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KARST AND CAVE RESOURCE SIGNIFICANCE ASSESSMENT KETCHIKAN AREA, TONGASS NATIONAL FOREST, ALASKA.

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Report of the Karst Resources Panel

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EXECUTIVE SUMMARY

Karst is a three dimensional terrane developed on, and within, a soluble bedrock. At least 700 square miles of the Ketchikan Area of the Tongass National Forest (the "study area") is karst, and it is likely that the extent of karst will prove to be larger when more detailed geologic mapping is conducted. Karstlands extend from salt water to some of the peaks. Springs, caves, sinkholes, losing streams, and a host of other karst features are abundant and often spectacular.

A Karst Resources Panel ("the Panel") was established under contract to the Forest Service to: (1) assess the significance of the karst, (2) determine the effectiveness of present strategies for protecting karst resources and recommend appropriate changes, and (3) recommend focused resource evaluation goals and research for karst areas. This report documents the results of this work.

The climatic, geological, and biological setting of the study area is fundamental to an adequate understanding of the significance of its karst resources. The climate is temperate and maritime. Precipitation is abundant; it may exceed 250 inches a year at some higher altitudes; annual runoff ranges from about 60 to 200 inches a year. The carbonate rocks that comprise these karst areas originated on tropical Pacific islands that were transported by plate tectonic movements to their current locations. There is no other place in the world where tropical limestones have travelled so far, been involved in such an oblique collision with a continent, and ended up emplaced in an archipelago setting at such high latitudes. Finally, karst portions of the study area are found in temperate coniferous rain forests, adjacent to peatlands, and in both subalpine and alpine zones.

The diversity of karst resources, features, and cave types present in the study area exhibit unusual breadth. Epikarst is an intensely dissolved veneer of intersecting roofless dissolution-widened fissures, cavities, and tubes dissolved into the surface of the carbonate bedrock. Typical thicknesses of the epikarst zone range from more than 100 feet in recently unglaciated alpine areas to

less than 5 feet in recently glaciated low elevation areas. The quality of some of the epikarst in the study area is surpassed only by selected tropical epikarsts in places such as China, Papua New Guinea, and Madagascar; certainly there is no better epikarst in the United States.

Vertical shafts and caves are abundant. Some areas have sinkhole densities estimated at 3,000 to 10,000 per square mile. The caves are highly diverse in form and age. Some of them are of great antiquity. Other are intimately associated with up-gradient peatlands. Portions of the area contain superb littoral (sea) caves, some of which were formed when massive weights of glacial ice had depressed the land surface relative to sea level.

A troglobitic amphipod, Stygobromus quatsinensis, was discovered on Heceta Island (55°45′53″N) during the Panel's visit. This discovery is a high-latitude Western Hemisphere record for a cave—adapted species.

Archeological and paleontological deposits in the area are primarily known from cave and rockshelter sites. Preservation of bone and organic materials is exceptionally good in these cold environments. To date, significant archeological and paleontological materials have been discovered in at least thirty caves and rock—shelters on seven islands in the study area. Such material is of international importance in tracing the regional prehistory, the effects of climatic changes, and the colonization of the Alexander Archipelago by wildlife and humans at different times in the past.

The karstlands of the study area, and the caves within, have enormous recreational values. They offer beauty, discovery, and adventure. The entire Panel was extremely impressed by the exceptional recreational values existing in the karst of the area.

It is the conclusion of the Panel that karst resources of the study area possess eight attributes which are of international-scale significance. These are:

1. The occurrence of major karst development in the unique geologic and archipelago setting of Southeast Alaska.

2. The occurrence of significant portions of the karst in a largely undisturbed, high-latitude temperate

coniferous rain forest. Such settings are, for practical purposes, globally limited to Southeast Alaska. Small amounts of karst in temperate coniferous rain forest remain on Vancouver and Queen Charlotte Islands.

3. The tremendous diversity of karst features present in the study area.

4. The quality of natural preservation of karst resources.

5. The density and degree of development of karst features.

6. The existence of large and extremely well—preserved littoral (sea) caves, some of which are now located at elevations higher than present—day sea level.

7. The presence and abundance of archeological resources which include cave art and may include critically important deposits helping us understand prehistoric colonization of the North American Continent.

8. The existence of outstanding and unique paleon—tological deposits of international significance in understanding climatic changes and their effects.

The panel further concludes that karst resources of the study area possess nine attributes of national—scale significance. These are:

1. Regional karst dissolution rates (regional denudation rates) on the order of at least 4 to 8 times greater than rates in most other American karst areas.

2. Abundant and unique moonmilk deposits.

3. Intimate relationship between peatlands and vertical shaft development in adjacent down—slope carbonate rocks.

4. Contribution of runoff water to some of the most significant fisheries streams in the study area; it is probable that streams draining karst areas have appreciably greater aquatic productivity than streams draining nonkarst areas. The fisheries resources of streams in the study area are clearly of national significance.

5. Troglobitic (cave—adapted) invertebrates on inner islands (such as Prince of Wales) are either very rare or absent; such species are found on outer islands (such as

Heceta and Dali). This difference is probably attributable to differences in the extent of recent glaciation.

6. Discovery of a troglobitic cave amphipod, Stygobromus quatsinensis, in a cave on Heceta Island.

7. Cave use by large mammals to an extent no longer seen in the “Lower 48 States”.

8. The unique opportunity to study evolution and adaptation of invertebrates in an archipelago setting with a complex geologic and glacial history.

9. The recreational potential of vast and largely untouched and unexplored caves and cave passages beneath “the last frontier” of Alaska.

Karst systems impose major land management liabilities not encountered in nonkarst areas. The subsurface karst drainage networks generally operate independently of, and with more complexity than, the surface drainage systems above them. Three important considerations apply. First, the size and shape of the karst systems often have little or no relationship to the overlying surface drainage systems. Second, the direction of flow through the karst systems often cannot be predicted from surface topography or geologic mapping. Third, the discharge from a karstic groundwater system is not always localized at one spot as occurs in a surface drainage basin. Water entering one sinkhole in a basin may discharge from several springs at diverse compass bearings from the input sinkhole. Flow velocities in the groundwater system often equal or approach surface stream velocities. Pollutants such as diesel fuels or fine sediments from roads or other disturbed lands can arrive unexpectedly at one or more distant springs within hours to a few days. Human water supplies and fisheries are routinely, and severely, impacted by such events in karst areas.

In nonkarst portions of the study area sediment must move laterally to a stream, and then flow down the stream. Management efforts are made to protect riparian corridors from logging and its impacts. The large amounts of slash and cull materials remaining on the ground after logging, plus the heavy moss growths on the ground prior to logging, help trap and retain substantial amounts of the sediment. Vegetation can rapidly become established on trapped sediments.

Karst areas transport sediment differently from nonkarst areas. In karst, much of the sediment must move laterally for only a few feet before it is directly transported downward into conduit portions of the karst groundwater system. Once sediment is in the conduits there are no effective natural processes for trapping and retaining it within the system; as a result, it is delivered to a receiving spring or stream. As demonstrated by the dye—tracing work conducted by the Panel, the receiving spring or stream may be several thousand feet away from the point of sediment introduction.

Areas with deep and well—developed epikarst have more closely spaced near—surface openings into which sediments can be flushed than is the case in areas with only shallow epikarst. As a result, sediment transport potential is typically much greater in areas underlain by deep and well-developed epikarst. Observations by this Panel indicate that most of the thin epikarst occurs in areas at relatively low elevations on the inner islands. These are also areas with typically less rugged relief. Much of the remaining virgin forest on karst is underlain by deep and well-developed epikarst and is characterized by steeper slopes. When timber harvest and road construction occur on well—developed epikarst with steep slopes, sediment transport and erosion problems will be substantially greater than on the thin epikarst and lower relief lands.

The importance of cave resources has been recognized by the Forest Service in the study area since 1988. This recognition, and the enactment of the Federal Cave Resources Protection Act in 1988, led to cave inventory work and ultimately to the development of standards and guidelines. These contain laudable features and in some cases provide adequate protection for cave features. Cases where adequate cave protection occurs typically have both of the following characteristics:

1. The block of forest in which the cave entrance is located has not been logged or roaded and the cave is far enough from clearcut areas that accelerated windthrow of trees does not reach to areas close enough to the cave

entrance to alter entrance microclimate.

2. None of the area which contributes water to the cave is affected by logging or road construction.

Cases where implementation of the existing standards and guidelines has not provided adequate protection for cave features typically have some or all of the following characteristics:

1. The area around the cave entrance has been logged and no buffer zone, or else only a narrow buffer zone, of uncut trees was left around the entrance. Windthrow of trees, when they are left in small, isolated patches, is excessive and appears to almost always occur.

2. Roads, quarries, or clearcuts were located in areas which contribute waters to the cave.

3. Caves were not discovered early enough to modify the cutting area and/or road construction.

We have identified six short comings of present cave resource protection actions in the study area. They are:

1. The level of effort expended in reconnaissance work to locate and assess caves has been inadequate. This is to be expected in a fairly new program.

2. Insufficient time between reconnaissance work to locate and assess caves and the start of road construction or timber harvest activities. This results in last minute surprises and band—aid—mitigation efforts instead of sound resource management.

3. Inadequate recognition of the adverse impacts of roads on cave resources.

4. Inadequate recognition of the adverse impacts of quarries on cave resources.

5. Typical cave resource protection in the study area has focused almost exclusively on those caves reached through humanly accessible cave entrances. Such humanly accessible caves are only a fraction of the total cave resource. There are karst portions of the study area where surface features clearly demonstrate that caves, and probably very sizeable caves, underlie the area. Such caves are not receiving resource management attention compatible with that provided for caves with open entrances; this is not a desirable resource management

situation.

6. Cave resource protection actions have focused upon cave features (and particularly cave entrances) rather than upon cave systems. Cave resource protection must shift its focus from feature protection to system protection strategies.

A management strategy of recharge area delineation and vulnerability mapping is recommended by the Panel. The recharge area for a cave or spring is the area that contributes water to the cave or spring. In some cases the recharge area is little more than the land that overlies the cave. However, in many cases (and especially when the cave contains streams or lakes) the recharge area may be very large. Groundwater tracing is a fundamental tool for recharge area delineation.

Vulnerability mapping is a land management tool that has been used effectively in a number of karst areas. It utilizes the fact that some lands in a karst area create appreciably greater groundwater contamination risks than other lands. Recharge area delineation, in concert with vulnerability mapping, is appropriate and necessary for sound land management in the karst of the study area. Such delineation and mapping will help insure that land use and land management actions in karst portions of the study area are appropriately tailored to site conditions. Features and conditions that should be incorporated into a recharge area delineation and vulnerability mapping strategy are outlined.

The Panel reached 12 summary conclusions:

1. The karst and caves of the study area have attributes of international—scale significance.

2. The karst and caves of the study area have attributes of national—scale significance.

3. Significant karst resources are likely to extend into other areas of the Tongass National Forest.

4. Karst attributes of national and international scale significance are being degraded by (1) timber harvesting, (2) road location, construction, and operation, and (3) quarry construction and inadequate closure.

5. Resource management in the study area must be conducted with adequate recognition of the archipelago

setting of the area and its associated ecosystems.

6. Unique karst-specific conditions require that management of karstiands must follow a different management track from the track appropriate to nonkarst areas. The karst areas should be thought of, and managed, as islands within islands.

7. The Panel is concerned about reforestation conditions that commonly occur on the karstiands following timber harvest and that degrade the utility and/or the utilization of karst resources.

8. Karstiands are of critical importance to the fisheries of the area. Maintenance of long term high productivity in these streams will be a major benefit from improved karstiand management.

9. Cave resource protection actions by the Forest Service have been laudable, but have commonly not provided adequate protection for cave features.

10. Management of karstlands should involve four key components: (A) inventories of karst features, (B) recharge area delineations, (C) vulnerability mapping, and (D) incorporation of results from items A through C into planning and land management decisions.

11. The Forest Service should identify one or two high-quality, but minimally-impacted, karst areas for possible designation as a Research Natural Area.

12. Ten future study topics have been identified and prioritized. Concurrent efforts on multiple items will probably be superior to placing all effort on a single item. Top priority should be given to:

A) Protection and study of archeological and paleontological deposits because they are fragile and irreplaceable.

B) Testing and implementation of the outlined approach for recharge area delineations and related vulnerability mapping.

C) Cave resource inventories and mitigation assessments should be expanded and enhanced to ultimately insure that they are reflective of the entire range of karst resources.

D) Karst resources on other areas of the Tongass National

Forest are largely unknown and may be of comparable, and potentially complimentary, significance to those now known in the Ketchikan Area; they should be assessed.

It is only very recently that the Forest Service has begun to recognize the significance of karst resources in the study area. With this ever-growing recognition of significance has come awareness of resource vulnerability. This recognition and awareness led to the work of this Panel. Our Panel's conclusions have clearly demonstrated that the karst resources of the study area are of tremendous national and international significance for a substantial number of reasons. We have also demonstrated that many of these unique and priceless resources are also highly vulnerable to resource damage. The challenge facing the Forest Service is to integrate management of karstlands into general land management. The Forest Service must adequately protect and utilize the host of newly—recognized resources and resource interactions; recognizing new resources does not mean forgetting older resources. The Forest Service goal must be ecologically sound and scientifically credible resource management of the karstlands of the study area.

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INTRODUCTION

KARST DISTRIBUTION IN THE STUDY AREA

Karst is a three dimensional terrane developed on, and within, a soluble bedrock. Karstlands commonly contain springs, caves, sinkholes, and losing (sinking) streams. At least 700 square miles of the Ketchikan Area of the Tongass National Forest (hereafter called the "study area”) is karst (Baichtal, 1993>; it is likely that the extent of karst will prove to be larger when more detailed geologic mapping is conducted. These karstlands extend from salt water to some of the peaks. Springs, caves, sinkholes, losing streams, and a host of other karst features are abundant and often spectacular. Figure 1 shows known occurrences of carbonate rocks in the Ketchikan Area of the Tongass National Forest; we anticipate that all of the identified areas are karst.

THE KARST RESOURCES PANEL

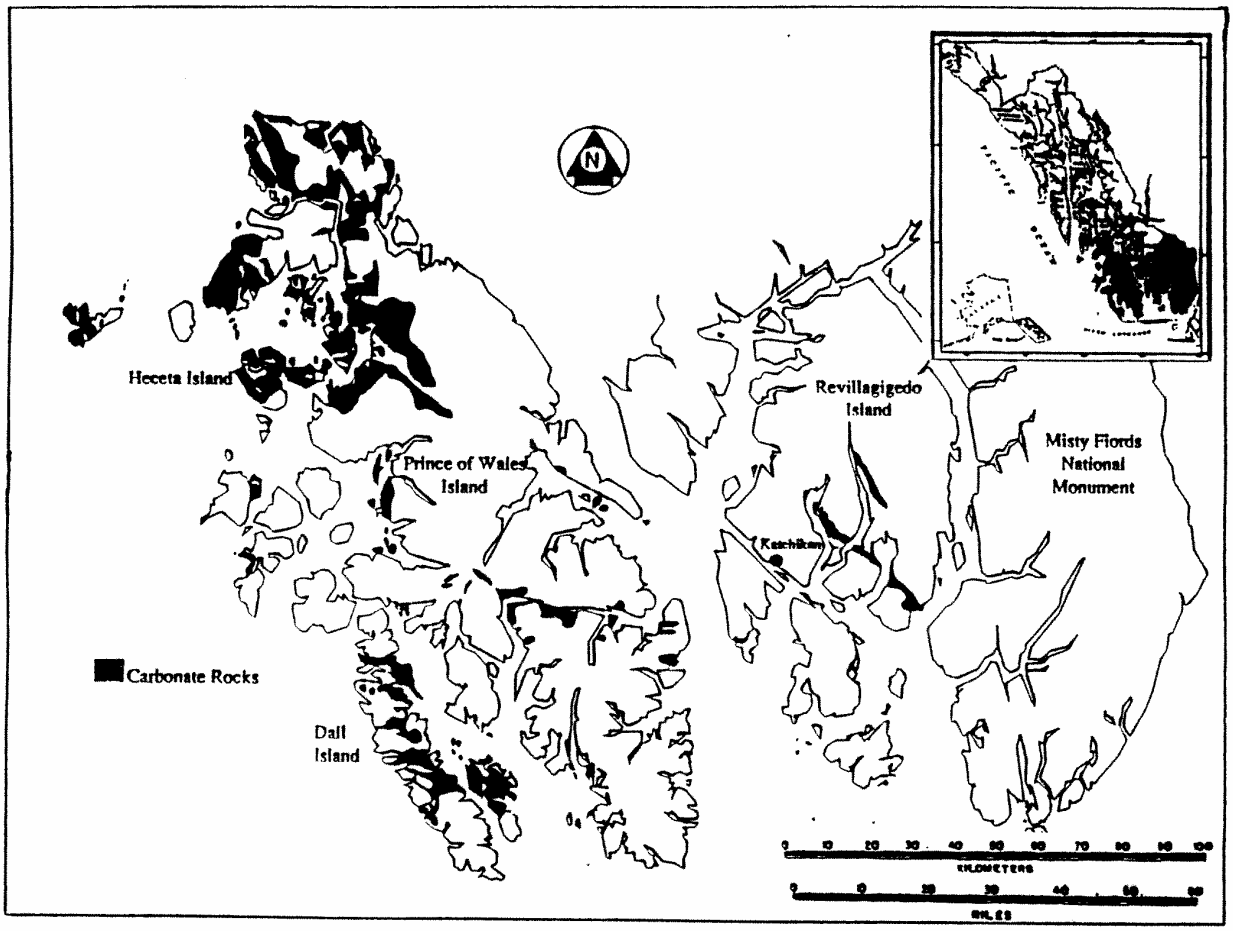
Only in the past few years have karst resources in the study area been recognized as unique and potentially significant. This recognition has come largely from within the U.S. Forest Service and the speleological community; this recognition of a previously unconsidered assemblage of resources is highly laudable.

When previously unconsidered resources are recognized, their significance must be assessed. Such assessment requires expertise in those particular resources; this is especially true if the resources appear to be of major significance. Recognition of karst resources by the U.S. Forest Service led to the formation of the Karst Resources Panel (hereafter called the “Panel”) and the investigation reported upon in this report.

The Panel was to conduct the following three tasks:

1) Determine the significance of the karst and cave resources on the Ketchikan Area of the Tongass National Forest with respect to similar resources in the United States and abroad.

Figure 1. Known Occurrences of Carbonate Rocks on the Ketchikan Area of the Tongass National Forest. Illustration from Baichtal (1993).



2) Evaluate the effectiveness and adequacy of current Forest Service standards and guidelines designed to protect the cave and karst resources; recommend changes as appropriate.
3) Recommend focused resource evaluation goals and research to continue Forest Service efforts to characterize and classify the karst ecosystem.

Our Panel is composed of four members with diverse experience and professional backgrounds, but with a common professional focus on karst resources. The Panel has a total of over 100 years of experience in resource studies and land management problem—solving in karst areas.

Tom Aley is the Panel leader. Tom holds B.S. and M.S. degrees in forestry from the University of California and is President of the Ozark Underground Laboratory. From 1966 to 1973 he was an employee of the U.S. Forest Service and directed studies on the Hurricane Creek Barometer Watershed in Missouri. These studies were focused on assessing the interactions of land management activities on water quality and quantity in a karst region (Aley, 1978).

Tom Aley's professional work has focused on karst, karst hydrology, and cave management. Much of his work has dealt with interactions between surface land use activities and resulting impacts on karst features and groundwater quality. In addition to his forestry expertise, he holds national certification as a professional hydrogeologist, and is a registered professional geologist.

Cathy Aley holds B.S. and M.S. degrees in biology and zoology from Wichita State University, Wichita, Kansas. Her work has focused upon karst hydrology, cave biology, and water quality issues; she has conducted numerous groundwater traces in karst areas. She has a broad background in stream ecology and general ecological investigations. Cathy has worked with caves and karst in high rainfall areas and/or in alpine karst areas throughout the West. This work has included assessment of the impacts of timber harvest and associated activities on caves and karst aquifers (Aley and Aley, 1986).

Bill Elliott holds a B.A. degree in zoology from the University of Texas in Austin and M.S. and Ph.D degrees in zoology from Texas Tech University. Bill has an extensive background in cave biology and has conducted work from Alaska to Central America. He has published approximately 30 professional papers focusing upon cave fauna and management issues related to rare and endangered cave species. In addition, he has conducted numerous cave and karst biology investigations for resource management agencieè (e.g., Elliott, 1991).

Peter Buntoon holds B.S., M.S., and Ph.D. degrees in hydrology from the University of Arizona. He is currently Professor of Geology, University of Wyoming. Peter has been involved in karst work for over 30 years and has specialized in karst geology and karst hydrology issues. He has recently published a series of highly regarded professional papers on the deforestation of karst areas in China and the resulting impacts upon water, soil, and vegetation resources (Huntoon, 1992 and 1992a). Much of this work has focused on areas with high annual rainfall. Peter holds certification as a professional hydrogeologist, as a certified ground water professional, and he is also a registered professional geologist.

