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A Historical Résumé of Research in Neogene Marine Molluscan Paleontology and Biostratigraphy in Western North America*

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INTRODUCTION

Investigation of Neogene marine mollusks of the Pacific coast of North America was initiated during the middle of the 19th Century with the description of a Miocene molluscan assemblage from near Astoria, Oregon (Conrad, 1848). Description of new species continued for about a decade, then dropped off until about 1900, when demands for stratigraphic paleontology in petroleum exploration led to a significant intensification of study. A surge in paleontologic research has taken place during the past two decades. Research on Neogene mollusks has been concentrated along the conterminous Pacific coast of the United States. California has been the center of teaching and research, and it is there that the sequence of Neogene faunas is most complete and best understood. Knowledge of Neogene faunal succession in the Pacific Northwest states of Oregon and Washington is less complete because the coastal ranges of that region are dominantly Paleogene terrane, and petroleum exploration there has been nil. A current frontier for Neogene studies is the Pacific coast of Alaska, where paleontologic investigation is still in its initial stages. Yet there are almost equally important needs for refined biostratigraphic and monographic studies of Neogene sequences in other, more thoroughly studied regions.

The purpose of this résumé is to identify some of the trends in Neogene molluscan research and to point out some of the more important contributions to this field. Trends are based upon an annotated bibliography of publications dealing with Miocene and Pliocene marine mollusks of the west coast of North America, principally from northwest Mexico to Arctic Alaska (Addicott, 1972b). An analysis of the nearly 1,200 reports making up this study (Addicott, 1972a) indicates pulses and plateaus in the growing body of knowledge of Neogene marine mollusks. Three periods of heightened investigation are evident from a chart depicting levels of publication of paleontologic reports during the period 1840–1969 (Fig. 1): an initial descriptive phase, 1850 to 1860; an intermediate phase, 1900 to 1954; and a current phase, 1950 to the present. The best evidence of these phases is the curve representing reports containing systematic descriptions or illustrations of mollusks; approximately 20 percent of the reports published before 1970 from the core of Neogene research (Fig. 1, vertical bars). They are also evident from the curve representing all reports containing data on Neogene mollusks (Fig. 1, solid line).

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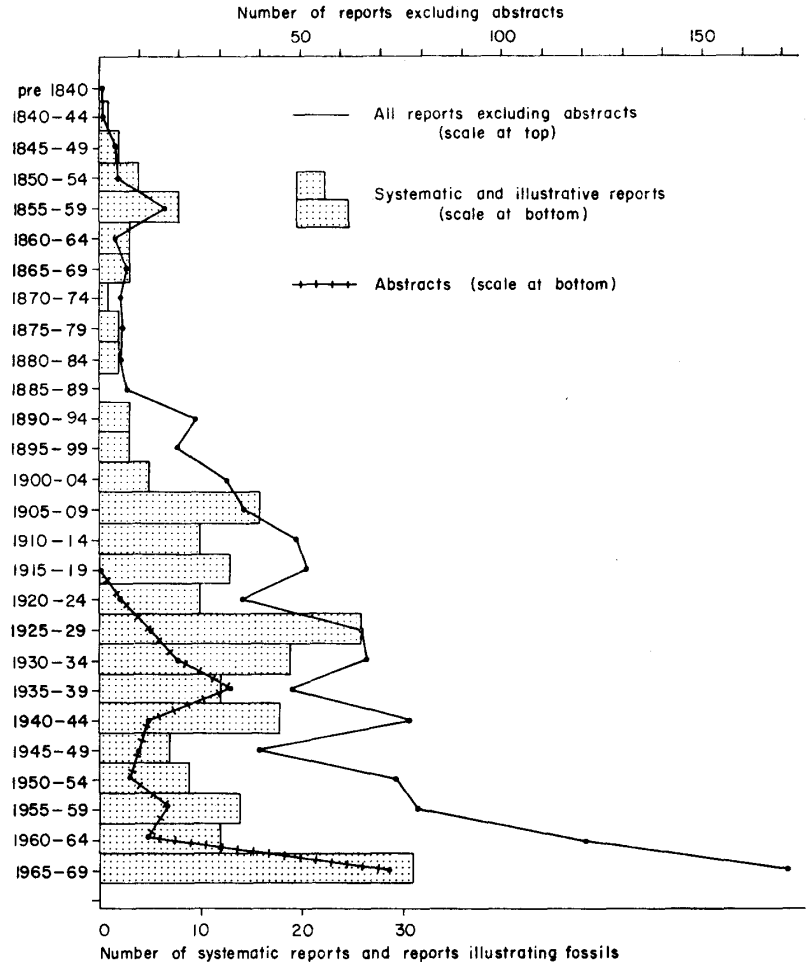

