miles south and one-half mile west of the Crane and Dodd quarry sites or about 4.25 miles south of Kansas highway 31 leading into Osage City from the west. The outcrop forms the bed and banks of a small intermittent stream tributary to Salt Creek. A second new fossil footprint locality was found a short distance west of the center of the SW¼ sec. 35, T. 16 S., R. 17 E., about 0.35 mile west and a similar distance north of the Crane and Dodd quarry in the SW cor. SE¼ sec. 35, T. 16 S., R. 17 E. The flagstone occurs in the creek bed of a small stream bisecting the Osage City golf course. Normally the site is under water, being part of the Osage City municipal water reservoir. Due to drought conditions this portion of the reservoir was completely dry in September, 1954, exposing portions of the same flagstone cropping out in section 15 almost three miles farther south. Whether the footprints in this locality occur in exactly the same bed as those obtained farther to the south could not be ascertained in the field. There is no question, however, that the horizon is the upper part of the Utopia limestone member.

REFERENCES

ADAMS, G. I., GIRTY, G. H., & WHITE, DAVID, 1903, Stratigraphy and paleontology of the Upper Carboniferous rocks of the Kansas section: U. S. Geol. Surv., Bull. 211, 123 p., 4 pl.

BAIRD, DONALD, 1952, Revision of the Pennsylvanian and Permian footprints Limnopus, Allopus and Baropus: Jour. Paleontology, vol. 25, p. 832–840, pl. 122–124.

BRANSON, E. C., & MEHL, M. G., 1932, Footprint records from the Paleozoic and Mesozoic of Missouri, Kansas, and Wyoming: Geol. Soc. America Bull., vol. 43, p. 383–398, pl. 10.

HAWORTH, ERASMUS, 1895, Stratigraphy of the Kansas Coal Measures: Am. Jour. Sci. 3d ser., vol. 50, p. 452–466, pl. 9.

——, 1895a, The stratigraphy of the Kansas Coal Measures: Kansas Univ. Quart., vol. III, no. 4, April 1895, p. 271–290, pl. 20.

——, 1895b, The coal fields of Kansas: Kansas Univ. Quart., vol. III, no. 4, April, 1895, p. 297–309.

——, et al., 1896, Univ. Geol. Surv. Kansas, vol. 1, chapter 5 by Hall, J. G., A geologic section from state line, opposite Boicourt, to Alma, principally along Osage River, p. 99–106, pl. 5.

——, & CRANE, W. R., 1898, Special report on coal: Univ. Geol. Surv. Kansas, vol. 3, 347 p., 70 pl.

——, KIRK, M. Z., & PIATT, W. H. H., 1894, Report on field work in geology for season of 1893, by the Department of Physical Geology and Mineralogy, University of Kansas: Kansas Univ. Quart., vol. 2, no. 3, p. 99–142, pl. 4,5.

MARSH, O. C., 1894, Footprints of vertebrates in the Coal Measures of Kansas: Am. Jour. Sci., 3d ser., vol. 48, p. 81–84, pl. 2,3.

MOORE, R. C., 1936, Stratigraphic classification of the Pennsylvanian rocks of Kansas: Kansas Geol. Surv. Bull. 22, 256 p.

MUDGE, B. F., 1874, Recent discoveries of fossil footprints in Kansas: Kansas Acad. Sci. Trans., vol. 2, p. 7–9; 1896, reprint, p. 71–74.

SCHOEWE, W. H., 1946, Coal resources of the Wabaunsee group in eastern Kansas: Kansas Geol. Surv. Bull. 63, 144 p., 5 pl.

UPWELLING AND ASSOCIATED MARINE LIFE ALONG PACIFIC BAJA CALIFORNIA, MEXICO*

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INTRODUCTION

Recent studies of the marine benthic organisms inhabiting the northwestern coast of Baja California, Mexico, indicate the presence of discontinuous intertidal and inner neritic distribution for certain forms. This unusual distributional pattern requires an oceanographic explanation, apparently explained by local upwelling of cold water. This investigation is concerned primarily with the influence of upwelling upon the distribution of the marine invertebrates, especially the mollusks, and the application of this phenomenon to paleoecological interpretations. It seems advisable to place the preliminary findings on record. An analysis of the importance of upwelling on the climate, physiography, and non-marine biotas of adjacent land areas is beyond the scope of this paper. The reader is referred to Brongersma-Sanders (1948) for a critical re-

* Contribution from the Museum of Paleontology, University of California, Berkeley.

view of the known effects of upwelling and to Sverdrup et al. (1946) for an explanation of this phenomenon.