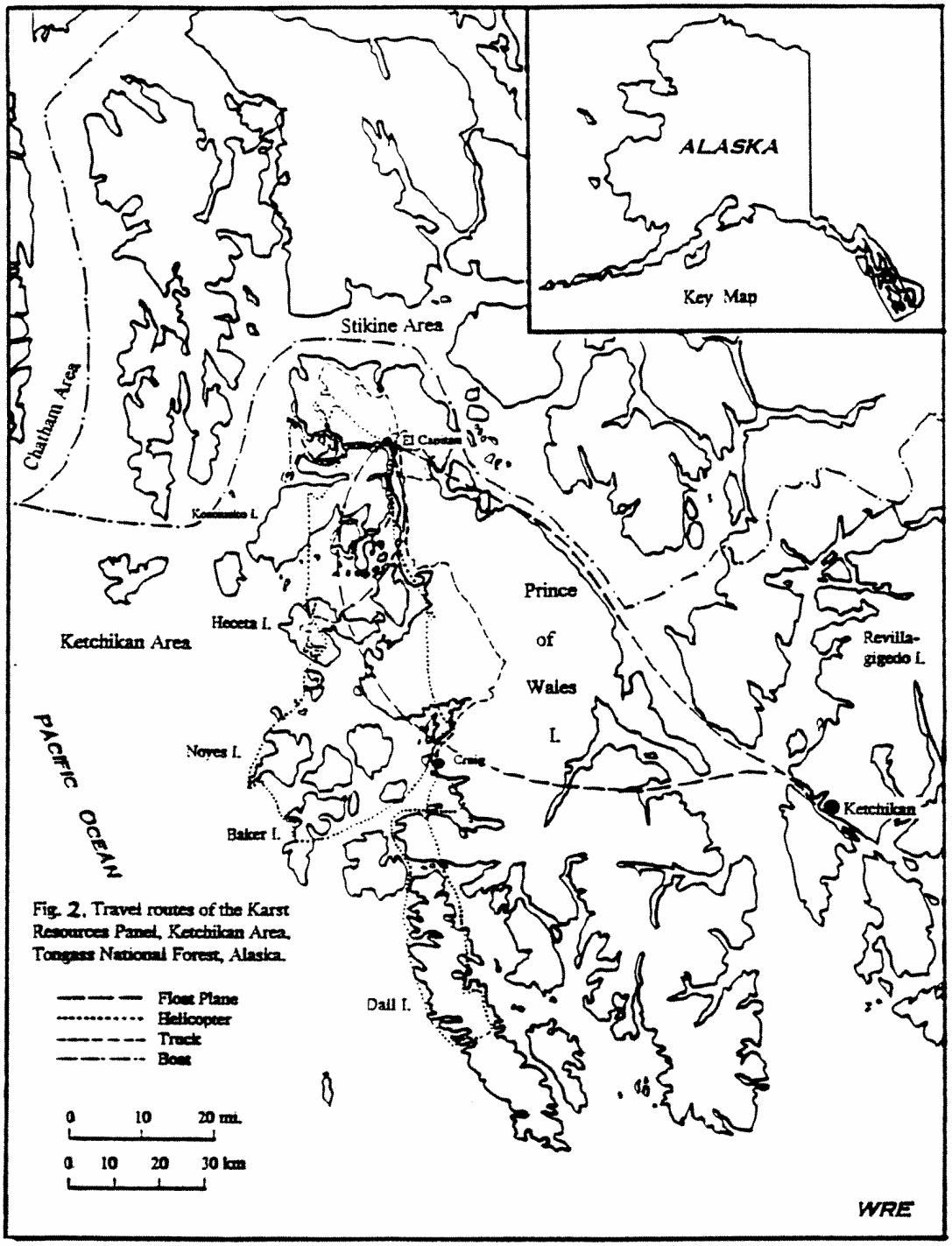
METHODS

During the course of the field work the Panel traveled 1,508 miles and viewed karst on eight islands (Figure 2). About 302 miles were covered by float plane, 412 miles by helicopter, 625 miles by truck, and 169 miles by boat. In descending order of emphasis, the following islands were seen: Prince of Wales, Heceta, Dall, Baker, Kosciusko, Marble, Noyes, and Tuxekan. The Panel visited the first five listed and flew over or navigated by the others. During the field work Panel members took about 1,000 photographs. The itinerary of the Panel is outlined in Appendix A.

Huntoon primarily conducted (1) a field and aerial photographic assessment of the geologic uniqueness of the karst resources within the study area, and (2) an assessment of the hydraulic function and genesis of the karst systems present. These efforts involved field reconnaissance by foot of as many karst features and caves as possible; transects from shoreline to peak on Heceta, Dali and Prince of Wales islands; visits to quarries to examine fresh rock faces; and examination of the exposed shorelines around the islands. Geologic information assessed included rock types and distributions on the surface, rock types and rock fabrics in caves, and tectonic fabrics. Hydrologic information examined included localization of karstic permeability, epikarst distribution and function, cave morphology, spring locations and discharge characteristics, and temperature and moisture distributions.

Elliott computer-searched and reviewed the bio-speleologicai literature for Alaska, Canada, and the Pacific Northwest in preparation for the study. Bibliographies were generated for future reference.

Figure 2. Travel route of the Panel.



Elliott, assisted by Cathy Aley and others, made collections of invertebrates in most of the caves visited. Small specimens were taken with alcohol-moistened paint brushes or by hand and preserved in 70% ethanol. We searched on walls, floors, under stones, and near any organic matter, such as guano, wood debris, or sediments. Cave streams and springs were sampled by hand and with small dip nets. Four springs (El Capitan Resurgence, Cataract Cave, Mop Spring, and Three Stooges Resurgence) were also sampled using the "mop method", which involves anchoring a new cotton mop in the water, then rechecking it for fauna after a microbial slime has grown on the cotton, usually after one or two weeks. A plankton net tow was taken in the sump at the end of El Capitan Cave, which involved repeatedly tossing out the net with attached sampling tube and towing it in on a cord. A soil-moss sample was taken at Flicker Ridge and processed in a Berlese funnel, which uses the heat of a light bulb to drive small invertebrates down into a preservative bottle. Elliott took macrophotographs of some fauna when time permitted. An Atkins digital psychrometer, accurate to 0.1°F, was used in some caves to measure dry and wet bulb temperatures for calculation of relative humidity. Psychrometer readings also were taken on two days during forest studies on Flicker Ridge.

Some of the most interesting specimens were Stygobromus amphipods collected in Nautilus Cave on Heceta Island. These were sent to Dr. John Holsinger of Old Dominion University, Norfolk, Virginia, for identification; they represent the highest-latitude troglobitic species in the Western Hemisphere. Other specimens are still being sorted and packaged for study by various taxonomic authorities on the different groups.

Kent Carlson, a biology graduate student, provided Elliott with information on cave and spring invertebrates that he collected in 1992-1993. These included troglobitic Stygobromus sp. amphipods collected from caves on Dall Island.

Tom and Cathy Aley focused upon water quality issues and related assessments of land use impacts. Portable field meters were used to measure pH, specific conductance, dissolved oxygen, and turbidity of water. Four dye-tracing studies were conducted to gain insight into the nature of karst groundwater systems in the region. The tracer dyes that were used were fluorescein, eosine, and Rhodamine WT. Sampling for the dyes used activated carbon packets; these are cumulative samplers that were left in place at springs and streams for varying periods of time. All analysis used a Shimadzu RF-5000U Spectrofluorophotometer operated under a synchronous scan protocol with an excitation slit of 5 nanometers (nm), an emission slit of 3 nm, and a bandwidth separation of 17 nm.

Tom Aley served as the Panel leader and compiled individual reports into this document. All Panel members have reviewed the report and concur with its conclusions.

KARST OF THE STUDY AREA

THE SETTING

The Climatic Setting

Southeast Alaska has a temperate, maritime climate moderated by the Alaska Current, an eddy off the Kuroshio Drift, which flows across the North Pacific. The sea moderates winter temperatures and cools the area in summer, when sea temperatures average 55°F, producing thick clouds and fog. Large amounts of precipitation occur annually in the study area; the amounts vary substantially among areas and tend to increase dramatically with increases in elevation. Precipitation in Ketchikan averages 160 inches per year (O'Clair, Armstrong, and Carstensen, 1992) ; precipitation probably exceeds 250 inches per year at high altitudes (Schmiege et al., 1974). Surface runoff in Southeast Alaska from lower elevation basins is about 60 to 100 inches per year and 150 to 200 inches per year from intermediate and high elevation basins (Schmiege et al., 1974). Short dry periods occasionally occur. As an illustration, little rain fell in the area for the period preceding and during this Panel study; this resulted in a noticeable decrease in the flow rates of many cave streams. The sump in El Capitan Cave dropped seventeen feet below its norm; this allowed cavers to explore farther than ever before.

Elliott recorded temperatures in four caves in February, 1993, and in seventeen caves and at a spring in July, 1993 (data are in Appendix B). In Beaver Falls Cave, between February and July the air temperature increased from 40° to 42.6°F while water temperature increased from 42° to 44°. February cave air temperatures in the four caves averaged about 40° (range 34-45°). July air temperatures averaged about 46° in eight caves on three islands (range 41-50.4°). February water temperatures averaged 40.5° in two caves. Summer cave water temperatures averaged about 43° in seven resurgences (range 41-44°). The only insurgence (a point where surface water enters the karst groundwater system) checked was Sinuous System on Heceta Island, which was taking 50° water from a peatland.

Relative humidifies were measured in three caves in July and averaged 99.2%. Such nearly saturated conditions are common in most humid region caves and are important for many reasons, including providing appropriate microhabitat for invertebrates and bats.

The Geologic and Hydrogeologic Setting

The origin and migration of the carbonate rocks that host the karst portions of the study area is every bit as fascinating as the karst itself, adding appreciably

to the geologic uniqueness of this karst province. The carbonate rocks that comprise these karat areas originated cm tropical Pacific islands that were transported by plate tectonic movements to their current locations. There is no other place in the world where tropical limestones have travelled so far, been involved in such an oblique collision with a continent, and ended up emplaced in an archipelago setting at such high latitudes.

The limestones found in the study area originated as marine reef and lagoonal deposits that were building on volcano-cored islands straddling the equator during Silurian time, 438 to 408 million years ago. Those islands were much like, but considerably larger than, the actively growing Mariana Islands in the western Pacific of today. It is quite probable that some of the limestones now in the Prince of Wales region were deposited on islands located south of the equator.

The interbedded, massive carbonate breccias represent over-steepened island shelves that collapsed from the island coasts. The broken limestone debris - the breccias - flowed down the flanks of the islands below sea level where they came to rest. New reef and lagoonal limestones were deposited on them increasing the diameter of the islands, and the process was repeated many times. See Figure 1 in Appendix C.

The story of moving these limestones to the southeast Alaska coast many thousands of miles across the Pacific ocean is dramatic. The limestones comprising the north end of Prince of Wales Island were incorporated into a thick sequence of rocks of sub-continental size now called the Alexander Terrane. The volcanic island arc rocks

comprising the Alexander Terrane accumulated over a vast amount of time, from Late Proterozoic to Triassic, above a dense oceanic crust that floored the ocean. These rocks did not sit still. Rather they were rafted across the Pacific ocean on the Pacific plate as it drifted toward, and was subducted under, the American continents. The path followed as the terrane wandered is unknown, but its net translation was generally eastward and northward relative to the Americas. The ultimate northward component of drift was at least on the order of 4,000 miles.

Eventually the terrane collided with North America during Middle Jurassic to Late Cretaceous time (between about 187 and 66 million years ago).

Appendix C, Figure 2 illustrates the docking process wherein the oceanic plate peels from the lighter island terrane above, sinks into the mantle, and is melted. The detached island terranes were thrust upon and welded to the continental margin in a process known as accretion.

The docking of the Alexander Terranes was complicated by the fact that the island rocks did not collide with the coast head on, but rather hit obliquely much like a ship sliding up to a pier. The result was that not only were the rocks compressed from east to west, they also were being smeared northward along the coast. This collision is shown diagramatically in Appendix C, Figure 3.

Upon its arrival, the Alexander Terrane fragmented along northwesterly trending strike-slip faults. These rifts allowed the outboard fragments to slide progres sively further north than the inboard pieces. Consequently the carbonate rocks on one large inboard fragment that now comprises Prince of Wales, Heceta and Kosciusko islands nicely match the carbonates on an outboard fragment that encompasses the northeast part of Chichagof Island. The offset between these once joined pieces was accommodated by some 100 miles of slip along a series of faults, the largest being the Chatham Strait Fault.

The discussion above was drawn from conclusions presented in Coney, Jones and Monger (1980), Brown and

Yorath (1989), Brew, Himmelberg, Loney and Ford (1992), Brew, Lawrence and Ludington (1992), Gehrels and Berg (1992), and Brew (in press).

The limestones that host karst portions of the study area did not passively ride through this tumultuous activity unscathed. First, they were buried by thousands, even tens of thousands, of feet of overburden during the island building phase, and were simultaneously intruded by magmas. The result was that they were pressurized and heated, processes that metamorphosed them into dense, beautifully veined and banded marbles attesting to a distorting past. The banding is a texture that was imposed as the rocks recrystallized and flowed during their metamorphosis, rather than representing deformed original bedding that has been largely obliterated in many outcrops. As the Alexander Terrane docked along the coast of western North America, probably far to the south of its present southernmost position, it was compressed against the mainland. This compressional event left its record in the form of thrust faults and sheared, overturned folds that are common in outcrops where bedding can still be discerned.

The Alexander Terrane was spectacularly fractured and then fragmented at all scales as it was rifted apart and smeared northward along the Alaska coast. The grand scale-fracture pattern is revealed in Appendix C, Figure 4, and that pattern is characterized by through-going northwesterly trending strike-slip faults along which the outboard bands of rock moved northward relative to the mainland. Second order, intersecting, north-trending strike-slip faults allowed the bands to break into huge blocks. Glacial erosion along these two sets of largest-scale faults now define the principal straits and passages in the southeast Alaska waterways.

Appendix C, Figure 5, illustrates the sense of motion along these largest faults. What makes the picture more interesting is that the grand blocks bounded by the large faults are themselves broken into smaller blocks by smaller faults that mimic their large counterparts in trend and sense of shear. In fact, this same fault pattern is repeated at many scales throughout the region, first as

terrane boundaries (tens to hundreds of miles), then on a full island scale (tens of miles), mountain block scale (a few miles or less), and so forth down to the outcrop and hand specimen scales observed on well-exposed beaches. The accumulated displacements within this pervasive fracture pattern allowed the width of the Alexander Terrane to slim down substantially perpendicular to the coast, and lengthen greatly parallel to the coast much as if it underwent a great taffy pull.

Although the fracturing is of academic interest in terms of the structural evolution of the Alaska coast, it had profound significance in guiding the genesis of the karst that is the subject of this report. We have found that the fractures serve two very important functions in the karsts associated with the Alexander Terranes. First, the intea-island and mountain-block scale faults commonly define karst system boundaries, a conclusion that has direct management significance. Secondly, cave passages, chains of sinkholes, and many other karst features are localized along sets of small to intermediate scale faults.

The tectonic processes described here added other terranes to the Alaska coast after the Alexander Terranes arrived, and smeared them northward along the coast in similar fashion. In fact, the Pacific Plate is still sliding northward along the west coast of Alaska. Active subduction occurs along the Aleutians. Consequently, Alaska is earthquake-prone.

The study area has also experienced appreciable glaciation, the extent of which varies substantially on both an inter-island and intea-island basis. The glacial history is important in understanding some of the karst features (or their absence). However, it is clear that glaciations such as occurred in the study area did not destroy all karst features (and specifically not all caves). Sea-level changes were also associated with glacial activity and its recession; such changes have also affected the study area. The magnitude of relative sea-level changes also varies substantially within the study area.

Clay deposits derived from glacial activity are found in some of the karst areas. Some of these clay deposits probably fill farmer sinkholes. Many peatlands (or muskegs) are separated from underlying limestone units by these clay deposits.

The Biological Setting

The flora and fauna of southeast Alaska are very diverse due to a number of factors that include:
1) An extremely wet climate where moisture availability is of less significance than in many other areas.
2) The glacial history of the region and major differences in the extent of recent glaciation within the study area. 3) The biogeographic: complexity associated with an archipelago of hundreds of islands.
4) The complex interplay of the sea with the extensive coastline.
5) The altitudinal and geologic differences present on the islands.
All of these factors enhance diversity and are associated with species variation. Such variation was noted by Swarth (1911) , who commented that nearly all mammal species in southeast Alaska vary throughout their ranges. Surfing et al. (1993) analyzed the distributions of vertebrates in Southeast Alaska and noted that several species or subspecies have ranges limited to this region.

The study area contains substantial areas of temperate coniferous rain forest. Alaback (1988, 1990) has characterized temperate rain forests as having the following characteristics:
1) An over-abundance of water throughout the year, and the absence of fire as a major ecological factor.
2) A location limited to areas of moderate maritime climate typified by at least 80 inches of rainfall spread out over at least 100 days of the year, 10% or more occurring during summer months.
3) Cool summers with July (or austral January) isotherm of less than 16 degrees C. (61 degrees F.) and a lack of persistent snow.
4) A general location less than 150 kilometers (93 miles) from the coast.

Sunlight in temperate rain forests is at a premium because of the dense forest canopy. Natural windthrows, which cause gaps in the forest, are important in main taining productivity and species diversity. The total biomass in temperate rain forests is greater than that in tropical rain forests. The total area of temperate rain forests is approximately 2.5% of the area occupied by tropical rain forests (Alaback, 1988).

Harris and Farr (1974) discussed tree species composition in Southeast Alaska and noted: "Tree species composition varies by location, topography, drainage, soil type, and stand history." Unrecognized in this list of variables is rock type and, where carbonates are present, the extent of karst development. Tree and other plant species appear to vary in composition between karat and nonkarst areas; they may also vary with the extent of dissolutional weathering of the underlying bedrock. Within the karst areas stand composition and apparent site index vary dramatically. However, even in karat areas, on commercial forest land it is western hemlock (Tsuga heterophylia) and Sitka spruce (Picea sitchensis) which are the principal tree species. Some stands of these species remain uncut on some of the karstlands of the study area. Very dense regeneration with these species exists on most, but not all, karat areas that have been clearcut.

Peatlands (locally called muskegs) are common. Their vegetation is dominated by sphagnum mosses or sedges (or both). Low shrubs and f orbes are present, but only scattered and small trees occur. Harris et al. (1974) reports that about 14% of Southeast Alaska is peatland. When runoff water from peatlands reaches carbonate rock units it commonly creates vertical-shaft-cave systems; these will be discussed later.

FEATURES OF THE KARST

Geologic and Hydrogeologic Features

Karst has two unique hydraulic characteristics. First, the permeability structure within the karst is organized to facilitate the circulation of fluids in the down gradient direction. Such an organization is absent in most other hydrogeologic settings. Secondly, the organization and hierarchy of the collector structures and permeability pathways were actually created by the circulation system, not some independent inherited static attribute of the rock.

The diversity of karst features and cave types present in the study area exhibit unusual breadth. This results, in part, because there is such diversity in physical environments. Karst areas on the typical island range from sea-level to the tops of 3,500-foot high mountains. Although the peaks are modest in height, the climatic zones grade with elevation from temperate marine along the coast to alpine above elevations of about 2,000 to 2,500 feet. Thus there exists, in compact form, essentially every elevation-dependent cave forming environment possible at this high latitude. Coupled with the complex structure of the limestone substrate and the complex glacial pre-history in the region, the result is a spectacular display of diverse karst forms. The following are selected highlights; they should not be taken as an exhaustive treatment of the diversity of features present.

Epikarst is an intensely dissolved veneer consisting of an intricate network of intersecting roofless dissolution-widened fissures, cavities and tubes dis solved into the surface of the carbonate bedrock. The dissolution features in the epikarst zone are organized to move infiltrating water to down-gradient seeps and springs, or to vertical collector structures such as shafts, that conduct the water into underlying karst conduits. Lateral circulation is lower than plant rooting depths and predominates over vertical circulation in most epikarst zones.

Epikarst is exceptionally well developed throughout the study area except at low elevations on those islands where it was destroyed by the last glaciers. Based upon the nature and magnitude of its features, the epikarst in the alpine zone is world class. It is characterized by deep shafts, crevasse-like dissolved fissures, eroded dissolution rills of all sizes, and spires and spikes of limestone. In the subalpine zone, the epikarst has virtually the same characteristics found in the bare alpine settings except it is- vegetated. Consequently, the subalpine epikarst yields an exotic landscape that is difficult to traverse, particularly in directions perpendicular to the grain of the fractures that have localized vertical dissolution.

Typical thicknesses of the epikarst zone range from more than 100 feet in alpine areas to less than 5 feet along the coast. Epikarst thickness appears to be more

a function of glacial history than altitudinal belt. The epikarst is extremely important in moving water, nutrients, organic matter, and soil from the land surface and from the rooting zone into the subsurface where these materials can move laterally to seeps and springs or to vertical collector structures that channel them downward into cave networks.

The quality of the epikarst in the study area is surpassed only by selected tropical epikarsts in places such as China, Papua New Guinea and Madagascar. Certainly

there is none better in the United States, even in the alpine karst areas of the Rocky Mountains of Wyoming and Montana.

Shafts. The climate and geology have been ideal for the development of deep vertical shafts in the limestones within the higher elevation karstlands of the study area. Those present in the alpine and subalpine zones occur in unusual density that is commonly unmatched elsewhere in the United States. They also possess great depth. For example, the deepest known vertical pit in the United States occurs on El Capitan Peak, providing a free fall of 600 feet. Other shafts nearby exceed free fall depths of 500 feet. Shafts having depths of 50 to 200 feet occur in exceptional abundance throughout the subalpine karst

areas. The number of shafts, and their depth potential, securely yields for the study area a status as a premier vertical cave province in the United States.

Caves. The caves in the study area are highly diverse in form and age. They occur in most of the carbonate rock type present in the study area and in the carbonate breccias. Carbonate rocks are those where the minerals calcite and dolomite comprise 50% or more of the rock. Most caves pre-date the recent glaciations; this is based upon the presence of glacial clays, glacial breccias, wood, and possibly even ancient ice, in some of the caves. Some caves exhibit exceptional evidence for having experienced episodes of geologic destruction and re-excavation. For example, passages in Beaver Falls Cave on Prince of Wales Island have dissolved through Tertiary(?) paleokarst breccias. Paleokarst refers to a karst in which the organized permeability structure has been destroyed through processes such as burial, infilling, collapse, compaction, brecciation, cementation, and structural fragmentation. Clearly, at this location, we observed at least two separate, superimposed generations of caves. The second developed with no control exerted by the orientation of the first. Paleokarst is also visible on the walls' of the Alaska Room in El Capitan Cave.

The caves in the study area are usually difficult to traverse because they tend to have stepped profiles wherein short horizontal or sloping reaches are interconnected by vertical shafts. The horizontal segments are usually localized along structural fabric elements such as fractures and shallowly dipping thrust faults. The vertical segments tend to crosscut all structural elements regardless of their presence. Pits have been found that even bored through basalt dikes. Caves with highly uneven floor morphologies and 3-dimensional mazes of passages, such as found in the upper two levels of El Capitan Cave, have the appearance of having formed under low-gradient, fully saturated conditions. This leads to the tantalizing conclusion that this cave, and possibly many caves, developed near or below sea-level. It should be remembered

that the relative elevations of the land and the sea have changed through time. These relative differences vary substantially across the study area.

Unambiguous evidence demonstrates that some of the caves have great antiquity for a glaciated area and have experienced cyclic filling and emptying. A marmot tooth in excess of 30,000 years old has been found in Devils Canopy` Cave. Lags of appreciable antiquity occur in caves where no present passage can accommodate their ingress. An example is El Capitan Cave where the oldest dated log was carbon-dated at 6,500 years before present (Baichtal, 1993). They obviously entered' from above through now plugged shafts. Breccias and glacial clay plugs form the ceilings of domed rooms in many caves. Those rooms were re-excavated from old, infilled shafts that remain closed to the surface. The fact that the bridging material is comprised of glacial clay or breccia reveals that the infilling took place during some past glaciation.

Peatlands are common in the study area. They are typically found either underlain by noncarbonate rocks or else perched upon glacial clay deposits. Some debate exists in the literature about whether or not peatlands are advancing into presently forested areas. Where peatlands underlain by glacial clays are bounded on the down-slope side by carbonate rocks there is no question but that the peatlands are being encroached upon by the karstlands. In such settings highly acidic runoff waters from the peatlands (C. Aley measured pH of such water as low as 2.4) commonly create systems of vertical shafts in the adjacent carbonate rock units. These shafts enable surface streams leaving the peatlands to downcut into the peat and glacial clays and reach underlying carbonate rocks. This results in headward migration of the systems of vertical shafts. The Panel quickly discovered that many caves in the study area were localized in this type of setting.

Portions of the study area also contain some superb littoral (sea) caves. Such caves have formed by wave action concentrated along structural features in the bedrock. Some of these littoral caves are in carbonate

bedrock and have been modified by some speleothem decorations. Some large littoral caves are now at elevations higher than present-day sea-level. The present position of the littoral caves may be due to eustatic sealevel change, isostatic rebound, or tectonics, i.e., fault displacement. Littoral caves with such a history (and particularly those in limestones) are extremely rare. Furthermore, these littoral caves are large and extremely well preserved.

