ABSTRACT

Pacific coastal Tertiary basins of South America exhibit a wide variety of clastic fill. Some basins are sand-starved relative to others which are sand-rich. These differences cannot be explained by utilizing the classical tectonic-sedimentary approach of source area relief, distance, tectonic intensity or lithology. Many of the basins studied are approximately equal with respect to these factors but contain markedly different fill.

The potential for high organic content in shales appears to differ between these basins when based upon the occurrence of oceanic upwelling during the Tertiary.

Tertiary oceanic and atmospheric circulation appears to have played a significant role in influencing the distribution of potential source rocks, and may have acted as the controlling factor over the processes responsible for the generation, transport and deposition of reservoir sandstone. By mapping these circulation patterns on paleogeographic maps, it is generally possible to predict in advance of drilling, those basins that should contain the fortuitous combination of potential source rocks and reservoir sandstone, and those that should not. Case studies of oil fields and basins along western Colombia, Ecuador, Peru and Chile are examined in light of these ideas.

INTRODUCTION

This paper examines the distribution of Pacific Tertiary basins and associated oil and gas accumulations of coastal South America (fig. 1). It is not the intent here to examine every field or structure from which hydrocarbons are produced. Focus is directed toward regional geologic and paleoenvironmental factors directly responsible for the formation and emplacement of potential source and reservoir rocks.

GENERAL FRAMEWORK

Paul Trask (1932) early recognized that the formation and distribution of organic-rich sediments played an important role in the origin of petroleum. Since then, many geologists have studied the subject from various perspectives, including the process of upwelling (Dow, 1978; Parrish, 1982; and numerous others). These writers recognized the importance of zones of upwelling within oceans, where vertical currents transport nutrients to the photic zone, resulting in high phytoplankton productivity. Sediments deposited in upwelling zones are usually highly organic-rich and are potential candidates for petroleum source rocks.

Ancient Circulation Models. By using the basic principles of atmospheric circulation and analogies from present circulation patterns, Parrish et al. (1982 a) constructed Mesozoic and Tertiary atmospheric circulation models on paleogeographic maps. The resulting patterns were related to known occurrences of petroleum source rocks. These models were also used for predicting the locations of ancient zones of upwelling. Their work with respect to South America forms the basis for locating potential source rocks in the Tertiary, and for predicting the relative rainfall over regions of South America through time (Parrish et al. 1982 a, b).

Sedimentary Processes. The role of climate as a controlling factor of sedimentation was advanced by H. F. Garner (1959). In a study of contemporary climate, relief, and associated sedimentary deposits in four regions of the Andes Mountains, Garner demonstrated that, "humid weathering, as a dominantly chemical process, generates fine clastic material which is protected from fluvial or eolian erosion by vegetation and forms soil. Arid weathering, as a dominantly mechanical process, generates a high percent of coarse alluvium which tends to accumulate within arid regions due to eolian removal of fine fractions and absence of perennial runoff." This climatic concept is useful in evaluating and predicting the distribution of potential reservoir and source rocks.

TERTIARY BASINS COASTAL SOUTH AMERICA

FIGURE 1.

Whether predicting upwelling or rock deposits, there are complications which should be kept in mind. For example, upwelling alone cannot account for all the petroleum source rocks of the world (Parrish, 1982 a). Other explanations are possible. Global changes in seawater chemistry and organic productivity through time could alter the value of upwelling. Not all organic matter in source rocks need come from oceans (e.g., land derived organic matter deposited in anoxic waters).
The efficiency with which fluvial processes remove sediment from provenance to basin is variable. Deposition centers shift through time. Ocean currents rework and transport sediment in varying degrees from their initial point of entry into a depositional area. Thus, there is not necessarily a simple, predictive, correlation between the continental sedimentary processes and the final depositional products. With this in mind, an examination of some case histories from the Tertiary of coastal South America is in order.