Fig. 1. Levels of publication of reports containing information on marine Neogene mollusks from the Pacific coast of North America and Arctic Alaska for 5-year periods from 1840 through 1969.

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INITIAL PHASE

A brief report by T.A. Conrad (1848) naming and illustrating Miocene mollusks from the mouth of the Columbia River at Astoria, Oregon, began an initial descriptive phase that continued through the 1850's (Fig. 1). This early work by Conrad consisted of taxonomic description of small collections of fossils made by others, principally during explorations for a transcontinental railroad route to the Pacific coast. Conrad was the first paleontologist to make European series or epoch assignments for Pacific coast faunas; his age determinations were based upon faunal correlation with the Atlantic coast of the United States and, in turn, with Europe. Later geologic reconnaissance in California during the 1860's led to some additional description of Neogene mollusks by W.M. Gabb (1866, 1869), but Gabb's research dealt mainly with Cretaceous and Paleogene mollusks. Notably, Gabb was the first paleontologist to become directly involved in field work on the Pacific coast Neogene.

Paleontologic investigation subsided during the latter part of the 19th Century, but the use of paleontologic data in geologic reports again gained momentum before 1900 (Fig. 1, solid curve). Presumably this upturn reflects support of exploration for mineral resources in Alaska and renewed geologic reconnaissance of the California Coast Ranges.

INTERMEDIATE PHASE

A second period of accelerated paleontologic investigation began during the early 1900's with the initial utilization of molluscan fossils in geologic mapping and in stratigraphic correlation of Neogene formations. Initial biostratigraphic study of Neogene strata and the resurgence of taxonomic work was centered in the California Coast Ranges. The period 1900–1910 saw a broad diversification of paleontologic research including formulation of the first framework for provincial Neogene age determination and correlation in California (Arnold, 1906, p. 9–39) and somewhat later in Washington (Weaver, 1912; Arnold and Hannibal, 1913). Other developments included the utilization of molluscan biostratigraphy in geologic mapping (Arnold, 1909a; Arnold and Anderson, 1910), the first detailed systematic descriptions of late Cenozoic molluscan faunas (Arnold, 1903, 1909a; Dall, 1909), the first monograph of a fossil molluscan genus (Arnold, 1906), the first paleogeographic maps of marine Neogene basins (Arnold, 1901b), and the first paleoclimatic analysis based upon molluscan faunas (Arnold, 1909b). The paleontologist most closely identified with the innovative paleontologic research of this period was Ralph Arnold of the U.S. Geological Survey. Arnold combined the classical taxonomic-stratigraphic approach to paleontologic research with the initial interpretive use of molluscan data in fields such as paleogeographic mapping and paleoclimatology. Arnold's most significant contribution probably was the development of the first sequence of Neogene time stratigraphic units for California in his monograph of fossil pectens of the Pacific coast (Arnold, 1906), for his so-called formations closely fulfill present-day criteria for the definition of stages. Remarkably, most of Arnold's work was completed and published before 1910.

Important descriptions of Neogene faunas from Oregon and from Alaska were made by W.H. Dall, of the U.S. Geological Survey (1904, 1909, 1920), who, however, is best known for his extensive publications on malacology and monographic study of the Tertiary mollusks of Florida.