Caves and shafts in the study area are commonly scoured by storm flows. Additionally, secondary calcite deposition in area caves is minimal due to a combination of climatic, hydrological, and chemical conditions. Consequently the walls are often exceptionally clean and thus allow for detailed analysis of the rocks and structural fabrics present. This situation is not common in most karst provinces, and will become increasingly important as scientists visit the area and try to unravel questions concerning the genesis of dissolution permeability. The evidence concerning just why karst permeability is localized where it is can be read directly from the cavern walls here. Similarly the qualities of surface exposures in the alpine, and even subalpine, areas cause those areas to be of great value to geologists and hydrologists interested in karst permeability. Caves are not the only component of karst, and karst scientists appreciate the exceptional quality of exposures of all the surface karst features found in the study area.

The exceptionally clean exposures of some of the karst features in the study area invite special acclaim. Vertical shafts are particularly aesthetic owing to well-developed, large-scale vertical fluting of the walls. The clean walls of many caves and shafts gives one the sense of moving through grand marble halls. There is little comparable in the other karst provinces of the United States.

The sheer concentration of karst features in the study area deeply impressed this Panel. A good example is the number of sinkholes per square mile. On some portions of Flicker Ridge we estimated that there were between 3,000 and 10,000 sinkholes per square mile. This contrasts

with an internationally significant sinkhole plain area in Indiana that has approximately 1,4417 sinkholes per square mile.

There are dozens of significant shafts per square mile in many subalpine and alpine zones of the study area. This is an exceptional concentration even from a global

perspective. Similar statements can be made for densities of cave entrances in several lower elevation areas.

To date, El Capitan Cave is the longest explored cave in Alaska, with some 2.5 miles of mapped passage. Such caves do not occur alone. The concentration of surface karst features, such as those on Flicker Ridge, indicate the presence of large cavern networks. We anticipate the eventual discovery of many large cave systems as the potential of this area is realized.

Hydrogeology. Most of the study area caves are hydrologically active. Those that carry streams are subject to extreme variations in flows. Stream flow rates through the caves typically vary by more than a factor of 144. Some of the largest floods occur when heavy rains fall on wet snow packs. Based upon flow rate estimates made at El Capitan Resurgence during the summer of 1990 (Allred, 1994), typical response times at springs lag daily snow melt cycles and precipitation events by less than a day; the response time at El Capitan Resurgence was on the order of 6 to 10 hours. At this spring, summer precipitation can increase flow rates from about 1 cubic foot per second (cfs) prior to a storm to peaks of 50 to 75 cfs approximately two days later.

Many of the caves display abundant evidence of turbulent storm flows which transport sediment, organic material, and even rocks through the karst groundwater system. Foam derived from dissolved organic matter in storm waters is often seen high on the walls of cave chambers; this indicates flooding levels in the chambers. While the cave systems are capable of transporting substantial amounts of material, they can also be plugged by such materials. Mint Cave on Heceta Island is an example of a cave plugged by large amounts of woody debris.

Tom and Cathy Aley injected tracer dyes for three groundwater traces in the study area during the course of the investigation (see Appendix 10. Additionally, they conducted sampling for a fourth dye injection made earlier by cave explorers working in the area. There were positive dye recoveries from 3 of the 4 traces.

In the first trace fluorescein dye injected in the discharge from Sink Hole Lake upstream of Thunder Falls on July 23, 1993, was visible in 108 Creek at Road 2720 on August 16, 1993. This dye apparently discharged from a spring tributary to 108 Creek a short distance upstream of the road crossing. The straight line travel distance through the groundwater system was approximately 4,800 feet in 24 days under low flow conditions.

The second trace used Rhodamine WT dye, which was injected at Rivers End Cave on July 25, 1993. This dye was recovered from Cataract Cave (approximately 4,500 feet to the southwest) in activated carbon samplers in place for the period July 25 to August 2, 1993; the travel time through the groundwater system was thus less than a week.

The third trace used eosine dye, which was injected in a sinking stream near Beaver Falls Cave on July 25, 1993. None of this dye was recovered, probably because the sampling period was too short or else the discharge point for the dye was not sampled. Some samplers remain in place and may contain dye. All of our tracing was designed with only short term, non-intensive sampling; failure of some or all traces was a recognized possibility.

The fourth trace involved fluorescein dye injected by Steve Lewis into water sinking at Slate Cave. We began sampling at El Capitan Resurgence immediately after learning of this dye injection; this was approximately two weeks after dye introduction. Fluorescein dye was present in our first sampler from El Capitan Resurgence, which is approximately 3,700 feet straight line distance from the point of dye injection.

The limited tracing work to date demonstrates that karst groundwater systems in the study area routinely transport water for several thousands of feet to receiving caves, springs, and surface streams. Shorter and longer distances and times than those demonstrated to date will be found as more groundwater tracing work is conducted.

Appendix D includes hydrogeologic data collected by members of the Panel. These include specific conductance measurements of water. Specific conductance is a measure of the ability of water to conduct electricity. In karst areas, specific conductance is an indicator of the amount of dissolved rock contained in the water. Based upon the limited sampling conducted, specific conductance values in karst portions of the study area are about half the mean values typically encountered in most American karst areas (such as the Ozarks of Missouri). However, karst portions of the study area yield annual runoff that is typically on the order of 8 to 16 times greater than that found in areas such as the Ozarks. The net effect is that solution of soluble bedrock occurs on the order of at least 4 to 8 times faster in the study area than in regions such as the Ozarks. This difference is of scientific interest, and may be associated with differences in solutional features and their densities in the study area as contrasted with other American karst areas.

Mineralogical Features

As noted earlier, most of the caves of the study area contain only limited speleothem development. However, beautiful and delicate decorations are found in some caves. Probably the most unique mineralogical feature found in the caves of the area is moonmilk. Hill and Forti (1986) state that moonmilk: "...is a term used to describe aggregates of microcrystalline substances of varying composition. Most usually, moonmilk is composed of carbonate minerals, but sulfates, phosphates, and other, rarer, cave minerals can also form as moonmilk. Texture, not composition, is implied by the term 'moonmilk,. Moonmilk is soft, plastic, and pasty when wet, but crumbly and powdery when dry. Wet moonmilk looks and feels like white cream cheese when rubbed between the fingers."

There are several modes of origin proposed for some of the different types of moonmilk. Some of these involve bacterial activity and the presence of organic carbon.

Detailed chemical and biological information on the moonmilk found in the study area has not been developed. The moonmilk deposits in the study area are abundant and often of large size as compared with deposits elsewhere in the United States and in the tropics. Moonmilk flowstone was noted in some of the caves. There are several postulated modes of origin for moonmilk; more than one mode of origin may be possible. Based upon our present level of study and understanding, the most important characteristics of the moonmilk in the study area are abundance, size, and presence in the form of speleothems such as flowstone.

Biological Features

Karst portions of the study area contain important forest resources. Harvested trees are used for pulp and sawlogs, and they represent important economic benefits

to residents of the area. Based upon the Panel's observations and information from Streveler and Brakel (1993), karst areas support some of the largest trees and highest volume stands found in the study area.

A much greater percentage of karstlands have been cut over than has been the case with nonkarst areas. There are various factors that contribute to this, yet the high timber yields of the karstlands have clearly been a great attraction. Based upon the work by Streveler and Brakel (1993), about 70% of high volume timber stands on karstlands in the study area have already been cut. This percentage may be greater within selected areas.

Karst portions of the study area are important wildlife habitats. Additionally, streams draining karst areas are clearly of great importance to the fisheries of the area.

In fact, it is probable that streams draining karst areas have appreciably greater aquatic productivity than do streams draining areas where karst is absent. As a general rule, stream water that is slightly basic tends to be more biologically productive than stream water that is acidic to slightly acidic.

Some interesting distributions of plants may be associated generally with karst landscapes in Southeast Alaska. It is not known if these plant distributions are related to carbonate geology per se or to possible glacial refugia on the outer coast. Due to a general lack of baseline plant surveys it appears to this Panel that there is only a rudimentary knowledge of the inter-island variation of plant species. However, it is worth noting that alpine floristic differences between the calcareous Alps and the crystalline siliceous central Alps are very pronounced (Walter, 1973).

Species variations could have arisen since the end of the Wisconsin glaciation (about 10,000 years ago) as animals and plants colonized the different islands. Little is known of the details of glacial refugia in the Alexander Archipelago (Perue, 1992; Mann, 1986), so some variants could derive from refugia. In the case of cave faunas, most incidental species probably have utilized caves only since the Wisconsin, but a few cave-adapted species (troglobites) could pre-date the Wisconsin or even the Illinoisan glacials. In the case of Stygobromus amphipods, their ancestors may have colonized groundwater systems many millions of years ago.

This Panel visited a total of twenty-four caves on five islands and invertebrate collections were made in all but six caves; resulting data are included in Appendix B. The overall pattern seen thus far in the invertebrate cave fauna is that no troglobitic (cave-adapted) species occur on Prince of Wales while troglobitic species (blind Stygobromus amphipods) occur in karst groundwater on the outer islands of Dall (K. Carlson, 1993) and Heceta.

A troglobitic amphipod (Stygobromus quatsinensis)was collected by the Panel on Heceta Island (55°45'53"N). This discovery is a high-latitude, Western Hemisphere record for a cave-adapted species. The only cave-adapted species that is found further north is a Crangonyx species from a cave in the Ural Mountains of the former Soviet Union.

Stygobromus guatsinensis was described from caves on Vancouver Island, British Columbia (Holsinger and Shaw, 1987). Its presence on Heceta Island raises interesting questions about a pervasive, regional, fresh-groundwater system which may have existed during the last glaciation. Despite the apparent absence of troglobitic species on Prince of Wales Island, some interesting species records have been found. For instance, Crangonyx richmondensis (an amphipod) was collected in River's End Cave, Prince of Wales Island (K. Carlson, 1993). This eyed species had not been found previously in northwestern North America. Additional disjunct or new species probably will be found once all collections from this investigation have been studied. Furthermore, more important discoveries will undoubtedly result from more biological cave studies.

The apparent lack of troglobites on Prince of Wales appears to be correlated with the glacial history of the region. It appears likely that glaciation on Prince of Wales Island during the last ice age (Wisconsin) was substantially more extensive than that on the outermost islands. Glaciation could have caused the extinction of any cave-adapted species that may have inhabited Prince of Wales Island. Since the glacial history of the islands has not been worked out in detail, the possibility remains that some unstudied karst areas on Prince of Wales and other islands were ice-free during the Wisconsin glaciation and may still retain troglobites. It is also possible that a few cave species survived under glaciers, as in the case of Stygobromus canadensis, a troglobitic amphipod that survived under a glacier in Castleguard Cave, Alberta, Canada (Holsinger, 1980).

Prince of Wales Island caves usually have streams containing eyed flatworms, nearly transparent oligochaete worms, and stonefly, caddisfly, or mayfly nymphs (with some adults on the walls). Some contain Crangonyx and Gammarus amphipods which have eyes and pigment. On pool surfaces one may find small, white mites walking on the surface tension. These appear to be members of the Family Rhagidiidae, and could well be new species of troglobites or troglophiles. Collembolans (springtails), tiny hopping insects, are

sometimes found on organic material, and may comprise several new species. On the walls one may find adult stoneflies, daddy longlegs harvestmen, and occasional spiders. The presence of daddy longlegs in the winter is unusual compared to southern species, which have massive die-of fs in the autumn. Alpine caves visited on Prince of Wales and Dall islands contained cyanobacterial slime, which could be in association with bacteria.

Vertebrates also use caves. These include occasional salmon, Sitka deer, wolves, black bears, otters, mice, and bats. D. Baichtal and Cook (1993) have reported Myotis californicus bats hibernating in El Capitan Cave, the first report of a hibernating bat in Southeast Alaska. The use of caves by bats in a region so far north is a recent discovery and is of great value in understanding the extremes to which bats can adapt. More bat studies are in progress.

Salmon have been seen in Cavern Lake Cave and Salmon Fry Cave and may rest, feed, or spawn there. Mammal droppings provide food for invertebrates or fungi and

bacteria on which an invertebrate food chain is started. Some caves are important hibernacula or den sites for black bears, otters, other fur-bearers, and bats. Brown bears, now extinct on Prince of Wales, used caves there in the past (Heaton and Grady, 1992). The importance of these caves as occasional habitat for vertebrates in Southeast Alaska has been overlooked in the past.

Paleontological and Archeological Features

The Pleistocene paleontology of the area is primarily known from cave and rockshelter deposits, which are often intimately related to archeological sites. Preservation of bone and organic materials is exceptionally good in these cold and basic environments (Heaton and Grady, 1992; Dixon et al., 1992; R. Carlson, 1993). To date, significant archeological and paleontological materials have been discovered in at least thirty caves and rockshelters on seven islands in the study area (R. Carlson, 1993). Such material is of international importance in tracing the

regional prehistory, the effects of climatic changes, and the colonization of the Alexander Archipelago by wildlife and humans at different times in the past.

The following paragraph from Dixon et al., (1992) is reflective of the significance of the prehistory and paleoecology resources of the study area.

"A previously unknown and spectacular system of caves has been discovered recently within the coastal temperate rain forest of Southeastern Alaska. The caves of the Tongass National Forest are located in a unique environment representing a major area of North America in which the regional paleoecology and cultural chronology are largely unknown. As such, it presents one of the last major scientific frontiers of its type in North America. The caves and their associated deposits provide an unparalleled opportunity to interpret a rich cultural and paleoecological record dating to the late Pleistocene and possibly earlier. In the highly acidic depositional environment of the temperate rain forest, the caves provide a unique context in which abundant organic remains necessary to interpret and date regional paleoecological and cultural development are preserved."

Our Panel visited several of the caves that contain significant archeological and paleontological resources. In one littoral cave there are scores of well-preserved logs deposited in a cave that is 30 feet or so above present sea-level. One of these logs was carbon-14-dated at 4,200 years +/- 70 years before present. These logs, which could be identified to tree species, may provide unique information about past oceanic circulation patterns and/or the past vegetation of the region. Another cave in the study area visited by the Panel contains prehistoric paintings which incorporate speleothems and structural folding into the art. While such cave art is famous in Europe, it is extremely rare on our continent.

Recreational Features

The karstlands of the study area, and the caves within, have enormous recreational values. They offer beauty, discovery, and adventure. The entire Panel was extremely

impressed at the exceptional recreational values existing in the karst of the area. The previous discussions of karst resources are indicative of the recreational values possessed by the study area and its caves.

The Panel was particularly impressed with the recreational and esthetic values found in several blocks of old-growth-forested karsts. The El Capitan Peak and Perue

Peak-Flicker Ridge areas on Prince of Wales Island, Bald Mountain area on Heceta Island, and the unlogged karsts of Dall Island from coast to peaks are representative examples of such quality areas visited by this Panel. As a purely aesthetic experience, the synergy between the old growth stands, superior surface karst morphology, and presence of caves gave us all a sense that we had walked through enchanted lands.

The Panel believes that the feasibility of recreational developments related to the karst resources of the area should be studied by the Forest Service. Interpretive

and recreational trails might be constructed around Starlight Cave, the Sinkhole Lake area, Yukon Shaft, Rivers End Cave, and Beaver Falls Cave. A trail from Flicker Ridge to the Perue Peak area would provide access to some superb karst features. Other trail opportunities exist in the vicinity of El Capitan Peak. Trails that provide access to, and interpretation of, surface karst features should be of substantial public interest.

SIGNIFICANCE OF THE KARST

The Panel has concluded that the karst and caves in the study area possess attributes that are of international and national-scale significance. These attributes, and

their scale of significance, are identified in the following pages.

Conclusion 1. The karst and caves of the study area contain features that are of international-scale significance. The attributes of international significance are as follows:

1. The occurrence of major karst development in the unique geologic and archipelago setting of Southeast Alaska.

2. The occurrence of significant portions of the karst in a largely undisturbed, high-latitude temperate coniferous rain forest. Such settings are, for practical purposes, globally limited to Southeast Alaska. Small amounts of karst in temperate coniferous rain forest remain on Vancouver and Queen Charlotte Islands.

3. The tremendous diversity of karst features present in the study area.

4. The quality of natural preservation of karst resources.

5. The density and degree of development of karst features. As one illustration, sinkhole densities in some areas were estimated to be as great as 3,000 to 10,000 per square mile.

6. The existence of large and extremely well-preserved littoral (sea) caves, some of which are now located at elevations higher than present-day sea-level. Those located at elevations higher than present-day sea-level were formed when massive weights of glacial ice had depressed the land surface relative to sea-levels.

7. The presence and abundance of archeological resources that include cave art and may include critically important deposits helping us understand prehistoric colonization of the North American Continent. At least twenty-three caves and rockshelters in the study area are known to contain archeological deposits.

8. The existence of outstanding and unique paleontological deposits of international significance in understanding climatic changes and their effects. The

deposits will also provide critical information on the colonization of the Alexander Archipelago by wildlife at different times in the past. Well-preserved logs with ages in the 4,000 to 6,000 year range are found in at least two caves; such materials are potentially of tremendous scientific importance.

Conclusion 2. The karst and caves of the study area contain features that are of national-scale significance. The attributes of national significance are as follows:

1. The karst area is characterized by very high annual precipitation. This results in regional karst dissolution rates (regional denudation rates) on the order of at least

4 to 8 times greater than rates in most other American karst areas.

2. Several caves in the study area contain abundant and unique moonmilk deposits.

3. Relationship between peatlands (muskegs) and vertical shaft development in adjacent down-slope locations are common and obvious in the study area. While such relationships occur in localized areas elsewhere in the world, they are essentially absent from other portions of the United States.

4. Karst areas contribute waters to some of the most significant fisheries streams in the study area. It is probable that streams draining karst areas have appreciably greater aquatic: productivity than streams draining nonkarst areas. The fisheries resources of streams in the study area are clearly of national significance.

5. Troglobitic (cave-adapted) invertebrates on inner islands (such as Prince of Wales) are either very rare or absent; such species are found on outer islands (such as Heceta and Dally. This difference is probably attributable to differences in the extent of recent glaciation. This relationship) is of national-scale biological interest.

6. The discovery of a troglobitic cave amphipod, Stygobromus quatsinensis by the Panel in a cave on Heceta Island. This species was previously known only from caves on Vancouver Island. This discovery at

latitude 55°45'53"N, is a high-latitude Western Hemisphere record for a cave-adapted species. The only Stygobromus species which is found further north is an undescribed species that occurs at 57°N in a stream entering Surprise Lake, Aniakchak National Monument, Alaskan Peninsula; this is not a karst site.

7. Caves in the study area are used by large mammals to an extent no longer seen in the "Lower 48 States". 8. The caves present a unique opportunity to study evolution and adaptation of invertebrates in an archipelago setting with a complex geologic and glacial history. The only similar opportunity in the nation exists in Hawaii, which contains numerous lava caves and has a completely different evolutionary, geologic, and climatic history. Comparison of the cave faunas of these two archipelagoes could lead to new scientific insights on species diversity and related issues.

9. From a recreational perspective, the fact that the caves and karst occur in Alaska. This fact imbues these features with a singular mystique of its own. Furthermore, the cave resources are vast and largely untouched and unexplored. As a result, there are unprecedented opportunities for explorers to discover virgin caves and to probe yet unfathomed passages in the known caves. Discovering virgin passage is the greatest thrill in cave exploration. The romance attached to the possibility of going beyond the frontier in Alaska translates into an irresistible draw for cavers worldwide, and assures lasting attention focused on caves and karst in the study area.

LAND MANAGEMENT IN KARST

PHYSICAL CONSTRAINTS

As a practical matter, any land in the study area underlain by carbonate rocks should be considered a karst environment. This approach is appropriate in the study area because climatic circumstances here are particularly favorable for the development of dissolution permeability in all the carbonate rocks present. No carbonate blocks within the region have been identified that do not contain karst features.

The rapid circulation of water in karst areas is fully three dimensional as contrasted to two dimensional for areas underlain by other rock types. The reason is that karst landforms shunt surface flows into the subsurface where the water moves through open conduits at velocities equal to, or approaching, typical surface streams. Not only are waters shunted downward, but karsts in the study area easily accept and transport everything that normally passes along surface streams including nutrients, soils, and organic debris. Some karst groundwater systems in the study area accept and transport rocks and logs.

In contrast to most of the study area, some karst areas are blanketed with thick layers of soils or residuum that at least partially insulate underground conduits from the impacts of surface land use. This is not the case in most of the study area for a collection of reasons. First, the mineral component of soils in karst areas is generally derived almost solely from the insoluble fraction of the bedrock. In the study area this fraction is often only one to three percent. As a result, soils on karst in the study area are extremely shallow and contain very little inorganic matter. Secondly, past glaciation has removed much of any residuum that might once have covered the bedrock. Some portions of the study area do have glacial clays which have been deposited over the carbonate bedrock. Finally, the rugged topography and very abundant precipitation enhance erosion and subsequent sediment transport.

Karst systems impose major management liabilities not encountered in nonkarst areas. The subsurface karst drainage networks generally operate independently of, and

with more complexity than, the surface drainage systems above them. Three important considerations apply. First, the size and shape of the karst systems often have little or no relationship to the overlying surface drainage systems. Second, the direction of flow through the karst systems often cannot be predicted from surface topography or geologic mapping. Karst systems have the annoying trait of accepting water from one surface drainage system and shunting it to another drainage basin on the other side of the ridge or mountain. Third, the discharge from a karstic groundwater system is not always localized at one spot as occurs in a surface drainage basin. Water entering one sinkhole in a basin may discharge from several springs at diverse compass bearings from the input sinkhole. Furthermore, exactly which outlet, or group of outlets, will be used can depend on the volume of water in the system at the time.

Rapid rates of water flow through karst systems is of management significance. Flow velocities often equal or approach surface stream velocities. Thus, karst groundwater systems are fast response systems. Pollutants such as diesel fuels or sediments from roads or other disturbed lands can arrive unexpectedly at one or more distant springs within hours to a few days. Human water supplies and fisheries are routinely, and severely, impacted by such events in karst areas.

Karst systems should not be viewed solely as hydraulic features. Their open nature provides unique habitats for all sorts of living creatures including invertebrates, bears, bats and economically important fish such as salmon. Consequently, as we define the dimensions of a karst system, we are simultaneously delineating a karst environmental system.

The above factors predicate that karst areas be treated with special management approaches and careful planning. It is therefore appropriate to identify and segregate the lands underlain by

carbonate rocks from those underlain by noncarbonates. Karstlands must be placed on a different management track and managed differently from most other lands.

RESOURCE MANAGEMENT

Present Land Uses and Management

At present timber production and harvest is the dominant land use in the study area. However, fishing and hunting are also important land uses; they are related both to subsistence and recreation. Streams in the study area are of critical importance to salmon spawning and thus contribute to the economically important fisheries industry of the region.

Road construction in the study area is driven almost exclusively by timber harvest and the establishment of road access into virgin forest stands. In many forested

areas (but not the study area) timber access roads are constructed largely of compacted soils. In response to the large amount of annual precipitation, the amount of rock required for road construction in the study area is much greater than in many other forested areas. As a result, rock quarries have been established every couple of miles along the roads to provide rock for the roadbeds. Abundant quarries help minimize haul distances. Carbonate rocks are more desirable for road construction in the study area than most other rock types. As a result, quarries have been disproportional ly located in karst portions of the study area.

