Geologic Map of the Humboldt Lopolith and Surrounding Terrane, Nevada

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ABSTRACT

The Humboldt lopolith, an igneous complex of Middle Jurassic age, underlies an area of about 1,000 km^2 and occupies a volume of between 1,700 and 2,500 km^3 in the western Basin and Range province. Intrusive rocks constitute the lopolith, except for a cap of volcanic rocks in the central part of the complex.

The lopolith almost exclusively intrudes or is in depositional contact with a suite of Jurassic sedimentary rocks that are the youngest marine deposits of the region. The lopolith and its Jurassic wall rocks lie, with thrust contact, above thick basinal pelitic rocks of early Mesozoic age. Pelitic rocks are intruded by the lopolith only at its western margin, where a nappe of pelite is included within the terrane of allochthonous wall rocks. Regionally, the lopolith, its wall rocks, and the subjacent pelitic rocks constitute the Fencemaker allochthon, which was thrust over early Mesozoic shelf deposits during or after emplacement of the lopolith.

Volcanic rocks of the lopolith consist of basaltic lava, breccia, and dikes, together with basalt-derived sedimentary rocks. The upper part of the volcanic cap consists of chiefly stratified rocks and the lower part of chiefly massive rocks. Intrusive rocks are of two major compositional groups: gabbroic (gabbro, picrite, and anorthosite) and sodic (keratophyre, albitite, scapolitite, and diorite). Layering and igneous foliation are well developed in intrusive rocks of the peripheral zone. There, layered rocks occur either as thick bistratal sheets of picrite and anorthosite or as finely rhythmic alternations of mafic and felsic gabbro. In the interior, gabbroic rocks are generally unlayered and grade up to sodic rocks within 100 to 300 m of the intrusive roof.

INTRODUCTION

The Humboldt lopolith is a dish-shaped complex of intrusive and extrusive rocks of Middle Jurassic age. The lopolith underlies an area of about 1,000 km^2 in the western Basin and Range province; its volume is calculated to be between 1,700 and 2,500 km^3 by magnetic modeling.

Earlier literature related to rocks of the lopolith deals with ore deposits (Reeves and Kral, 1955), regional geology (Page, 1965; Wallace and others, 1969; Willden and Speed, 1974; Speed, 1975), and local petrologic problems (Speed, 1963). This contribution is the first to treat the geology of the igneous complex as a whole and to indicate that the shape of the complex is lopolithic (Fig. 1). The map shows lithic units of the lopolith and of the surrounding terrane at a scale of about 1:81,000; an inset on the map assists in location of named thrust fault traces. Figure 1 shows generalized cross sections of the lopolith. Age, lithic types, and stratigraphic relationships of units shown on the map, other than those of the lopolith, are briefly described in Table 1. I describe here the basic attributes of the Humboldt lopolith to aid in the use of the geologic map; data, models, and interpretation of the origin of the lopolith will be given elsewhere.

BASIN-RANGE STRUCTURE

The Humboldt lopolith crops out in three fault-block ranges (West Humboldt Range, Stillwater Range, and Clan Alpine Mountains) and occurs in the subsurface of the two intervening valleys (Carson Sink and Dixie Valley). Continuity of the igneous complex between the ranges below the Cenozoic valley fills is indicated by a magnetic anomaly and by several wells. Depth to the pre-Tertiary basement in the valleys, shown by contours on the map, was approximated by two- and three-dimensional gravity models using methods of Talwani and others (1959) and Talwani and Ewing (1960). Density contrast between Cenozoic and basement rocks was assumed to be 0.65 g/cm^3 over the lopolith and 0.55 g/cm^3 over Mesozoic sedimentary rocks for two-dimensional models. A uniform value of 0.6 g/cm^3 was used for three-dimensional models. The gravity models were constrained to fit a few well depths in the Carson Sink and several short refraction-line depths of Meister (1967) in Dixie Valley. Section A–A′ of Figure 1 shows an interpretation of basin-range structure and the distribution of buried normal faults.