**PACIFIC BASINS**

**Production.** There are about twenty-four Tertiary basins or sub-basins along the Pacific margin. Most of the deeper and more prospective have been tested by at least one exploratory well. Many of these wells have encountered shows of various quality, but to date only those basins listed in Table 1 have commercial or potentially commercial accumulations.

Commercial Tertiary oil and gas production is restricted to two basins, the Talara of northwestern Peru and the Santa Elena of southwestern Ecuador (Fig. 2). Potentially commercial gas discoveries have been made in Progresso basin of Ecuador, and the Valdivia basin of Chile. The geology of these basins and fields will be discussed in detail in a different section of this paper. Basic field characteristics, reserves, and historical data are summarized in Table 1.

**Basin Comparisons.** Generalized columnar sections from several Pacific coastal basins were constructed (Fig. 3). Each basin contains different types and amounts of fill. Some are mostly shale filled, while others are rich in sand content.

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### Table 1

<table>
<thead>
<tr>
<th>FIELD</th>
<th>COUNTRY</th>
<th>AGE/ROCK</th>
<th>TECTONIC ENVIRONMENT</th>
<th>TRAP TYPE</th>
<th>DEPTH (FEET)</th>
<th>YEAR DISCOVERED</th>
<th>ULTIMATE RECOVERY</th>
<th>CUMM. PROD. TO 1981</th>
</tr>
</thead>
<tbody>
<tr>
<td>TALARA</td>
<td>PERU</td>
<td>EOCENE</td>
<td>CONTENZAL ARC - TRENCH</td>
<td>MOSAIC OF FAULT ROCKS</td>
<td>2,600 - 8,700</td>
<td>1966</td>
<td>1,200 (MMBO)</td>
<td>1,052 (MMBO)</td>
</tr>
<tr>
<td>SANTA ELENA</td>
<td>ECUADOR</td>
<td>EOCENE</td>
<td>MOSAIC OF FAULT ROCKS</td>
<td>2,300 - 4,000</td>
<td>1913</td>
<td>115 (MM3BO)</td>
<td>115 (MM3BO)</td>
<td></td>
</tr>
<tr>
<td>AMISTAD</td>
<td>ECUADOR</td>
<td>OROcline</td>
<td>ANTICLINE</td>
<td>9,000 - 14,000</td>
<td>1920</td>
<td>145 BCF</td>
<td>373 BCF</td>
<td>NONE</td>
</tr>
<tr>
<td>VALDIVIA</td>
<td>CHILE</td>
<td>OROcline</td>
<td>ANTICLINE</td>
<td>5,584</td>
<td>1972</td>
<td>NO DATA</td>
<td>NONE</td>
<td></td>
</tr>
</tbody>
</table>

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**FIGURE 2.**

![Map of South America showing commercial basins](image-url)