Preparation of an area for quarry development involves removal of overlying soils and vegetation. The Panel has seen cases where surface overburden and vegetation has been removed from the quarry site and shoved into nearby sinkholes; the result is that large volumes of sediment and organic material are directly introduced into the karst groundwater system where they will be transported to receiving springs and streams. Additionally, poorly controlled blasting during quarry operations throws chunks of rock over a wide area around the quarries.

The typical quarry is abandoned after use. It is our conclusion that abandoned quarries are typically inadequately reclaimed and inadequately revegetated. Quarries sometimes contain trash and show evidence of waste oil and other petroleum products disposal.

In most cases contaminants from such activities will enter the karst groundwater system and yield contaminants to downstream waters.

Because quarries are located very close together to minimize hauling distances, the net result is more land disturbed by quarries than would be the case with greater spacing between quarries. Quarries, as presently located, designed, constructed, and operated, routinely result in excessive introduction of poor quality water into karst groundwater systems, caves, and receiving springs and streams.

The typical road in karst portions of the study area is largely comprised of crushed limestone. The rock is crushed in place on the road and is not washed. A substantial amount of fine textured materials exist in the road because of this and because of the abrasion between rocks when the road is traversed by vehicles. As a result, the roads create substantial amounts of sediment. Additionally, in more rugged terrains, we observed a number of steep and poorly revegetated cut and fill slopes. These are particularly common where localized deposits of glacial clays are encountered. Sediment traps downstream of roads are rare to nonexistent in the study area.

Many roads dispose of runoff waters to nearby sinkholes or to losing streams. In some cases water is run in road ditches for several hundred feet and then directed into a sinkhole. Such sinkhole disposal activities elsewhere in the United States have been viewed by the Environmental Protection Agency as practices regulated by the Underground Injection Control Program of the Federal Safe Drinking Water Act. Sinkholes receiving such runoff waters are viewed as Class V injection wells under the Underground Injection Control Program.

An illustration of the diversion of road runoff into sinkholes and caves is provided by Thrush Cave on Prince of Wales Island. The cave entrance is located in a large sinkhole; the entrance is about 150 feet downslope of a main spur road which provided access to a cutting unit. Approximately 700 feet of road ditch feeds water to a

culvert; this culvert discharges water to the cave at the point along the road nearest to the cave entrance. Because of the long road ditch, the area topographically tributary to the cave entrance has been increased about ten fold. There is appreciable sediment and organic material within the road ditch, and abundant new debris and sediment have been washed into the cave. A buffer zone of trees was left around the cave entrance; it was not capable of mitigating the impacts from road runoff.

Sediment and detritus produced by roads and other land disturbances in karst areas is often missed by the surface observer because it rapidly moves underground and, seemingly, disappears. Introduction of these contaminants into the karst groundwater system constitutes a significant resource protection problem that must be effectively addressed.

There are various structural and vegetational approaches that can be used to reduce erosion and to decrease the deposition of sediment and detritus in undesirable locations. In many cases the best approach will be road locations and designs that are compatible with water quality protection in karst areas. Such roads will avoid sinkholes and losing streams, and will not directly discharge waters to such important groundwater recharge features. In addition, greater attention needs to be focused on revegetation and erosion control. Sediment traps should be designed and constructed in some areas. Many timber roads should be closed and revegetated after harvest.

In the "Significance of the Karst" portion of this report we listed karst attributes that we determine to be of international significance. One of the seven listed attributes was: "The occurrence of significant portions of the karst in a largely undisturbed, high-latitude temperate coniferous rain forest. Such largely undisturbed karst settings are, for practical purposes, globally limited to Southeast Alaska." On lands where timber harvest occurs, this land use directly removes this internationally significant karst attribute.

Timber harvest in karst portions of the study area creates other impacts on attributes that this Panel has determined are of international or national significance. Let us discuss some of the mechanisms involved.

It is well established that logging activities result in increased erosion and resulting sediment transport by runoff waters. There are dramatic differences in sediment transport conditions between karst areas and nonkarst areas.

In nonkarst portions of the study area sediment must move laterally to a stream, and then flow down the stream. Management efforts are made to protect riparian corridors

from logging and its impacts. The large amounts of slash and cull materials remaining on the ground after logging, plus the heavy moss growths on the ground prior to logging, help trap and retain substantial amounts of the sediment. Vegetation can rapidly become established on trapped sediments. As a result of these and other factors, statements such as the following from Schmiege et al. (1974) are reasonable:

> "Suspended sediment loads of nonglacial streams in southeast Alaska are extremely low, even in heavily logged watershed. For instance in two watersheds near Hollis where clearcuts exceeded 2,000 acres in size, suspended sediment during and following logging in the Harris River never exceeded 3.7 ppm (parts per million) under average flow conditions or 148 ppm during peak flows, and in Maybeso Creek 7 ppm during average flow or 38 ppm during peak flows. Such low suspended sediment levels are due to the unique watershed characteristics, namely, low intensity rainfall; soils with thick, tough organic surfaces; extremely rapid infiltration and percolation rates; and lack of surface runoff except on badly disturbed ground. The difficulty of obtaining precise measurements in the field may also have been a factor."

Karst areas transport sediment differently from nonkarst areas. The most important difference is that in many karst portions of the study area much of the sediment must move laterally for only a few feet before it is directly transported downward into conduit portions of the karst groundwater system. Once sediment is into the conduits there are no effective natural processes for trapping and retaining it within the system; as a result, it is delivered to a receiving spring or stream. As demonstrated by the dye-tracing work conducted by the Panel, the receiving spring or stream may be several thousand feet away from the point of sediment introduction.

Features of the epikarst have previously been described. Areas with deep and well-developed epikarst have more closely spaced near-surface openings into which sediments can be flushed than is the case in areas with only shallow epikarst. As a result, sediment transport potential is typically much greater in areas underlain by deep and well-developed epikarst. Observations by this Panel indicate that most of the thin epikarst occurs in areas at relatively low elevations on the inner islands. These are also areas with typically less rugged relief. Much of the remaining virgin forest on karst is underlain by deep and well-developed epikarst and is characterized by steeper slopes; sediment transport and erosion problems will be substantially greater on such lands than on the thin epikarst and lower relief lands.

Harding and Ford (1993) studied the impacts of clear cutting on soil erosion in karst areas of northern Vancouver Island. Their observations were compatible with those of our Panel. Harding and Ford (1993) recognized that much of the erosion in the karst area they studied involved soil movement into the underlying epikarst. If the depth of the epikarst is greater than the rooting depth of the vegetation, the eroded soil and nutrients are effectively lost to the surface ecosystem.

The previously quoted passage from Schmiege et al. (1974) recognizes the importance of soils with thick, tough, organic surfaces in minimizing erosion. Such organic soils are present after clearcutting in the lower elevation karst areas visited by the Panel.

However, much of the organic material has been destroyed subsequent to clearcutting in karst areas at intermediate elevations; mineral soils can be seen in many locations. The Flicker Ridge area on the north end of Prince of Wales Island is a good example. The loss of this organic material may be associated with the relatively sparse regeneration found in the Flicker Ridge area. The exposure of mineral soil in a karst area underlain by well-developed epikarst is a prescription for erosion and sediment transport.

Introduction of increased amounts of organic material (both suspended and dissolved) into karst groundwater systems after clearcutting is also to be anticipated. The transport of suspended organic materials is similar to that for sediment. This is especially true for suspended organic material introduced into the karst groundwater system because of rapid subsurface travel rates and cold underground temperatures. Dissolved organic matter often creates foam at points where the water flow is particularly turbulent. Large amounts of foam attributable to dissolved organic matter are found in many of the stream caves of the study area; distinct lines of foam indicating peak flow elevations are often seen in such caves.

The potential impacts upon receiving streams of sediment and organic matter derived from logging activities in karst areas requires very careful management attention. The Panel concurs with the following statement by Meehan (1974):

> "Sediment and fine logging debris (bark, leaves, twigs) are not compatible with high quality fish habitat. There is an inverse relationship between the accumulation of these materials and salmonid production. This consequence must be considered when timber sales are laid out and during the logging (e.g., road location, falling, and yarding away from streams."

The previous discussions indicated that, in nonkarst areas, sediment and suspended organic matter transport is via surface water. In contrast, in karst

areas, sediment transport is largely via short distance surface flow then groundwater transport through karst conduits. The same dichotomy occurs with plant nutrient flow paths.

There is substantial technical literature demonstrating that clearcutting results in increased nutrient concentrations in underlying soils and in runoff water. The duration of such effects has generally not been well studied. Limited data for Southeast Alaska (Schmiege et al, 1974) suggest that increases in nutrient concentrations in underlying soils and runoff water occur in the study area; the results are particularly clear for nitrates. Nitrates are very mobile in karst groundwater. Because of the flow paths followed by runoff water, it appears almost certain that karst areas tend to yield more nutrient runoff for a few years after cutting than do nonkarst areas. Increased nutrients added to receiving streams can increase algal growth, and may create adverse impacts. In some streams increased nutrients may enhance aquatic productivity for a few years after cutting; after this nutrient flush, aquatic productivity may decrease due to nutrient concentrations being smaller than under pre-cutting conditions.

The Panel is concerned by reforestation conditions that commonly occur on the karstlands of the study area following the present clearcutting practices. We have identified three conditions of concern; these are restricted to those that adversely affect potential ultilization of karst resources, although we recognize that some of them are also relevant to nonkarst areas.

First, much of the low elevation karst has extremely dense stocking (trees) per acre. The cut-over lands produce a nearly impenetrable forest where karst resources cannot be realistically utilized by people for probably 70% of the duration of the rotation cycle. While this will protect some karst features from human disturbance, any suggestion that such a situation reflects good public land management policy is specious. The dense stocking effectively prevents access to the non-timber resources and thus effectively diminishes the extent of the karst resource base. This is particularly important when one recognizes that approximately 70% of the karstlands in areas charac-

terized by extremely dense reproduction have already been logged. Human-caused inaccessibility of 70% of the karstlands (and their unique resources) for 70% of the duration of the rotation cycle clearly diminishes resource utilization in the karstlands.

Second, there is less than desirable stocking in some of the higher elevation areas where clearcutting has been conducted (Flicker Ridge is an example). This situation enhances sediment introduction into the karst groundwater system and the subsequent discharge of the sediment into fishery streams and water supplies. Regeneration and growth to date in the Flicker Ridge area suggest that the land will become adequately reforested, but that the rotation age will be much longer than that in lower elevation areas. The result of these conditions is a less than desirable utilization of the karst resources.

Third, it appears that high timber yields per acre and accessibility have led to a highly disproportional amount of timber harvest on karstlands in the study area. As a result, subsequent rotations will face a skewed age distribution on karstlands. This will be especially true on smaller islands and in areas with a smaller karst base. This may adversely affect cave fauna. The Panel notes that the Tongass Timber Reform Act contains language relevant to disproportionate timber harvesting; the language is not specific to karst.

In summary, timber harvest in karst portions of the study area often create adverse impacts on several of the karst attributes that this Panel has determined are of international or national significance. These attributes were identified in the report section entitled "Significance of the Karst". Attributes that are, or can be, adversely impacted by timber harvest include Internationally Significant Attributes #2 and #4 and Nationally Significant Attributes #4, #9, and #10.

Present Cave Resource Protection

The importance of cave resources has been recognized by the Forest Service in the study area since about 1988 (Baichtal, 1993). This recognition, and the enactment of the Federal Cave Resources Protection Act in 1988, led to cave inventory work

and ultimately to the development of a nine-page document entitled: "Cave Resources, Forest-Wide Directions, Standards, and Guidelines". A copy of this document is included as Appendix E.

The existing directions, standards, and guidelines contain laudable features and in some cases provide adequate protection for cave features. Cases where adequate cave protection occurs typically have both of the following characteristics:

1. The block of forest in which the cave entrance is located has not been logged or roaded and the cave is far enough from clearcut areas that accelerated windthrow of trees does not reach to areas close enough to the cave entrance to alter entrance microclimate. As general guidance, we recommend that the distance between a cave entrance and the edge of clearcutting and subsequently induced windthrow of trees should not be less than three times the height of dominant trees in the stand. As an illustration, if mean dominant tree heights in an area are 100 feet, and if induced windthrow will probably not exceed one tree height, the minimum distance between a cave entrance and the edge of a clearcut block would be 400 feet.

2. None of the area that contributes water to the cave is affected by logging or road construction. Cases where implementation of the existing directions, standards, and guidelines has not provided adequate protection for cave features typically have some or all of the following characteristics:

1. The area around the cave entrance has been logged and no buffer zone, or else only a narrow buffer zone, of uncut trees was left around the entrance. Windthrow of trees, when they are left in small, isolated patches, is excessive and appears to almost always occur.

2. Roads, quarries, or clearcuts were located in areas that contribute waters to the cave.

3. Caves were not discovered early enough to modify the cutting area and/or road construction.

We have identified six short comings of typical present cave resource protection actions in the study area. They are as follows:

l. The level of effort expended in reconnaissance work to locate and assess caves has been inadequate. This is to be expected in a fairly new program. Adequate reconnaissance, especially in the densely forested and rugged topography of the study area, requires detailed field examination.

2. There has been insufficient time between reconnaissance work to locate and assess caves and the start of road construction or timber harvest activities. This results in last minute surprises and band aid mitigation efforts instead of sound resource management.

3. There has been a lack of adequate recognition of the adverse impacts of roads on cave resources. Impacts of roads on sediment production and discharge of road runoff to sinkholes and losing stream segments have previously been discussed.

4. There has been a lack of adequate recognition of the adverse impacts of quarries on cave resources; this issue has previously been discussed.

5. Typical cave resource protection in the study area has focused almost exclusively on those caves reached through humanly accessible cave entrances. This is in part a reflection of the definition of "cave" used in the Cave Resources Protection Act, which is as follows:

> "Cave means any naturally occurring void, cavity, recess, or system of interconnected passages which occurs beneath the surface of the earth or within a cliff or ledge (including any cave resource therein, but not including any vug, mine tunnel, aqueduct, or other manmade excavation) and which is large enough to permit an individual to enter, whether or not the entrance is naturally formed or manmade. Such term shall include any natural pit, sinkhole, or other feature which is an extension of a cave entrance".

There are karst portions of the study area where surface features clearly demonstrate that caves, and probably very sizeable caves, underlie the area. Many of these caves could be made accessible by removing relatively small amounts of rubble in the bottoms of sinkholes. We do not propose such excavations as a general approach. However, the fact remains that such caves are not receiving resource management attention equal to that provided for caves with open entrances. This is not a desirable resource management situation.

6. Typical cave resource protection actions have focused upon cave features (and particularly cave entrances) rather than upon cave systems. At No-Seeum

Cave on Prince of Wales Island a road was moved to help protect a cave, yet runoff from the road was diverted to a point from which it almost certainly flows into the cave. Cave resource protection must shift its focus from feature protection to system protection strategies.

Cave management is required under provisions of the Cave Resources Protection Act. While we recognize that this is a cave resource protection act and not a karst resource protection act, credible land management strategies in the study area must recognize that adequate cave management requires karstland management.

RECOMMENDED KARSTLAND MANAGEMENT

Recharge Area Delineation and Vulnerability Mapping

A recharge area for a cave or spring is the area that contributes water to the cave or spring. In some cases the recharge area is little more than the land that

overlies the cave. However, in many cases (and especially when the cave contains streams or lakes) the recharge area may be very large. Groundwater tracing is a fundamental tool for recharge-area delineation. The general approach is to introduce fluorescent tracer dyes at points where surface waters sink into the groundwater system and then sample for these dyes at springs, caves, and other relevant points.

An approach called "vulnerability mapping" (sometimes called "hazard area mapping") is a land management tool that has been used effectively in a number of karst areas (Aley and Aley, 1993). Vulnerability mapping utilizes the fact that some lands in a karst area create appreciably greater groundwater contamination risks than other lands. As an illustration, lands in close proximity to a sinkhole or other direct and open connection with the karst groundwater system represent greater contamination risks than similar lands further from such features.

We believe that recharge-area delineation, in concert with vulnerability mapping, is appropriate and necessary for sound land management in the karst of the study area. Such delineation and mapping will help insure that land use and land management actions in karst portions of the study area are appropriately tailored to site conditions.

Designing a vulnerability mapping strategy for the study area and field testing it to insure its adequacy is beyond the scope of the present investigation. However,

based upon our field work we have identified features and conditions that we believe should be incorporated into a recharge-area delineation and vulnerability mapping strategy.

The reader must recognize that the vulnerability mapping approach is a hydrology-driven strategy. As such it does not address vulnerability issues which are not water related.

Vulnerability Mapping Steps

The first step is to separate lands underlain by carbonate rocks from those underlain by noncarbonates. The carbonates clearly require a higher environmental vulnerability rating for management purposes. The recommended vulnerability mapping would apply only to carbonate rock areas or areas that contribute waters to such areas. For our purposes carbonate rocks are those which are comprised of 50% or more of the minerals calcite and dolomite.

The second step is to identify important features through inventory methods. These features would include, but not necessarily be limited to, the following:

A) The presence and locations of caves that contain, or may contain, features of significance as provided for in the Federal Cave Resources Protection Act. This type of inventory work is already being done on the study area; this inventory work should be intensified and expanded. B) The presence and locations of springs, active swallow holes in streams, and apparent losing stream segments (surface stream segments that appear to lose appreciable water into the groundwater system).

C) The location of sinkholes or, where sinkholes are particularly abundant, the boundaries of areas with intensive sinkhole development. Some of the karst areas we visited contain linear karst valleys; such valleys should be viewed as sinkholes even though they may not be totally encircled with closed topographic contour lines.

The location of sinkholes, sinkhole areas, and linear karst valleys is of particular importance because of the hydrologic functioning of such features. Sinkholes are visible in forested areas because they function as transport features for water, sediment, and organic material. Sinkholes that were incapable of transporting sediment and

suspended organic material would soon plug with these materials and either fill with water or else lose their surface expression because of infilling. The existence of a sinkhole is an ipso facto demonstration of the sinkhole's ability to transport sediment and suspended organic material into the karst groundwater system. Furthermore, if the karst groundwater system could not also transport the introduced sediment and suspended organic material then the sinkholes would plug with introduced materials and either create small ponds or else ultimately lose their surface expression.

D) Identification of sensitive habitats and features that might be adversely affected by land use changes in the area being investigated. These habitats and features must specifically include, among other things, streams important to fisheries and streams or springs used as domestic water supplies. The inventory work must recognize that many sensitive habitats and features are likely to be located appreciable distances away from points where waters enter the karst groundwater system.

The third step is to conduct groundwater tracing to determine the point(s) to which a particular karst area drains. Such tracing work will also provide useful insight into the responsiveness of the karst systems within the area under investigation. The tracing work is a crucial component of vulnerability mapping; you must know where the water goes if you are to credibly assess and characterize impacts. Furthermore, the tracing work must place particular emphasis on features identified in step 2. The intensity of the tracing work should be greatest in areas near recharge area boundaries and in areas which may contribute water to important caves, springs, and streams.

Step 4 is to delineate the land under investigation into various vulnerability categories. In general we find that four vulnerability categories can be established for most karst areas. For the study area we believe that these categories and their characteristics should be similar to those outlined below. We again emphasize that developing and testing a vulnerability mapping strategy for the study

area is work that needs to be done, but that such an effort is outside of the scope of the present investigation.

Criteria for Vulnerability Assessments

We have identified 11 vulnerability criteria which should be included in vulnerability assessments. These are identified and discussed in the following paragraphs.

1) Lands lying within sinkholes or within a minimum of 100 feet horizontal distance of the lip of a sinkhole if field evidence or groundwater tracing studies indicate that the sinkhole, or nearby sinkholes, directly (discharge waters during any period of the year to a Class I or Class II stream or to a spring or stream used as a domestic water supply.

Class I and Class II streams are as defined in the Region 10 Aquatic Habitat Management Handbook (FSH 2609.24) of June, 1986. It is our conclusion that any groundwater discharge point located within 100 feet of a Class I or Class II stream would constitute a direct discharge to that stream.

The rationale for this criterion is as follows. Section 103 of the Tongass Timber Reform Act uses similar language for fisheries protection when surface streams with fisheries are involved. What we have outlined is a similar strategy applied to the underground streams. Atypical sinkhole in the study area and its connected down-gradient natural plumbing system of solutionally enlarged conduits functions as a natural pipeline to transport water, sediment, contaminants, nutrients, and organic matter from the sinkhole to the receiving body of surface water. The natural conduit system provides ineffective natural cleansing for waters that enter through sinkholes; the conduit systems are transport systems, not cleansing systems.

In the Tongass Timber Reform Act the 100 foot minimum buffer for surface streams is designed to minimize the introduction into fisheries streams of sediment and organic matter derived from timber harvest and related activities. The same type of protection must be afforded

to underground karst streams. The surface water buffer zone also helps reduce warming of surface streams; a similar benefit is not relevant to underground streams, yet we do not see this as a credible flaw in the rationale.

We considered measuring the 100 foot minimum buffer from the drainage point of the sinkhole rather than the lip of the sinkhole. However, the typical sinkhole is steep; essentially all sediment, organic matter, and nutrients reaching the lip of the sinkhole will subsequently be introduced into the karst groundwater system. As a rule of thumb, the ability of water to transport sediment varies with the sixth power of the velocity. In other words, if the water velocity is doubled (and this would typically be the minimum case as water entered a sinkhole from the sinkhole lip), the ability of that water to transport sediment and other materials in suspension would increase by a factor of 64. In simple terms, if contaminants reach the lip of the sinkhole, they subsequently enter the karst groundwater system.

2) Lands lying within sinkholes or within a minimum of 100 feet horizontal distance of the lip of a sinkhole if groundwater tracing studies have not been conducted to determine whether or not the sinkhole or nearby sinkholes directly discharge waters during any period of the year to a Class I or II stream or to a spring or stream used as a domestic water supply.

3) Lands lying within a minimum of 100 feet horizontal distance of an identified losing stream if field evidence or groundwater tracing studies indicate that the losing stream segment, or nearby losing stream segments, directly discharge waters during any period of the year to a Class I or Class II stream or to a spring or stream used as a domestic water supply.

4) Lands lying within a minimum of 100 feet horizontal distance of an identified losing stream if field evidence or groundwater tracing studies have not been conducted to determine whether or not the losing stream, or nearby losing stream segments, directly discharge waters during any period of the year to a Class I or II stream or to a spring or stream used as a domestic water supply.

5) Lands lying within sinkholes or within a minimum of 100 feet horizontal distance of the lip of a sinkhole if field evidence or groundwater tracing studies indicate that the sinkhole, or nearby sinkholes, contribute waters to a significant cave as defined under the Federal Cave Resources Protection Act (FCRPA). All further use of the term "significant cave" relates to the definition under the FCRPA.

6) Lands lying within sinkholes or within a minimum of 100 feet horizontal distance of the lip of a sinkhole if field evidence or groundwater tracing studies have not been conducted to determine whether or not the sinkhole, or nearby sinkholes, discharge waters during any period of the year to a significant cave.