Research on Neogene mollusks at the California Academy of Sciences began during the late 1800's with Cooper's (1888, 1894) catalogues of California fossils; but the first monographic studies were made by F.M. Anderson (1905, 1914) on the Neogene sequence of the Diablo and Temblor Ranges bordering the southern part of the Great Valley of California. Anderson was followed, at the California Academy, by G. Dallas Hanna and L.G. Hertlein, both of whom participated in the descriptions of Cenozoic mollusks for several decades.

The training of paleontologists and incorporation of paleontologic curriculum in geology departments at certain Pacific coast universities played an important role in the upswing in paleontologic research during the early part of the 20th Century. At Stanford University, J.P. Smith trained many students, and although primarily interested in Mesozoic mollusks, published definitive reports on molluscan zonation of the California Miocene (Smith, 1912) and on climatic change along the west American coast during the Cenozoic (Smith, 1919). At the nearby Berkeley campus of the University of California, J.C. Merriam, and his student and successor B.L. Clark, were deeply engaged in research and teaching of Cenozoic paleontology. Clark's interests lay mainly in late Paleogene molluscan faunas, but he published significant reports on Miocene faunas and provincial correlation (Clark, 1915, 1921, 1923). His students published extensive faunal monographs and biostratigraphic studies in the University of California Publications in Geological Sciences. At about this time, C.E. Weaver, another of Merriam's students, became associated with the University of Washington. He laid out the basic biostratigraphic documentation of the Neogene faunas of western Washington (1912, 1916a, 1919b), in

addition to conducting more extensive research on the Paleogene of that State. Seemingly Weaver was unique among his and the following generation of paleontologists in specifying the time-stratigraphic nature of his correlation framework; his "faunal horizon" being defined as "..a deposit formed at a particular time and identified by distinctive fossils" (Weaver, 1916a). Nevertheless, confusion of time-stratigraphic units with lithostratigraphic units continued to plague attempts to refine provincial age determination and correlation. It was much later that distinction between these concepts was clearly made, and, at the same time, implemented with the formulation of a sequence of Miocene foraminiferal stages and zones (Kleinpell, 1938, p. 88–136).

A renewal of research on Neogene mollusks during the late 1920's is reflected in a sharp increase in indices of publication (Fig. 1). Intensification of research and teaching at this time was brought about by the utilization of stratigraphic paleontology in petroleum exploration. During the 1920's surface and subsurface geologic mapping led to the discovery of significant reserves of petroleum in California (Pemberton, 1943), nearly all of which was in reservoirs of Neogene age. The complex structure and rapid facies changes characteristic of Neogene basins of California required extensive use of biostratigraphy in delineating geologic structures. Molluscan biostratigraphy, for example, was employed in the development drilling of many Pliocene oil and gas fields of central California, where the highest stratigraphic occurrences of bivalves such as *Mya* or *Pseudocardium* in well cores were utilized as key horizons for subsurface structural mapping. To meet the needs for petroleum exploration, stratigraphic paleontologists were trained at several universities along the Pacific coast: the University of California, Berkeley, under B.L. Clark; Stanford University, under H.G. Schenck; the University of California, Los Angeles, under U.S. Grant IV; the University of Oregon, under E.L. Packard; and the University of Washington, under C.E. Weaver.

The flurry of research on Neogene mollusks of the late 1920's gradually subsided to a low point about 20 years later (Fig. 1, vertical bars). Leading to this decline were the severe economic depression in the United States, a slowing of petroleum exploration owing to the unusually high level of discovery during the 1920's (Pemberton, 1943), and a gradual changeover from the use of mollusks to foraminifers for subsurface correlation and age determination. An apparent low point in Neogene molluscan research during the period 1945–1949 (Fig. 1) resulted from a decline in the training of paleontologists during World War II and in all probability from completion of the switch from mollusks to foraminifers in petroleum exploration.