MESOZOIC REGIONAL GEOLOGY

The structure and tectonic history of Mesozoic country rocks that surround and underlie the Humboldt lopolith are important in understanding the configuration, emplacement, and later deformation of the lopolith. Country rocks are conveniently considered in three major rock-stratigraphic units: (1) the carbonate sequence and underlying Koipato Group, (2) the pelite sequence (all of these are defined in Table 1), and (3) a suite of syntectonic sedimentary rocks comprising the Boyer Ranch Formation, the limestone of Grimes Canyon, and the Lovelock and Muttlebury Formations, which are described individually in Table 1. The carbonate sequence contains shelf deposits, and the pelite sequence contains rapidly subsiding basin deposits; all accumulated synchronously during at least part of Late Triassic time (Norian) and perhaps much farther back in Triassic time. Marine deposition apparently ceased on the shelf before the Jurassic but continued in the basin at decreasing rates of subsidence well into the Early Jurassic. The late Early to Middle Jurassic syntectonic suite constitutes the last marine deposits of the region. Rocks of the syntectonic suite were apparently deposited only on the pelite sequence, probably just before and during tectonic disruption of the area of formerly rapid subsidence.

The Middle Jurassic Humboldt lopolith occurs within and above the syntectonic suite. Volcanic rocks of the lopolith lie conformably above beds of the syntectonic suite, and intrusive rocks of the lopolith invade such beds. The lopolith and its wall rocks of the syntectonic suite are thrust over the pelite sequence on the Boyer and Wildhorse thrust faults. The igneous mass nowhere intrudes the pelite sequence at the current level of exposure except in the West Humboldt Range. There, wall rocks (the Wildhorse allochthon of Fig. 1, sec. A–A′) consist of a thrust nappe of Triassic pelite together with the Muttlebury Formation. Structural relations between the lopolith and country rocks inward from the lopolith periphery are less certain. I believe, however, that the pelite sequence directly floors the central part of the lopolith.

A major regional structural feature of the study area is the Fencemaker thrust (see Fig. 1 for generalized trace). This thrust brought an extensive allochthon comprising the pelite sequence, syntectonic suite, and Humboldt lopolith over the carbonate se-

TABLE 1. LITHIC UNITS OF THE CARSON REGION

Major unit	Map unit (symbol and name)	Age	Maximum thickness (m)	Unit relationships* and lithology	Remarks and references*
	Post-allochthon rocks				
	Qs upland slide deposits	Quaternary	50		
	Qal alluvium and sediments of Lake Lahontan	Quaternary	3,700		Morrison (1964)
	QTb basalt	Pleistocene to possibly upper Miocene	500	Basaltic lava and minor intercalated sediments	Unit includes syn-Lahontan lavas (Lone Rock) and lavas that are probably Pliocene but conceivably as old as late Miocene; Willden and Speed (1974); McKee and Silberman (1970)
	Tvs rhyolitic rocks and intercalated sedimentary rocks	Oligocene and Miocene	650	Mainly ash-flow tuff and tuff breccia; intercalated lacustrine sediments and alluvium	Tuffs in CAM range from 29.7 to 22.0 m.y. (K-Ar, biotite; McKee and Stewart, 1971, and Riehle and others, 1972); basal tuff in WHR is 28.0 m.y. (K-Ar, biotite; this report)
	Ta andesite	Oligocene	650	Andesite lava and breccia, andesite sedimentary rocks; basalt and dacite	Andesite in CAM dated at 35.0 m.y. (K-Ar, hornblende) by Riehle and others (1972)
	Kg granitic rocks	Cretaceous: seven dated plutons in map area and near vicinity with K-Ar ages between 69 and 104 m.y.		Granodiorite and quartz monzonite	Smith and others (1971), Speed and Armstrong (1971), Silberman and McKee (1972)
	Fencemaker allochthon				
Humboldt lopolith	See Table 2	Middle Jurassic (K-Ar ages between 150 and 165 m.y.)			
	Jm Muttlebury Formation	Upper Lower Jurassic (upper Toarcian) and (or) Middle Jurassic (Bajocian)	70	Extensive tabular nappe of carbonate rocks in WHR above Wildhorse thrust; mainly carbonate breccia and intercalated zones of unbrecciated marble, micrite, calcarenite, and gypsum; intruded by lopolith	Speed (1975)
	Jl Lovelock Formation	Upper Lower Jurassic (upper Toarcian) and (or) Middle Jurassic (Bajocian)	200	Basal micrite member conformable above Jurassic-Triassic pelite in WHR; middle member of limestone conglomerate and sedimentary breccia; upper member of gypsum and calcarenite	Speed (1974)
	Jal limestone of Grimes Canyon	Upper Lower Jurassic (upper Toarcian) and (or) Middle Jurassic (Bajocian)	35	Calcarenite, limestone conglomerate, and metalimestone unconformably above pelite sequence and a nappe of Triassic pelite in SR; intruded by lopolith	Originally mapped by Page (1965); lithology described by Young (1963)
	Jb Boyer Ranch Formation	Upper Lower Jurassic (upper Toarcian) and (or) Middle Jurassic (Bajocian)	200	Basal carbonate conglomerate and limestone, upper unit of quartz arenite; lies unconformably over Mud Springs Canyon Formation in CAM; largely allochthonous elsewhere; widely intruded by lopolith	Speed and Jones (1969)
Pelite sequence	West Humboldt and Stillwater Ranges				
	JTrs Jurassic-Triassic pelite	Upper Upper Triassic and Lower Jurassic (upper Upper Norian, Hettangian, Sinemurian, and Toarcian)	>1,100	Silty mudstone, calcareous siltstone, sandstone, sandy limestone; clastic rocks all thin-bedded; map unit contains tectonic intercalations of carbonate correlated with Muttlebury Formation; conformable over Triassic pelite	Pelite sequence is an extensive terrane of basinal terrigenous clastic rocks, including turbidites in lower strata and minor carbonate rocks at top, especially in CAM; comprises Winnemucca sequence (Silberling and Roberts, 1962) south of Fencemaker thrust (this map), and units II and III of Speed and Jones (1969); regional extent south of this map shown by Page (1965) and by Willden and Speed (1974); lithology and stratigraphy of pelite sequence in local areas discussed by Silberling and Wallace (1969, Humboldt Range), Speed (1974, 1975) and Sulima (1970) in WHR, Speed and Jones (1969) and Willden and Speed (1974) in CAM, and Page (1965) in SR; pelite sequence differentiated into two informal units in WHR and SR; in CAM, upper 3,700 m of pelite sequence is divided into three formations that are newly named in this work
	Trs Triassic pelite	Upper Triassic (Norian)	>8,000	Dominantly slaty silty mudstone and locally abundant quartz arenite and wacke; sparse fragmental limestone; bottom unexposed; stratigraphic thickness in CAM >8,000 m, probably similar elsewhere	
	Clan Alpine Mountains				
	JTrm Mud Springs Canyon Formation	Upper Upper Triassic (upper Norian) and possibly Lower Jurassic	600	Massive- to medium-bedded limestone and dolomite and minor quartz sandstone; faunas of *Rhabdoceras suessi* zone of Silberling and Tozer (1968) within 400 m of eroded top; conformable over Hoyt Canyon Formation	
	Trh Hoyt Canyon Formation	Upper Triassic (upper Norian)	500	Alternating black thin-bedded micritic limestone and slaty silty mudstone, siltstone, and minor sandstone; carbonate and clastic subunits 20 to 100 m thick; conformable over Bernice Formation	
	Trb Bernice Formation	Upper Triassic (middle and upper Norian)	2,600	Slaty silty mudstone; minor wacke, quartz arenite, and clastic limestone; overlies undifferentiated Triassic pelite	
	Fencemaker autochthon				
Carbonate sequence	Tru post–Star Peak strata	Upper Triassic (upper Karnian through middle Norian)	1,300	Clastic rocks (mudstone, sandstone) and intercalated limestone; overlain by 250 m of massive carbonate rock and higher calcareous clastic rocks in SR	Carbonate sequence is named for Triassic shelf deposits composed of carbonate rocks and lesser intercalated terrigenous clastic rocks; includes Augusta sequence and part of Winnemucca sequence north of Fencemaker thrust (this map) of Silberling and Roberts (1962), unit I of Speed and Jones (1969), and Auld Lang Syne sequence (Burke and Silberling, 1973) north of Fencemaker thrust. Post–Star Peak strata include Grass Valley, Dun Glen, Winnemucca, and Osobb Formations named by Muller and others (1951), studied by Silberling and Wallace (1969) and Wallace and others (1969), and revised in part by Burke and Silberling (1973).
	Trsp Star Peak Group	Middle and Upper Triassic (Anisian through Karnian)	1,000	Thin- to medium-bedded dark limestone locally containing mafic lava and tuff overlain by massive limestone and dolomite	
	Trr Koipato Group	Lower Triassic	4,000(?)	Rhyolite ash-flow tuff, bedded tuff, intrusive porphyries, greenstone	Silberling (1973), Wallace and others (1969)

*Geographic abbreviations: WHR = West Humboldt Range, SR = Stillwater Range, CAM = Clan Alpine Mountains.

quence. The age of the Fencemaker thrust is poorly known; its last motions surely postdated formation of the lopolith but probably occurred in Jurassic time. The inception of the Fencemaker thrust, however, may have been concurrent with first deformation of the basinal terrane, deposition of the syntectonic suite, or emplacement of the lopolith. In fact, all of these events were probably penecontemporaneous.

The structure of the Fencemaker allochthon is enormously complicated. At shallow stratigraphic levels in the Mesozoic section, rocks of the pelite sequence and syntectonic suite are commonly in successions of thrust nappes. At deeper levels, as exposed in the Stillwater Range and Clan Alpine Mountains, however, the strata of the pelite sequence were deformed in apparent continuity. There are rather few structural symbols on the map for the area underlain by the Fencemaker allochthon because it is impossible to portray the spatial variability of structural elements at a scale of 1:81,000. Only the attitudes of a few homoclines are shown. In contrast to deformation in the Fencemaker allochthon, beds in the autochthon (carbonate sequence) are only openly folded except at places within 1 or 2 km of the Fencemaker thrust where folding is more severe.

HUMBOLDT LOPOLITH

Shape. The Humboldt lopolith is elliptical in plan view; its northwest-trending long axis is 50 km, about twice the length of the short axis. The configuration of the bottom of the lopolith near its margin in the mountain ranges was assessed by two-dimensional gravity models calculated from profiles of closely spaced complete Bouguer gravity data and by attitudes in exposures and downward projection to conform with major folds in wall rocks. Elsewhere, the depth to the lopolith bottom was obtained by modeling aeromagnetic data supplied by J. K. Hayes and data from Smith (1965). The bottom is generally flat in the lopolith interior but dips steeply inward near the periphery. Farther outward, the lopolith occupies a thin, shallowly dipping flange. The flange of the lopolith has been folded along with its wall rocks; such folding is especially strong in the West Humboldt Range (Fig. 1, sec. A–A′).

Structure. The Stillwater Range exposes a nearly continuous profile across the upper part of the lopolith. There, the lopolith has a roof of volcanic rocks whose maximum preserved thickness is about 750 m. The top of the roof is erosional, and I believe that it has been so since formation of the lopolith. At its northern margin in the Stillwater Range, the lopolith is rimmed by a tract of deformed Boyer Ranch Formation. The Boyer Ranch and lopolithic rocks compose the upper plate of the Boyer thrust, and the pelite sequence composes the lower plate. Toward the lopolith interior, the rim of the Boyer Ranch Formation splits into an upper and a lower tongue. The upper tongue lies between volcanic and intrusive facies of the lopolith, and the lower tongue lies below the intrusive rocks but above the Boyer thrust. Each tongue thins toward the lopolith center. Where the upper tongue vanishes, intrusive rocks directly invade the volcanic rocks. The base of the igneous complex is not exposed more than a few kilometres from its periphery, and it is not certain that the lower tongue of the Boyer Ranch Formation totally pinches out toward the center of the lopolith. The structure of the southern half of the lopolith in the Stillwater Range is virtually a mirror image of that of the northern half (Fig. 1). The chief difference is that a continuous rim of Boyer Ranch Formation is lacking at the southern margin, probably because of erosion.

The structure of the lopolith in the Clan Alpine Mountains is like that of the Stillwater Range: wall rocks of the lopolith are exclusively Boyer Ranch Formation, and the lopolith and its wall rocks lie above the Boyer thrust. Volcanic rocks are absent in the Clan Alpine Mountains, however. It is not clear whether the intrusive rocks there were roofed in part by now-eroded volcanic rocks or entirely by Boyer Ranch Formation.

As elsewhere, the lopolith in the West Humboldt Range intrudes and lies above allochthonous wall rocks, here called the Wildhorse allochthon. The Wildhorse thrust separates the intruded terrane from subjacent rocks of the pelite sequence and syntectonic suite that occupy piled-up thrust nappes. Wall rocks of the lopolith in the West Humboldt Range differ, however, from those in the other ranges: the Wildhorse allochthon comprises a pair of nappes, the upper of Triassic pelite and the lower of Muttlebury Formation. Boyer Ranch Formation rocks and volcanic rocks of the lopolith are absent from the West Humboldt Range. The Muttlebury nappe is thought to have supplied a viscous sole on which the Wildhorse allochthon was transported (Speed, 1975). Several small outliers of igneous rocks of lopolith affiliation occur in the Wildhorse thrust zone as far as 10 km from the main lopolith margin. Such igneous masses appear generally to be cut by the Wildhorse thrust, but at one place, lower plate rocks are metamorphosed by outlying gabbroic rocks. From these and other relationships (Speed, 1975), I have suggested that motion on the Wildhorse thrust and emplacement of the lopolith were generally concomitant. Several thrusts occur within the lopolith in the West Humboldt Range. Each thrust juxtaposes different intrusive facies, and at the bottom of each upper plate are slivers of wall rocks.

Volcanic Rocks. Volcanic rocks occur only in the central part of the Humboldt lopolith. The volcanic rocks are divided into two units on the map: chiefly stratified rocks and chiefly massive rocks. The stratified rocks are generally but not exclusively at a higher stratigraphic level than the massive rocks.

Stratified volcanic rocks consist of basalt and olivine basalt lava and intercalated breccia, conglomerate, sandstone, and hematitic mudstone. The sedimentary rocks are composed entirely of volcanogenic particles, except for sparse lenses and interbeds of quartz sandstone like that of the subjacent Boyer Ranch Formation. Mafic dikes and sills cut the stratified rocks and are increasingly abundant near the contact with the unit of massive volcanic rocks. Breccias are of many types and include rocks interpreted as debris flow deposits, autobrecciated lava, fluvial deposits, intrusive breccia, and air-fall accumulation of volcanic bombs.

The unit of massive volcanic rocks consists of structureless porphyritic amygdular basalt, massive breccia, and minor lensy basaltic sandstone. Such rocks are widely intruded by dikes, sills, and plugs of porphyritic basalt that is characteristically greener and more pyroxene rich than the host rocks. At many places, intrusive basalt is more abundant than the intruded rocks.

Intrusive Rocks. Intrusive rocks of the Humboldt lopolith are largely in one of two major compositional groups: gabbroic (gabbro, olivine gabbro, picrite, anorthosite) and sodic (keratophyre, quartz keratophyre, albitite, scapolitite, diorite, quartz diorite, and analcite gabbro or teschenite). Gabbroic rocks are coarse grained, except for chill zones near certain contacts with wall rocks; rocks in the chill zone, called microgabbro, have grain size as fine as that of a typical basalt lava but are entirely holocrystalline. Coarse-grained gabbroic rocks ubiquitously contain an early-crystallized assemblage: labradorite, diopsidic augite, and, in some rocks, olivine. Early minerals are clearly cumulus in many rocks. Late-crystallized and intercumulus minerals are hornblende (kaersutite), ulvospinel-magnetite solid solution, ilmenite, apatite, locally occurring titaniferous biotite, bronzite, analcite, and thomsonite. Late phases constitute between 3 and 35 percent of the rock, in inverse proportion to the strength of igneous foliation. Table 2 indicates modal ranges of gabbroic rocks.

TABLE 2. MODAL RANGES (PERCENT) IN GABBROIC ROCKS

Map unit and rock type	Olivine	Diopsidic augite	Plagioclase	Late phases
Hornblende picrite	10–40	20–30	20–30	20–30
Hornblende gabbro				
Olivine hornblende gabbro	1–10	15–40	40–60	20–30
Hornblende gabbro	..	15–30	50–70	20–30
Anorthositic hornblende gabbro	..	5–15	70–90	5–15
Anorthosite	..	..	90–97	3–10

Gabbroic rocks in an annular zone several kilometres wide at the lopolith periphery differ from those in the central zone of the complex. The peripheral zone has strongly layered and moderately foliated to well-foliated rocks, whereas the central gabbros are more homogeneous and isotropic in fabric. The foliation is created by alignment of platy labradorite grains. Gabbro is divided on the map into three units on the basis of existence and strength of foliation. Units of strongly foliated rocks (Jg3) are almost exclusively sheets of anorthositic gabbro or anorthosite that lie above picrite or occupy discrete thrust nappes. Much layering occurs in the peripheral zone, and individual layers vary in thickness from 1 cm to more than 10^4 cm. Where strata are thin, layering is rhythmic; where strata are thick, two layers, picrite and anorthositic gabbro, compose bistratal sheets (Speed, 1963).