**PACIFIC COAST FIELD DATA**

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**FIELD**

- **OFFSHORE**
- **PARTLY OFFSHORE**

**COUNTRY**

- **PERU**
- **ECUADOR**
- **CHILE**

**AGE/ROCK**

- **EOCENE**
- **OROcline**

**TECTONIC ENVIRONMENT**

- **CONTENZAL ARC - TRENCH**
- **MOSAIC OF FAULT ROCKS**
- **ANTICLINE**

**TRAP TYPE**

- **MOSAIC OF FAULT ROCKS**
- **ANTICLINE**

**DEPT H (FEET)**

- **2,600 - 8,700**
- **2,300 - 4,000**
- **9,000 - 14,000**
- **5,584**

**YEAR DISCOVERED**

- **1966**
- **1913**
- **1920**
- **1972**

**ULTIMATE RECOVERY**

- **1,200 (MMBO)**
- **115 (MM3BO)**
- **145 BCF**
- **NO DATA**

**CUMM. PROD. TO 1981**

- **1,052 (MMBO)**
- **115 (MM3BO)**
- **373 BCF**
- **NONE**

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Lithology of source areas are reflected in numerous published geologic maps. Gansser (1973) published several representative maps from the western Cordilleras. In detail, a great variety of lithologies are present in individual fields. Most lithologies present are capable of forming sands. Yarbrough (1977) stated that arc-trench basins may lack reservoir sands and that clastics derived from andesites, basalts, pyroclastics and metamorphics generally have poor permeabilities. While this is partially true, it does not mean that the lithologies will not form sands. They can form productive reservoirs. In a study of southeastern Japanese oil and gas fields, individual reservoirs greater than 6 million barrels of oil equivalent gas, sixteen fields were found to be producing from turbiditic sandstones, andesite and tuffaceous tuffs, breccias and agglomerates (Katahira et al., 1976). The relative lack of sandstone in some Pacific coastal basins cannot be strictly attributed to source area lithology.

If the physiographic and spatial relationships of source and basin are not controlling factors over basin fill, then what is? Before this question can be properly answered, it is well to consider what the writer believes is a misconception concerning the origin of the abundant Palaeogene - Eocene sandstones in the productive Talara-Santa Elena basins of Peru-Ecuador (fig. 3). These sands are usually attributed a "west-flowing Amazon River." Fantasy River theory states that during the early Tertiary the Amazon River flowed west. It united with other rivers of the Subandean province and flowed through a gap in the Andes in northern Peru or southern Ecuador and debouched into the Pacific from a delta built up in the Gulf of Guayaquil (Weeks, 1947 p. 122; Williams, 1949 p. 19; Worsley, 1954 p. 180; Hill, 1957 p. 31; Harrington, 1963 p. 180; Campbell, 1972 p. 285; Kulm et al., 1981 p. 501).

Evidence supporting a west-flowing Amazon and portal includes: 1) a river course that follows an east-west megashear, 2) an Oligocene "marine transgression" from the west into eastern Peru and, 3) large sediment influx into the Atlantic Foz do Amazon basin in the late Miocene-early Pliocene.

Megasearch. A morphothetic map of northwestern South America shows the orientation of the megasearch. 1) Shepard and Moberly (1961) point out that westward flowing in the Amazon basin have encountered different basement on respective sides of the Amazonas shear, and it is at this shear that the trend of the Andes changes from southeast-northwest to southwest-northeast. Andean modeling is about 2000 ft. (1000 m) lower between the Amazonas and Tumbes shears. Assal plains of the westward and align with the Amazonas shear. These observations suggest old lines of stress or weakness which could be favored by a west-flowing river. Perhaps the area between the shears was a west-dipping graben into which thalid drainage flowed.

Upon closer inspection, the evidence for these shears is not as strong as initially appears. First, there is no evidence that the megasearch exits west of the Andes. Although Paleozoic or older in age, their role as a conduit is tectonic in nature and is related to regional structural trends from Cuzco to Oligocene plate reconstructions (Fanning et al. 1980). There also is no change in Amazon Basin stratigraphy.
trend at the Tumbes shear. The elevation of the Andes is not appreciably lower in the area between the megashears than in other areas to the north (e.g., Quito, Ecuador to Pasto, Colombia). As previously discussed in the section on source area relief, the Andean trend as a whole is lower north of central Peru. This is not an anomaly, merely a general trend. In fact, there are two peaks either directly on the megashears or just inside of them that are greater than 17,000 ft. (5183 m) (Bartholomew, 1978). Attempts to trace fold axes across continents can be misleading. Gilliland (1962) found a remarkable alignment of basin deeps, sedimentation patterns, an interruption of a major magnetic anomaly, and inflection of structural trends along a line from the Mendocino Fracture Zone offshore northern California, eastward along the 40th parallel into Pennsylvania. Initially he concluded megashear influence. After the introduction of plate theory he changed his mind, concluding the alignments were coincidental (Gilliland pers. comm., 1972).

**Andean Portal.** The only evidence for an Andean portal through which a west-flowing Amazon could reach the Pacific is found in a possible Oligocene marine transgression from western to eastern Peru (fig. 5). This transgression is represented by the Pozo Formation, a limy black shale intercalated with the continental “red beds” of eastern Peru (Williams, 1949).

Based upon physical appearances, Hosmer (1959) dated the Pozo as middle to late Oligocene, correlative with the marine shale of the Heath formation of western Peru and Ecuador. Using fossils, Williams (1949) dated the Pozo as early Oligocene - a more reliable date.

If the Pozo is not late Oligocene as Hosmer suggests, but early Oligocene as the paleontology indicates, then it does not correlate with the black marine Heath shale to the west but with the Mancora sandstone and conglomerate instead, a most unusual geographical distribution of grain sizes considering that the sediment is supposedly supplied from the east by the Amazon River.

The origin of the Pozo as a marine deposit is even questionable. Recent work by PETROPERU, presumably with access to more complete data than was available in the late 1940’s, has designated a lacustrine origin for the Pozo (Rivero et al, 1974).

**OLIGOCENE ANDEAN PORTAL & MARINE TRANSGRESSION**

A record of global sea level fluctuations for the Paleogene indicates early Oligocene sea level was low relative to the late Eocene and late Paleocene (fig. 6). Late Oligocene sea level was lower than the Paleocene maximum, and about the same as the Eocene maximum, yet no transgressions into eastern Peru were reported for the Eocene or Paleocene. Paleogeographic reconstructions suggest a substantial ancestral Andean barrier between east and west Peru, one requiring significant subsidence to breach (Hosmer, 1959). Even if these problems associated with the Pozo are resolved, and a stronger case can be made for an Oligocene portal, its existence in the Oligocene is irrelevant to the deposition of Paleocene and Eocene sands in the Talara-Santa Elena basins.

Other information is relevant to the Amazon Theory. A summary of Paleogene grain size relationships in the Subandean province by Hosmer (1959) states that “grain size is progressively finer to the east, away from the Andean front, and fine grained mudstone and siltstone are dominant in the central part of the basin. Farther to the east, grain size increases as the Brazilian Shield is approached.” This suggests a dual source for Subandean sediment. Furthermore,
I am unaware of a fluvial-deltaic sand body clearly traceable across the Subandean province and along the proposed course of a west-flowing Amazon to the location of the postulated portal. If such a body exists, a map of it is not in the readily available published literature usually cited regarding this subject.

**POZO FM. RELATIVE TO SEA LEVEL CHANGES**

![Graph showing sea level changes with time]

Finally, the large influx of clastics into the Atlantic Ocean during the early Pliocene does not appear to be due to a "reverse flow" of the Amazon. Clastic sediment was being deposited in the Atlantic throughout the Tertiary (Ojeda, 1982). The large Pliocene influx is the result of the origin of the modern Amazon drainage system during the late Miocene. The Amazon River system is relatively young. In part its drainage net reflects post-Miocene continental physiography, not a simple flow reversal of a pre-existing, west-dipping river trunk. Prior to the Amazon's recent development, continental drainage was accomplished by numerous river systems from the shields and the ancestral Andes mountains. Some rivers drained east, others west. This view is compatible with the grain size trends discussed earlier.

Missing from those studies that attribute Talara - Santa Elena sandstones to a west-flowing Amazon, are references to petrological data, as well as the paleotectonic setting of the region. The petrology and early Tertiary tectonic history of the basins are discussed here.

**Petrology.** Travis (1953), described the Paleocene-Eocene sediments of the Talara basin as being of "orogenic derivation," and consisting of micaceous shales, feldspathic sands and a few pebble conglomerates. Sorting is moderate. Grains are subangular. Dorreen (1951) described large clasts from an Eocene rubble bed. The clasts were found to be 60% quartz, 30% Andean pebbles of andesite, porphyries, and basic igneous rocks, and 10% