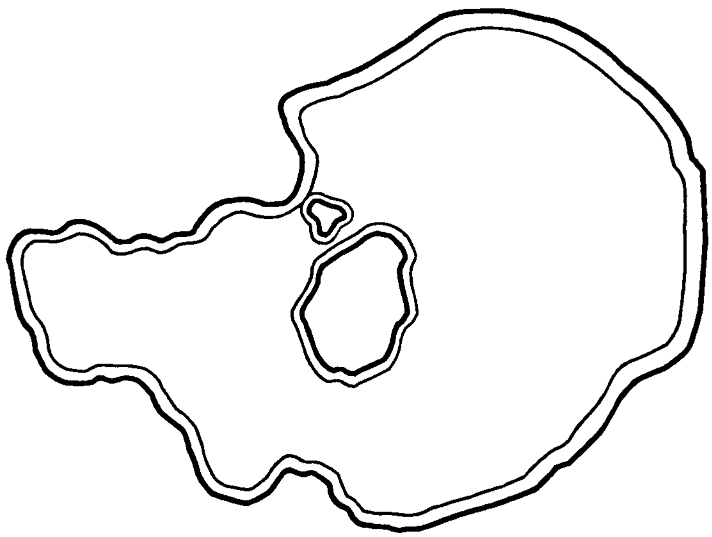
An Auxiliary Report
Prepared for the

MONO BASIN WATER RIGHTS EIR

Distribution of Substrate Types at Mono Lake, California



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Mono Basin EIR Auxiliary Report No. 20

An Auxiliary Report
Prepared for the
Mono Basin Water Rights EIR Project

This auxiliary report was prepared to support the environmental impact report (EIR) on the amendment of appropriative water rights for water diversions by the City of Los Angeles Department of Water and Power (LADWP) in the Mono Lake Basin. Jones & Stokes Associates is preparing the EIR under the technical direction of the California State Water Resources Control Board (SWRCB). EIR preparation is funded by LADWP.

SWRCB is considering revisions to LADWP's appropriative water rights on four streams tributary to Mono Lake, Lee Vining Creek, Rush Creek, Parker Creek, and Walker Creek. LADWP has diverted water from these creeks since 1941 for power generation and municipal water supply. Since the diversions began, the water level in Mono Lake has fallen by 40 feet.

The Mono Basin water rights EIR examines the environmental effects of maintaining Mono Lake at various elevations and the effects of possible reduced diversions of water from Mono Basin to Owens Valley and the City of Los Angeles. Flows in the four tributary creeks to Mono Lake and water levels in Mono Lake are interrelated. SWRCB's decision on amendments to LADWP's water rights will consider both minimum streamflows to maintain fish populations in good condition and minimum lake levels to protect public trust values.

This report is one of a series of auxiliary reports for the EIR prepared by subcontractors to Jones & Stokes Associates, the EIR consultant, and contractors to LADWP. Information and data presented in these auxiliary reports are used by Jones & Stokes Associates and SWRCB, the EIR lead agency, in describing environmental conditions and conducting the impact analyses for the EIR. Information from these reports used in the EIR is subject to interpretation and integration with other information by Jones & Stokes Associates and SWRCB in preparing the EIR.

The information and conclusions presented in this auxiliary report are solely the responsibility of the author.

Copies of this auxiliary report may be obtained at the cost of reproduction by writing to Jim Canaday, Environmental Specialist, State Water Resources Control Board, Division of Water Rights, P.O. Box 2000, Sacramento, CA 95810.

Distribution of Substrate Types at Mono Lake, California

A report to
The Califonia State Water Resources Control Board
and
Jones and Stokes Associates, Sacramento

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January, 1993

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A report to
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1. INTRODUCTION

A. Background

Mono Lake (present surface elevation 6374 feet) is a large body of hypersaline, hyperalkaline water that abuts the steep Sierran front immediately east of Yosemite National Park (Figure 1). The lake has no outlet, and so fluctuates in elevation, rising when inflow exceeds evaporative loss, and falling when the relationship is reversed. These transgressions and regressions result in changes in the spatial dimensions of the habitats used the lake's biota, including the alkali fly *(Ephydra hians)*, an insect that constitutes an important food source for Mono Lake's large migratory bird population. During its pupal life-stage, the fly attaches itself to the various "substrates" (rock, beach pavement, tufa towers, and pumice blocks, and to a lesser extent sand and mud) that lie submerged in shallow water (to ~33 feet depth) around the margin of the lake. During its larval stage, the insect grazes organic detritus from these surfaces (Herbst, 1988). Rises and falls of the lake cause the availability of these different substrate types (and thus the availability of brine fly habitat) to vary markedly. This report identifies and describes the different types of substrates that occur around and under Mono Lake, and documents the distribution and spatial dimensions of those substrate types. The report is

