, age and evolution of deep crust and mantle source regions beneath the arc. The lower crust and mantle source regions beneath the arc are likely to vary along strike, because the arc is built across the Columbia embayment, a reentrant in the pre-Tertiary orogenic belt in Cascadia. Primitive basalts along the arc should provide isotopic signatures characteristic of the mantle source regions, whereas granitic plutons may contain a signature of lower-crustal variations. A systematic isotopic mapping of arc source variability in space and time could provide important constraints on deep continental structure when combined with the geophysical and geological data.

### **FY 95**

#### **Task 95. 3--Teleseismic imaging of the deep lithosphere (DCS/NEHRP)**

Teleseismic studies of P- and S-wave velocities and attenuation would provide constraints on the composition, structure, and current state of the whole lithosphere and underlying asthenosphere of the Cascadia plate system. After FY 95, these studies would have the advantage of a relatively detailed crustal velocity model constrained by a network of controlled-source seismic experiments. Temporary arrays of short-period and broad-band seismographs will augment the regional seismic network and permit the application of a broad suite of seismic techniques, ranging from teleseismic delay times to surface wave inversions for crustal and upper mantle structure. Important objectives include: 1) high-resolution images of the subducting slab beneath the arc and forearc, with particular emphasis on apparent segment boundaries inboard of Cape Blanco and the mouth of the Columbia River; 2) comparative anatomy of the lithosphere and asthenosphere beneath the compressional, extensional, and transtensive Cascade arc segments; and 3) characterization of the mantle source of late Cenozoic volcanic fields of eastern Oregon and the Columbia Plateau.

## RELATIONSHIP OF CASCADIA TO OTHER TRANSECTS AND PROGRAMS

### **Existing transects**

The CASCADIA experiment is built on an existing, but widely spaced framework of lithospheric studies in the Northwest. The internationally acclaimed LITHOPROBE transect of the Canadian Cordillera has recently been completed just north of the U.S. border and provides a model for successful interdisciplinary study. Although the extensive young volcanic terrane of Cascadia is in marked contrast to the Canadian Cordillera, Lithoprobe affords an integrated view of the mostly pre-Tertiary orogenic belt which projects southward beneath the volcanic rocks and provides a northern anchor for the experiment. In Oregon, the recently completed EMSLAB experiment has produced the most comprehensive electromagnetic study of a convergent margin, and has determined a lithospheric conductivity structure that demands testing by other geophysical and geological methods. Glimpses of deep crustal structures can also be seen on industry, DOE, and COCORP seismic reflection lines in the forearc, arc and backarc. Widely spaced academic and USGS seismic refraction lines provide provincial velocity structure, but require tie lines across important tectonic boundaries.

### **Other USGS Programs**

A long term investment in the Northwest by several USGS programs (particularly Geothermal Research (GRP), Volcano Hazards (VHP), Earthquake Hazards Reduction (NEHRP), Mineral Resource Surveys (MRS), National Geologic Mapping (NGM), and Pacific Marine Geology (PMG)) has provided the geological and geophysical framework for identifying critical gaps in our knowledge and defining critical experiments. CASCADIA is cooperating with those USGS programs having strategic interests in the Pacific Northwest. The project advisory committee includes representatives from Earthquake Hazards Reduction, Energy Resource Surveys (ERSP), Geothermal Research, Volcano Hazards, Geologic Mapping, Mineral Resources, and Pacific Marine Geology. We are addressing issues of common scientific interest and effectively marshalling our resources through a series of workshops co-sponsored by DCS and other USGS programs.

The potential for large subduction-zone earthquakes is a good example of a first order problem that is also of primary interest to the National Earthquake Hazards Reduction Program and the Nuclear Regulatory Commission. Another example of potential collaboration between programs is the proposed joint purchase by DCS, ERSP, and NEHRP of industry seismic data in southwest Washington in order to examine the relationship between crustal seismicity and three-dimensional forearc crustal structure. We expect a combined effort among DCS, NEHRP, and PMG on several large onshore-offshore geophysical experiments.

### **Participation by Academia, Industry, and other Agencies**

The steering committee is coordinating USGS goals with those of the National Science Foundation, Department of Energy, Nuclear Regulatory Commission, State Geological Surveys, universities, and industry to insure an integrated approach to deep continental investigations in the Pacific Northwest.

Our geologic and land refraction expertise in the Mendocino research corridor compliments the Mendocino academic consortium experiment (funded by NSF) to study the structure and deep crustal processes associated with migration of the Mendocino triple junction along the continental margin. Additional academic collaboration is expected on evolution of the accretionary wedge (e.g. Brandon and others, Yale University); geochemical evolution of the

arc and forearc (e.g. Leeman, Rice University; Duncan, Oregon State); and teleseismic structure of convergent margin (Nabelek, Oregon State; Humphreys, University of Oregon; Crosson, University of Washington).