Gabbroic rocks in the central zone grade up within several hundred metres of the intrusion's roof (either volcanic or Boyer Ranch Formation rocks) to rocks classed as diorite or quartz diorite on the map. The dioritic rocks are more feldspathic and have more albitic feldspar than subjacent gabbro; they are sporadically rich in pyroxene, euhedral hornblende, coarse-grained quartz (xenocrystic?), and analcite. Rocks at higher levels of the diorite unit are remarkably like the red granites that cap other lopolithic complexes.

Keratophyre and scapolitite constitute plugs and dikes that invade gabbroic rocks of the lopolith. Only a few such bodies are shown on the map. Though widespread in the lopolith, these late-stage sodic igneous rocks are probably small in volumetric proportion. Unmapped magnetite-apatite (plus hornblende-chlorite-analcite-sphene) rocks occur in veins and breccia in the Buena Vista hills and in the Stillwater Range near the contact of volcanic and intrusive rocks of the lopolith.

Strong and pervasive deuteric alteration is a characteristic feature of the Humboldt lopolith. Albitization is intense in gabbroic rocks in the outermost 1 or 2 km of the lopolith, especially in the West Humboldt Range and in the wall rocks of the lopolith. At places, keratophyre, albitized microgabbro, and albitized wall rocks are so intimately associated and so lithologically similar that differentiation is difficult, and I have assigned such terranes to a unit of mixed albitic rocks. Sodic scapolitization is widespread and intense in gabbroic rocks more than 1 or 2 km inward from the lopolith margin. Scapolitization caused the partial replacement of labradorite by poikiloblastic networks of marialite ($Ma_{80}Me_{20}$). In scapolitized rocks, the proportion of scapolite is as high as 75 percent. Ankeritization is a later but widespread alternation.

Polymict Breccia. Patches of breccia composed exclusively of fragments of lopolithic rocks lie unconformably above the pelite sequence at a number of places within several kilometres of the periphery of the lopolith. Only the largest of these breccia patches are shown on the map. Clasts in the breccias represent most if not all igneous facies of the lopolith. The deposits are unlithified and unsorted and consist entirely of angular debris whose particles are locally as large as grand pianos. The age of the polymict breccia is unknown. I believe they are deposits from landslides that were active at a time when the lopolith was topographically high, certainly before basin-range faulting and perhaps as far back as the Jurassic.

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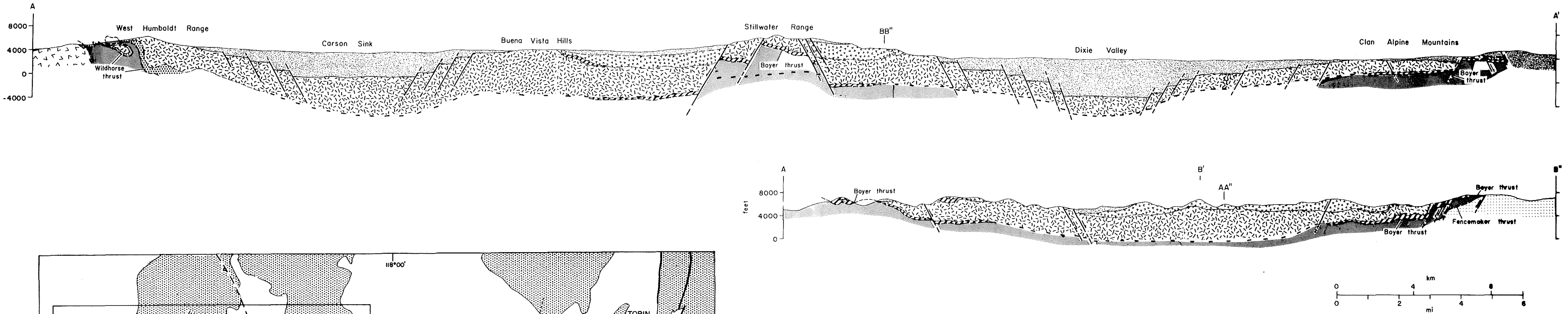