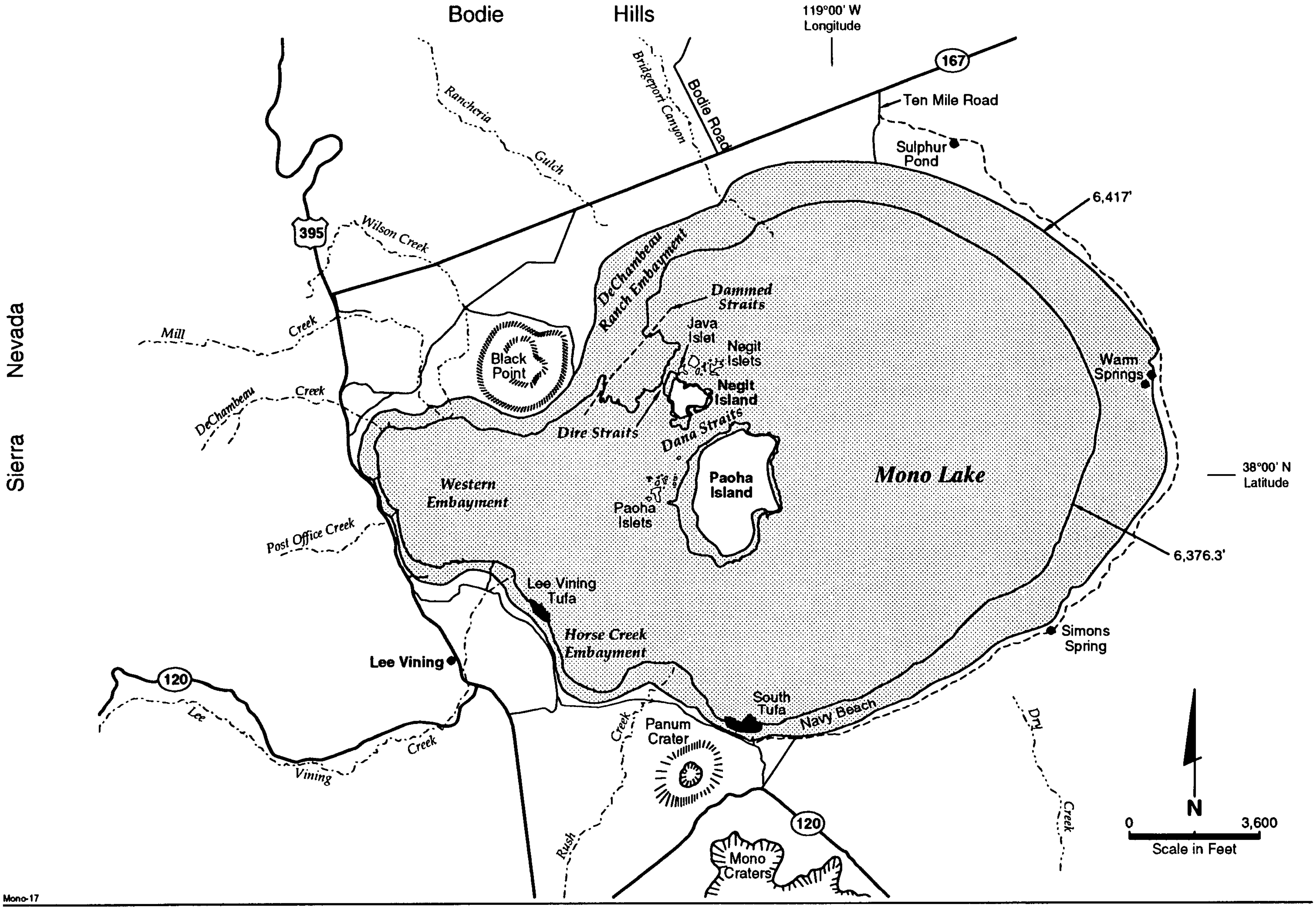

Figure 1.
Index Map of Mono Lake

intended to provide a basis for assessing the acreage of the different substrate types that exists at various lake levels.

B. Sources of Information: Interpreting the Pelagos Charts

The subaerial (above-lake) distribution of the various substrate types, shown on large-scale work maps that were provided to Jones and Stokes Associates, and included here in reduced form as Figure 2, is based on interpretation of aerial photographs and on "ground-truthing" in the field. The sublacustrine (below-lake) boundaries, also shown on the plates, are taken from the bathymetric charts produced by the Pelagos Corporation of San Diego. While the charts have contributed immensely to the scientific understanding of Mono Lake, they are not without errors and inaccuracies. Some of these relate to the configuration of isobaths. The isobath errors typically occur close to the lake margin and around the periphery of the islands, where navigation hazards (pumice blocks, tufa towers, and shallow water) precluded close approach by the sounding vessel. Jones and Stokes Associates, has been made aware of these isobathic inaccuracies (Stine letters of 1991 to K. Casaday, JSA), and have taken these into account in producing the work maps and Figure 2.

Similarly, Pelagos' interpretation of geologic features of the lake bottom, while reasonable in most areas, can be shown to be in error in a number of places. The Pelagos work was conducted in August and September of 1986, when the lake stood at ~6380 feet. Since that time it has dropped 6 vertical feet, to an elevation of ~6374 feet. Field examination, as well as examination of aerial photographs taken in May of 1991 (lake level 6374.5 feet), and in October of 1982 (lake level 6372 feet) makes it possible to check, subaerially, the nature of the substrate that stood underwater when it was mapped by Pelagos. In several areas that Pelagos mapped as "tufa" or "boulders and tufa", no tufa deposits (towers or beach rock) are evident on the ground. Instead, pumice blocks (Pelagos' "boulders") characterize these sites. Along the northern shore, to the north and east of Black Point, the combination of an abundance of pumice blocks and low-gradient shorelands made it impossible for the sounding vessel to approach the shore closely enough to map the

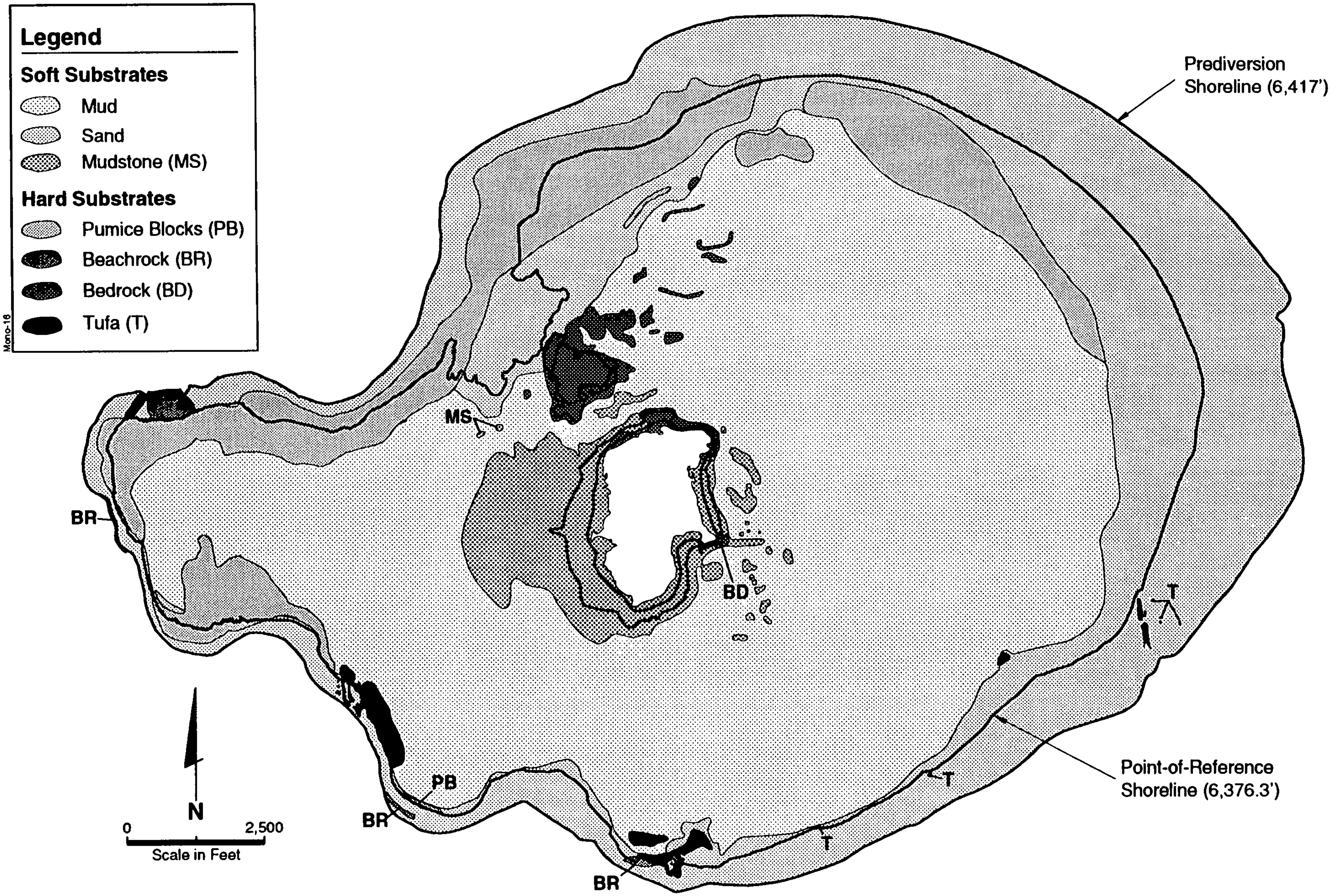

Figure 2.
Distribution of Substrates

substrate, and so their map lacks information for these areas. For the purposes of this report, the substrate in this area was mapped using the 1982 aerial photos. Finally, the Pelagos charts, for reasons of navigation hazard, are an imperfect guide to the sublacustine distribution of sand, particulary the band of littoral sand that has built up along the immediate shoreline. This band, too, was mapped based on field observation and interpretation of aerial photos.

2. LITTORAL, DELTAIC AND LAKE-BOTTOM SEDIMENTATION AT MONO LAKE

A. Introduction

Generally speaking, Mono Lake is characterized by three depositional environments--littoral, deltaic, and profundal (deep-lake). Understanding these environments, the processes that define them, and the manner and extent to which they vary due to lake transgressions and regressions, are essential to predicting the acreage of substrate available at a given lake level. Each of these depositional environments is discussed below.

B. The Littoral Depositional Environment

Introduction. Sands and gravels (and, locally, cobbles and boulders) are delivered to the shore of Mono Lake through a variety of means and from several notable sources. Once there, long-shore ("littoral") currents distribute this sediment along the lake margin as "littoral drift" (see below). The band of shoreland on which littoral drift is actively (over a period of, say, weeks) being deposited delimits the littoral depositional environment.

Nature and sources of littoral drift. Among the most important sources of littoral drift are Mono Lake's principal tributary streams. Under natural conditions, Rush, Lee Vining, Mill, Dechambeau, and "Post Office" creeks transport large amounts of sand and gravel to the lakeshore year-round.[1] (The

[1] Under modern conditions flow on Rush, Lee Vining, and Mill creeks has been interupted by diversions. Wilson Creek--formerly a tiny stream that seldom carried water all the way to the lake--has been artificially enlarged, and so has become an important modern source of sediment.

ephemeral streams of the northern Mono Basin--Bridgeport, Cottonwood, and Rancheria creeks--supply sediment to the lakeshore only intermittently.) While the bulk of this sediment accumulates at or near each of the stream mouths as a delta (see below), some is swept downshore as littoral drift.

Mono Lake also derives littoral drift at points where the shoreline abuts steeply inclined deposits of loose, unconsolidated sediment. Most important among these are Black Point (Figure 1)--the large cone of readily erodible basaltic cinder on the northwest shore of the lake--and the cliffs of rhyolitic Mono Craters tephra that lie along the southern lakeshore. Other points of erosion include the cliff-exposures of littoral and lacustrine sediment along the southeastern and eastern shores.

Littoral currents. The prevailing southwesterly winds of the Mono Basin stir the littoral currents that entrain and transport sediment along the lake margin. The distribution of the various types of drift has been used to trace the direction of the prevailing currents (Stine, 1987). Those currents, described below, are mapped on Figure 3.

The sweeping northern shore of the lake is characterized by embankments and sheets composed primarily of basaltic sand and gravel eroded from the flanks of Black Point. The presence of these shoreline deposits as much as 10 miles to the east of Black Point clearly indicates the prevalence of clockwise currents in this quadrant of the lake. Along the southeastern and eastern shores, in contrast, the prevailing littoral currents flow counterclockwise, carrying rhyolitic sand and gravel eroded from deposits of Mono Craters tephra. Bars and berms of this pumiceous drift extend east- and northward from Navy Beach for a distance of ~15 miles.

These two opposing currents collide along the lake's north shore, and dump their loads of drift, much of which is then blown landward to form the large field of dunes in that sector. The collision necessitates a "return-

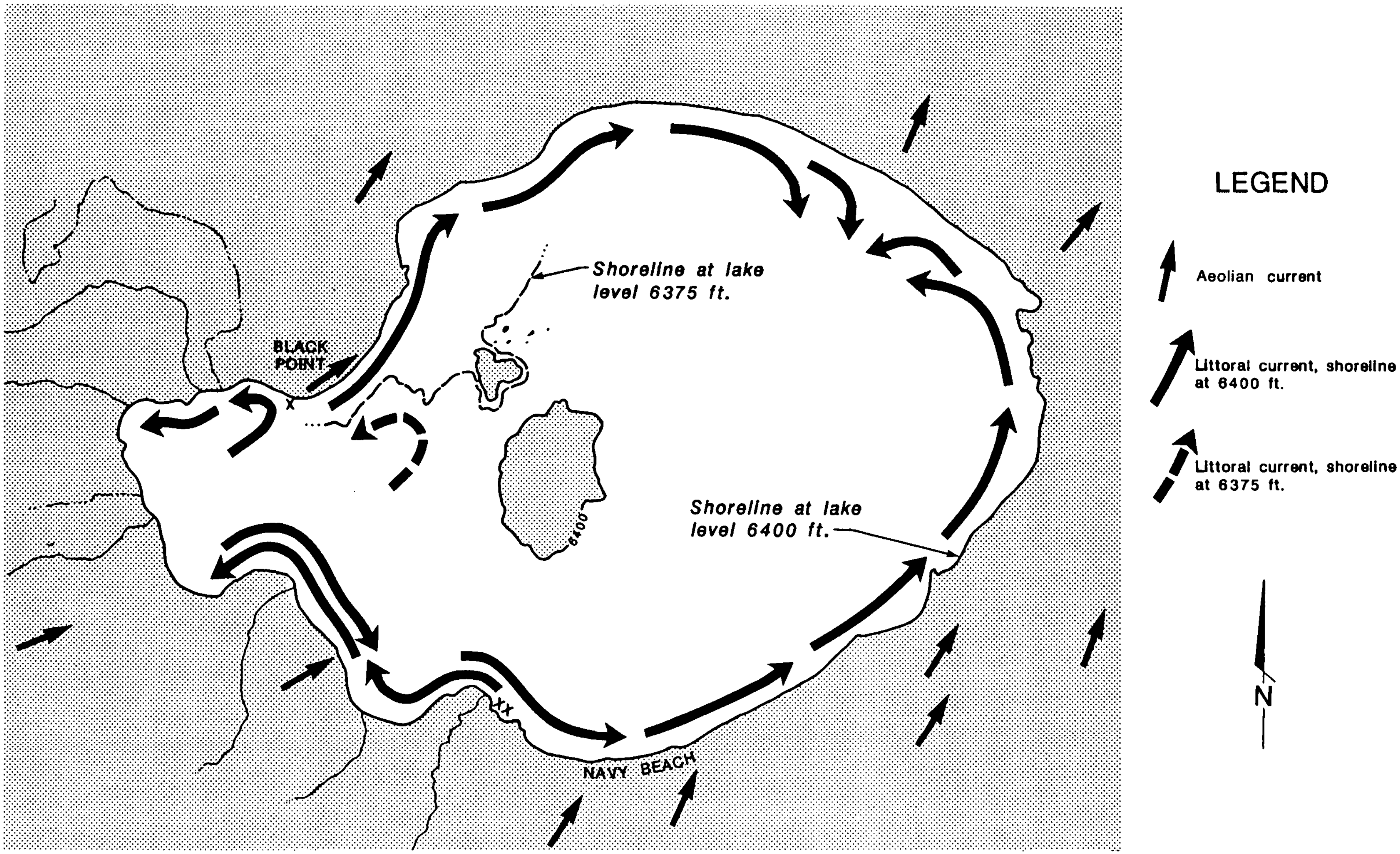

Figure 3.
Prevailing Littoral and Aeolian Currents of the Mono Basin

current", which flows, perhaps largely at depth, offshore to the southwest.

Littoral flow along the western third of the lake is more complex, more variable, and generally weaker, than the persistent currents described above. Because it is typically secluded from strong winds, the margin of the Western Embayment is characterized by particularly feeble waves and littoral currents.

It is reiterated that the currents described above are the prevailing currents, reflecting the prevailing windflow at Mono Lake. With variations in the wind direction come variations in the direction of long-shore currents.

Depth of littoral deposition. On numerous occasions during the summers of 1980 and 1981 it was possible to observe the depth to which sand is deposited by littoral processes. These observations were made immediately after windstorms severe enough to stir whitecaps on the surface of the lake. At the time of each measurement the lake was lower than it had been for at least 130 years, thus assuring that the littoral deposits found in shallow water along the lake shore were thoroughly modern. Fine sand was typically found to a depth of less than 3 feet, though in one instance it could be found to a depth of approximately 4 feet. Littoral sand might find its way into deeper water during times of very severe winds; as a rough estimate, then, the maximum depth of sand deposition by littoral currents at Mono Lake is taken to be approximately 5 feet. This estimate is in accord with underwater observations by Dr. David Herbst (pers. comm.). Several non-littoral mechanisms act to transport sand into deeper water locally (see below, and Stine, 1987.)

The effect of lake-level fluctuations. Changes in lake level (and thus in offshore water depth, and in the orientation and configuration of the shoreline) can affect dramatically the direction of the littoral currents, the sources of littoral drift, and the locations at which that drift is deposited. When the surface of the lake declines to below 6401 feet, for example, the regressing shoreline loses contact with the steep flank of Black Point, effectively cutting off the supply of basaltic cinder to the littoral currents. When the lake surface exceeds approximately 6435 feet the shoreline takes a sharp northerly bend just east of Black Point, creating an embayment (the "Dechambeau Ranch Embayment"--Figure 1) that is bypassed by the currents. This, too, effectively cuts off the supply of cinder to beaches downshore. Beach deposits of Black Point cinder along the northern shore are thus restricted to a well-defined band that lies between elevations of 6401 and about 6435 feet. At lake elevations above and below this band of cinder, the littoral drift along the northwestern shore is composed primarily of andesitic sand transported in small quantities to the lake margin from the Bodie Hills by the aforementioned ephemeral streams.

The quantity of gravel and sand that the streams deliver to the littoral currents can likewise change with fluctuations in lake level. As long as the shoreline occupies the gently sloping "plains" of the deltas, as it does at lake levels between roughly 6400 and 6440 feet, waves and currents can rework newly deposited stream sediment and transport it to distant points around the lakeshore. When the lake rises above the plain of the delta, engulfing the trunk-stream canyon, the stream dumps its load in the canyon, away from the direct influence of the littoral processes. If the shoreline drops below the delta plain onto the steeply inclined "delta front", as it does at lake levels below ~6400 feet, the great bulk of the stream sediment falls off the delta into deep water, beyond the reach of waves and currents.

The series of ~north-striking faults that disect the southeastern lakeshore exert another type of influence on littoral transport. The tufa deposits that have formed along several of these lineaments constitute jetties that shunt the normally easterly- to northeasterly-flowing currents, and any sediment that they carry, northward toward the open water of the lake. As a result, littoral flow is "sediment-starved"--and thus highly erosive--in the lee of the jetties (the northeast side), and "sediment-stuffed"--and thus prone to deposition--on the up-current side. This has created "scallops" on the southeastern shorelands--shallow, asymetrical embayments whose shorelands grade from a relatively low gradient south and west of the faults, to a relatively high gradient to the north and east. The massiveness of the jetties, and thus their effectiveness in deflecting the littoral currents, varies asystematically with lake level. The asymetry in erosion/deposition tends to be accentuated during rises in lake level, when shoreland erosion is most pronounced (Stine, 1990).

Lake-level fluctuations can influence current direction to an even greater degree along the northwest shore. There, as the lake recedes to an elevation of ~6390 feet, portions of the Negit landbridge begin to protrude from the lake surface, deflecting the normally clockwise flow of water into a counterclockwise backset eddy. The effect is intensified as the lake falls to lower elevations. This, in combination with the dearth of sediment sources that exists at low lake levels on the northwest shore, and with the current-dampening effect of the pumice blocks that litter the shorelands in this sector (see below), accounts for the relatively thin blanket (and locally, the absence) of littoral sand observed on low-elevation beaches north and east of Black Point.

Littoral processes and their influence on shoreland gradient. At several points around the lake (including Black Point, the Sierran escarpment, and the high cliffs of lacustrine sediment near Simon's Springs) the gradient of the shorelands is dictated by structural features of the landscape. Away from these features, it is the littoral processes themselves that dictate shoreland gradient. Consider the shorelands northeast of Black Point: Because the basaltic cinder eroded from the flanks of the volcano is relatively coarse and abundant, its transport by waves and littoral currents necessitates a steep beach, which the waves and currents build through deposition. Thus, between elevations of 6401 feet and 6435 feet (where, for reasons given above, Black Point cinder is deposited), gradients along the northern shore of the lake are steep (~70-100/1000). Both landward and lakeward of this band, where the andesitic sand that composes the littoral drift is both scarce and fine, shorelands tend to be far gentler (~18/1000). This same principle applies around most of the Mono shorelands. Since many factors (see above) tend to deprive the littoral system of both an abundance of drift, and of coarse drift, as the lake falls to lower elevations (most notably, to below ~6400 feet), shorelands tend to flatten dramatically in the lakeward direction. This trend toward flattening is reversed at the lakeward margin of the "Scholl terrace"[2] (elevation ~6368 feet) where, around most of the lake periphery, the lake bottom steepens abruptly. Reasons for the formation of the abrupt steepening (the "nick point") at 6368 feet are discussed by Stine (1987).

C. The Profundal Depositional Environment: Deep-Lake Muds

Away from the immediate shores of Mono Lake, on the moderatly deep- to deep-lake floor, deposition is dominated by a highly flocculated, biogenic ooze. This black to olive-green "seston" (or, in simpler terms, "mud" or "muck") is composed primarily of clay-sized, and fine-silt-sized particles. Fossil diatoms, as well as oolitic sand and algal mats, characterize the mud at some localities.

When first deposited, the seston is water-rich and unintegral. Over time an individual year's accretion settles, and becomes more compact and coherent. Burial by subsequent deposits further compresses the mud, constricting its interstitial space, and decreasing its water content.

Because of this transformation, "Mono mud" displays different degrees of erodibility (as well as different habitat suitabilities for the brine fly) depending on its age and degree of compaction. As the lake shallows during a regression, muds that accumulated in the quiet of relatively deep water suddenly are subjected to waves and currents (see above)--agents that have the capacity to remove some or all of the youngest, least solidified material. In general, relatively soft muds are retained on shorelands subjected to low-energy waves and currents (e.g. the shorelands of the Western Embayment and Dammed Straits, and areas with a high density of pumice blocks that mute the waves and currents--see below); in general, shorelands subjected to higher-energy processes during a lake drop are stripped of their soft muds. Further

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2 The Scholl Terrace is a gently inclined wave-cut platform that encircles the lake. See Stine, 1987.

shallowing causes the muds to be blanketed with a greater or lesser thickness of littoral drift.