The later part of the intermediate phase saw some of the most significant contributions to the growing body of knowledge on Neogene mollusks, as well as further diversification of research. As before, most of the work was on the Neogene of California. But this period also saw the initial monograph on Neogene mollusks from the Gulf of Alaska (Clark, 1932), development of a middle Tertiary stage and zonal chronology for western Washington (Durham, 1944), compilation of an illustrated systematic monograph of Tertiary mollusks of Oregon and Washington (Weaver, 1942), and the initial monographic study of mollusks from northwestern Mexico (Hertlein, 1925). During this period many monographs of stratigraphically or biogeographically significant molluscan genera were completed, notably *Turritella* (Merriam, 1941), *Epitonium* (Durham, 1937), *Clementia* (Woodring, 1926), and *Acila* (Schenck, 1936). Interest in the paleoecologic significance of Neogene mollusks was stimulated by Woodring's (1938) analysis of paleobathymetry of the Los Angeles basin during the Pliocene. Important syntheses of molluscan data were made by Grant and Gale (1931) and by Keen and Bentson (1944); both remain extremely valuable. Utilization of biostratigraphic units in geologic mapping reached a high degree of refinement with mapping of Pliocene faunal zones at Kettleman Hills, Calif.,

by Woodring and others (1940). Probably the most significant faunal monograph of this period was Loel and Corey's (1932) treatment of their Vaqueros Formation.

Near the close of this intermediate phase, the first synthesis of megainvertebrate and foraminiferal sequences produced a correlation chart from marine Cenozoic sequences from northwestern Mexico to southwestern Canada (Weaver and others, 1944).

CURRENT PHASE

A third, or current phase of investigation, began during the early 1950's (Fig. 1). By the later part of the 1960's publications dealing with Neogene mollusks had increased by two-fold and the rate seems to be continuing. This dramatic increase is taken as an index of the importance of paleontology in deciphering the history of the continental margins during the late Tertiary. A recent analysis of this phenomenon (Addicott, 1972a) suggests that the systematic description of new Neogene taxa is largely complete, particularly with regard to the conterminous Pacific Coast States. (An alternative view, however, is set forth by Durham, 1967). The large number of systematic and illustrative reports of Neogene mollusks published during the period 1965–1969 (Fig. 1, vertical bar) reflects a trend toward documentation of interpretations through illustration or systematic treatment of chronologically or environmentally significant mollusks (Addicott, 1972a, fig. 4).

New directions that molluscan research has taken during the last few years include detailed paleoenvironmental analysis of basin margins (Stanton, 1967; Stanton and Dodd, 1972), refined analysis of late Cenozoic marine climate by geochemical or paleontologic techniques (Valentine and Meade, 1961; Addicott, 1970; Stanton and Dodd, 1970), delineation of Neogene molluscan provinces (Hall, 1960), determination of lateral slip along the San Andreas fault through definition of zoogeographic patterns (Hall, 1960; Addicott, 1968), coordination of paleontologic and radiometric time scales (Turner, 1970), and definition of patterns of faunal migration along the North Pacific margin (MacNeil, 1965; Durham and MacNeil, 1967). The success of these topical studies is founded upon continuing detailed taxonomic and biostratigraphic treatment of Neogene molluscan faunas such as that of Moore (1963), Adegoke (1969), Kanno (1971), and Hertlein (1972).

The level of research activity and diversity in research in molluscan paleontology was recently summarized by Kanno and Addicott (1969).

SUMMARY

Investigations of Neogene marine mollusks of the Pacific coast of North America span a 125–year period dating from Conrad's (1848) initial description of Miocene mollusks from the Astoria Formation of Oregon. Pulses in research on Neogene mollusks occurred during the periods 1850 to 1860, 1900 to about 1945, and 1950 to the present. The first phase involved initial description of species and was an outgrowth of geologic reconnaissance of the Pacific coast of the United States. The second phase was stimulated, in large part at least, by the need for stratigraphic paleontology in petroleum exploration in California. A surge of publications that began about 1950 and intensified during the 1960's defines a third period of research. This current phase seems to reflect the increasing importance of paleontology in deciphering earth history. It also marks a basic change from the description of new taxa toward the use of fossil illustrations and refined taxonomy in faunal analysis and documentation.

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