7) Lands lying within a minimum of 100 feet horizontal distance of an identified losing stream if field evidence or groundwater tracing studies indicate that the losing stream segment, or nearby losing stream segments, contribute waters to a significant cave.

8) Lands lying within a minimum of 100 feet horizontal distance of an identified losing stream if field evidence or groundwater tracing studies have not been conducted to determine whether or not the losing stream, or nearby losing stream segments, contribute waters to a significant cave.

9) Lands that overlie a known significant cave or are otherwise likely to contribute waters to any known significant cave.

10) Lands that are close enough to the entrance of a significant cave to be capable of altering cave features or the microclimate of the cave entrance.

Delineated lands surrounding the cave entrance must be of sufficient size to insure that the cave features and entrance microclimate will be maintained under essentially natural conditions even if blowdown of forest stands should be induced by contemplated timber harvest activities. There is no credible standard buffer distance

that will provide the assurances required under this item. Each cave entrance and adjacent lands must be individually assessed.

11) Slopes which equal or exceed 70%. Such steep slopes have enhanced erosion potential.

Vulnerability Categories

The vulnerability categories characterize resourcedamage threats associated with land management and land use activities, and specifically those threats created by timber harvest and associated quarry development, road construction, and the continued existence of roads and quarries. The vulnerability categories specifically address water quality threats posed to significant caves, cave features, springs, and spring-fed streams.

Low Vulnerability

Resource-damage threats associated with land management activities in these areas are not likely to be appreciably greater than those posed by similar activities on noncarbonate rock units. Based upon our work to date it appears that there are few karst portions of the study area that could appropriately be classified as "Low Vulnerability". If such areas exist they are likely to be underlain by an epikarstic zone less than about five feet thick, to be near sea-level, and to contribute recharge waters to a salt water lens or to trivial springs that flow directly into salt water.

No area could be mapped as Low Vulnerability if it possessed any of the eleven identified vulnerability criteria. Furthermore, Low Vulnerability areas must exclude areas within sinkholes, or within 100 feet of sinkholes, and areas within 100 feet of losing streams regardless of the points to which these features drain.

Moderate Vulnerability

Resource damage threats associated with land management activities in these areas are appreciably greater than those posed by similar activities on noncarbonate rock units. However, timber harvest and related activities could be conducted in such areas under more restrictive

guidelines than normally employed on lands underlain by noncarbonate rock units. Moderate Vulnerability areas would include all karstlands not meeting the criteria for placement in one of the other vulnerability categories.

Moderate Vulnerability lands would not possess any of the eleven identified vulnerability criteria. However, Moderate Vulnerability areas would include sinkholes and losing streams if groundwater tracing or field evidence had shown that they did not discharge waters directly to a Class I or Class 2 stream, to a spring or stream used as a domestic water supply, or to a significant cave or cave system. Moderate Vulnerability areas would typically be underlain by an epikarstic zone less than about five feet thick and/or by glacial clay deposits.

High Vulnerability

Resource damage threats associated with land management activities in these areas would be appreciably greater than those posed by similar activities on Moderate Vulnerability lands. Timber management and related activities should be excluded from High Vulnerability areas, except that small amounts of such areas might be crossed with roads (and the removed timber salvaged) if alternate routings across Low or Moderate Vulnerability areas did not exist and if such crossings were limited in size and occurred only on relatively gentle slopes so as to minimize erosion and the transport of sediment and detritus.

High Vulnerability lands would include any lands possessing one or more of the eleven identified vulnerability criteria. However, High Vulnerability areas would exclude any lands which met the criteria for Extremely High Vulnerability lands.

Extremely High Vulnerability

Resource damage threats associated with land management activities in these areas would be appreciably greater than those posed by similar activities on High Vulnerability areas. Timber management and related activities would be excluded from Extremely High Vulnerability areas.

Extremely High Vulnerability lands would include lands which possess one or more of the eleven identified vulnerability criteria. Lands which would otherwise be classified as High Vulnerability lands would be classified as Extremely High Vulnerability lands if:

1) They discharge waters to an especially significant Class I stream or to a spring or stream used as a particularly sensitive domestic water supply.

2) They overlie a known cave of special significance or are otherwise likely to contribute waters to such a cave.

Karstland Management Summary

The study area has an assemblage of features and conditions that make it globally unique. Past land management has tended to view the study area as a single large entity; this has unduly over-simplified management of the existing ecosystems. More appropriate ecosystem management within this archipelago setting must be consistent with present ecological understanding of island biogeography and maintenance of biodiversity in such settings. Such ecosystem-sensitive approaches will undoubtedly′ necessitate that land management and land use decisions be island-specific. Such island-specific approaches will not permit a relatively rare resource on one island to be given short shrift even if it is abundant on another island. It is the Panel's view that islandspecific: management of karat resources is the first critical and fundamental foundation-stone for karat resource management in the study area.

Karstlands in the study area have resources and vulnerabilities dramatically different from those in nonkarst areas. As a result, management and use of karstlands must develop and utilize different approaches and strategies from those appropriate to nonkarst areas. It is the Panel's view that establishment of a karstspecific management track for lands in the study area is the second critical and fundamental foundation-stone for karat resource management.

In the previous pages we have outlined a karat-specific management approach for the study area. The approach includes three key components:

1. Inventories of karst features.
2. Recharge-area delineations.
3. Vulnerability mapping.

A fourth component must be added, namely, results from items 1 through 3 must be effectively incorporated into planning and land management decisions.

It is only very recently that the Forest Service has begun to recognize the significance of karst resources in the study area. With this ever-growing recognition of significance has come awareness of resource vulnerability. This recognition and awareness led to the work of this Panel. Our Panel's conclusions have clearly demonstrated that the karst resources of the study area are of tremendous national and international significance for a substantial number of reasons. We have also demonstrated that many of these unique and priceless resources are also highly vulnerable to resource damage. The challenge facing the Forest Service is to integrate karst land management into general land management. The Forest Service must adequately protect and utilize the host of newly recognized resources and resource interactions; recognizing new resources does not mean forgetting older resources. The Forest Service goal must be ecologically sound and scientifically credible resource management of the karstlands of the study area.

FUTURE STUDY PRIORITIES

The Panel recommends the following study priorities for the study area. The priority rankings are for general guidance only since we anticipate that focusing concurrent efforts on several items will prove to be superior to placing all efforts on a single item.

1. Archeological and paleontological deposits are fragile and irreplaceable. Much of their value can easily be destroyed by accident or by vandals. As a result,prompt and adequate study of such deposits must be made as quickly as possible.

2. We have outlined a general approach for recharge-area delineations and related vulnerability mapping of karst areas. The approaches must be tested and modified as needed to insure that they are adequately tailored to conditions in the study area.

3. Cave resource inventories and mitigation assessments now being conducted have been of tremendous value in the recent past. They should be expanded and enhanced to ultimately insure that they are reflective of the entire range of karst resources. Such inventories should specifically devote effort to locating springs, gaining stream segments, active swallow holes, and losing stream segments. In many cases these hydrologic elements are actually more important in delineating karst system functioning and vulnerability than are inventories of dry caves and other karst features.

4. Karst and cave resources on other areas of the Tongass National Forest are largely unknown and may be of comparable, and potentially complimentary, signifi
cance to those now known in the Ketchikan Area. These areas should receive a karst significance and resource management assessment similar to the one conducted by the present Panel.

5. Karstlands in the study area have tremendous potential for important scientific and land management discoveries. Some of these studies will undoubtedly require karstlands that have not been appreciably disturbed by man. Many of the low to middle elevation

karstlands have already been harvested or fragmented by roads and timber harvesting. The Forest Service should identify one or two high quality, but minimally impacted, areas for possible designation as a Research Natural Area.

6. Forest Service management in the study area has encouraged and facilitated research and other studies on karst and karst-related resources. This should be con tinued and expanded as possible. Emphasis should be placed on investigations that will either improve land management in karst areas or else protect unique or particularly vulnerable resources. Cave biology studies are particularly appropriate investigations.

7. Three types of karst groundwater systems appear to operate in the study area. The simplest class involves shallow unconfined and partially confined drains typified by the El Capitan Cave and spring system wherein karst basins drain to specific springs or groups of springs. There is the possibility that some of the islands are underlain by salt water lenses upon which karstic fresh water lenses have developed, a possible example being the north end of Heceta Island. A third suspected possibility is confined systems that discharge to subsea springs. The latter are suspected to exist because many karst watersheds in the region yield less-than-expected volumes of water to discrete springs. Definitive studies should be carried out to characterize which types of systems occur in the region, and how to differentiate between them during basin inventories. This is important because system responses in groundwater lenses are several orders of magnitude slower than the other two.

8. Soil biota critically contribute to forest sustainability. Mosses are particularly important in the karst portions of the study area because they hold water, regulate chemical processes, and store and release nutrients. Symbiotic fungi are essential for tree establishment and growth. Microbial organisms are decomposers, and microfauna are regulators of microflora populations. The mutual interactions between these communities, with emphasis on how they respond to large-scale impacts and how soil water chemistry adjusts with time after impacts, needs serious study in karst

portions of the study area. Such fundamental science would be particularly appropriate in a Research Natural Area.

9. Linkage between peatlands and karst development is extremely important and is worthy of research effort to guide management of peatland lands adjacent to karst.

10. There are unique opportunities for basic studies of evolution and adaptation of invertebrates in an archipelago setting with a complex geologic and glacial history. These should be encouraged and facilitated.

SUMARY CONCLUSIONS OF THE PANEL

Conclusion 1. The karst and caves of the Retchikan Area of the Tongass National Forest are of international-scale significance. International-scale attributes include:

A) The occurrence of major karst development in a unique geologic and archipelago setting.

B) The presence of the karst in a largely undisturbed, high-latitude temperate coniferous rain forest.

C) The tremendous diversity of karst features present. D) The quality of natural preservation of karst resources. E) The density and degree of development of karst features. F) The existence of large and extremely well preserved littoral (sea) caves, some of which are located at elevations higher than present-day sea-level.

G) The presence and abundance of archeological resources that include cave art and may include critically important deposits helping us understand prehistoric colonization of the North American Continent.

H) The existence of outstanding and unique paleontological deposits of international significance in understanding climatic changes and their effects.

Conclusion 2. The karst and caves of the Retchikan Area of the Tongass National Forest contain features that are of national-scale significance. National-scale attributes include:

A) Regional karst dissolution rates (regional denudation rates) on the order of at least 4 to 8 times greater than rates in most other American karst areas.

B) Presence in several caves of abundant and unique moonmilk deposits.

C) Relationship between peatlands (muskegs) and vertical shaft development in adjacent down-slope locations; such features are essentially absent elsewhere in the United States.

D) Association between karst areas and highly significant salmon streams.

E) Significant differences in the presence of troglobitic (cave-adapted) invertebrates on inner and outer islands. This difference is probably attributable to differences in the extent of recent glaciation.

F) The discovery of a troglobitic cave amphipod, Stygobromus quatsinensis, by the Panel in a cave on Heceta Island. This discovery at latitude 55°45'53"N, is a high-latitude Western Hemisphere record for a cave-adapted species.

G) Cave use by large mammals to an extent no longer seen elsewhere in the United States.

H) Unique opportunities for studies of evolution and adaptation of invertebrates in an archipelago setting with a complex geologic and glacial history.

I) The presence of vast and largely untouched and unexplored caves.

Conclusion 3. Significant karst resources are likely to extend into other areas of the Tongass National Forest; activities of the Karst Resources Panel were limited to the Ketchikan Area of the Tongass.

Conclusion 4. Karst attributes of national and international scale significance are being degraded on the Ketchikan Area of the Tongass National Forest by the following activities:

A) Timber harvesting.

B) Road location, construction, and operation.

C) Quarry construction and inadequate closure.

Conclusion 5. Resource management of the Ketchikan Area of the Tongass National Forest must be conducted with adequate recognition of the archipelago setting of the area and its associated ecosystems.

Conclusion 6. Unique karat-specific conditions require that management of karstlands on the Ketchikan Area of the Tongass National Forest must follow a different management track from the track appropriate to nonkarst areas. The karst areas should be thought of, and managed, as islands within islands.

Conclusion 7. The Panel is concerned about reforestation conditions that commonly occur on the karstlands following timber harvest. These include:

A) The dense stocking per acre in low elevation karst areas. This results in a nearly impenetrable forest where karst resources cannot be realistically utilized for

probably 70% of the duration of the rotation cycle. This thereby diminishes the extent of the karat resource base. B) The less than desirable stocking in some of the higher elevation areas where clearcutting has been conducted. This results in less than desirable long term utilization of the natural resources of the karstlands.

C) The apparent fact that large timber yields per acre and accessibility have led to a highly disproportional amount of timber harvest on karstlands. As a result, subsequent rotations will face a skewed age distribution on karstlands and especially on smaller islands and/or in areas with a smaller karat base.

Conclusion 8. The karstlands of the Retchikan Area of the Tongass National Forest are of critical importance to the fisheries of the area. Maintenance of long term high productivity in these streams will be a major benefit from improved karstland management.

Conclusion 9. Cave resource protection actions by the Forest Service have been laudable, but have commonly not provided adequate protection for cave features. Cases of inadequate protection typically have some or all of the following characteristics:

A) Uncut buffers around important features were absent or small; windthrow of remaining trees was excessive.

B) Roads, quarries, or clearcuts were located in areas that contribute waters to caves.

C) Caves were not discovered early enough to modify the cutting area and/or road locations.

Conclusion 10. Management of karstlands should involve four key components.

A) Inventories of karat features. B) Recharge-area delineations. C) Vulnerability mapping

D) Incorporation of results from items A through C into planning and land management decisions.

Conclusion 11. The Forest Service should identify one or two high-quality, but minimally-impacted, karat areas for possible designation as Research Natural Areas.

Conclusion 12. Ten future study topics have been identified and prioritized. Concurrent efforts on multiple items will probably be superior to placing all efforts on a single item. Top priority should be given to:

A) Protection and study of archeological and paleontological deposits because they are fragile and irreplaceable.

B) Testing and implementation of the outlined approach for recharge-area delineations and related vulnerability mapping of karat areas.

C) Cave resource inventories and mitigation assessments now being conducted have been of tremendous value in the recent past. They should be expanded and enhanced to ultimately insure that they are reflective of the entire range of karat resources.

D) Karst and cave resources on other areas of the Tongass National Forest are largely unknown and may be of comparable, and potentially complimentary, significance to those now known in the Ketchikan Area. These areas should receive a karat significance and resource management assessment similar to the one conducted by the present Panel.

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APPENDIX A

ITINERARY OF THE KARST RESOURCES PANEL

Itinerary

During the course of the field work the Panel traveled 1,508 miles and viewed karst on eight islands (Figure A-1). About 302 miles were covered by float plane, 412 miles by helicopter, 625 miles by truck, and 169 miles by boat. In descending order of emphasis, the following islands were seen: Prince of Wales, Heceta, Baker, Dall, Kosciusko, Marble, Noyes, and Tuxekan. The Panel visited the first five listed and flew over or navigated by the others. During the field work Panel members took about 1,000 photographs. The itinerary of the Panel was as follows.

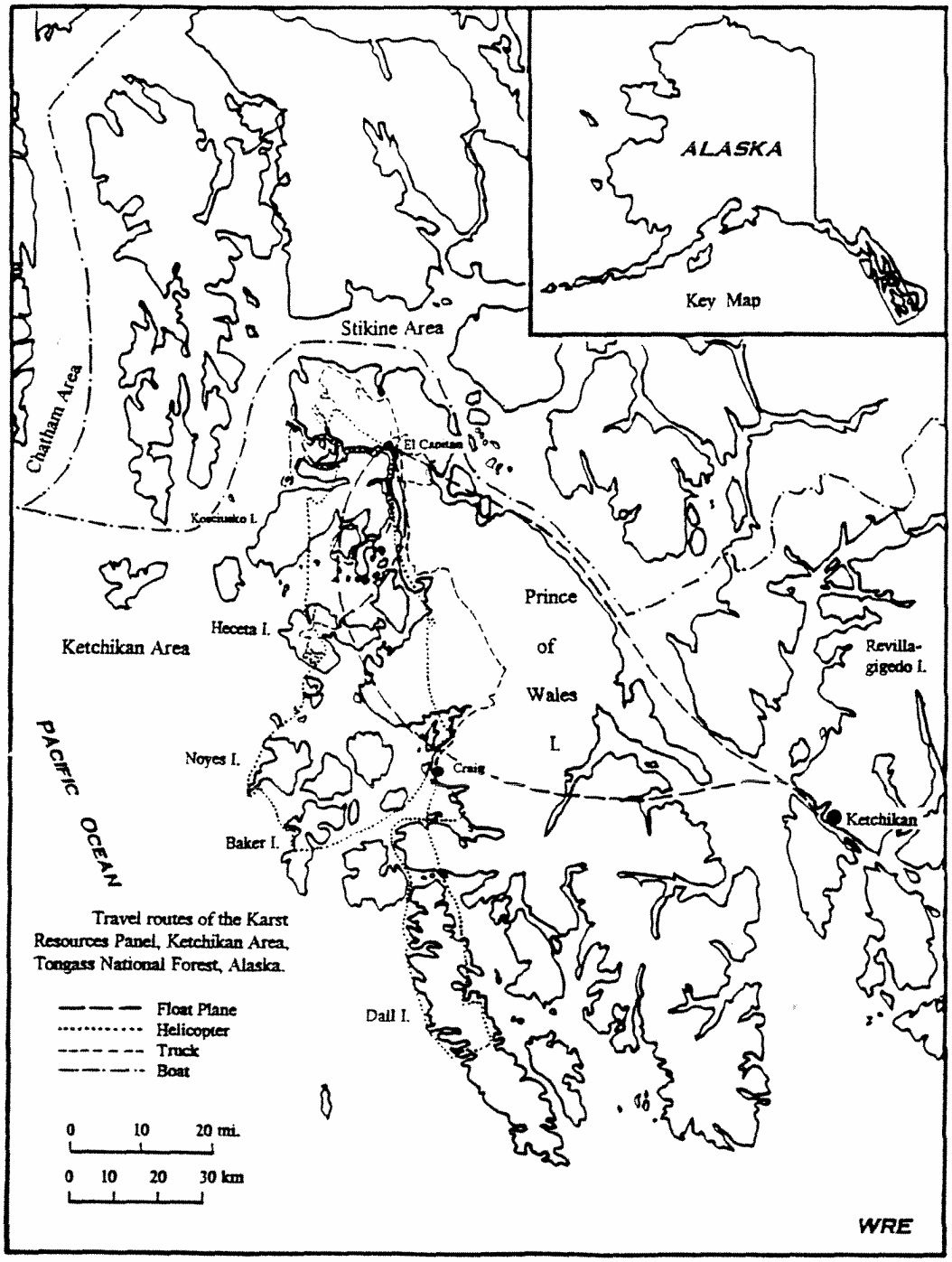
July 14, 1993. Karst Resources Panel flew to Ketchikan, Alaska, and met at The Landing hotel. Discussion with Jim Baichtal.

July 15. Met at Forest Supervisor's office with Jim Baichtal, Bob Vaught, and Steve Patton for discussions of study goals and contract requirements. Purchased same additional field gear.

July 16. Flew by float plane to Prince of Wales Island (POWI), El Capitan Work Center. Drove roads to look at karst areas: gravel in sinks, Historian, Novice's Nightmare, Snow White, grikes. Walked through clearcut around large doline at Seven Dwarves area. Visited Bear's Plunge Cave, Slide Cave, quarries, Carcass Pit, No-See-Um Cave, and entered Cavern Lake Cave.

July 17. Discussion of study goals and limits. Boat trip to Cascade Cave. This cave is a discharge point for a spring; it is located on Kosciusko Island across El Capitan Passage from El Cap Work Center. Elliott collected flatworms at this site. Took boat to Cataract Cave, set biological collecting mop, collected eyed amphipod (Gammarus sp.). Set mop in "Mop Springs".

Figure A-1. Map showing areas visited by the Panel



-A-2-

July 18. Set mop in El Capitan Resurgence. Drove to Flicker Ridge accompanied by Dee Casey, who collected plants. Cathy Aley made water chemistry measurements along the way at Red Creek, Duck Creek, East Alder Creek, Alder Creek, and at an unnamed creek. Visited Movethe-Road-Cave area and observed windthrow of buffer around cave, extent of logging residue, and soil and vegetative disturbance associated with yarding of logs. In the Flicker Ridge area we observed impacts of road construction and quarry operations on sinkholes and other karst features. In this area we also considered loss of soil and moss and general site dessication resulting from timber harvest. Elliott made psychrometer measurements for comparison of intact forest with adjacent clearcuts. Impacts on cave and karst resources of a new road under construction were considered.

July 19. Helicoptered to Perue Peak. Hiked and climbed through alpine karst. Observed many sinks, grikes, rillen-karren, etc. Visited "Alpine Algae Cave", about 75 feet long. Another cave was found and Huntoon decended in it for about 120 feet. A large, deep sink was seen from the air on departure. In the evening three members of the Panel were interviewed by a National Public Radio crew for the "Sound Print" program. Informal discussions were held with cavers working out of El Capitan Work Center.

July 20. Met with USFS Washington office and Region 10 representatives Leslie Lago, Martin Lew, Ron Dipold. Discussed karst problems and ecosystem management strategies while visiting entrances to Devil's Canopy Cave, O.S. Pit, Yukon Pit, and River's End Cave. Panel flew to Heceta Island for three days of field work. Visited Goose Glade Cave which is now choked with blowdown; the blowdown occurred shortly after an adjacent area was clearcut. Visited Mint Cave and collected fauna. At this cave we observed trash and logs washed in from the outflow of Mint Lake. Discovered that Mint Lake contains some thermal springs; lake temperatures were in the range of 66-72° F.

July 21. Heceta Island. Visited Bedded Doe Cave where Elliott collected flatworms, aquatic annelid worms, fungus gnats, and spiders. In Nautilus Cave

we found blind, white amphipods (Stygobromus sp.) in pools. Also collected flatworm, diving beetles, annelid, and a dead pseudoscorpion. Drove to Timber Knob area where we found a large sink undermining half of the road. Found a sink field with six or eight sinkholes on the edge of a muskeg; two of these were connected at the bottom. Found one very deep sink.

July 22. Heceta Island. Drove to Bald Mountain area. Tom Aley and Huntoon climbed to northeast corner of Bald Mountain ridge, looked at continuity of epikarst from subalpine to lower alpine zones. Cathy Aley conducted water chemistry measurements at a muskeg feeding a deep pit, "Sinuous System", which Elliott rappelled into, stopping at the -60 foot level. The pit continues down another drop with a waterfall to the -85 or -90 foot level, then goes into a high passageway and may drop again. Drysuits will be needed for further exploration. Walked up a spring-fed creek with dense, filamentous algae growths; may be reflective of appreciable nitrate concentrations in the water. Returned to Timber Knob sink field again where Huntoon and Elliott rappelled into "Capybara Cave" to the -90 foot level, but it continued to about -170 feet and would require more rope. Cathy Aley did further water chemistry work at Mint Lake.

July 23. Returned to Prince of Wales Island. Set up dye traces and placed charcoal packets at several possible discharge points. Elliott and Jim Baichtal visited Whispering Canyon Cave and collected numerous flatworms and annelids in the stream. Tom and Cathy Aley injected fluorescein dye at Thunder Falls; this water discharges from Sinkhole Lake. Informal discussions were held with cavers in the evening.

July 24. Up at 4:30 a.m., drove to Craig to take helicopter at 7:30 to Dall Island in two runs. All of the Panel studied alpine karst on Devil’s Karst Area and Windy Karst Area. Many large sinks and deep fissures are found in both areas. Elliott rappelled into "Rainbow Pit", a 35 foot deep fissure with blue-green algae at bottom. Tom Aley, Huntoon, and

Baichtal were flown to a resurgence-fed stream; they were dropped off at salt water for a brief reconnaissance.

July 25. Rested, wrote notes. Tom and Cathy Aley did additional dye tracing work which included injections of eosine and Rhodamine WT dyes. Elliott set a mop in resurgence at the Three Stooges area and placed charcoal packets in "Mop Springs". Huntoon took boat trip with Carol Clemens to Tokeen Marble quarries to view epikarst and search for springs and seeps at sea level along limestone coasts.

July 26. Review literature and cave files. Elliott visited Eagle's Roost Cave with Jim and Doreen Baichtal. Collected planarians and annelids in stream. Huntoon visited El Capitan Cave with cavers to see geology and type of dissolution patterns.

July 27. Returned to Flicker Ridge, accompanied by Amy Russell. Elliott took psychrometer readings at numerous spots in clearcut and forest. The Aleys made sample plots to estimate regeneration in clearcuts. Huntoon and Russell looked at geology and vegetation. A new cave was found (no name).

July 28. Visited Beaver Falls Cave, accompanied by Amy Russell and David Herron. Tom Aley, Elliott, and Jim Baichtal flew in helicopter along the outer coast to Wolf's Lair and Pictograph Cave. They returned to E1 Cap by way of Klawock, Tuxekan Island, etc. Huntoon climbed to El Capitan peak with Amy Russell to examine karst vegetation, karst geomorphology, fracture localization on limestone part of peak, and ground water discharge characteristics of the peak.

July 29. The Panel worked on a preliminary findings to be presented to USFS the next day.

July 30. Met from 10:15 am to 2:00 pm with USFS officials David Rittenhouse, Bill Edwards, Kimberley Bowen, Anne Archie, Bob Vaught, Lynn Shipley, and Greg Griffith. The Panel's preliminary findings were presented orally and discussed.

July 31. The Aleys, Elliott, and Baichtal visited Starlight Cave and El Capitan Cave. Huntoon, accompanied by Carol Clemens and David and Deborah Herron, examined the coastline by boat to Summer Strait via Bluff Island to view the tectonic record in Alexander Terranes and search for ground water discharges along coast. Worked on report outline.

August 1. Day off. Discussions. Huntoon went by boat with Clemens to Summer Strait via Hole-in-the-Wall Bay to continue work from the previous day.

August 2. Tom Aley accompanied District Ranger Anne Archie to Flicker Ridge to view significant karst features near the end of the new road. Huntoon, Cathy Aley, and Elliott took boat to Cataract Cave to retrieve charcoal packets and fauna from sampling mop. Also visited Devil Fish Bay, Kosciusko Island, and followed a large stream uphill over granite in search of a karst spring, but did not find one. Huntoon later observed logging operations northeast of El Cap camp.

August 3. Elliott and the Aleys retrieved charcoal packets and the sampling mops at Mop Springs and Three Stooges Resurgence. Huntoon photographed logging and yarding practices northeast of El Cap camp.

August 4. Flew back to Ketchikan, visited USFS office to xerox literature and maps. Worked on report outline. August 5. Met with Forest Supervisor David Rittenhouse. Worked on report outline. Huntoon departed.

August 6. The Aleys and Elliott departed.

APPENDIX B

BIOLOGICAL AND METEOROLOGICAL OBSERVATIONS MADE BY WILLIAM R. ELLIOTT

Biological and meteorological observations made by William R. Elliott.

All temperatures are given in F°. Atkins digital psychrometer readings are given in the form 55.5°/52.3° (82%) for dry bulb/wet bulb and relative humidity. Other readings were taken with an alcohol thermometer or a Micronta digital thermometer. All dates are 1993.

Dall Island

Rainbow Pit. July 24. 44° air temperature in the cave. Elliott rappeled in 35 feet. Only life observed was apparent cyanobacteria and mosses on walls. Photos were taken.

Heceta Island

Bedded Doe Cave. July 21. 44° air temperature in cave. Collected flatworms, aquatic annelids, fungus gnats, and spiders. Photos were taken.

Capybara Cave. July 22. Elliott and Huntoon explored to the -90 feet level. Cave could go to -170 feet or more. No collection were made.

Mint Cave. July 20. 50.4°/50.0° (98.9%). Collected millipedes, springtails, gnats, spiders, etc. There is much fauna on rotting logs and debris that has been washed into the cave.

Nautilus Cave. July 21. 43° pool; 44.1°/43.8° (99.3%). Collected tiny white mites (probably Rhagidiidae) on pool surfaces; one dead, eyed pseudoscorpion from pool; one flatworm, two dytiscid beetles, and one annelid from sump; ten troglobitic amphipods from two small pools. Photos were taken.

Sinuous System. July 22. 48° air on ledge 30 feet down; 50° waterfall into cave. Elliott collected forest millipedes and snails on ledge. Cave drops about 60 feet to second pitch, then about 25 feet to cobble floor. A high, arched passage leads off. Dry suits will be needed for further exploration. Cave looks promising.

Kosciusko Island

Cascade Cave. July 17. Collected eyed flatworms in pool just inside the entrance. Photos were taken. The resurgence was not flowing.

Outer Coast

Pictograph Cave. July 28. Photos were taken, but no cave fauna collections were made.

Wolf's Lair. July 28. Photos were taken, but no cave fauna collections were made.

Prince of Wales Island:

Alpine Algae Cave. July 19. Only life observed appeared to be cyanobacteria. Photos were taken. 41°. Beaver Falls Cave. February 19. 40° water, 42° air. Photos were taken. Two gnats were collected and given to Kent Carlson, a graduate student at American University, Washington, D.C. July 28, 44° water and 42.6°142.4° air (99.3%) near end. Collected a spider on web, one flatworm in pool near sump, one stonefly nymph, one black millipede. Cataract Cave. July 17. 46° water, 54.1°153.5° (98.1% air. Photos were taken and mop for biological sampling was placed. Collected one gray Gammarus amphipod in pool near upper end of stream and one small black insect on flowstone. On July 25 Jim Baichtal collected insect nymphs from mop and green, eyed amphopods from sump inside dry entrance. The amphipods turned orange in alcohol. On August 2 we retrieved and rinsed mop and Lycopodium net being used by the Aleys. Collected a few insect larvae and plant detritus.

Devil's Canopy Cave. 34-39° on Feb. 19. Ice in entrance and at bottom of cave. Photos were taken. Collected gnats, spiders, daddy longlegs harvestmen, and aquatic oligochaetes. Collections given to Kent Carlson. Bat skull discovered by Tom Aley collected by Jim and Doreen Baichtal.

Eagle's Roost Cave. July 26. Collected and photographed planarians and annelids in stream, which was 43.5°. Collected stone and caddis flies.

El Capitan Cave. Feb. 20. 45° air at top of climb above Cathedral Room. Photos were taken. July 31. 43° in sump. Took plankton tows in sump for fifteen minutes but caught nothing.

El Capitan Resurgence. July 18. 44° water, placed mop in pool just inside entrance. Aug. 2. Retrieved and rinsed mop, obtained nothing of note.

Flicker Ridge. July 18. 55.5°/52.3° (82%) in clearcut, 54.3°/52.1° (88%) in old growth forest. Photos were taken. July 27. Photos and psychrometer transects through clear-cut and old growth; values are shown in Table B-1 (at the end of this appendix). Collected soil millipedes and soil sample from old growth for Berlese extraction.

Mop Spring. July 17. 41.4° water (Micronta), placed mop. July 25. Placed charcoal packets. Collected the following from the mop: algae, two flatworms, several insect nymphs. Water 6 inches deeper than on July 17. Aug. 3. Retrieved mop, which was very tannin-stained. It contained a few flatworms, two insect nymphs.

River's End Cave. Feb. 19. 39° water, 40° air. Collected springtails on pool, spider, gnat. Collections given to Kent Carlson.

Roaring Road Cave. Feb. 19. Two daddy longlegs (saw five others), one stonefly collected and given to Kent Carlson. July 18. Jim Baichtal collected four black beetles in "boiling" pools 300-400 feet from the entrance. Aug. 2. Photos were taken.

Slide Cave. July 16. Collected two gnats, two spiders, one snail, one millipede. Cave is choked off and one cannot get into dark zone.

Starlight Cave. July 31. Collected beetles and took photos.

Three Stooges Resurgence (Unit 534-110). July 25. 44° water, placed mop. Aug. 3. Retrieved and rinsed mop. Nothing of note on mop.

Thrush Cave. July 27. Collected one spider, one daddy longlegs, one millipede (all are eyed). Saw fungus gnat larvae. Cave has basalt ceiling.

Whispering Canyon Cave. July 23. 42° water; collected planarians, aquatic annelids in stream pools, nothing in sump. A millipede also collected. Collection was later broken in the mails.

Table B-1. Microclimate conditions at Flicker Ridge, Prince of Wales Island. "Dry Bulb" and "Wet Bulb" refer to Atkins digital psychrometer readings in degrees F. in the shade. "RH" is relative humidity. Wind velocities estimated. Clearcut areas were drier due to less soil and moss, higher temperatures, and greater wind velocity.

Location	Date and Time 1993	Dry Bulb	Wet Bulb	RH %	Wind MPH
Clearcut in large doline; no moss, sunny. Uphill wind	7/18 1704	55.5	52.3	82	10-20
Old growth, 200 ft. inside forest. Shady with damp moss	7/18 1802	54.3	52.1	88	0-3
Clearcut, Unit 259-111	7/27 1412	58.6	51.7	63	10-25
Clearcut, some moss and sedge meadow remnants	7/27 1424	60.0	52.5	61	10-15
Clearcut, some damp soil from recent rain	7/27 1435	61.5	53.3	58	5-25
Clearcut, 0.5 mi. downhill of above location, wind shadow	7/27 1506	63.5	54.5	56	0-5
Clearcut, large doline of July 18. Downhill wind	7/27 1518	60.7	53.5	63	0-15
Clearcut Means	**7/27**	**60.9**	**53.1**	**60**	**5-17**

Table B-1 (continued). Microclimate conditions at Flicker Ridge, Prince of Wales Island.

Location	Date and Time 1993	Dry Bulb	Wet Bulb	RH %	Wind MPH
Forest, 200-300 ft. inside, open, moss and low plants	7/27 1221	55.7	52.4	80	5-10
Forest, 600 ft. inside, moss	7/27 1233	54.6	51.7	82	0-5
Forest, nr. top of ridge, tall trees, moss, breezy	7/27 1335	55.4	50.3	71	10-20
Forest sedge meadow close to clearcut	7/27 1408	58.7	53.4	70	0-2
Forest, 200 ft. inside, same as July 18	7/27 1530	59.4	53.8	70	0-3
Forest Means	**7/27**	**56.8**	**52.3**	**75**	**3-8**

APPENDIX C

GEOLOGICAL ILLUSTRATION
PETER W. HUNTOON

Figure 1. Favored model for the origin of the interbedded breccias found in the carbonate terranes in the Tongass National Forest. Other breccia landslides or reef limestones successively buried the breccia deposit shown.

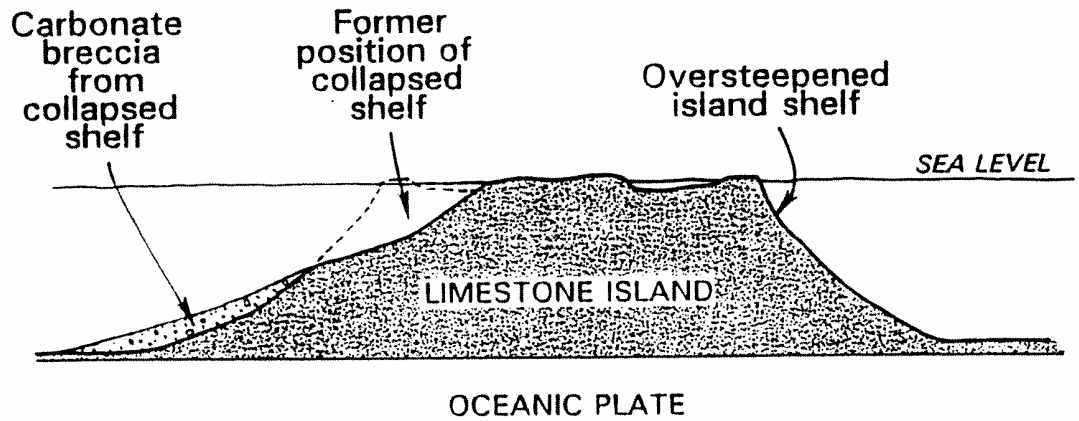
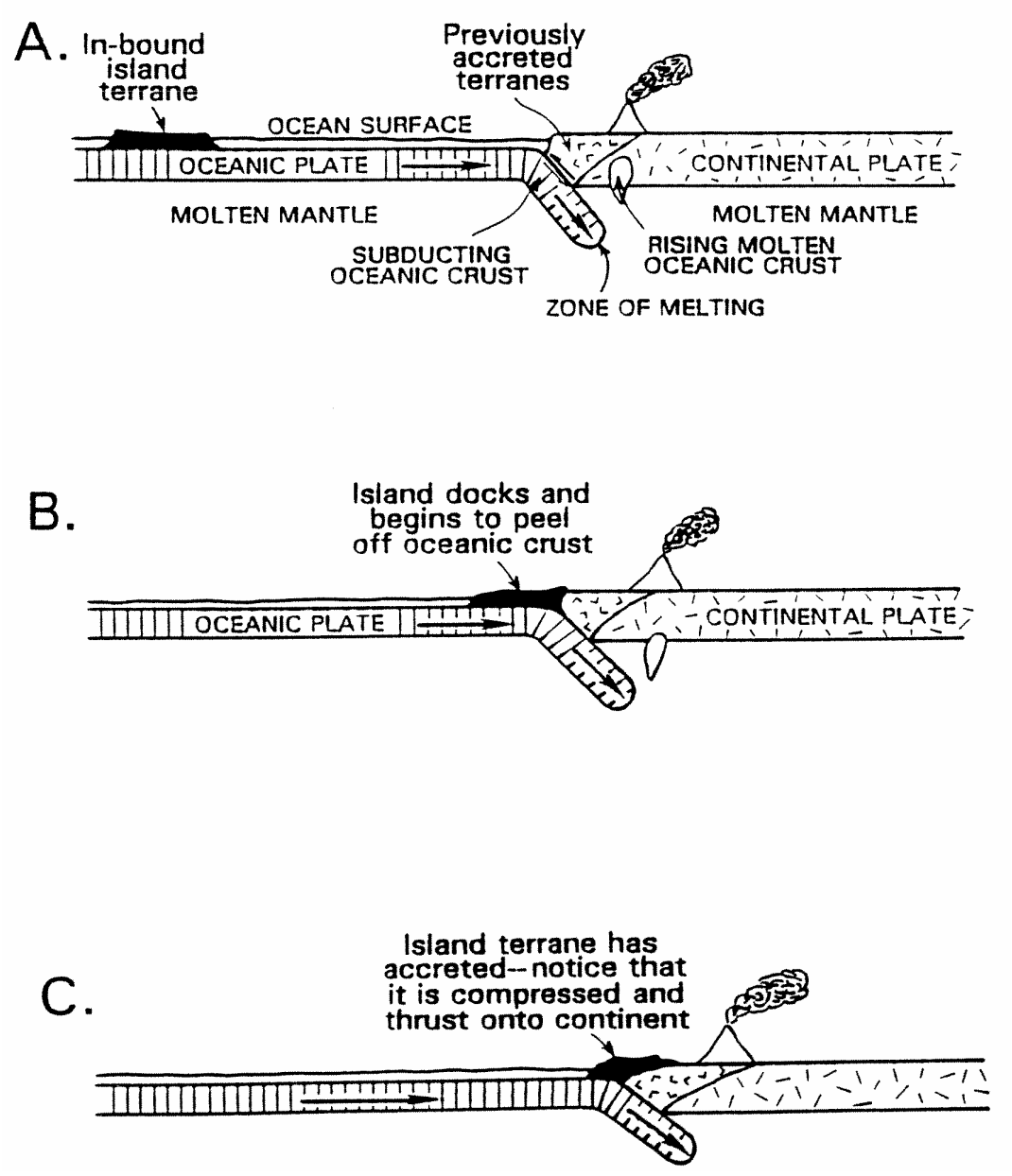
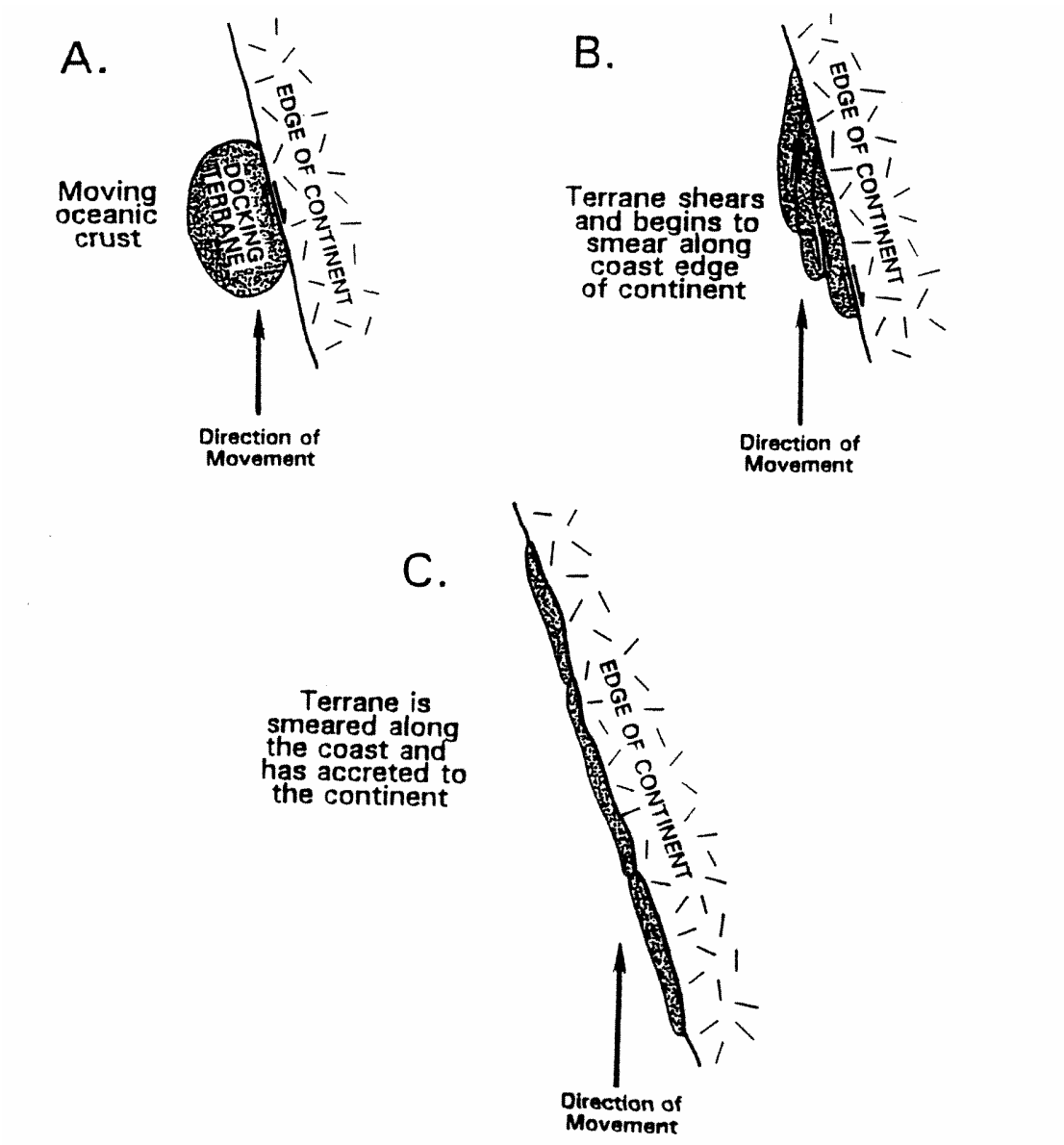


Figure 2. Cross section across the coast of southeastern Alaska showing how exotic terranes such as the Alexander terrane were accreted to the North American continent.



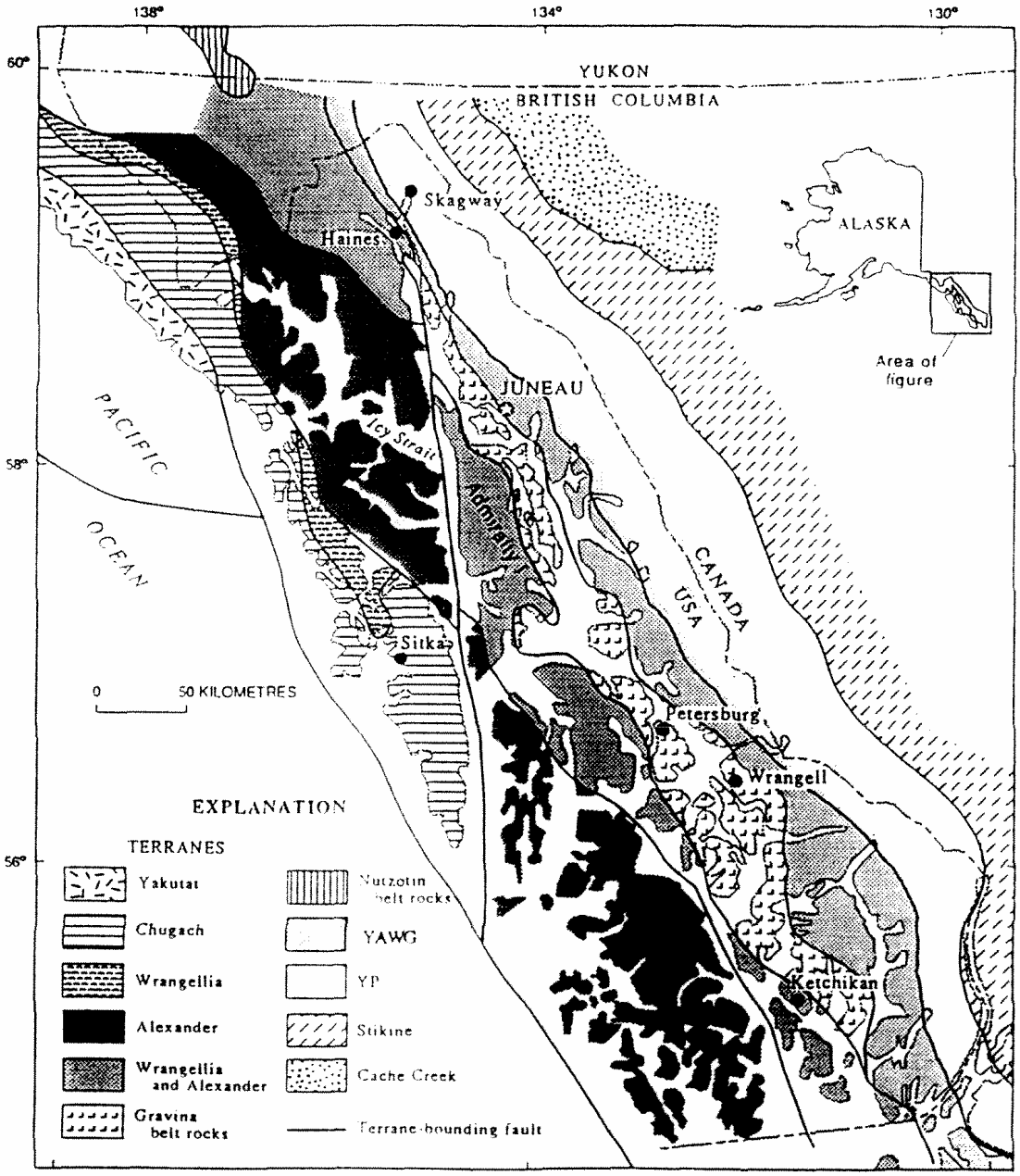
-C-2-

Figure 3. Planimetric map showing how exotic terranes docking at shallow angles to the Alaskan coast were sheared and smeared out as they accreted to the North American continent. All the faults shown are strike-slip faults with the sense of motion revealed by the arrows. By panel C, the sheared segments have compressed against the coast and been lengthened substantially.



-C-3-

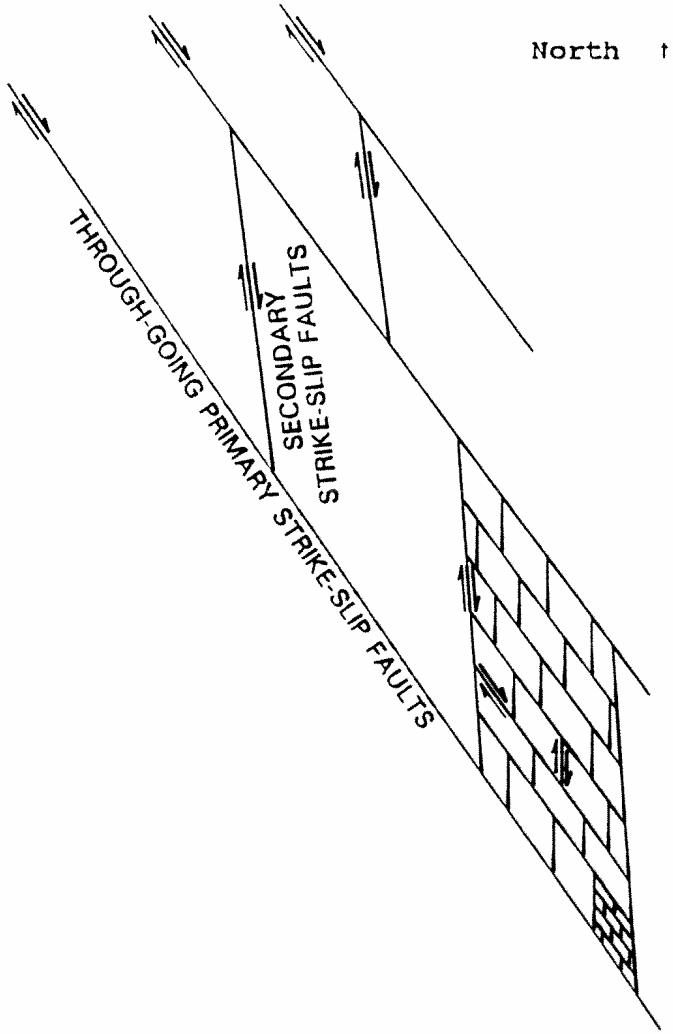
Figure 4. Map of southeastern Alaska and adjacent regions showing lithotectonic terranes. Taken without modification from Brew, Himmelberq, Loney and Ford (1992). Prince of Wales Island lies within the Alexander terrane west of Ketchikan.



From: Brew, Himmelberg, Loney and Ford (1992, Figure 2).

-C-4-

Figure 5. Planimetric map of the strike-slip fault pattern that developed as exotic terranes were sheared and smeared out along the southeastern coast of Alaska. This is the same pattern observed on Figure 4 where distances are measured in hundreds of miles. The large blocks thus defined, are themselves internally sheared by intersecting sets of parallel but smaller scale faults as shown in the lower right block, and those blocks are in turn likewise progressively sheared on down to outcrop and hand specimen scales. The cumulative movement along all of these strike-slip faults allowed the exotic terranes to compress greatly perpendicular to the coast, and lengthen greatly along it.



-C-5-

APPENDIX D

HYDROLOGICAL DATA COLLECTED BY CATHY ALEY AND TOM ALEY

Water Chemistry Data

Various water chemistry measurements were made during the course of the investigation. All measurements were made with portable instruments which were operated in accordance with manufacturer's recommendations and normal field procedures. Table D-1 presents data from Prince of Wales Island. Table D-2 presents similar data from Heceta Island.

Table D-3 provides data from a transect of streams crossing the road between El Capitan Spring (the starting point) and Turn Creek (the ending point). All measurements were made during the late afternoon of August 1, 1993. The results are illustrative of the substantial fluctuations in specific conductance values in nearby streams. Streams that are fed by peatlands have the lowest specific conductance values. Some springs have values substantially greater than those recorded at El Capitan Spring during the transect.

Specific conductance measurements (in micromhos/cm were made with a Yellow Springs Instrument Company Model 33 SCT meter.

Air and water temperatures were made with a Micronta Mod. 63-843 digital thermometer.

Measurements of pH were made with a Cole-Parmer Model 5985-80 pH meter.

Dissolved oxygen measurements were made with a Horizon Ecology Company Type 5946-10 meter.

Turbidity measurements were made with a LaMotte Chemical Co. Model 2008 meter.

Table D-1. Water chemistry data from Prince of Wales Island, July and August, 1993. S.C. is specific conductance measured in micromhos/cm. Air and water temperatures are in degrees F. Turb. is turbidity measured in NTU units. D.O. is dissolved oxygen measured in mg/l. pH is in pH units. Numbers in the notes column related to footnotes at the end of the table.

Location	Date	S.C.	Wat. Temp	Air Temp	Turb	D.O.	pH	Notes
Cascade Cave Str.	7/17	125						
Str. nr. Cascade Cave	7/17	279						
Mop Spr. nr. MP 101.1 on Rd. 20	7/17	172	41.4					
El Capitan Spr.	7/18	121	44.4	57.4		10.4	7.5	(1)
El Capitan Spr.	7/18	140						(2)
El Capitan Spr.	7/19	180						(3)
El Capitan Spr.	7/26 1340	129	45.7	64.6	0.17			(4)
El Capitan Spr.	7/29 2100	145	49.3		1.31			(5)
El Capitan Spr.	7/30 0900	140	46.8		48.0			(6)
El Capitan Spr.	8/1 1600	97						(7)
Red Cr. @ FH 43	7/18	181	54.0		0.5	10.2	7.4	

Table D-1 (continued). Water chemistry data from Prince of Wales Island, July and August, 1993.

Location	Date	S.C.	Wat. Temp	Air Temp	Turb	D.O.	pH	Notes
Duck Cr. nr FH 43	7/18	141	43.2		0.24	9.4	7.3	(8)
Duck Cr. nr FH 43	7/18	173	51.8		0.1	9.4	7.8	(9)
Just above quarry nr. Duck Cr.	7/18	24	58.5			5.0		peat-land
E. Fk. Alder Cr. @ FH 43	7/18	121	58.8		0.30	8.5	7.1	
Alder Cr. @ FH 43	7/18	90	60.1		0.40		7.3	
Cr. off Flicker Ridge	7/18	163	44.8			12.5	7.5	
Limestone trib. into Twin Is. Lake	7/23	180						
Windy Cove Stream	7/24	145						
Left trib. to str. next to Cataract Cave.	7/25	118						
Str. 100 ft. N. of Cataract Cave Spr. Br.	7/25	21						
Cataract Cave Str.	7/25	181						

Table D-1 (continued). Water chemistry data from Prince of Wales Island, July and August, 1993.

Notes by identification numbers.

l. Spring water not contaminated with road dust. 2. Spring water contaminated with road dust.

3. Same sample as (2) above, but measurement made after 24 hours.

4. Flow rate approximately 0.5 cfs.

5. Flow rate approximately 2.0 cfs after 24 hrs. moderate rain

6. Flow rate approximately 3.0 cfs. 7. Flow rate approximately 1.5 cfs. 8. Downstream of carbonates

9. Upstream of carbonates; siltstone bedrock and conglomerate cap on hill above.

Table D-2. Water chemistry data from Heceta Island, July, 1993. S.C. is specific conductance measured in micromhos/cm. Air and water temperatures are in degrees F. Turb. is turbidity measured in NTU units. D.O. is dissolved oxygen measured in mg/1. pH is in pH units. Numbers in the comments column related to footnotes at the end of the table.

Location	Date	S.C.	Wat. Temp	Air Temp	Turb	pH	Notes
Goose Glade Cave	7/20	151					(1)
Mint Lake	7/20	121	67.1			6.93	(2)
Mint Lake	7/21	119	65.7			6.25	
Nautilus Cave Str.	7/22	283	43.0	44.1		6.16	(3)
Bald Mtn. peatland	7/22	55	51.8	57.4		2.5	(4)
Bald Mtn. peatland	7/22	31	50.7	56.7		4.0	(5)
Bald Mtn. peatland	7/22	59	55.0	55.8		2.4	(6)
Bald Mtn. peatland	7/22	98	50.9	53.8		5.7	(7)
Str. downstream of above peatland	7/22	210	43.9	63.0		6.6	
Grassy peatland on Bald Mtn.	7/22	36				6.9	
Str. at Rd. 1427	7/22	35				6.8	

Table D-2. Water chemistry data from Heceta Island, July, 1993.

Notes by identification numbers.

1. Large sink with detritus; flow rate about 30 gpm. 2. At five foot depth; lake appears to have thermal water input. This lake discharges through a cave.

3. Stream provides habitat for newly discovered troglobitic amphipod.

4. Pool in stream in center of peatland. 5. Pool in stream at edge of peatland. 6. Pool in red spaghnum in peatland.

7. Str. from peatland where it enters Sinuous System Cave.

Table D-3. Estimated flow rates and specific conductance values of streams crossing FR 15 between El Capitan Spring and Turn Creek. Distances are from the road crossing of El Capitan Spring. All measurements made August l, 1993.

Distance (feet)	Estimated flow rate	Specific Conductance (micromhos/cm)
0 ft. (El Capitan Spr)	1.5 cfs	97
1280	20 gpm	146
1380	5 gpm	160
2110	1 gpm	142
2320	12 gpm	149
2620	5 gpm	69
2860	2 gpm	153
3070	8 gpm	129
3380	4 gpm	21
3560	3 gpm	13
3950	5 gpm	25
4220	5 gpm	13
4970	30 gpm	12
5640 (Turn Cr.)	10 cfs	99

Dye Tracing Data

Dye injection OUL 93-01 was called the Thunder Falls Trace. Three pounds of fluorescein dye was injected in the discharge from Sinkhole Lake (Sty 1/4 Section 3, T66S, R79E) upstream of Thunder Falls. The dye injection was made on July 23, 1993 at 1625 hours. Dye attributable to this injection was visually seen on August 16, 1993 at 1100 hours in the main stream feeding 108 Creek at the point where road 2720 crosses that stream upstream of Cavern Lake. This dye apparently discharged from a spring tributary to 108 Creek a short distance upstream of the road crossing. The straight line travel distance through the groundwater system was approximately 4,800 feet in 24 days under low flow conditions.

Dye injection OUL 93-02 was called the Rivers End Trace. Two pounds of Rhodamine WT dye (20% solution) was injected into a flow of approximately 50 gallons per minute entering the cave system; the location is in the SW 1/4 Section 30, T66S, R79E at an elevation of about 350 feet. The dye injection was made on July 25, 1993 at 1815 hours. This dye was recovered in activated carbon samplers in place in Cataract Cave for the period July 25 to August 2. The dye concentration in the sampler was 169 ppb with an emission fluorescence peak at 565.0 nm. The straight line travel distance was approximately 4,500 feet.

Dye injection OUL 93-03 was called the Beaver Falls Trace. Two pounds of eosine dye was injected in a sinking stream near Beaver Falls Cave on July 25, 1993. The injection site was in the SW 1/4 Section 17, T66S, R79E at an elevation of approximately 650 feet. None of this dye was recovered, probably because the sampling period was too short or else the discharge point for the dye was not sampled. Some samplers remain in place and may contain dye. All of our tracing was designed with only short term, non-intensive sampling; failure of some or all traces was a recognized possibility.

The fourth trace involved fluorescein dye injected by Steve Lewis into water sinking at Slate Cave. We began sampling at El Capitan Resurgence immediately

after learning of this dye injection; this was approximately two weeks after dye introduction. Fluorescein dye was present in our first sampler from El Capitan Resurgence, which is approximately 3,700 feet straight line distance from the point of dye injection. The sampler had been in place for the period July 26 to August 2. The dye concentration in the sampler was 90.0 ppb with an emission fluorescence peak at 513.0 nm. The straight line travel distance was approximately 3,700 feet. The elevational difference between injection and recovery sites was about 900 feet.

Sampling conducted in conjunction with the groundwater tracing studies is summarized in Table D-3; dye injection and dye sampling stations are not shown on a map since some of the cave locations are not public information. Replacement. samplers were placed in early August and will be analyzed if they can be recovered. Photocopies of all analysis graphs follow Table D-3.

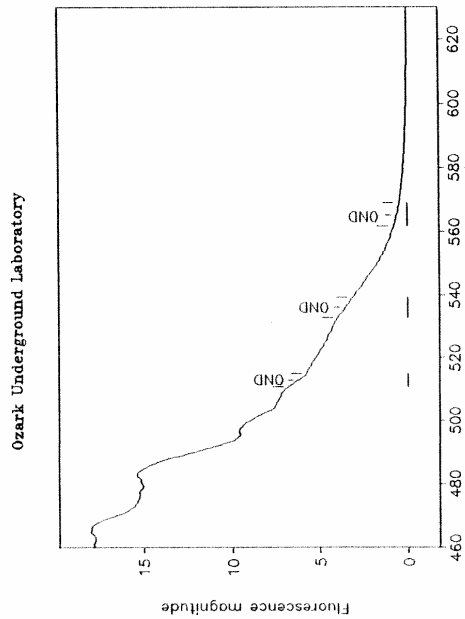
Table D-3. Sampling conducted in conjunction with groundwater tracing studies. All dates are 1993.

Station Number and Name	Location	Sampling Period	Results
1. 108 Creek below Cavern Lake		7/18 to 8/2	ND
2. Twin Island Lake	SW corner of lake nr. suspected spring rises.	7/18 to 8/2	ND
3. Stream into Twin Island Lake	Nr. Sta. 2; stream flow from karst area.	7/18 to 8/2	ND
4. Cataract Cave	Stream inside cave	7/25 to 8/2	Rhodamine WT. Peak at 565.0 nm, 169 ppb.
5. El Capitan Spr.	Resurgence nr. rd. xing.	7/26 to 8/2	Fluorescein. Peak at 513.0 nm, 90.0 ppb.
6. Northernmost stream in bay below Cataract Cave.		7/25 to 8/2	ND
7. Creek below Vauclusian Cave.		7/25 to 8/2	ND
8. Salmon Bay Lake Creek	Downstream of inflow from Three Stooges Cave	7/18 to 8/3	ND
9. 108 Cr. at Gaging Station	At USGS gage station nr. Whale Pass.	7/18 to 8/3	ND

Table D-3 (continued). Sampling conducted in conjunction with groundwater tracing studies. All dates are 1993.

10. Snoos Cr. at old bridge	Downstream of beaver ponds	7/25 to 8/3	ND
11. Karst Canyon Trib. to 108 Cr.	Along FH 45	7/18 to 8/3	ND
12. Mop Spring	Trib. to Twin Island Lake	7/25 to 8/3	ND

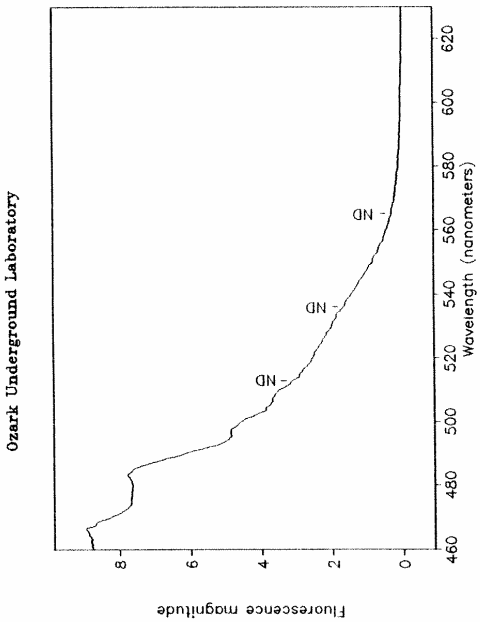
ND = None Detected



Station 1: 108 Creek below Cavern Lake
OUL number: C2091 Type: Charcoal Analyzed: 08-10-1993
Date placed: 07-18-1993 Date recovered: 08-02-1993
Time placed: Time recovered: 1745

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.9	510.7	515.0	0	0	0	ND
536.1	532.8	539.4	0	0	0	ND
565.3	561.7	568.9	0	0	0	ND

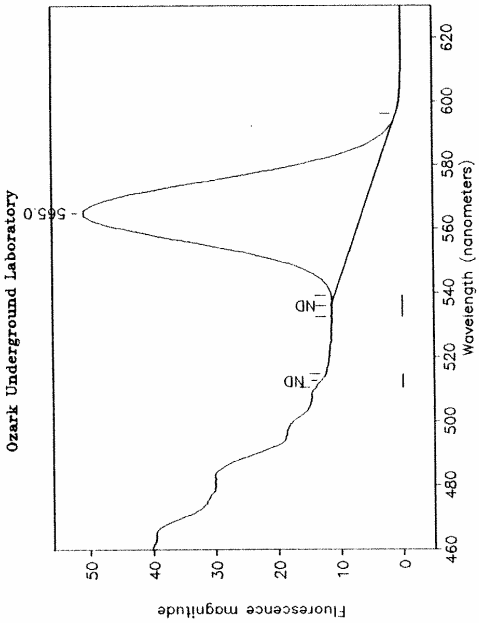


Station 2: Twin Island Lake
OUL number: C2092 Type: Charcoal Analyzed: 8-10-1993
Date placed: 7-18-1993 Date recovered: 8-2-1993
Time placed: Time recovered: 1715

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.9	510.7	515.0	0	0	0	ND
536.1	532.8	539.4	0	0	0	ND
565.3	561.7	568.9	0	0	0	ND

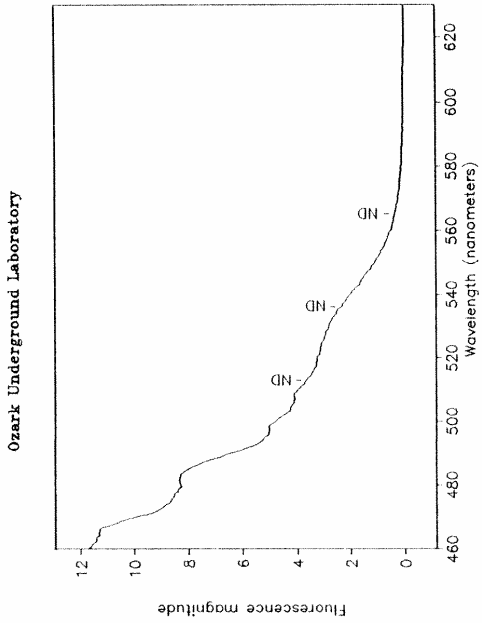
-D-12-



Station 4: Cataract Cave
OUL number: C2094 Type: Charcoal Analyzed: 8-10-1993
Date placed: 7-25-1993 Date recovered: 8-2-1993
Time placed: Time recovered: 1100

Peaks within normal range of tracer dyes:

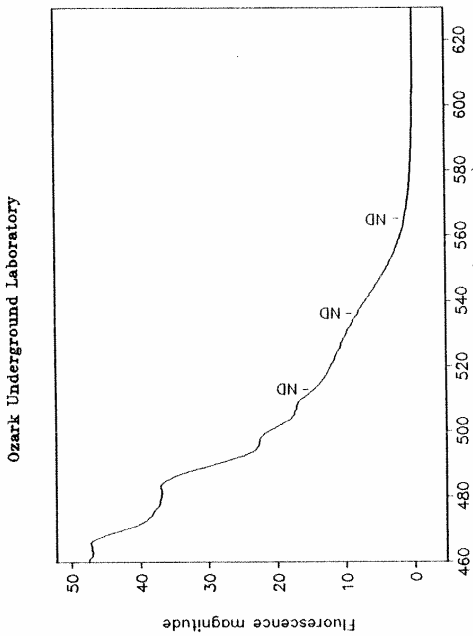
Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.6	510.5	514.8	0	0	0	ND
535.8	532.6	539.2	0	0	0	ND
565.0	536.0	596.0	44.70	1022.69	0.04	169



Station 3: Stream into Twin Island Lake
OUL number: C2093 Type: Charcoal Analyzed: 8-10-1993
Date placed: 7-18-1993 Date recovered: 8-2-1993
Time placed: Time recovered: 1710

Peaks within normal range of tracer dyes:

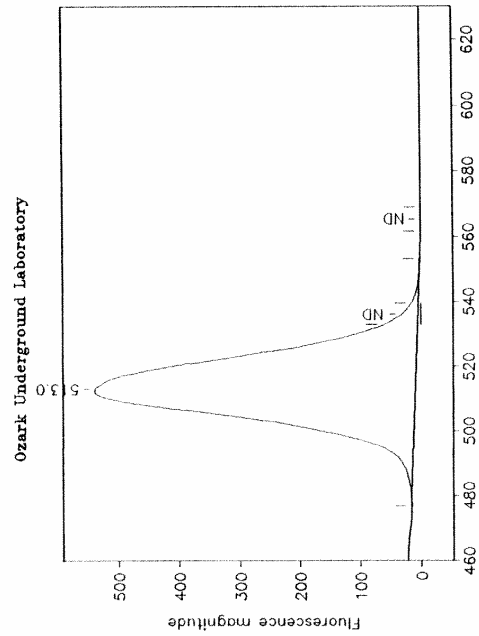
Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.9	510.7	515.0	0	0	0	ND
536.1	532.8	539.4	0	0	0	ND
565.3	561.7	568.9	0	0	0	ND



Station 6: Northern most Stream in Bay below Cataract Cave
OUL number: C2096 Type: Charcoal Analyzed: 8-10-1993
Date placed: 7-25-1993 Date recovered: 8-2-1993
Time placed: Time recovered: 1205