D. Deltaic Sedimentation

At the mouths of Mono Lake's main influent streams, alluvium (river-transported sediment) constitutes the predominant deposit. While a portion of the sands, gravels, cobbles and boulders are entrained by littoral currents and transported long-shore (see above), the majority of the alluvium from each river comes to rest in close proximity to the stream mouth, where it forms a delta. In contrast to the sediments that characterize the other depositional environments, the delta deposits are coarse and relatively immobile, particularly if they become cemented with tufa to form beachrock. While the largest deltas occur at the mouths of Rush, Mill, and Lee Vining creeks, other streams--including the small, unnamed creeks tributary to the Western Embayment--are characterized by deltaic deposits at their mouths.

3. THE "SOFT-SUBSTRATES"

A. Introduction

The three sedimentary environments described above constitute the backdrop upon which the various habitat-related substrate types are superimposed. Biologists studying the alkali fly have divided the substrate types into "soft" and "hard" catagories, based on mobility, surface characteristics, and habitat potential (Herbst, 1988; Little, et al, 1990). While these types and catagories are not necessarily the same as those that would be employed by a geomorphologist, they nevertheless have a basis in geomorphology and so are described and discussed in geomorphological terms.

The soft-substrate types include fine, unconsolidated sediments that are subject to wave- and current-induced shifting. Based on mode of origin, and on distribution, the soft-substrates are conveniently divided into two types: i) mud, and ii) littoral sand/gravel. The present-day distribution of these soft-substrates, and information required to predict their future areal extent under certain transgression/regression scenarios, are presented below.

B. Mud Substrate

Present-day distribution. The present-day distribution of lake mud is shown on Figure 2. Subaerial portions of the polygons were drawn based on aerial photographic interpretation and field examination. The sublacustrine distribution is based on the bathymetric and "geologic-features" charts produced by Pelagos, and on assumptions stemming from the discussions of depositional environments presented above.

Lake-bottom mud is by far the most areally extensive of the substrate types. It covers the great bulk of the lake bottom, and constitutes the medium upon which most of the other important substrate types have been deposited. For the sake of accuracy and consistency, any calculations of present-day mud-substrate area should subtract out the 2-dimensional area of other substrate types (most importantly, the pumice blocks) that overlie the muds.

Changes in distribution with fluctuations in lake level. In assessing the impact of lake fluctuations on the distribution of mud substrate, it is reasonable to consider the entire lake floor at any given lake level as mud, and then subtract out the areas of the substrate types that overlie the mud (most importantly, sand and pumice blocks). The distribution of these other substrate types is discussed below.

C. Littoral Sand and Gravel Substrate

Present-day distribution. Littoral sand (and locally, littoral gravel) occurs as a band that encircles Mono Lake (Figure 2). Observations (see above) suggest that, where waves and long-shore currents are the primary depositional agents, littoral sediments typically accumulate at depths of from 0-5 feet of water. Exceptions are found along the northeastern shore of the lake, where the previously described return-current apparently carries sand to a depth of around 12 feet (depth based on the Pelagos charts); at the mouths of the main tributary streams, where sand falls off the steep delta front into deep water; and along the southeastern shore, where sand is shunted off the Scholl Terrace into deep water (to depths of ~30 feet) by the natural jetties.

In most areas the sand constitutes a more or less continuous sheet. At South Tufa, in contrast, sand overlies beachrock locally, and appears to provide only ~50% cover. Note that the sublacustrine sand distribution mapped by Pelagos and shown here on Figure 2 reflects the fact that the lake fell to as low as 6372 feet in 1982.

The littoral sand is not of uniform thickness throughout its distribution. In places (most notably on the northwestern shore) it thins to a layer less than 1/16-inch thick that overlies mud. At several points in this quadrant it is not uncommon under some wind/wave conditions to see a thin accumulation of littorally-transported mud overlying the thin layer of sand. At any given moment along some portions of the littoral zone, there may be a mercurial patchwork of sand and mud.

Changes in distribution due to fluctuations in lake level. In the most general sense, a transgression of the lake will force an upslope migration of the band of littoral deposits. This applies to the upper boundary of the band (since it will move landward with the rising shoreline), as well as to the lower boundary (where, due to deepening water, littoral deposition will cease, and previously deposited sands will become covered with muds).

For two reasons, the band of littoral sand surrounding the lake should, generally speaking, become narrower as the lake moves from its present level to higher elevations. First, the steepening of the shorelands in the upslope direction dictates that a band of sand extending into 5 feet of water will be narrower at high elevations that it will at low; and second, as the shoreline migrates an increasing distance from the distal margin of the Scholl terrace, there should be less tendency for sand to spill off the terrace into deep water (this pertains particularly to sand deposition along the southeastern shore).

Should the lake fall to elevations below the level of the Scholl terrace the shoreline will again abut relatively steep slopes--so steep, in fact, that sand might be expected to spill to deep water around much of the lake periphery. Thus, the tendency for the sand band to widen, and to cover an ever greater percentage of the lake floor, may increase markedly at lake levels below ~6370 feet.

I know of little basis for predicting any lake-fluctuation-induced changes in the pattern of sand deposition associated with the return-current of the northern shore. Perhaps this sand field is best treated as a constant percentage of the fluctuating area of the lake floor.

4. THE "HARD-SUBSTRATES"

A. Introduction

The hard-substrate types are characterized by durable (and, ideally, microtopographically intricate) surfaces that are not subject to shifting by waves. Included here are tufa-covered pumice blocks, beach rock, tufa towers, hard-rock outcrops, and mudstone. Each is discussed in turn.

B. Pumice Blocks

Introduction. Around 1700 years ago a volcanic eruption on the floor of Mono Lake produced the islet named "Java" (Figure 1). Included in the ejecta associated with this eruption were tens of thousands of large (typically >3 feet, and up to >30 feet), vesicular blocks of pumice. During and shortly following the eruption, these highly buoyant "Java blocks" floated to the surface of Mono Lake and drifted to shore, where they shoaled, waterlogged, and became coated with tufa (Stine, 1987). They were subsequently partially (around most of the shorelands) to completely (near the deltas) buried in sediment. The pumice blocks are, in shear acreage, by far the most abundant of the hard-substrate types. Because of their durable but porous surfaces, these anchored prominences, acre for acre, also constitute the most productive substrate type for the pupal stage of the alkali fly (David Herbst, pers. comm.).

Distribution. The pumice blocks (see Figure 2) litter thousands of acres under and about the western half of Mono Lake, from the Horse Creek Embayment in the south, to the 119th meridian in the north. They occur up to, but not above, an elevation of 6390 feet--the approximate level of the lake at the time of the causal eruption. (In many areas the highest blocks have been buried in sediment over the centuries, and so appear to have their upwardmost limit of distribution at levels considerably lower than 6390 feet.) Aerial photographs[3] taken when the lake was both low and pelucid show that the blocks occur down to and below the lakeward margin (i.e. 6368 feet) of the Scholl terrace. The Pelagos bathymetric charts indicate that the blocks also occur below the Scholl terrace, on the deep-lake floor.

The distribution of the pumice blocks is mapped on Figure 2. Boundaries of the subaerial blockfields were drawn from air photos; sublacustrine boundaries were derived from the Pelagos charts.

Distributional densities and surface areas. On Table 1 each pumice-block polygon has been assigned a block density (blocks per acre), and an average block-surface area (derived by treating the blocks as 5-faced cubes). Also included is a 2-dimensional surface area, calculated so that the map-acreage of blocks could be subtraced from the acreage of the substrate type on which the blocks lie. Densities and surface areas of subaerially exposed blocks are based on field counts and field measurements within 100-yard X 100-yard squares at sites which, on aerial photographs and in the field, appear to be representative of the particular blockfield. Note that these estimates do not take into account the small pieces of broken tufa that, in some areas, lie scattered around the pumice blocks.

3 These photos include stereo pairs flown by the U.S. Forest Service in 1982, as well as low-altitude oblique photos taken by the writer during and shortly after that same year.

Table 1: Densities of Pumice Blocks

Polygon[a]	Blocks per acre	Two-dimensional area[b] (ft^2/acre)	Three-dimensional area[c] (ft^2/acre)
P1	sparse	(not estimated)	(not estimated)
P2	250	6000	31,000
P3	670	8040	26,800
P4	710	14,200	52,540
P5	710	14,200	52,540
P6	78	936	3120
P7	78	936	3120

[a] refer to Figure 2 for locations
[b] area of horizontal plane (= map area)
[c] entire exposed surface area

On the subaerial portions of the mapped area maximum block density (710 per acre), as well as maximum block surface-area (14,200 ft^2 per acre in 2 dimensions, and 52,540 ft^2 per acre in 3 dimensions), occur to the west and south of Java Islet near Black Point. The minimum density (78 per acre) and surface areas (936 ft^2 per acre in 2 dimensions, and 3120 ft^2 per acre in 3 dimensions) in a blockfield occur along the north shore.[4] At these two sites, as elsewhere, there is a tendency for the blocks to be shorter (that is, to protrude above the ground surface a lesser amount, and therefore to have a smaller exposed 3-dimensional surface area) and to be less densly distributed, in the landward direction, reflecting the greater degree of buriel at higher elevation. Indeed, at some sites (e.g. on the northern shore), all blocks above an elevation of ~6378 feet are nearly to completely buried in littoral and profundal sediment.

The Pelagos charts provide no information on the the sizes and densities of the blocks that lie on the deep-lake floor. It may, at first grasp, seem reasonable to assume that the lakeward trend toward larger blocks and greater

4 Occasional scattered blocks occur in lower densities locally (e.g. in the Horse Creek Embayment), but these do not constitute a blockfield, and so were ignored for the purposes of the substrate analysis.

concentrations continues into deep water. It is just as reasonable, however, to assume that densities decrease lakeward of the Scholl terrace, reflecting a tendency for blocks to drift close to shore and shoal, rather than to sink in open water. With this question not readily answerable, it has been assumed in the mapping that sublacustrine block densities and surface areas equal the average values calculated for the adjacent subaerial blockfield.

C. Beach Rock

Introduction. Beach rock (tufa-cemented sands, gravels, and cobbles), while far less common than the pumice blocks discussed above, constitutes another conspicuous hard-substrate type. Beach rock forms in the lake-shallows where calcium-bearing spring water mixes with the carbonate-rich lake water within the interstitial voids of coarse deposits, forcing the precipitation of calcium carbonate as a cementing matrix.

Distribution. Subaerial exposures of beach rock are found on portions of the Mill Creek delta, on the ground surface at South Tufa, and near the mouths of several small creeks along the westernmost shore of the lake. (Smaller outcrops of beach rock were considered insgnificant for the purpose of this analysis.) These sites, and the sublacustrine exposures inferred from the Pelagos charts, are mapped on Figure 2.

In most sites where beachrock extends into today's lake, the beach rock is partially (~50%) covered with sand down to depths of ~5 feet. The percentage of beach rock covered with sand may change dramatically through time. More importantly, perhaps, the sand may shift through time, changing the sand distribution. The effect of shifting sands on the suitability of beach rock for brine fly habitat is not known.

D. Tufa Towers

Introduction. Tufa towers are vertically- to sub-vertically-standing columns of calcite and aragonite (and perhaps mono-hydrocalcite and ikaite) that formed at sites where fresh water, eminating from the lake bottom at a spring orifice, mixed with lake water, instigating the precipitation of calcium carbonate. The towers occur as distinct phallically- to mushroom-shaped to bizarrely-configured protrusions ranging from a few inches to as much as thirty feet high and up to ~8 feet in diameter; as huge castellated domes up to 35 feet high and >60 feet in diameter; and as agglomerated spires that form continuous walls up to 30 feet high and hundreds of feet in length. These features are discussed in detail in another report to Jones and Stokes Associates (Stine, 1992).

