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High Stands of Quaternary Sea Level Along the Chilean Coast

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Abstract

Marine terraces partly cut in bedrock and partly filled or veneered with clastic deposits extend along much of the Chilean coast, particularly between the 23rd and 40th parallels. The highest terrace, about 250–400 m above present sea level in central and northern Chile, and 170–200 m above the sea in southern Chile, is probably Pliocene. Other terraces, at 150–240 m, 80–130 m, 30–40 m in central and northern Chile, and at 70 m, 20–38 m, 8–10 m in southern Chile, are Pleistocene. The most extensive and best preserved terrace is the one at 80–130 m. There are several lower terraces of Recent age.

Eustatic sea-level changes have been strongly modified by tectonic movements. During the Quaternary, epeirogenetic uplift has been dominant north of the 40th parallel, whereas sinking of the coast has generally prevailed farther south. Late movement of fault blocks has displaced terraces as much as 40–50 m locally.

Resumen. Terrazas marinas que en parte son cortadas en roca fundamental y en parte son rellenadas o revestidas por depósitos clásticos se extienden sobre un largo tramo de la costa chilena. La terraza más alta, que tiene alrededor de 250 a 400 m sobre el nivel del mar actual en el centro y el norte de Chile, y 170 a 200 m sobre el mar en el sur, probablemente es del Plioceno. Otras terrazas, a elevaciones de 150–240 m, 80–130 m, 30–40 m, en el sur de Chile son del Pleistoceno. La terraza la más

extensa y de mejor conservación es la que tiene 80 a 130 m. Hay varias terrazas m bajas que son del Holoceno.

Los cambios eustáticos del nivel del mar han sido fuertemente modificados p movimientos tectónicos. Durante el Cuaternario, el solevantamiento epirogénico sido dominante al norte del Paralelo 40, mientras en general el hundimiento de costa ha prevalecido más al sur. Localmente, algunas terrazas han sido desplazac hasta 40 o 50 m por movimientos tardíos de bloques fallados.

Содержание. Рассматриваются морские террасы в Чили, простирающие вдоль большей части ее побережья, в особенности между 23-ей и 40-ой п раллелями южной широты. Террасы частью врезаны в коренную пород и частью заполнены или покрыты тонким слоем отложений обломочны пород. Самая высокая терраса достигает примерно 250–400 м высоты на современным уровнем моря в центральной и северной частях Чили и 17 200 м в ее южной части, и, по всей вероятности, относится к плиоцену. Др гие террасы высотою в 150–240 м, 80–130 м, 30–40 м в центральной и севе ной частях, и 70 м, 20–38 м, 8–10 м в южной части Чили относятся к плейст цену. Терраса высотою в 80–130 м является наиболее вытянутой и бол всего сохранившейся. Имеется несколько более низких террас, принадлеж щих к современиому периоду.

Тектонические движения сильно повлияли на эвстатические изменен уровня моря. В течение четвертичного периода вертикальное поднятие ко тинентальных площадей было распространено к северу от сороковой пара лели, в то время как опускание берега в общем преобладало больше к юг В результате недавних движений сбросовых глыб террасы переместили в некоторых местах до 40–50 м.

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ATE FOLLOWING

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Introduction

he five authors of this paper are scientists with field experience in Chile. iscussion of the separate areas of study are arranged from south to north ig. 1): Ancud-Puerto Saavedra (Weischet), Río La Ligua-Río Elqui ascoff), La Serena-Río Huasco (Cooke), and Bahia Salado-Caldera (Segerrom).

Part 1. Coastal Terraces in Southern Chile

Wolfgang Weischet

ABSTRACT

bsidence of 1.4–1.6 m took place along the Chilean coast between lat. 38° and ° S. during the earthquake of May 22, 1960. A pre-existing terrace at 1.2–1.5 m

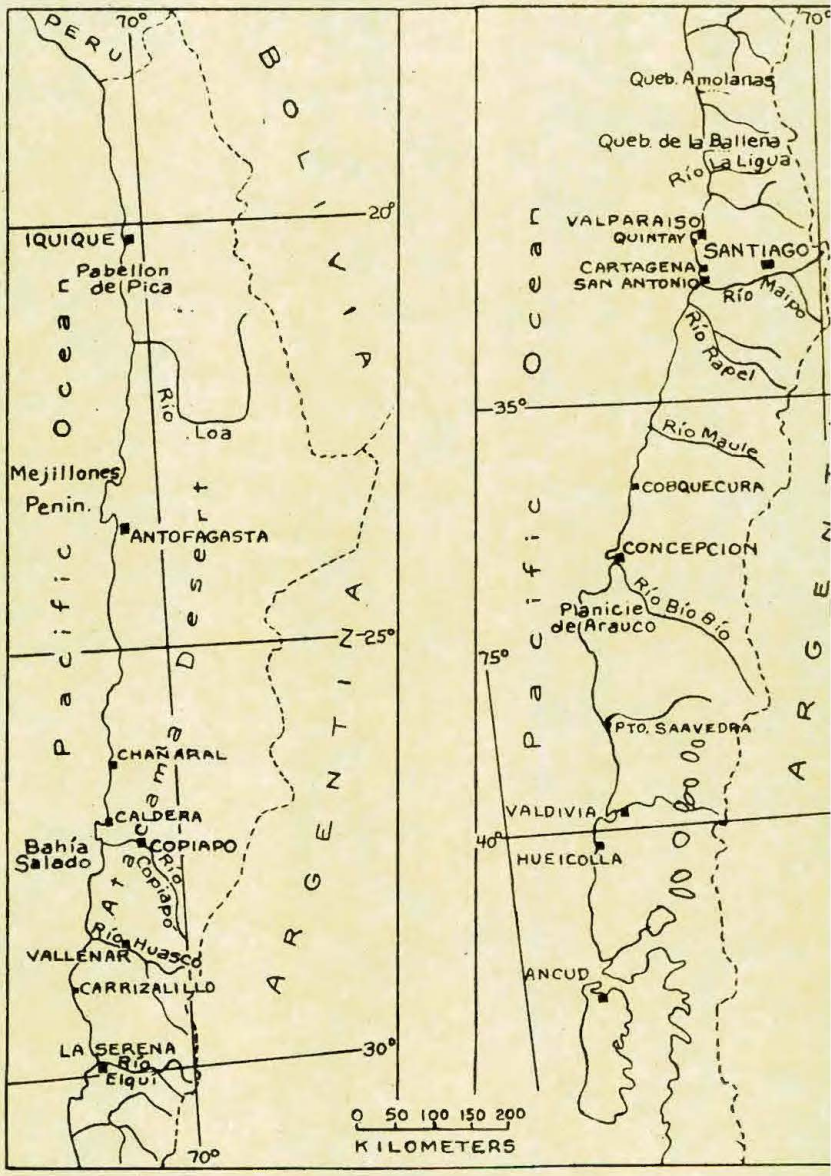


Figure 1. Index map of Chile (except for Aysén and Magallanes)

above sea level was inundated. Local discontinuous marine terraces exist in the same region at 8–10 m, 20–25 m, 35–38 m, 70 m, and 170–200 m above present sea level.

FORMER TERRACES AT 1.5 M ABOVE SEA LEVEL

During the earthquake of May 22, 1960, a tectonic depression 1.4 to 1.6 m along the coast line of southern Chile developed (Weischet, 1963a). This surprising observation was made at three widely separated places: near Puerto Saavedra, in Mehuín, and in the bay of Ancud (*see* Fig. 2).

Just north of Puerto Saavedra, on the landward side of a shallow lagoon that resulted from the May 1960 subsidence, the mean high tide washes over the surface of a layer of sediments cemented to a depth of about 10 cm by iron and manganese oxides (Pl. 1, fig. 1). This cemented zone is a result of a formerly higher water table. It is situated 1.5 m above the water table that existed prior to depression of the land.

An abrasion platform about 40 m wide cut in nearly vertical crystalline slates at the northern end of Mehuín Bay existed before the earthquake. The platform was about 1.2 m above mean high tide at its seaward end and about 1.5 m at its landward end, as shown by the upper limit of the marine fauna that litters it. After the May 1960 subsidence the same abrasion platform had sunk to the level of mean high tide.

In the southern part of Ancud Bay a wave-excavated cave and a wave-cut notch have been developed at the bottom of a cliff. Prior to the land depression in May 1960 both forms were situated well above the level of mean high tide. Now, however, both notch and cave are flooded at high tide (Pl. 1, fig. 2).

Before the recent land sinking a broad "vega terrace" was situated near the mouth of every river and brook in the region about 1.2 m above the level of mean high tide. The soil of the terrace was developed on coastal marine sediments. After subsidence in 1960 this terrace was flooded.

In the following contribution by Paskoff, geomorphic consequences of a former sea level about 1.2 m higher than the present one are related to a post-Pleistocene Dunkirkian transgression for central Chile. The very recent change of level by means of tectonic processes in southern Chile reminds us to be cautious about correlating terrace levels with glacio-eustatic changes of sea level. On the other hand, there is good conformity of terrace remnants found at different places along the coast of southern Chile above the 1.5-m level.

TERRACES ABOVE THE FORMER 1.5-M LEVEL

A 20-m level exists in the bay of Mehuín, first in a remnant of wave-cut bench in a cliff (Fig. 3, top diagram), and second on nearby Playa Chica, where a broad plain of gray sand has been formed. The 20-m level also is evident in eroded platforms on interfluvial slopes in the vicinity of Quele.

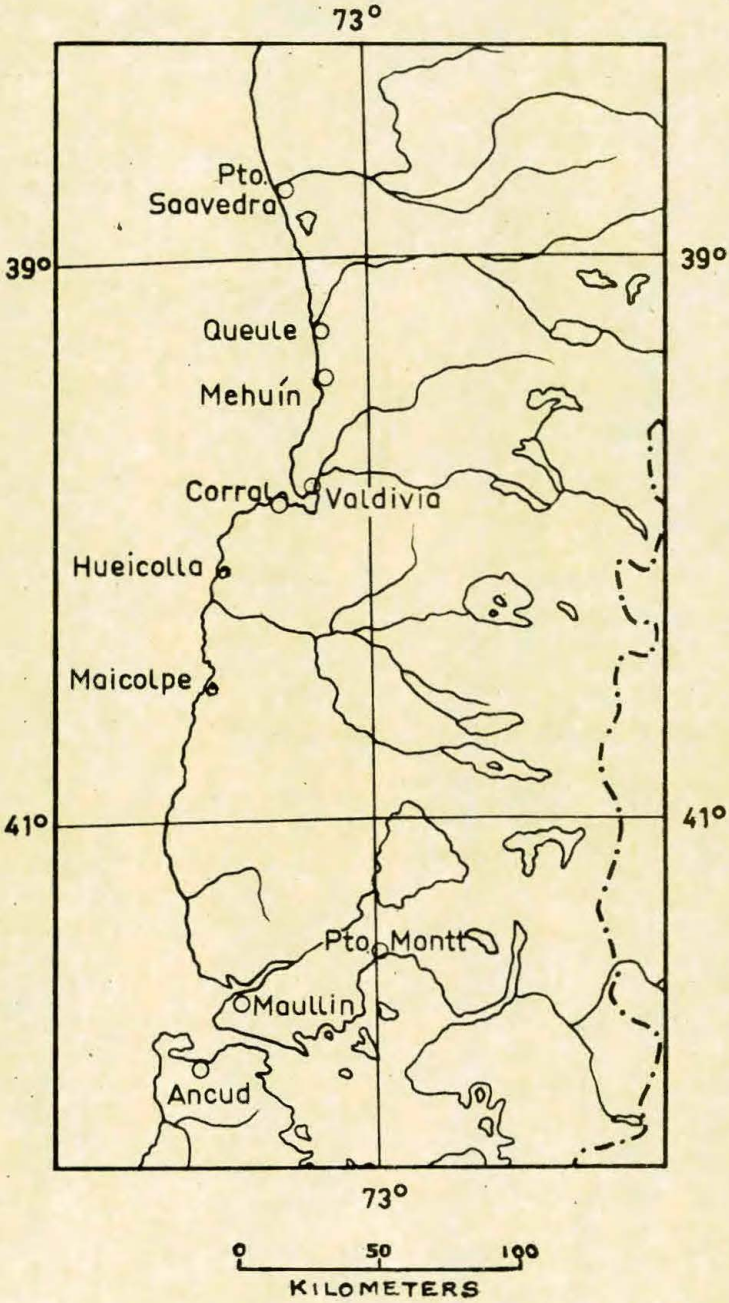
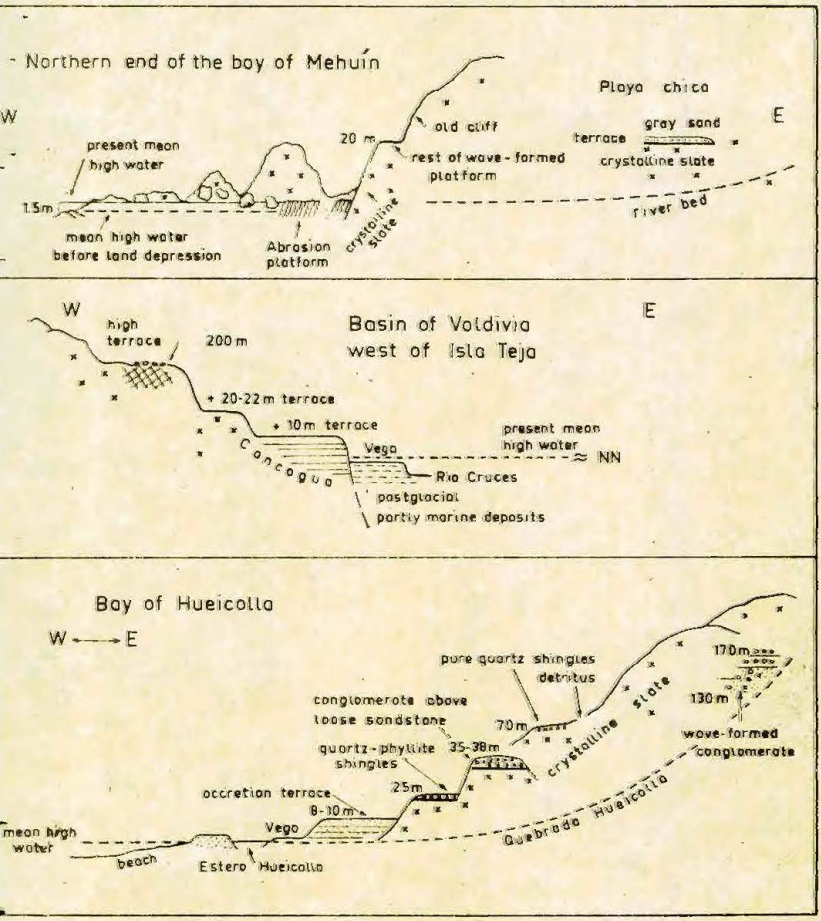


Figure 2. Index map of Valdivia area, Chile



gure 3. Schematic sections through terraces at Mehuín, near Valdivia, and on the Bay of Hueicolla, Chile. In the middle diagram, canagua refers to cemented volcanic ash with intercalated sediments; the high terrace is underlain by deeply weathered crystalline slate.

Earlier reports (Brüggen, 1950; Weischet, 1959; Illies, 1960) have de-ibed the striking terraces of accumulation at 10 and 20 m above sea level in bay near Corral and near Valdivia, about 15 km upstream (Fig. 3, middle gram). The terrace deposits consist mostly of "cancagua," a cemented canic ash with intercalated layers of brackish-water and marine sediments. e deposition surface of the cancagua in the Basin of Valdivia had been t deeply dissected, and then young sediments had accumulated on it eischet, 1963b). From the vega terrace (1.5 m above sea level before the thquake, now at sea level) down to 30 m below sea level, only tidal-flat

sediments have been found by means of drilling (Illies, 1960). A sequence events that seems to fit these observations is as follows: (1) formation of t races at 10 m and 20–22 m during the last interglacial period, (2) dissection rivers as a consequence of the lowered sea level in the last glacial epoch, (refilling with tidal-flat sediments up to the highest sea level (plus 1.5 m) in t postglacial period (vega-terrace), (4) new slight dissection of the vega, a (5) tectonic depression of the entire sequence 1.5 m in May 1960. In the sa area, at about 200 m above sea level, there are numerous remnants of a hi terrace with pure quartz grains upon deeply weathered crystalline sla This "peneplain" must have had its origin near the end of the Tertia period.

Landward from the dredged mouth of the Bay of Hueicolla (Fig. 3, low diagram), an 8- to 10-m level stretches in a crescent for a maximum distan of 250 m. This terrace is an accumulation of loose sediments. On a slo toward the inland mountains, areas similar to platforms can be noticed levels of 25, 35–38, and 70 m all around the bay. An exposure in the 25- terrace shows wave-formed rounded pebbles of quartz-phyllite. On the 35- terrace a slate conglomerate 3 m thick is rhythmically bedded with yell sand. This deposit is sufficiently consolidated to stand on vertical slop Neither conglomerate nor sandstone shows much weathering. At the 70- level, however, only pure quartz gravels are found.

In Maicolpe Bay the remains of an abrasion platform at an altitude 7–8 m exist. In a cliff behind the platform, 2 m of marine conglomerate exposed.

Part 2. Preliminary Results of Investigations of the Quaternary Geology of the Chilean Coast Between Lat. 30° and 33° S.

Roland Paskoff

ABSTRACT

Well-preserved graded terraces exist along the Chilean coast between lat. 30° a 33° S. at 5–7 m, 35–40 m, and 100–130 m above present sea level. Probable ages these terraces are Würm I/II interstadial, middle Quaternary, and early Quaterna respectively. Terraces at 4–5 m and 1.2 m that are less well defined than the high terraces are of possible Calaisian and Dunkerquian age. Origin of the two high terraces is not clear, but the lower terraces are probably of glacio-eustatic origin.

GENERAL STATEMENT

From a study now in progress of the Chilean coast between lat. 30° a 33° S., a few preliminary results may be announced. In the midst of are

trongly affected by late tectonic movements, there are portions that seem o have been more stable since early Quaternary time. These portions record he morphological changes during the Pleistocene and Recent that have ot resulted from tectonic movements. Three graded terraces imply three ong periods of high sea level. In addition, there is evidence of more recent nd less pronounced strand lines. The influence of climatic changes is also pparent.

HIGH TERRACE

At widely separated places (mouth of the Río Elqui, lat. 30° S.; Quebrada le la Ballena, lat. 32° 17′ S., and the Río La Ligua, lat. 32° 27′ S.), the exstence of an old shore line about 100–300 m above sea level is indicated by a igh terrace in a good state of preservation. The terrace occurs along the ase of a mountain slope and is partly covered with late alluvial fans. Its arine origin is unmistakable: its surface is littered with pebbles having attish shapes characteristic of shingle beaches. Moreover, there is a resistant oquina in places. The marine terrace grades upward to one of continental rigin, as described by the author (1963a) for the lower course of the Río La igua. The continental terrace deposit consists of coarse torrential accumulaons resulting from the last great land uplift and erosion under semiarid limatic conditions with well-defined wet and dry seasons.

As a result of malacological study of the coquina, the highest terrace is ssigned to the early Quaternary.

MIDDLE TERRACE

A lower terrace, separated from the high terrace by an escarpment, is onspicuously well preserved. The pebbles and coquina that cover the second errace are evidence of the wave action that took place when sea level was 5–40 m higher than at present. The topographic position of this terrace entatively implies an age of middle Quaternary.

LOW TERRACE OR CACHAGUA LEVEL

The latest marine platform is evidence of long stability of the shore line at –7 m above present sea level. The terrace is bordered by a sea cliff that is emarkable for its uniform height and its persistence. The terrace is correlated ith the low-Monasterian level of Europe of late Quaternary age—either iss-Würm Interglacial or, more probably, Würm I/II interstadial (Paskoff, 963b; 1963c).

RECENT SEA-LEVEL CHANGES

Archeological remains and shore deposits beyond reach of present ocean aves provide evidence for two probable postglacial shore lines slightly

above the present level of the sea (Paskoff, 1963c): (1) a 4–5-m level (Cal ian?) that could be contemporary with the Postglacial Climatic Optimu (2) a 1–2-m level (Dunkerquian?) that may date back to the beginning of Christian Era.

Interpretation of these terraces is part of the general problem of lower of the oceans during the Quaternary. The glacio-eustatic explanation se suitable for the lower levels, including the Cachagua level. The discussio still open concerning the middle and higher terraces—were they produced continental uplift, by ocean-level descent related to incomplete deglaciati or by the opening of new oceanic trenches?

Part 3. Evidence of Changing Sea Level Between Lat. 28° and 30° S. During Quaternary Tin

Ronald Cooke

ABSTRACT

Three major phases of sea-level movement are recognized along the coast of southern Atacama desert. Each phase is associated with a distinct group of ma and fluviatile land forms that are briefly described in four areas. Problems of dat correlating, and explaining sea-level movements are discussed.

PHASES OF SEA-LEVEL MOVEMENT

Three important phases of sea-level movement are recognized in the a (Brüggen, 1950, p. 191; Cooke, 1964). A fall of sea level from at least m to below its present height accompanied the first and by far the lon period of land-form evolution. Some raised-beach remnants on the h cliffs and several accordant summit levels in the western fringes of the coa mountains indicate the intermittent nature of this fall. The major ri flowed throughout the phase, and fragments of river terraces, valley p ments, and piedmont deposits record stages in the development of t basins. By the end of the phase, the rivers flowed to a sea level below tha the present.

During phase 2, the sea transgressed upon the phase 1 topography t height of 110 m above present sea level. The transgression was accompar by the deposition of fossiliferous marine sand and gravel along the co Contemporaneously, the valleys were aggraded by an efflux of fluviatile bris from the Andes. The phase culminated with the formation of an tensive aggradation surface or, locally, an abrasion platform related to 110-m shore line. This stage has been identified at Carrizal Bajo, Hua Carrizalillo, and La Serena (Fig. 4).

Sea level fell to its present height in phase 3, leaving shore lines, abra platforms, and fossiliferous deposits. The erosion of platforms was n

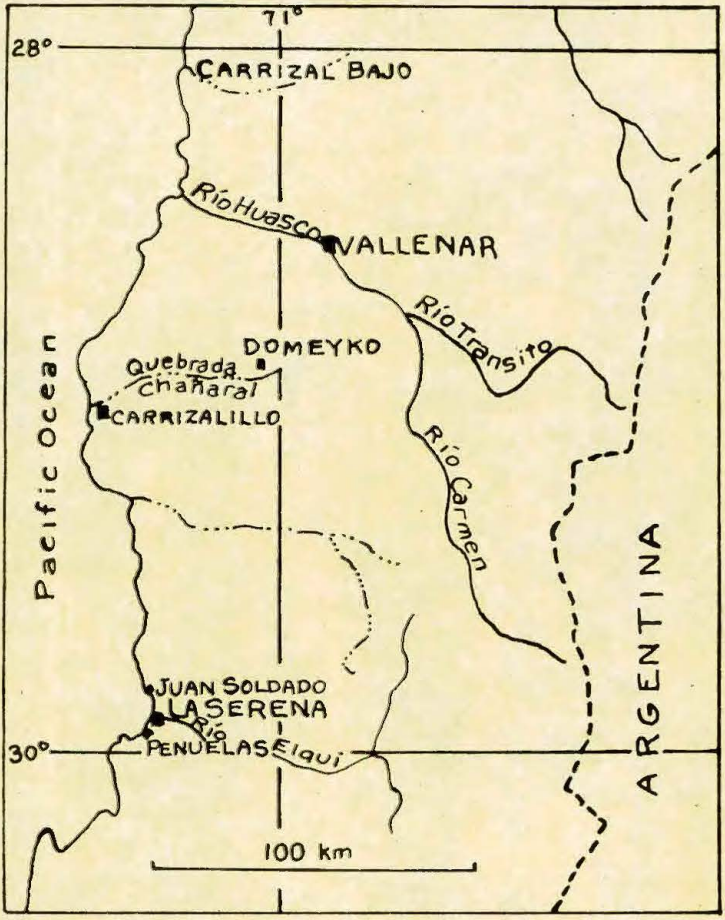


Figure 4. Index map of La Serena-Vallenar area, Chile

ective in the unconsolidated accumulation of the previous phase. Platforms e extensively and clearly preserved, for example in the deposits around the ys of La Serena and Coquimbo. Where the phase 2 succession has been noved and the phase 1 topography exhumed, as at Huasco and Carrizal jo, regression stages are generally more numerous, but narrower and less tinct. Major streams were rejuvenated at this time and cut remarkable viatile terraces within the weathered valley fill of phase 2. The terraces are nly but completely veneered with unweathered river gravels.

EVIDENCE OF FORMER SEA LEVELS

Important evidence of sea-level fluctuations exists on the southern side Huasco Bay (Fig. 5). There terraces above 110 m were formed during the

first major period of sea-level fall (phase 1). Several platforms and two sh lines of this phase occur on the Cordón El Espinazo. The surfaces, genera less than 20 m wide, were eroded in agglomerates, andesites, and diorit They were best developed on the western side of the range, which was m exposed to dominant wave attack from the southwest. Shore lines occur 125 m and 115 m (*a* and *b* respectively in Fig. 5). They are distinguished b sharp break of slope between cliff and platform at constant heights and a few patches of fossiliferous beach rock on the adjacent surfaces. Bea rock from the Cordón El Espinazo contains a fauna that may be useful dating the surfaces (Pl. 2).

The most extensive morphological feature in Huasco Bay is a compos erosion surface that extends from 85 m to about 110 m. Minor pauses in s level movements during its formation are identified by shore lines and bea rock deposits at 100 m (*c*) and 95 m (*d*). The great extent of the platfor compared with all other surfaces, suggests that sea level was within this ran of altitude for a considerable time. Deposits on the surface are largely confin to generally unfossiliferous beach rocks. It is perhaps surprising that a f scattered pebbles are the only relicts of the abrasion tools that must ha produced the surface.

Shore lines of the phase 3 regression at 80 m (*e*), 60 m (*h*), 54 m (*i*), a 43 m (*j*) are found around a broad embayment southeast of Quebrada (Fig. 5). They are associated with cliffs up to 5 m high and with surfaces t are thinly covered near the shore lines with indurated sand and shell be

Between the Cordón El Espinazo and the Alto spur, shore lines at 80 (*e*), 75 m (*f*), 71 m (*g*), and 43 m (*j*) mark successive stages in the developm of Huasco Bay, whose outline has become progressively smaller and m regular (Fig. 5). The only sound criterion for recognizing these shore line the sharp horizontal break of slope between platform and cliff. Few signs marine erosion exist. However, the cliffs are undoubtedly erosional: th local linearity suggests faulting, but they actually coincide with a system roughly parallel, resistant diorite dikes, whereas the platforms occur in m easily eroded schists and phyllites.

At 30 m (*m*), a badly preserved but important shore line is associated w several fossiliferous deposits up to 10 m thick. This is the only shore line t might have been produced after a minor transgression during the over-regression of phase 3. Furthermore, it is the only shore line that is confiden correlated with a fluviatile terrace by topographic continuity in the field.

Aerial photographs covering the coastal areas north and south of Huas Bay reveal that the steep and high cliff is a fairly persistent feature, its c demarcating direct drainage toward the sea from the intricate and deeply cised quebrada systems of the coastal cordillera. The cliff is flanked by a zo of marine terraces, in places more than 3 km wide. The best preserved terra

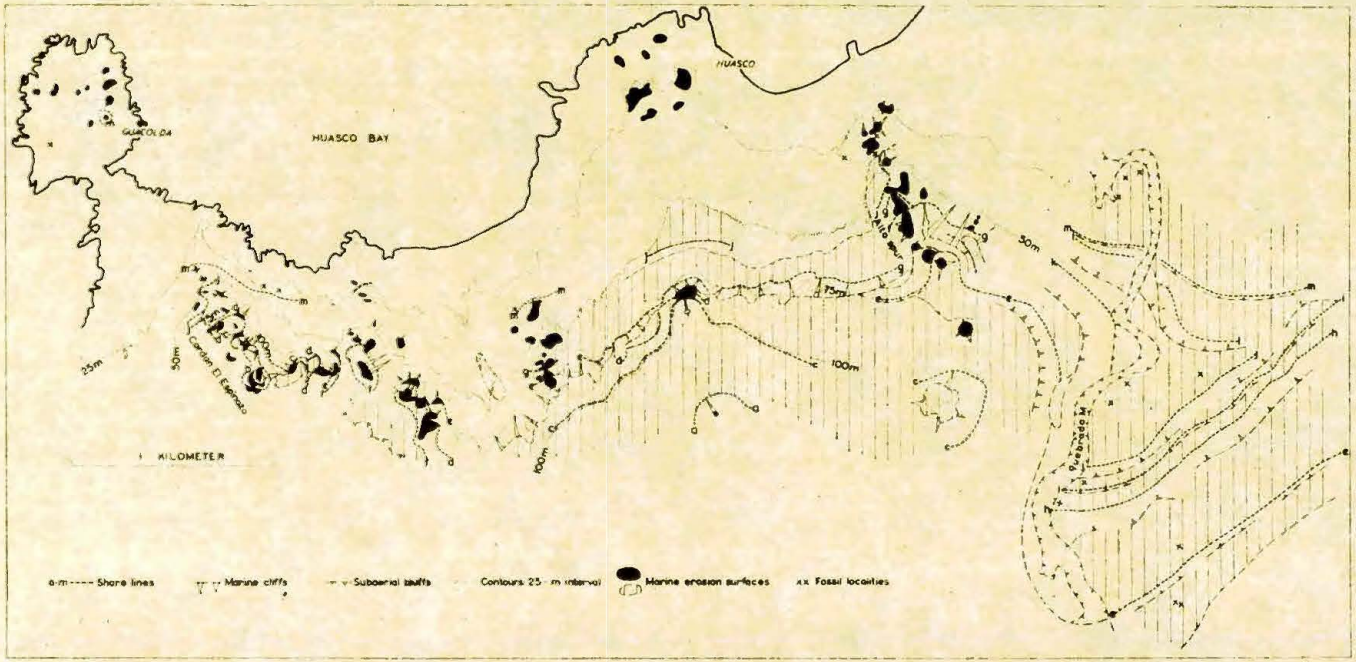


Figure 5. Geomorphic map of part of Huasco Bay, Chile, showing reconstructed shore lines, salient morphological features, and major fossil localities. Contours on part of this map are derived from a plan provided by the Instituto Geográfico Militar.

was formed at the end of phase 2. Below it are several other terraces and so exceptionally well-defined cliffs. In one locality, about 10 km north Huasco, a series of at least five terraces occurs. The elevations of shore li have yet to be determined in the field. Much of this coastal zone, especia south of Huasco, is masked by wind-blown sand.

Brüggen (1950, p. 188) recognizes a dissected marine surface in the C rizalillo area at about 500 m, another at about 250 m that he dates Pliocene, and a third between 220 m and 160 m that is more than 5 km w and is backed by a pronounced cliff. All belong to phase 1. The most ext sive surface, produced at the end of phase 2, slopes from a shore line at ab 110 m to the present cliffs of Carrizalillo Bay. Higher portions of the surf are associated with an indurated shelly limestone that contains an abunda molluscan fauna. This deposit overlies with apparent conformity a thick s cession of coarse, current-bedded yellow sands that contain some thin f siliferous horizons. Stages in the modification of the surface related to 110-m shore line during phase 3 are singularly scarce, although ma remnants of shore platforms are evident in the rocky peninsulas to the no and south. The bay is fringed by a shore line at 3–4 m above sea level.

Marine sediments deposited during the transgression of phase 2 are w preserved in La Serena Bay, where they are called the Coquimbo Formati Stages in deposition are represented by shell banks at frequent intervals. I example, on the south side of Quebrada Romeral, a short distance north of Serena, fossiliferous horizons occur at 35 m, 36 m, 38 m, 40 m, and 48 above sea level. A broad aggradation surface at about 100 m marks t culmination of this phase.

Remnants of surfaces formed during the regression of the sea in phas have been plotted approximately on a height-range diagram (Fig. 6). Th occur extensively and almost exclusively within the phase 2 deposits, though some small phase 3 platforms are found in the rocky peninsula Punta Teatinos. The main surfaces are located at 87–75 m, 80–40 m (w local developments at 70–63 m, 53–48 m, and 50–20 m), 35–15 m, 18–15 and below 10 m. It is difficult to locate old sea levels at the backs of these s faces because some have been obscured by slopewash and others have be masked by wind-blown debris.

DATING OF QUATERNARY LAND FORMS

Whereas the relative chronology of coastal evolution in the region is cle it must be admitted that no part of the sequence of shore-line changes has be accurately dated. Although several attempts have been made to date la forms and deposits, none of them is based on unquestionable evidence. I example, several paleontological studies of the Coquimbo Formation ha been made, but its age is disputed. Darwin (1896, p. 247) attributes the fau

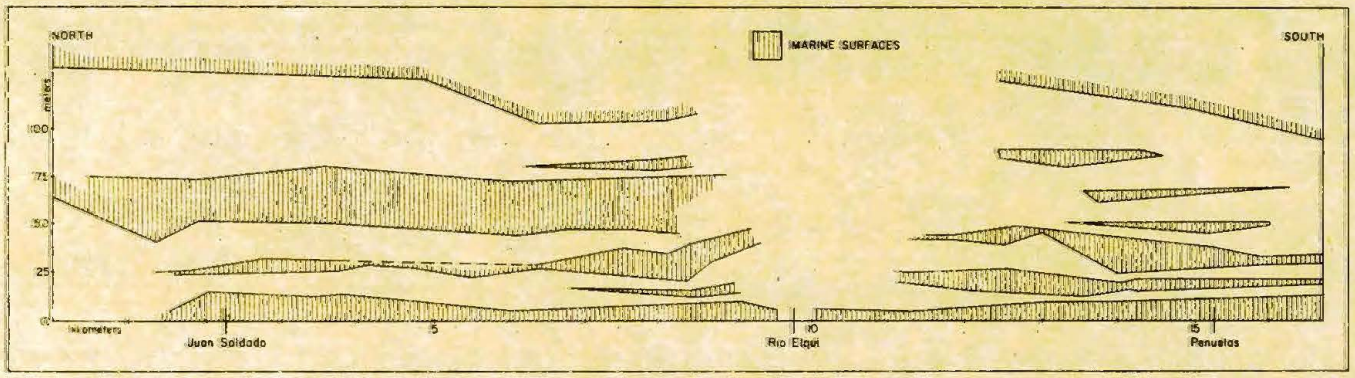


Figure 6. Height-range diagram of marine surfaces around La Serena Bay, Chile

to the early Tertiary, Steinmann's (1896, p. 535) detailed analysis leads hi to ascribe a Neogene age to the deposits, and Willis (1929, p. 101) conclud that the succession belongs to both the Pliocene and the early Pleistocene. A further example concerns phase 3. A shore line between 5 and 7 m occurs a several localities along the Chilean littoral and corresponds in altitude wit the Normannien shore line in western France. Paskoff (1963a, p. 191) be lieves that the two shore lines are contemporaneous. Recent archeologic investigations by Julio Montané (Personal communication, 1964), howeve suggest that such long-distance correlation may be inaccurate. Montané be lieves that the 5–7-m shore line was probably formed about 6000 years ag (Written communication, November 1964). Further work is essential befor shore lines of the Norte Chico can be correlated confidently with those i other areas. Moreover, until the absolute ages of deposits are known beyon doubt, interpretations of the processes that caused sea-level movements wi remain speculative.

INTERPRETATION OF THE SHORE-LINE SEQUENCE

The intermittent fall of sea-level during phase 1 was so great that it wa almost certainly the result of major earth movements. An intermitten epeirogenic uplift of the continent following the main Andean orogeny seem the most reasonable explanation. Examination of the phase 2 deposits sug gests that the marine transgression at this time was a continuous phenomeno that could be explained either by a continental submergence, as both Willi and Brüggen maintain, or by a major glacio-eustatic change of sea level.

Phase 3 poses greater problems. Some authors believe that glacio-eustati processes were responsible for sea-level changes, others consider intermitten tectonic activity the most important process of rejuvenation. If the phase be longs even in part to the Quaternary, which seems likely, there must hav been some glacio-eustatic control of sea-level movement. As many autho have pointed out, on the other hand, it is certain that some recent changes c sea level along the Chilean coast have been the result of tectonic movemen (*e.g.* Wright, 1961). Such movements may have occurred throughou Quaternary time. For example, epeirogenic uplift could have begun in phas 1, been interrupted by the transgression of phase 2, and continued into phas 3. The final solution to this problem will probably be a compromise be tween the opposing views.

Two further problems are associated with the interpretation of phase land forms:

(1) The condition of sea level at times when abrasion platforms wer formed is unknown. Were platforms cut during minor transgressions in th over-all regression? If this were so, platform erosion probably occurred durin interglacial or interstadial rises of sea level. Alternatively, were platforms cu during pauses in the regression? If this were the case, then intermitten

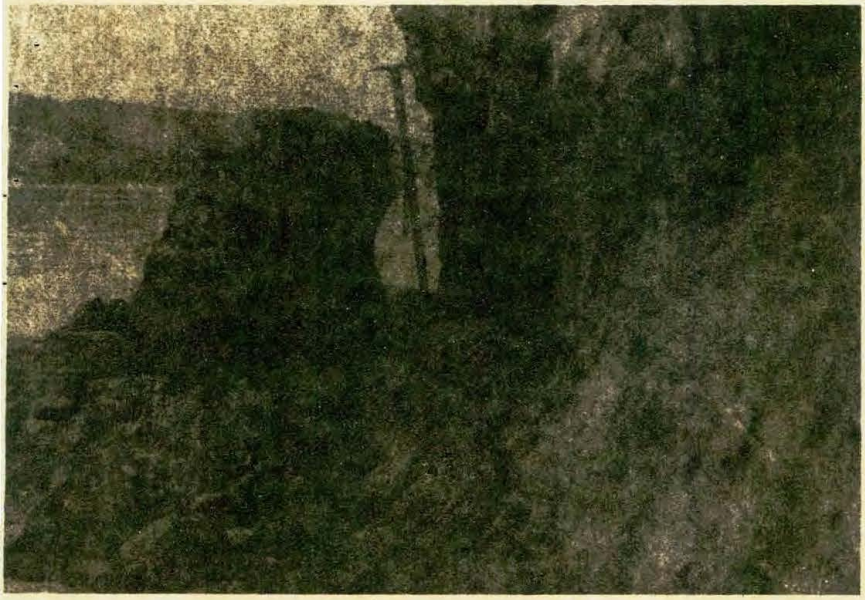


Figure 1. Part of section indurated with iron and manganese oxides, Puerto Saavedra

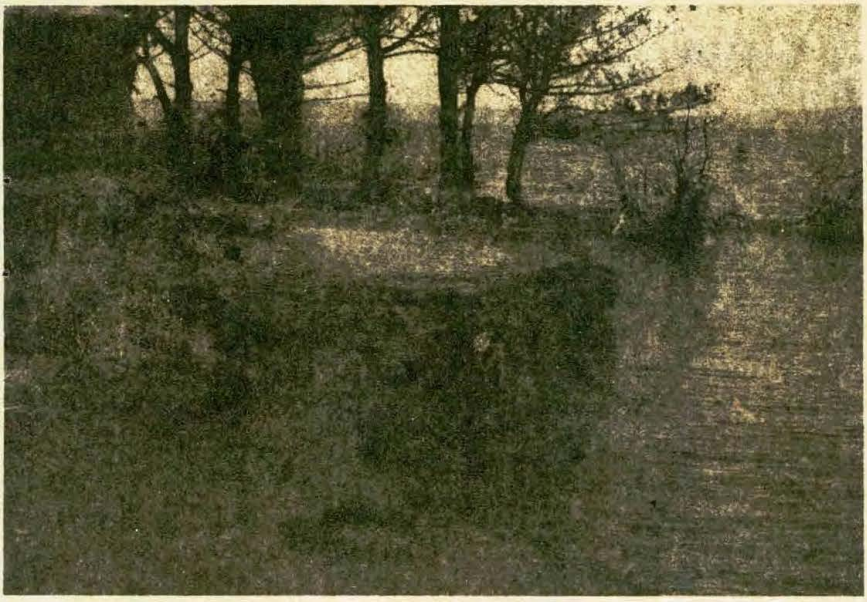


Figure 2. Notch in cliff at low tide, southern part of Ancud Bay. Before earthquake, the same feature was 1.5 m above high tide. Scale shown by ice axe near center of photo

INDURATED AND NOTCHED SEA CLIFFS, CHILE

THIN SECTION OF BEACH ROCK FROM THE CORDÓN EL ESPINAZO, CHILE

Magnification 6×. Larger fragments are derived principally from lamellibranch and gastropods. A few particles of grit, quartz, diorite, and unaltered plagioclase occur. Few fragments are in contact. They are set in a matrix of calcium carbonate

Figure 1. Unconformity between late Tertiary silt and overlying fossiliferous Quaternary gravel, northwestern part of Llano de Caldera

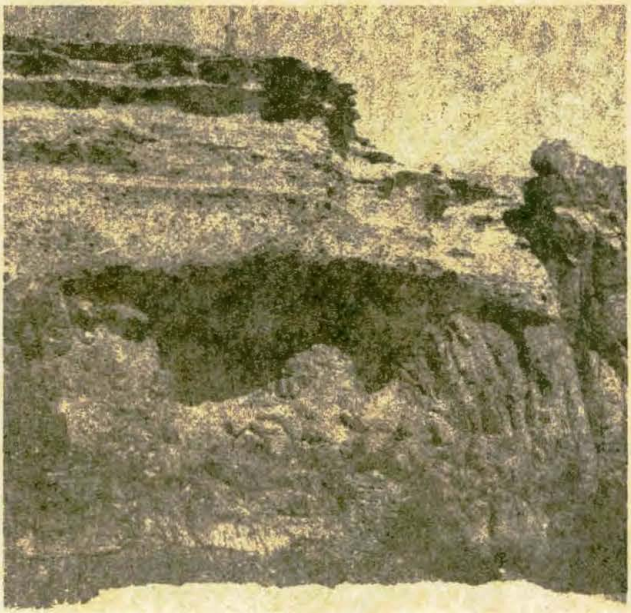


Figure 2. Sea cliff south of mouth of Río Copiapó, showing contact between Quaternary marine beds and underlying granitic rocks

UNCONFORMITIES ON THE CHILEAN COAST

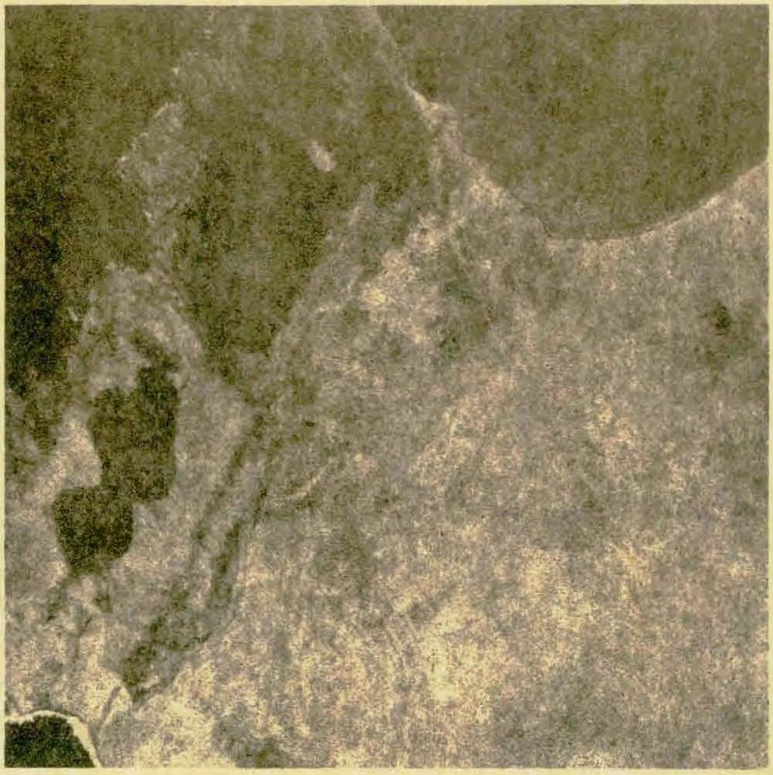


Figure 1. Vertical aerial photograph of Morro de Copiapó (black area) and adjacent part of Llano de Caldera, showing north-northeast fault. Photo taken by HYCON Company in 1955

Figure 2. Granite gorge cut by the Río Copiapó in bedrock ridge buried by the Llano de Caldera terrace deposits west of María Isabel

RÍO COPIAPÓ AREA, CHILE

peirogenic uplift may have been the cause. Unfortunately, the limited evidence of deposits and platform morphology is inadequate to answer these questions conclusively.

(2) Some shore lines occur at uniform altitudes for great distances along the coast. The 110-m, 15–18-m, and 5–7-m shore lines, for example, are apparently horizontal between Carrizal Bajo and La Serena. No differential tectonic movements have occurred in this area since the end of phase 2. The inferred changes of sea level were not necessarily induced by glacio-eustatic changes, however. An alternative explanation is possible. The Chilean coast closely parallels the main longitudinal axes of Andean orogeny. If epeirogenic uplift followed the orogeny, it almost certainly would have been parallel to those axes and uniform longitudinally. Epeirogenic uplift might reasonably be expected to have been uniform for many miles along the coast.

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Part 4. Evidence and Interpretation for High Stands of the Sea Along the Chilean Coast Between Lat. 27° and 27°45′ S.

Kenneth Segerstrom

ABSTRACT

A broad terrace partly cut in bedrock and partly filled or veneered with clastic deposits extends along the Pacific coast south of Caldera, Chile, for a distance of 60 km. Where it has not been eroded at the edge by running water or deflated in a central portion by eolian action the terrace ranges from about 95 to 137 m above present sea level. Three higher terraces, of which relatively narrow remnants remain, form seaward-facing escarpments at 150–175 m, 208 m, and 238 m. The terraces result from marine embayment of the lower Río Copiapó valley and adjacent areas and from subsequent withdrawal of the sea. Most terrace levels represent pauses in the general marine regression.

GENERAL STATEMENT

Marine terraces and elevated beaches south and southeast of Caldera, consisting principally of gravel, are as high as 268 m above sea level. The marine deposits contain abundant mollusks and some sharks' teeth, most of which are

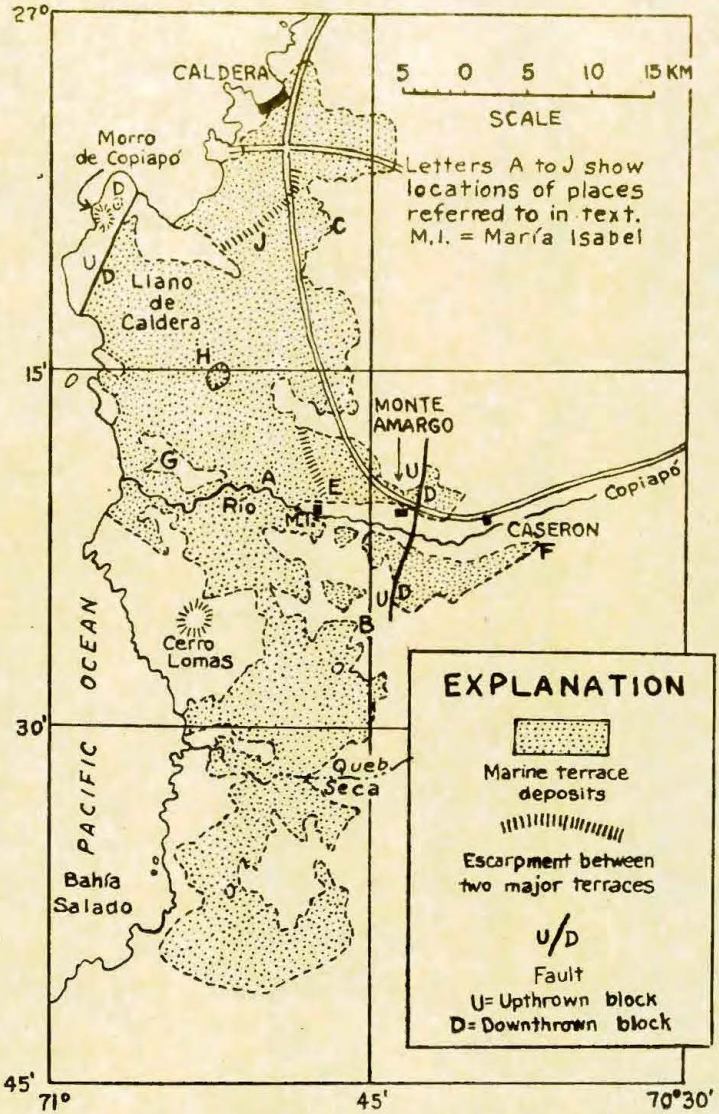


Figure 7. Map of coastal area between Caldera and Bahía Salado, Chile, showing distribution of marine terrace deposits

morphologically indistinguishable from the remains that litter moder beaches (Segerstrom, 1963). An *Isignomon* collected at about 100 m above se level near Quebrada Seca (Fig. 7) is probably larger than modern forms an possibly is a warm-water species (José Corvalán, oral communication, Jun 1962). It is believed that terrace and beach materials were deposited durin

(just south of *A* in Fig. 7) through the terrace deposits and a buried bedroc ridge (Pl. 4, fig. 2). From the foot of the escarpment north of María Isabel a 137 m, the terrace gradually descends seaward to an altitude of about 95 r in a distance of 16 km. A depression formed by eolian action lies about 8 kr north of the river gorge (at *H* in Fig. 7); there the terrace surface has bee lowered by deflation to the water table, at 83 m above sea level.

LOW TERRACES

Immediately bordering the coast there is a narrow zone of lower terrac levels and sea cliffs. Except for an area near Caldera, this zone is too narrov to be shown at the scale of Figure 7. The boundary between the Llano d Caldera terrace and the lower terrace is marked by a scarp about 10 kn south of Caldera (at *J*; near there, the most extensive one of the lower ter races is approximately 40 m above sea level). At the mouth of the Rí Copiapó there are narrow steplike platforms at 31, 28, and about 17 m abov sea level.

CONCLUSIONS

Observations that have been made of the terraces and related features lea to the following interpretations:

(1) There is evidence of a principal marine transgression that extended u the valley of Río Copiapó farther than Caserón, about 35 km east of the pres ent coast line. During a long pause in the withdrawal that followed, th broad Llano de Caldera platform was cut in sediments deposited during th transgression and planed on bedrock. The transgression was probably eustati and represents an early interglacial or interstadial episode of the Pleistocen epoch.

(2) The arcuate gravel ridges on the Llano de Caldera terrace represen strand lines of a receding sea.

(3) Altitudes of terraces and beaches have been locally influenced b tectonic movements. Depending on the amount of vertical displacement along the nearby fault, the high marine deposit immediately northeast of the Morr de Copiapó may possibly be correlated with the Llano de Caldera terrace o with the higher level farther east.

(4) Sea cliffs in the region are highly localized phenomena, and they do no result from significant stillstands in the regression of the sea as does the mor inland scarp at 150–175 m. Well-cemented shell beds are more resistant t erosion than relatively unconsolidated gravel and sand, so that reduction o the Llano de Caldera terrace along its outer edge tends to proceed by steps with each step capped by a shell bed. In some places where wave action ha been particularly effective, the lowest "step" is at the contact betwee diorite and overlying sediments.

Part 5. Summary

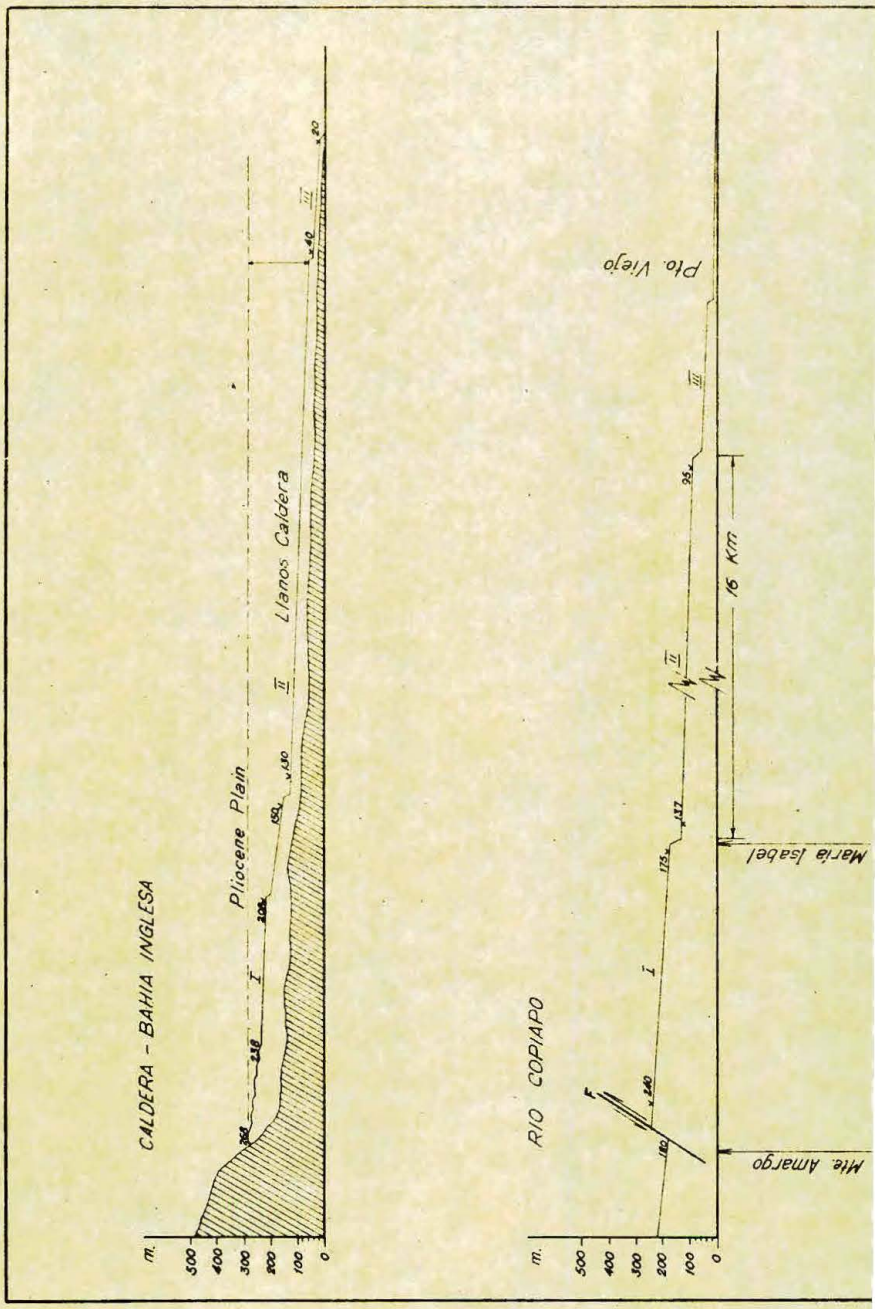
Humberto Fuenzalida V.

Along the Chilean coast, terraces are commonly present, but are unevenly listributed. In the southern part minor remains at 10–20 m above present ea level have been assigned to late-glacial time. Perhaps the poor preservaion of southern terraces can be ascribed to vigorous wave action in this belt f strong west winds. In central and northern Chile, where marine terraces re better preserved, three or four levels persistently occur (Brüggen, 1929, . 403–440). Paskoff suggests that, in addition to the levels recognized by Brüggen, there are others at 4–5 m and 1.2 m that are postglacial. Nine erraces of marine abrasion have been recognized between Valparaiso and Quintary (Alvarez, 1964). A coastal plain underlain by Pliocene sediments is vell preserved in the following areas: Planicie de Arauco, lower course of the Río Rapel, and Carrizalillo (Brüggen, 1950, p. 188–191). In northern Chile erraces are found on the Peninsula of Mejillones and between the mouth of he Río Loa and the town of Iquique (Fig. 1). At Mejillones a principal errace is cut in bedrock and coquina, and several steplike lower terraces ccur. Many recent faults make interpretations difficult in this part of the ountry.

For a long time, Brüggen's ideas have dominated theories on instability of he Chilean coast since Pliocene time. Weber (1938) assumed that the teraces result from stillstands of the continent in its general uplift during Pleistocene. Paskoff thinks that this uplift is not universal along the Chilean oast, that stable sectors exist where correlations with terraces of other coinents can be made, and/or that in late Pleistocene time the rate of uplift has lecreased. He believes that the tripartite arrangement of the terraces favors a ustatic explanation.

Cooke and Segerstrom believe that most of the terraces are results of a ingle transgression and a single withdrawal, with different pauses in the eneral regression that followed the transgression. Weischet and Cooke ccept the idea that during the Quaternary various minor advances and reeats took place—perhaps in connection with change in volume of water in cean basins.

We cannot deny that fluctuations of sea level have resulted from melting f continental ice. Ewing and others (1960) have pointed out that these luctuations were stronger than was believed before ice-depth surveys of Antarctica were made during the International Geophysical Year. If the luctuations have not left traces along the Chilean coast, it is because conemporary movement of tectonic or epeirogenic origin have compensated for he rise or fall of sea level. On the other hand, in a country like Chile we can


CALDERA - BAHIA INGLESA
m.
500
400
300
200
100
0
Pliocene Plain
Llanos Caldera
I
II
III
R/O COPIAPO
Mte. Amargo
Maria Isabel
Pto. Viejo
16 Km

be sure that tectonic movements, both epeirogenic and warping, have taken place throughout the epoch. Therefore it is reasonable to assume that both eustatic and tectonic movements have influenced sea-level changes.

Segerstrom shows that marine deposits in the Caldera-Bahía Salado area are older than marine-terrace cutting. Coquina sediments were deposited on a drowned coast, perhaps in early Pleistocene time. Sometime later, a still-stand during marine regression resulted in the cutting of a main terrace, Llanos de Caldera, 95–130 m higher than present sea level. Segerstrom's data, as compiled in Figure 8, reveal three levels separated by sea cliffs.

TABLE 1. SUMMARY OF SEA-LEVEL DATA, CHILE

Sector	Southern Chile		Central and northern Chile			
	Weischet		Paskoff	Cooke	Brüggen *in* Cooke	Segerstrom
Sea levels	Valdivia	Huecolla		Huasco	Carrizalito	Caldera
Pliocene level	200	170	..	?	250	268
High level	..	70	..	..	160–220	150–240
Medium level	20	25–(35–38)	100–130	85–110	80–110	95–137
Lower level	10	8–10	35–40	30	30	40
Minor levels	..	..	5–7	5–7	..	..
	1.5	..	1.2	..	..	..

Data shown in Table 1 for northern and central Chile are fairly consistent, but they do not agree with those for the southern part of the country. Terraces are well developed and are characterized by major steps of similar character as far south as Cobquecura (lat. 36° 08′ S.; Fig. 1). Farther south, a general sinking has occurred during Quaternary time, so that south of lat. 41° S. the main geomorphic units are drowned by the sea. Data provided by Weischet strongly suggest that this movement commenced in early Pleistocene; the minor vertical distances between terraces imply that is has been fairly continuous. Parts of central Chile (Valparaiso, Quebrada Amolanas; Fig. 1) have been strongly uplifted.

Studies of terraces along the Chilean coast generally reveal that one level is outstandingly well developed as compared with the others. Segerstrom, Cooke, and Paskoff recognize that the 85–110-m level is dominant in their areas of study. Along the Río Copiapó this level is 16 km wide. On Huasco Bay it is the most extensive morphological feature in the area. In the San Antonio-Cartagena area (lat. 33° 32′ S.), the 100–140-m terrace is the uppermost one and is at least 8 km wide, as compared with 1 or 2 km for the others. Correlation of this terrace with terraces at comparable altitudes in northern

Chile that also happen to be the best developed ones suggests that they are a related to a single, exceptionally long stillstand of the sea.

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