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.9	510.7	515.0	0	0	0	ND
536.1	532.8	539.4	0	0	0	ND
565.3	561.7	568.9	0	0	0	ND

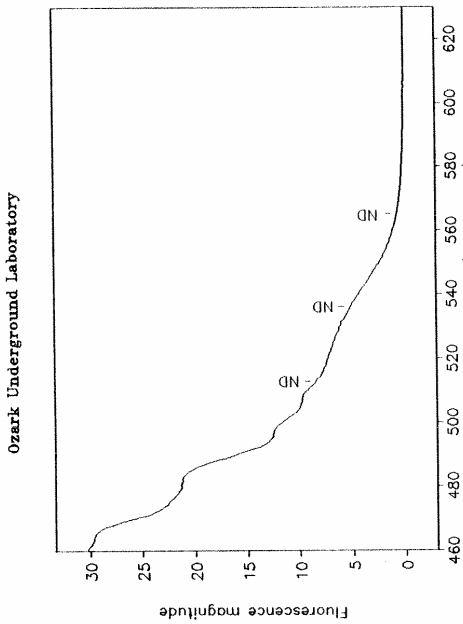


Station 5: EL Cap Spring
OUL number: C2095 Type: Charcoal Analyzed: 8-10-1993
Date placed: 7-26-1993 Date recovered: 8-2-1993
Time placed: 1400 Time recovered: 1600

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
513.0	476.8	553.2	531.07	11733.50	0.05	90.0
536.2	532.9	539.5	0	0	0	ND
565.4	561.8	569.0	0	0	0	ND

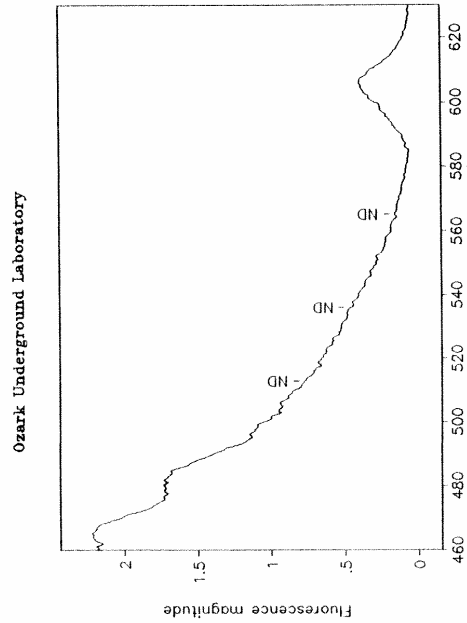
-D-14-



Station 8: Salmon Bay Lake Creek
OUL number: C2098 Type: Charcoal Analyzed: 8-10-1993
Date placed: 7-18-1993 Date recovered: 8-3-1993
Time placed: 1535 Time recovered: 1100

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.9	510.7	515.0	0	0	0	ND
536.1	532.8	539.4	0	0	0	ND
565.3	561.7	568.9	0	0	0	ND

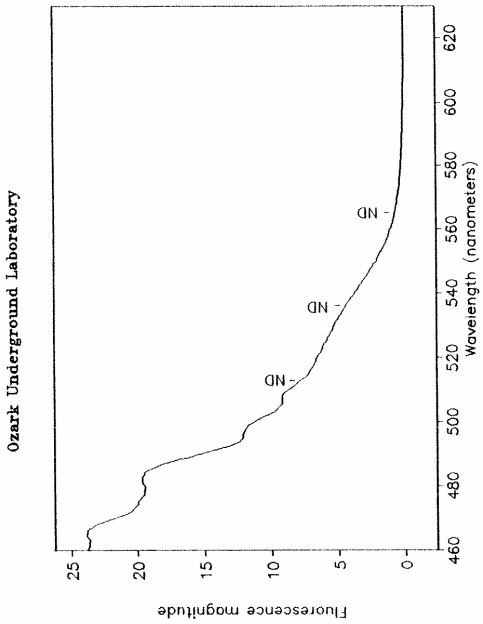


Station 7: Creek below Vaclusian Cave
OUL number: C2097 Type: Charcoal Analyzed: 8-10-1993
Date placed: 7-25-1993 Date recovered: 8-2-1993
Time placed: Time recovered: 1110

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.9	510.7	515.0	0	0	0	ND
536.1	532.8	539.4	0	0	0	ND
565.3	561.7	568.9	0	0	0	ND

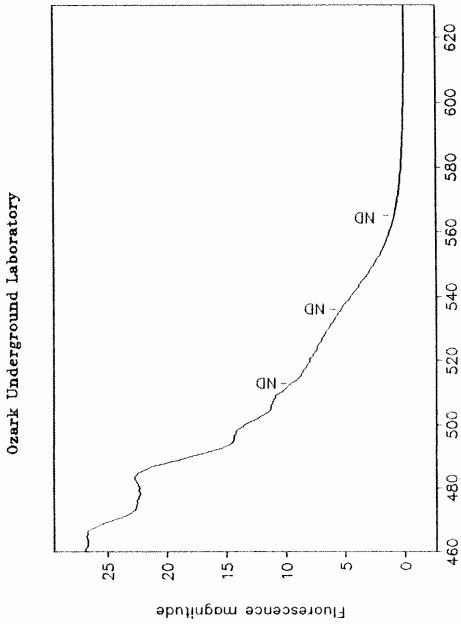
-D-15-



Station 10: Snoos Creek @ Old Bridge
OUL number: C2101 Type: Charcoal Analyzed: 8-10-1993
Date placed: 7-25-1993 Date recovered: 8-3-1993
Time placed: Time recovered: 1330

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.9	510.7	515.0	0	0	0	ND
536.1	532.8	539.4	0	0	0	ND
565.3	561.7	568.9	0	0	0	ND

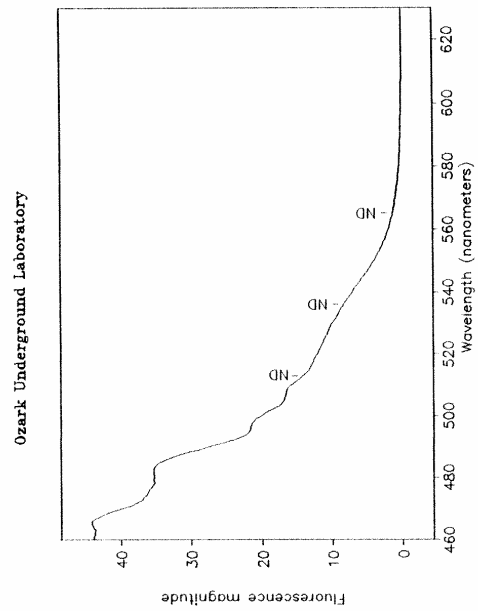


Station 9: 108 Creek @ Gaging Station
OUL number: C2099 Type: Charcoal Analyzed: 8-10-1993
Date placed: 7-18-1993 Date recovered: 8-3-1993
Time placed: Time recovered: 1230

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.9	510.7	515.0	0	0	0	ND
536.1	532.8	539.4	0	0	0	ND
565.3	561.7	568.9	0	0	0	ND

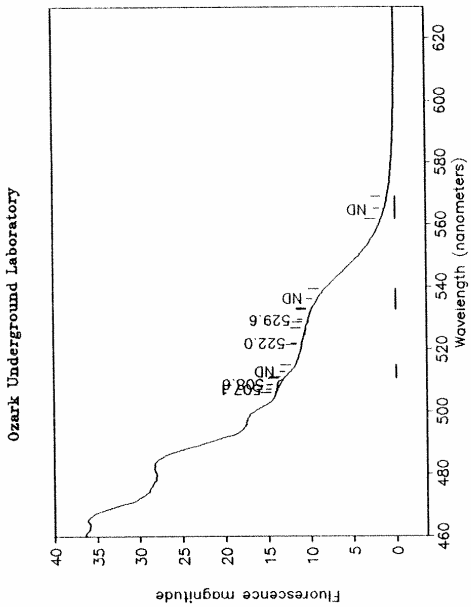
-D-16-



Station 11: Karst Canyon Tributary to 108 Creek
OUL number: C2102 Type: Charcoal Analyzed: 8-10-1993
Date placed: 7-18-1993 Date recovered: 8-3-1993
Time placed: Time recovered: 1145

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.9	510.7	515.0	0	0	0	ND
536.1	532.8	539.4	0	0	0	ND
565.3	561.7	568.9	0	0	0	ND



Station 12: Map Spring
OUL number: C2103 Type: Charcoal Analyzed: 8-10-1993
Date placed: 7-25-1993 Date recovered: 8-3-1993
Time placed: Time recovered: 0945

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.9	510.7	515.0	0	0	0	ND
536.1	532.8	539.4	0	0	0	ND
565.3	561.7	568.9	0	0	0	ND

Peaks close to normal range of tracer dyes:

507.1	506.0	511.2	0.14	1.06	0.14	
508.6	506.0	511.2	0.35	1.06	0.33	

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APPENDIX E

CAVE RESOURCES DIRECTIONS, STANDARDS, AND GUIDELINES PRESENTLY IN FORCE ON THE KETCHIKAN AREA OF THE TONGASS NATIONAL FOREST

CAVE RESOURCES
Forest-wide Direction and Standards & Guidelines

Cave Management Program

I. Management

A. The Forest shall maintain a cave resource management program to identify, evaluate, preserve, and protect caves and their environments. Cave resources shall be managed on a Forest-wide and project specific level in compliance with the Federal Cave Resource Protection Act of 1988 and its implementing regulations. Consult 36 CFR Part 261 and 290 and FSM 2356.

B. Land managers shall seek participation from interested publics, such as caving organizations, scientists, and recreationists in managing cave resources.

C. The Forest shall develop an appropriate interpretative plan which addresses caves and cave resources, how these relate to karst processes, the intrinsic karst resource values and other surface management programs. The Forest will promote public education programs to insure an increased understanding of the value of these irreplaceable resources and the need to manage these unique ecosystems appropriately.

D. The Forest shall coordinate cave resource management with the management of other surface resources.

II. Definitions

A. Due to the uniqueness of the cave resources, definition of several terms is needed for a better understanding of the resource. The following terms are used throughout the Forest-wide Direction and Standard and Guidelines. 1. “Cave” is legally defined under federal law as: any naturally occurring void, cavity, recess, or system of interconnected passages which occurs beneath the surface of the earth or within a cliff or ledge and which is large enough to permit an individual to enter, whether or not the entrance is naturally formed or man-made. Such term shall include any natural pit, sinkhole, or other feature which is an extension of the surface” (Federal Cave Resource Protection Act, 1988). This definition includes the following features:

a) **"**Significant Karst Features**"** (SKF) are those features within karst topography which have direct atmospheric and/or hydrologic connection. These may be streamsink, collapse, and solution dolines, solution channels, or vertical shafts. These are primarily stream insurgence and resurgence points, and cave entrances.

b) **"**Doline**"** or **"**sinkhole**"** (used interchangeably) are terms used to describe relatively shallow, bowl- or funnel-shaped depressions ranging in diameter from a few to more than 3000 feet. These depressions are generally formed by dissolution of and subsequent settlement of bedrock to form a depression or collapse of shallow cave roofs to form a depression.

Speleologists use "cave" to refer to all parts, regardless of size, of an underground system that links openings and chambers and that may connect the system to the surface. The most common type of cave is formed in limestone by dissolution. Included in the term caves are tree molds and lava tubes associated with lava flows, erosional caves, as well as those formed by dissolution of bedrock.

2. **"**Cave Resources**"** includes any material or substance occurring naturally in caves on Federal Lands, such as animal life, plant life, paleontological resources, cultural resources, sediments, minerals, speleogens, and speleothems.

3. **"**Significant cave**"** means a cave located on Federal Lands that has been evaluated by the authorized officer and determined to have biotic, cultural, mineralogical, paleontologic, geologic, hydrologic, or other resources that have important values for scientific, educational, or recreational purposes.

4. **"**Karst**"** is defined as a type of topography that develops in areas underlain by soluble rocks, primarily limestones. Dissolution of the subsurface strata results in areas of well-developed sub-surface drainage characterized by dolines, collapsed channels, vertical shafts, and caves. Areas on which karst has developed is said to display "karst topography" or referred to as a "karst landscape".

5. "Speleothem" means any natural mineral formation or deposit occurring in a cave or lava tube, including but not limited to any stalactite, stalagmite, helictite, cave flower, flowstone, concretion, drapery, rimstone, or formation of clay or mud.
6. "Speleogen" refers to relief features on the walls, ceiling, and floor of any cave or lava tube which are part of the surrounding bedrock, including but not limited to anastomoses, scallops, meander niches, petromorphs and rock pendants in solution caves and similar features unique to volcanic caves.

III. Planning

A. The Forest shall develop and maintain a cave resource inventory, identifying both known and potential cave locations including significant karst features. This inventory will provide resource managers with knowledge of areas where caves and related unique geologic features do, or are likely to exist. Areas where karst topography is known to exist and potential karst areas shall be identified. This will allow land managers to better schedule activities, knowing that a cave resource assessment is needed if the planned activity falls within an area where caves can and/or do exist.

B. Manage caves and cave resources using an interdisciplinary approach. Caves, including significant karst features, shall be considered in all land use planning decisions. Include interested publics and the caving community in the public involvement process.

C. The cave resource inventory shall be updated and maintained as new areas are identified. The inventory may be kept within the GIS system as long as adequate security of cave location can be maintained.

IV. Significance/Inventory/Project Clearance

A. Significance: Significant caves and cave resources will be evaluated as required by the Federal Cave Resources Protection Act of 1988. The first purpose of the Act is to secure, protect, and preserve these resources on Federal lands for the perpetual use, enjoyment, and benefit of all people. Within the Tongass NF, cave and cave resources generally occur in areas of karst topography. Inventory of karst topography to identify caves and cave resources is an essential first step to understand what "significant" resource values exist. Survey of all caves is needed to determine if significant resource values exist. The

current definition of “significant” may change as our knowledge of caves and cave resources increase. Caves and cave resources shall be classified as “significant”, if during survey any of the following resource values are inventoried:

1. Biological: If components are very numerous and highly sensitive to disturbance, if habitat is critical to species survival, and if the cave contains unique species, or ones found on State or Federal sensitive, threatened, or endangered species lists. If the cave provides important seasonal habitat for bats or other non-endemic species.

2. Hydrological: If components are unique, complex, or highly sensitive and part of a larger underground hydrologic system. If the cave conducts water to domestic water supplies or the water quality is important to wildlife, fisheries, or humans.

3. Geological: If unique geologic information is apparent within the passages of the cave. Also caves formed by unusual geologic processes or ones demonstrative of unusual geologic processes. The presence of sediment deposits or features important for evaluating geologic events locally or regionally.

4. Mineralogical: Presence of abundant, sensitive, or unique speleothems and/or minerals.

5. Paleontological: Presence of any important fossil remains, either within cave deposits or within the walls of the caves.

6. Educational or Scientific: Caves, which by virtue of their location, contents, or special associations offer unusual opportunity for interpretation and public education or scientific study.

7. Cultural: Presence of historic or prehistoric artifacts which would make the site eligible for the National Register of Historic Places or other materials or deposits which could be damaged if not managed. Also includes caves which are important to local regional or national history even though there may be no deposits to be disturbed as well as caves of important religious significance to native populations.

8. Recreational: Caves which receive heavy recreational use or ones considered by outside interests to be of importance for the challenge or adventure they provide including caves considered of interest to recreationalists or caves with high scenic values.

9. Regional/ National/ International Ranking: Caves which by nature of their length, volume, total depth, pit depth, or height places them within the upper 25 percent of regional, national, or international records. Caves with other unusual or unique features, associations, or recognition are also included.

Any cave may contain one or all of these values. The Forest shall consult the National Speleological Society, local Grottos, and experienced covers for assistance in determining significance. Caves determined to be significant, as defined above, will be considered for listing on the National Significant Cave List. Specific locations of Significant Caves are exempt from disclosure to the general public.

B. Inventory: The Forest shall continue to work with the national and local caving community and other interested publics to locate, map, and describe caves and to evaluate the significant resource values discovered. The inventory process should document all unique biological, hydrological, geological, mineralogical, paleontological, educational or scientific, cultural, and/or recreational values. Care should be taken to analyze the surface to sub-surface inter-connection of the ecosystem. Biological studies shall be conducted to determine the presence of threatened, endangered, and/or sensitive species and to better define the ecosystems present in the karst features. Forest personnel will be responsible for reporting any karst features found in the field. This includes features such as sinkholes, collapsed channels, caves, resurgence streams, and areas where surface drainage becomes subsurface, etc. To aid Forest personnel in identifying these features on the ground, education programs and an inventory reporting system should be developed.

C. A comprehensive analysis of Cave Resource Management should be completed by the Forest on known cave resources within five years after approval of the Forest Plan. Management strategies shall be prepared for caves determined to be significant and for others where hazardous conditions exist. The management strategy will include an inventory and mapping of cave resources, development of research and monitoring programs, interpretive and recreation programs, and when necessary, a cleanup or restoration programs. Management strategies will be developed on a cave by cave basis. If the analysis determines that cave management or protection is required, the cave should be placed in one of the following classes.

Class 1: Sensitive Caves

Caves considered unsuitable for exploration by the general public either because of their pristine condition, unique resources, or extreme safety hazards. They may contain resources that would be impacted by low level visitation. These caves are not shown on maps or discussed in publications intended for general public use such as guides, brochures, and magazines. Scientific studies within these caves will be encouraged.

Class 2: Directed Access Caves

Caves with directed public access and developed for public use and enjoyment. These caves are shown on maps or have signs directing visitor access. Regardless of the level of development, public visitation is encouraged. These caves could have improved access, developed trails, artificial lighting, and guided tours. Interpretive materials should be available on these caves. The caves may have sensitive resources that are protected. Access may be through a reservation system.

Class 3: Undeveloped Caves

Caves that are undeveloped or contain minimal developments that are suited for persons who are properly prepared. Some of these caves would require technical skills beyond that of the average Forest visitor and could present substantial hazards to the user. In general, these caves are those where it has been determined that recreational use will not substantially degrade the caves resources or special values. Location of these caves will be available to the public upon request, however, public use will not be directed toward them.

D. All newly discovered caves will be temporarily managed as Class 1 until an analysis of resource values is completed. Following analysis, each cave will be designated either Class 1, 2, of 3 if appropriate.

E. Caves determined through analysis to have no significant values, and documented as such, will no longer be protected.

F. Project Clearance: The Federal Cave Resources Protection Act of 1988 requires that surface management activities assure that caves under consideration for the National Significant Caves List are protected during the period of consideration. Any management activity that can directly or indirectly affect the ecosystem of the cave resource shall not proceed until cave resources clearance has been approved by the District Ranger or Forest Supervisor as appropriate. If a previously undiscovered site is found during the course of a project, the project administrator shall halt any work that might potentially damage the cave resource. Work may resume after consultation with the local cave management specialist, resource inventory and analysis has been completed to determine significance, and appropriate mitigation measures, if needed, are applied.

V. Standards & Guidelines

A. Prior to determination of significance under the 1988 Cave Act, or Forest-wide comprehensive cave management analysis, the following direction is applicable:

1. During the cave resource inventory process, caves, their subsurface extent and the position of all significant karst features and caves shall be mapped. Care shall be taken to note subsurface drainage patterns, resurgence areas, surface drainage, and drainage basin characteristics. This information is necessary to determine the cave's ecological relation to the surface. During the inventory process, note all biological, hydrological, geological, mineralogical, paleontological, cultural, recreational, or educational or scientific resource values. These values are needed to determine the significance of the cave.
2. Timber harvest, road construction, and other related management activities in the vicinity of a cave or significant karst feature or above the course of a cave, shall be designed in a way to insure protection of the cave resources.
3. Surface management activities should be designed to in-no-way impede or divert surface and groundwater flow into a cave or significant karst feature.
4. Retention of vegetation is required in the vicinity of a cave or significant karst feature to protect the cave's microenvironment. The extent and limits of windfirm no-harvest buffers surrounding significant karst features shall be determined on a case by case

basis. Topographic breaks and vegetation patterns should be utilized during buffer design and layout. The intent of the buffer is to insure stability of the cave ecosystem, the integrity of the slopes surrounding the feature, and adequate sediment filtration between management activities and the cave resources. In some instances, when a windfirm no-harvest buffer can not be designed, it may be possible to leave all nonmerchantable timber and ground cover intact, removing the overstory by directionally falling trees away from the significant karst feature. There shall be no ground disturbing activities on slopes steeper than 30 degrees adjacent to cave entrances. An example of this would be protection of a steep sided, closed basin in which surface drainage flows into a cave system or on steep slopes immediately adjacent and up hill of a cave opening.

5. Similar buffers shall be maintained around all direct drainages into significant karst features. This includes dolines, cave collapse areas known to open into a cave's drainage system, and perennial, intermittent or ephemeral streams flowing into caves. The immediate area surrounding resurgence streams shall be protected to insure stability of the cave systems's ecosystem. The intent of this direction is to insure that additional sediment is not introduced into the cave system, surface flows are not interrupted, and logging slash and debris is not transported into the cave system or allowed to plug the cave entrance.

6. Where timber harvest is occurring in the vicinity of a cave, fall trees directionally away from the cave and its course. Yarding should in no way drag timber across and/or through significant karst features. Full suspension, latteral, and/or split yarding or other mitigation measures which will insure the stability of the karst slopes is required in these areas. Trees felled into or across significant karst features shall be not be removed. Any small woody debris that has found its way into significant karst features shall be hand removed within 48 hours.

7. No significant karst feature shall be used as disposal sites for slash, spoils, or other refuse. When designing facilities, consider the possible effects of the facility on the karst system. Carefully plan sewer facilities, waste disposal sites, fuel storage areas, and hazardous material storage sites to mitigate possible effects on significant karst features in the event of a system failure, leakage, or spill.

8. Design roads and related construction to avoid altering surface drainage into significant karst features or focusing sediment from road surface and/or drainage into significant karst features. Any excavation requiring blasting in the vicinity of a cave should be carefully designed to insure that seismic shock does not affect the fragile formations in the cave, destabilize cave passages, or alter groundwater flow into the cave. Individual shots shall be designed to minimize overshot materials so vegetation is not damaged or destroyed. Blasting plans shall be required as well as careful monitoring of all such excavation.

9. Design quarry and material sources to insure that location and excavation in no way threaten cave resources.

10. Recognize that blasting and other surface management activities can result in significant disturbance of roosting and hibernating bats within the cave systems. Some bird species utilize the cave entrances for nesting and seabird rookeries have been found in some littoral caves. Seasonal closures prohibiting construction activities in some areas may be required to insure protection of these populations.

11. Limit public access, if required, to prevent damage to the cave resources and/or if there are safety hazards.

12. Information concerning the specific location of any significant cave may not be made available to the public unless disclosure of such information would further the purposes of the Act and would not create a risk of harm, theft, or destruction of the cave.

13. Scientific or educational use of caves will be authorized by the Forest Supervisor, where appropriate.

14. Communication and cooperation between the Forest Service, caving organizations, and recreationists will be fostered. Exchanged information will not be made public if it could lead to the degradation of sensitive caves.

15. Emphasize enforcement of laws protecting caves from relic collectors and vandalism.