- ░ Cenozoic deposits
- ▨ Cretaceous granodiorite
- Humboldt Lopolith
  - ▨ extrusive rocks
  - ▨ intrusive rocks
- ▨ Wildhorse allochthon (Muttlebury Fm. and Triassic pelite)
- ▨ Boyer Ranch Fm.
- ▨ pelite sequence
- ☐ carbonate sequence and Koipato Group
- contact
- thrust fault
- high angle fault
- lopolith bottom calculated by magnetic analysis

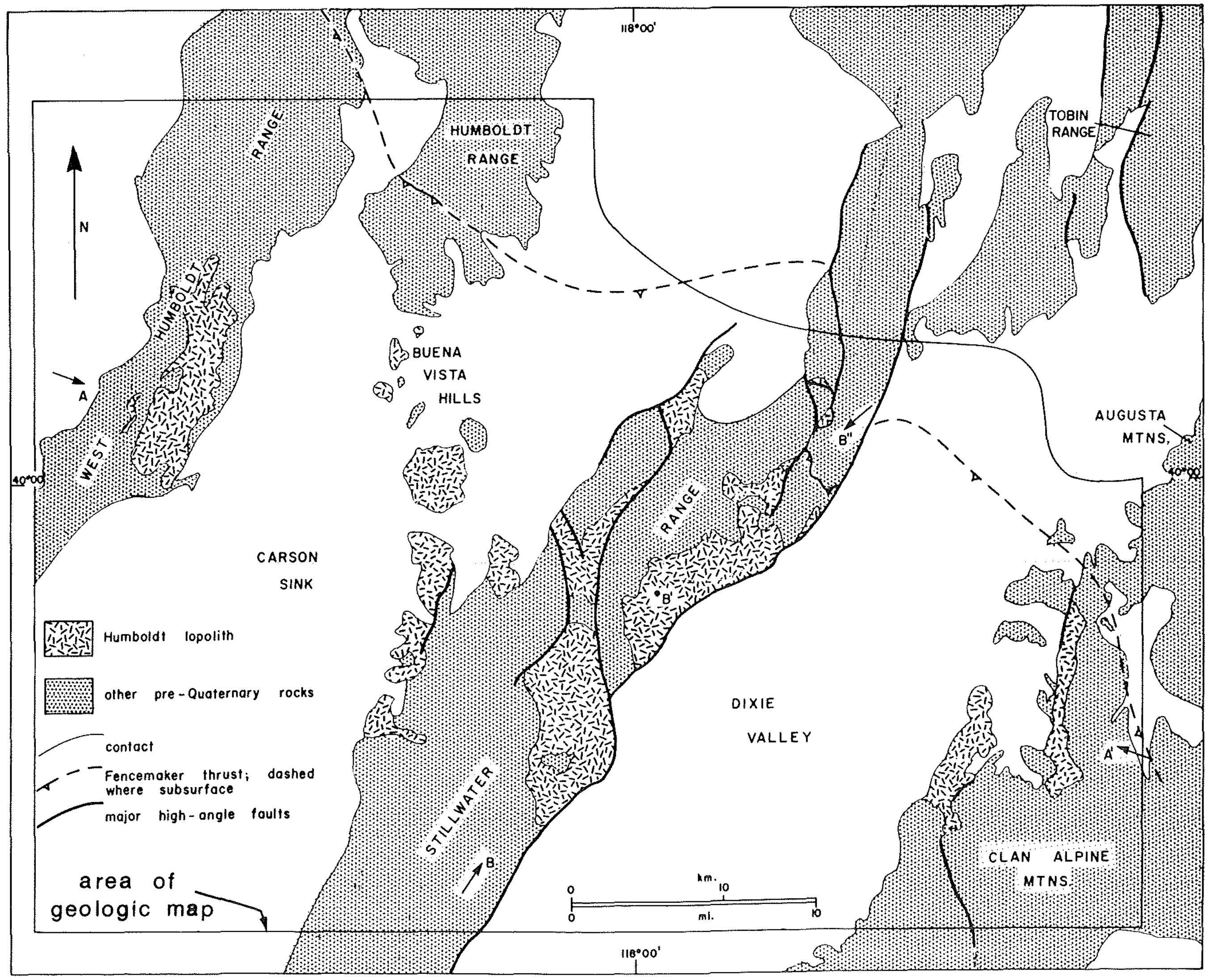

Figure 1. Cross sections of Humboldt lopolith along long axis (sec. A–A′, northwest-southeast) and short axis (sec. B–B″, northeast-southwest) of lopolith, and map showing end points of cross sections and area of map.