The Fossil Fuels Division of the Department of Energy has had a major interest in western Washington basins and especially in the southern Washington Cascades conductor (SWCC) region, where it funded major deep reflection surveys. DOE interest has currently shifted to the Gulf Coast, but our program may serve to interest DOE in renewed support of research or deep drilling.

The Bureau of Indian Affairs (BIA) has a mandated interest in geophysical and geological data for the CASCADIA region. Proposals with the USGS have been formulated to study specific reservations such as the Warm Springs reservation of Oregon and the Yakima reservation in Washington. Reservations in western Washington have been involved in proposals developed by BIA and USGS to evaluate energy and mineral resources in the numerous (25) reservations in the Puget Lowland and nearby environs. BIA is particularly interested in supporting data base development and regional syntheses of geology and resources. A total of 40 reservations occur in CASCADIA and close coordination with BIA and individual reservations will be necessary to provide access and cooperation with them. Energy and mineral assessment issues are handled by the BIA Division of Energy and Mineral Resources in Denver in coordination with the BIA Area Office in Portland.

The IAVCEI Mount Rainier Decade Volcano project to examine the evolution of the volcanic edifice, its tectonic setting, and its hazard implications coincides with DCS, NEHRP, and ERSP goals to study the deep structure of the tightly folded and seismically active arc in the vicinity of Mount Rainier. Decade Volcano mapping of the volcanic edifice and the bedrock foundation will be coordinated by the Branch of Volcano and Geothermal Processes; crustal structure will be addressed by DCS and NEHRP.

In addition to the active collaboration with the Mendocino group (Ann Trehu, Simon Klemperer, Alan Levander, and Anne Meltzer at Oregon State University, Stanford, Rice, Lehigh, respectively), a number of researchers have expressed interest in future collaboration with the USGS CASCADIA effort, including:

- Mark Brandon Yale University (Northwest tectonics)
- Ron Clowes University of British Columbia (Crustal structure of the Canadian Cordillera)
- Robert Crosson University of Washington (Northwest seismology)
- Robert Duncan, Doug Pyle, Oregon State University (Ar/Ar, Isotopes, Trace element geochemistry, Coast Range magmatism)
- Don Hull Oregon State Geologist
- Eugene Humphreys University of Oregon (Mantle structure and geodynamics)
- Ray Lasmanis Washington State Geologist
- William Leeman Rice University. (Trace element and Isotope geochemistry, Cascade Arc)
- Megan Miller Central Washington State University. (Blue Mts geology)
- Jim Monger Geological Survey of Canada (Geology of the Canadian Cordillera)
- Alan Niem Oregon State University (Coast Range basin history)
- George Priest Oregon Department of Geology and Mineral Industries (Cascade volcanism)
- Ray Weldon University of Oregon (Kinematics)
- Harve Waff University of Oregon (Electromagnetics)
- Tom Wylie Oregon Department of Geology and Mineral Industries (Klamath Mts. geology)

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APPENDIX I. USGS CASCADIA PROPOSALS FY94

Mendocino Research Corridor

*Geophysical surveys*

Mendocino triple junction refraction analysis **Luetgert, Mooney, and others**

Southern Cascadia subduction zone, marine seismic **Clarke**

Southern Cascadia electromagnetic studies **Stanley**

Triple junction potential fields **Jachens and Griscom**

*Supporting geoscience*

Volcanic framework of the southern Cascade Range **Guffanti**

Tulelake 30'X 60' quadrangle, California **Smith/Sawlan**

Digital geological framework **Harwood**

Washington Research Corridor

*Geophysical surveys*

Aeromagnetic survey of arc-forearc boundary, lower Columbia River **Finn**

SW Washington forearc structure based on industry seismic data **Potter**

Lower Columbia River structure and outer arc high from industry seismic data **Snavelly**

*Supporting geoscience*

Western Cascades geology NW of Mt. St. Helens **Ashley**

Geology of the Randle-Packwood area, S. Washington Cascades **Moore**

Geology of the French Butte area, S. Washington Cascades **Swanson**

Cascade arc-forearc transition, Washington **Evarts**

Oregon Research Corridor

*Geophysical surveys*

Potential field investigations of the Cascade arc and forearc **Blakely**

Cape Blanco wide angle refraction/reflection survey **Brocher**

Cape Blanco reflection survey **Clarke**

OBS upgrades for Cascadia **ten Brink**

*Supporting geoscience*

Petrologic evolution of the Oregon Cascade Range **Sherrod**

Synoptic Overview

*Cascadia Plate Map Series*

Digital topography and tectonic assemblage maps of Cascadia **Haugerud**

*Supporting geoscience*

Isotopic systematics of the Cascade arc **Gunn**

Coordination

**Wells**

APPENDIX II ADDRESSES  
USGS CASCADIA WORKING GROUP

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