Many species of stenothermal cold-water organisms frequent intertidal or shallow water in high latitudes and occur in progressively deeper water as they range toward the equator. The southern range limits of many of the northeastern Pacific forms are not known, due to a paucity of bathymetric records; however, the appearance of cold-water species in the intertidal zone along parts of the coast of Baja California presents an interesting problem to students of zoogeography and ecology.

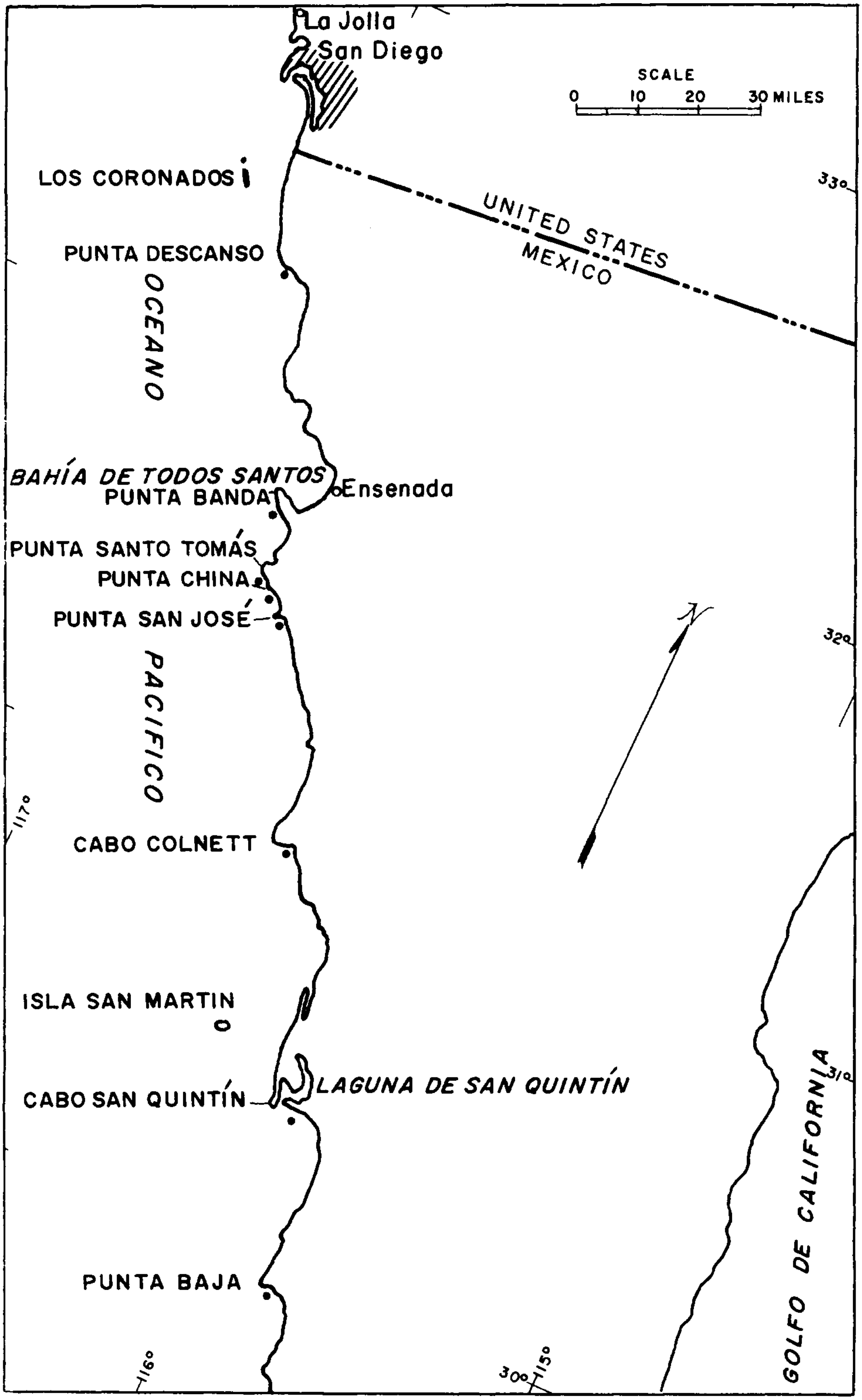
UPWELLING ALONG PACIFIC BAJA CALIFORNIA

A series of surface temperature observations and bathythermograms undertaken by Dawson (1951) demonstrated the occurrence of upwelling along virtually the entire Pacific coast of Baja California. Dawson's hydrographical and biological investigations indicate the presence of four regions which can be identified by differences in geographical or seasonal continuity of upwelling. North of latitude 27° N., upwelling appears to be seasonally continuous in local areas, some of which are rather extensive. The northernmost region, Punta Descanso to Bahía de San Quintín, is the area pertinent to this study (Text-fig. 1). Here much of the coastline trends in a north to northwest direction, but is broken by several large headlands, south of which the coastline is first east to west, then northwest to southeast. In this region, the intense along-shore upwelling occurs when the prevailing winds blow the water surface upward, to be replaced rapidly by water drawn from a few meters below the surface (personal communication, C. L. Hubbs, Aug., 1954). Inasmuch as the winds are predominantly from the northwest to the southeast, upwelling is intensified south of the headlands. Hydrographical and biological evidence support this tenet. The stretches of shore between the prominent headlands were found to have greater temperature variations, depending largely upon the degree of stagnation or movement of upwelled water along the shore. As would be expected, upwelling has little influence in areas of protected or semi-protected shoal water such as Laguna de San Quintín and Bahía de Todos Santos. In summary, this region is characterized by geographically discontinuous areas of upwelling in which the centers of intensity are located on the south sides of the more prominent headlands (*cf.* Dawson, 1951).