Distribution and surface area. Large concentrations ("groves") of towers are restricted to the western half of the lake, where they occur along the lateral fringes of the Pleistocene deltas of Rush, Mill, and Lee Vining creeks. Several much smaller concentrations are found along the southern and eastern shores. Many of the largest tower agglomerations occur in linear bulwarks associated with faults or slippage planes. The huge majority of towers (thousands in number) are found below an elevation of 6,406 ft (1,952.76 m); an inconsequential number (vis-a-vis brine fly habitat) have formed above that elevation. The four largest concentrations of tufa towers were mapped at the 1:24,000 scale. These occur at South Tufa, Simon's Springs, County Park (Dechambeau Creek) and Lee Vining Tufa (Figure 1).

For the purpose of calculating the 3-dimensional area of the tufa towers, a distinction was made between the large domes and bulwarks (i.e. the large, continuous agglomerations of tufa) on the one hand, and areas characterized by relatively small, solitary spires on the other. The large agglomerations at South Tufa were mapped separately and assigned an average summit elevation (estimated on the basis of field measurements). The areas of solitary spires were treated in a manner similar to that employed in the mapping of the pumice blocks--that is, each polygon was assigned an average tower size and a tower density. The data for the two largest groves of towers--Lee Vining Tufa and South Tufa--is summarized in Table 2.

Table 2
Summary of Tower Elevations and Diameters, Lee Vining and South Tufa Groves

Lee Vining Tufa Grove: Tower Density = 300 per acre
For tower summits 6405- to 6390-foot elevation:
average height = 4 ft, average diameter = 2 ft
For tower summits 6390- to 6380-foot elevation:
average height = 6 ft, average diameter = 2 ft
For tower summits 6405- to 6390-foot elevation:
average height = 4 ft, average diameter = 2 ft
For tower summits 6380- to 6372-foot elevation:
average height = 9 ft, average diameter = 4 ft

South Tufa Grove: Tower Density = 300 per acre
For bulwark summits 6390- to 6380-foot elevation:
average height = 12 ft
For bulwark summits below 6380-foot elevation:
average height = 16 ft
For solitary spire summits 6400- to 6390-foot elevation:
average height = 3 ft, average diameter = 2 ft
For solitary spire summits 6390- to 6380-foot elevation:
average height = 5 ft, average diameter = 3 ft
No solitary spires with summits below 6380 feet (all toppled)
Solitary spire density: 250 per acre

The data also provides a basis for calculating the 2-dimensional surface area (map area) of hard-substrate within the tufa groves, thus permitting a more accurate assessment of the area of substrate type that surrounds the towers. Density and distribution of towers in the sublacustrine groves mapped by Pelagos (and included here on Figure 2) are unknown.

Analysis of past toppling patterns at South Tufa (Stine, 1992) strongly suggests that, because of littoral undercutting of the ground surface in which the towers are rooted, few if any of the solitary towers lying above an elevation of 6381 feet will survive future rises in lake level. With this in mind, the subaerial polygons of solitary towers at South Tufa should not be included in calculations of hard-substrate. Note that this does not apply to the other tufa groves.

E. Mudstone Substrate

Paoha Island is composed mainly of ancient lake-bottom sediments that, over the millennia, have been compacted into mudstone. This material has been uplifted to its present position by lake-floor volcanism.

The mudstone is more durable than the younger muds of the shorelands, though far less durable than the bedrock that makes up the islands of the Negit Archipelago (see below). Paoha, and the slump-blocks of mudstone that lie submerged to its north, east and, most conspicuously, to its west, are peculiar not only in their composition, but in that they are not blanketed with littoral sands during rises and falls of the lake (this central-lake area is cut off from the lake-marginal sand supply).[5] The subaerial and sublacustrine distributions of mudstone are shown on Figure 2.

F. Hard-rock Substrate

A final hard-substrate type is found on the islands of the Negit Archipelago. There, volcanic boulders that make up the flanks of the islands have been coated with tufa. At modern-day lake levels the islands provide hundreds of acres of hard surface. Hard rock crops out at several points on Paoha Island as well, and as dikes associated with faults on the lake floor. The subaerial and sublacustrine distributions of hard-rock substrate are shown on Figure 2.

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[5] The Paoha Islets are highstanding portions of the mudstone block that slumped off the western flank of Paoha Island at the time it was hoisted into the lake.

5. COMPLICATIONS IN PREDICTING SUBSTRATE AREAS

Within the constraints enumerated above, calculation of the acreage of a particular substrate type *per given lake level* should be a relatively simple process. But the fact that the lake does not sit at some given level, but rather rises and falls over time, complicates this simple picture. There is a lag, for instance, between the time of a lake rise (be it an initial SWRCB-ordered adjustment of the lake, or a transgression resulting from natural, post-adustment hydroclimatic fluctuations) and the time when previously deposited sands in deep water are finally covered with mud. For this reason, the band of littoral sand that encircles the lake at any given moment can be expected to be wider than the value calculated from a map.

Vegetation introduces another complication. A lake transgression can submerge hundreds of acres of arbuscular and graminoid vegetation--plants that have a huge surface area and that act as attachment substrate for the alkali fly (Herbst, pers. comm., 1991). The amount of vegetation that is submerged during a lake transgression will depend on a number of factors, including the magnitude of the rise, the amount of time that vegetation has had to colonize the shorelands, and the elevation interval affected (with higher shorelands generally prone to more rapid colonization by both arbuscular and graminoid species). Information is also lacking on the amount of time that newly submerged vegetation remains available to the insects--that is, the amount of time that elapses before the vegetation is either uprooted by wave action, or covered with sediment. According to Herbst (pers. comm., 1991), at least some submerged vegetation persists as attachment substrate for at least 10 years.

A final complication derives from the recently discovered precipitation of gaylusite within the lake. Since it appears that the growth of these crystals requires sites of previously existing hard-substrate for nucelation, gaylusite precipitation will problably not affect materially the distribution of hard-substrate. Changes in the microtopography of various surfaces, however, may influence the overall habitat suitability of a particular hard-substrate type.

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