Previous work.—Although upwelling off western North America has been known for some time, with intensification along certain areas of the Baja California coast (McEwen, 1916), the role of this phenomenon as a factor in the distribution of marine organisms has received little attention until recently. Studies on the distribution of marine floras and faunas along the Pacific coast of Baja California by Dawson (1946–1952) on algae, by Hubbs (1948) on fishes, and by Emerson (1952) on invertebrates show a close correlation with the presence or absence of upwelling. Within the areas of upwelling many species characteristic of more northern waters occur far south of their expected latitudinal range, producing a discontinuous intertidal distribution for these organisms.

Neontological evidence.—Although the writer has not had an opportunity to make comprehensive collections from the upwelling "cold-spots," an hour's collecting at a low tide produced the following stenothermal cold-water organisms from the intertidal zone on the south side of Punta Santo Tomas:

1. *Balanophyllia elegans* Verrill, a stony coral; recorded range: British Columbia southward to Point Conception and through the Channel Isls., California, shore to 160 fathoms (Durham & Barnard, 1952); identification by J. Wyatt Durham.
2. *Acmaea mitra* Eschscholtz, a limpet; recorded range: Pribilof Isls., Alaska, to San Diego, California, infra-tidal in southern extent of range (Keen, 1937).
3. *Hapalogaster cavicauda* Stimpson, a crab; recorded range: Cape Mendocino, California, to Monterey and through the Channel Isls., California (Ricketts & Calvin, 1952; Johnson & Snook, 1935); identification by John S. Garth.
4. *Idothea stenops* (Benedict), an isopod; recorded range: Coos Bay, Oregon, to Monterey, California (Menzies, 1950); identification by Robert J. Menzies.



TEXT-FIG. *1*—Chart of the coastline from La Jolla, California, to the vicinity of Punta Baja, Baja California. Areas of local upwelling, which are indicated by solid circles, occur south of Punta Descanso, Punta Banda, Punta Santo Tomás, Punta China, Punta San José, Cabo Colnett, Cabo San Quintín, and Punta Baja (data after Dawson, 1951, in part).

According to Dr. E. Yale Dawson (personal communication, August, 1954) the algal flora of Punta Santo Tomás contains a number of northern species, including: *Laminaria farlowii* Setchell, *Zanardinula lanceolata* (Harvey) J. De Toni, and *Gigartina california* J. G. Agardh. These species occur intertidally in central California.

A number of other cold-water organisms is recorded from the intertidal zone of several Baja California localities which are now known to be areas of upwelling. Burch (1946) reported *Placiforella velata* Carpenter (a chiton which is recorded in infratidal waters south of Monterey, California) and *Acmaea mitra*, together with other northern species, on the south side of Punta Banda. At this locality, the writer found the water temperature to be 7° to 10°F. lower than that on the north side of the peninsula. Several northern species of pholad clams were collected by Fitch (1953) from localities along the Baja California coast. Hubbs (1948) recorded from south of the international border the intertidal occurrence of the abalone *Haliotis rufescens* Swainson and the sea urchin *Strongylocentrotus franciscanus* A. Agassiz, which occur near San Diego, California, in infratidal water or are rarely exposed by the extremely low, spring tides.

In the areas concerned here, upwelling appears to be at a maximum during the spring and summer months, the critical reproductive period for many of the invertebrates. It seems, therefore, that the cold-water invertebrates are able to maintain local populations within the areas of upwelling and do not require continual larval replenishment from off-shore sources or from more northerly located populations.

APPLICATION TO PALEOECOLOGY

At present, the permanence of the upwelling areas in time must be considered a matter for conjecture owing primarily to the multiplicity of the interacting factors upon which the phenomenon is dependent. The matter of temporal permanency is of prime importance for paleoecological considerations. Brongersma-Sanders (1948) interprets certain evidence from the fossil record as indicating the probable existence of upwelling in past geological ages. The paleontologist would possess a valuable new adjunct for ecological interpretations if the antiquity of upwelling could be unequivocally demonstrated and if it were possible to recognize with a reasonable degree of certainty the effects of this phenomenon in the fossil record. Its application to paleoecological interpretation would necessitate a reexamination of many of our present assumptions. For example, in some instances, upwelling rather than climatic isothermal shift may be the explanation for apparent critical changes in temperature conditions which are now recognized in some of the faunas of the West American Pliocene-Pleistocene sequence.

Paleontological evidence.—At Punta China (see Text-fig. 1) a large series of invertebrates were collected from a highly fossiliferous marine Pleistocene terrace deposit which occurs in the vicinity of this upwelling site. Field evidence based on geologic and faunistic data indicates the probable existence of the headland during the deposition of this terrace and a coastal topography essentially the same as today. A study of these fossils was undertaken to determine if the effects of upwelling could be detected in the composition of the faunule. The preliminary results of this investigation are not conclusive. Although stenothermal cold-water organisms, including the coral *Balanophyllia elegans* and the limpet *Acmaea mitra*, occur in this fossil tide-pool and rock-cliff assemblage, there are also present some northern species which have not been found living in the upwelling areas (e.g. *Tegula brunnea* Philippi and *Cryptochiton stelleri* Middendorff[1]). On the basis of the available data, it is difficult to determine if the cold-water elements in the fossil faunule reflect the influence of upwelling, isothermal shift, or possibly a combination of these, together with other factors. Valentine (1955) has interpreted the presence of cold water, exposed coast elements in the molluscan faunas of some Pleistocene terrace deposits of Southern California and Baja California to suggest the presence, at the time these faunas lived, of local upwelling with lower temper-

[1] It is interesting to note that valves of this chiton are commonly found in the kitchen middens which occur in the region, but the species has not been reported living along this coast. Drs. S. Stillman Berry and Carl L. Hubbs have in preparation a manuscript on the distribution of this species in the midden deposits of the Pacific coast of Baja California.

atures than exist in the present upwelling areas along northern Baja California.

It is evident that additional neontological and paleontological data must be obtained before more definite conclusions can be reached concerning the significance in this region of upwelling as a paleoecological factor. Carl L. Hubbs of the Scripps Institution of Oceanography is presently conducting an exhaustive thermal and zoological survey of the inshore area of northwestern Baja California. The results of this investigation, supplemented by oxygen[18] and carbon[10] studies, promise to yield much additional information on the relation of upwelling to temperature and animal distribution.

CONCLUSION

The possibility of the existence of upwelling in past geological ages and its potential role as an ecological agent should not be neglected by the paleontologist. A better understanding of the influence of this phenomenon on the distribution of living marine organisms, particularly benthic forms, holds promise for paleoecological applications. Moreover, the intertidal occurrence of frigophilic (cold-limited) plants and animals in the upwelling areas of the Baja California coast serves to demonstrate the advisability of utilizing thermophilic (warm-limited) species as indices for the interpretation of former climatic conditions of fossil faunal assemblages.

ACKNOWLEDGMENTS

For their kindness in reading the manuscript, and in offering constructive criticisms, I am indebted to Drs. Carl L. Hubbs, E. Yale Dawson, Donald E. Savage, and Ralph L. Langenheim and to Mr. Warren O. Addicott. At various times during the progress of this study I have been aided in field collecting by Dr. John D. Soule and Messrs. Addicott, Ralph O. Fox, and Arthur P. Loring, Jr.; their assistance is gratefully acknowledged.

LITERATURE CITED

Brongersma-Sanders, M., 1948, The importance of upwelling water to vertebrate paleontology and oil geology: Verh. Akad. Wet., Amst. Afd. Nat. (tweede sect.), vol. 45, p. 1–112.

Burch, J. Q., *in* J. Q. Burch (editor), 1946, Minutes Conchological Club Southern Calif., no. 57, p. 1–28.

Dawson, E. Y., 1946, Marine algae associated with upwelling along the northwestern coast of Baja California, Mexico, Bull. Southern Calif. Acad. Sci., vol. 44, p. 57–71.

——, 1949, Resultados preliminares de un reconocimiento de las algas marinas de la costa pacifica de Mexico: Rev. Soc. Mex. Hist. Nat., t. 9, p. 215–255.

——, 1950, A note on the vegetation of a new coastal upwelling area of Baja California: Jour. Marine Research, vol. 9, p. 65–68.

——, 1951, A further study of upwelling and associated vegetation along Pacific Baja California, Mexico: *ibid.*, vol. 10, p. 39–58.

——, 1952, Circulation within Bahia Vizcaino, Baja California, and its effects on marine vegetation: Amer. Jour. Botany, vol. 39, p. 425–432.

Durham, J. W., & Barnard, J. L., 1952, Stony corals of the eastern Pacific collected by the Velero III and Velero IV: Allan Hancock Pacific Expeditions, vol. 16, p. 1–110, pl. 1–16.

Emerson, W. K., 1952, The influence of upwelling on the distribution of marine floras and faunas of the west coast of Baja California, Mexico [Abstract]: Amer. Malacological Union, Ann. Rept. 1952, p. 32–33.

Fitch, J. E., 1953, Common marine bivalves of California: State Calif. Dept. Fish and Game, Fish Bull. 90, p. 1–102, 1 pl.

Hubbs, C. L., 1948, Changes in the fish fauna of western North America correlated with changes in ocean temperature: Jour. Marine Research, vol. 7, p. 459–482.

Johnson, M. E., & Snook, H. J., 1935, Seashore animals of the Pacific coast, p. i–xiv, 1–659, pl. 1–11.

Keen, A. M., 1937, West North American marine Mollusca, p. 1–84.

McEwen, G. F., 1916, Summary and interpretation of the hydrographical observations made by the Scripps Institution . . . of the University of California 1908–1915: Univ. Calif. Publ. Zool., vol. 15, p. 255–356.

Menzies, R. J., 1950, The taxonomy, ecology, and distribution of northern California isopods with the description of a new species: Wasmann Jour. Biol., vol. 8, p. 155–195.

Ricketts, E. F., & Calvin, J., 1952, ed. 3, [revised by J. W. Hedgpeth], Between Pacific tides: p. i–xiii, 1–502, pl. 1–46.

Sverdrup, H. U., Johnson, M. W., & Fleming, R. H., 1946, The oceans, their physics, chemistry, and general biology: p. i–x, 1–1087.

Valentine, J. W., 1955, Ecologic requirements and depositional environments of Pleistocene molluscan faunas from Southern and Baja California [Abstract]: Jour. Paleontology, vol. 28, p. 881.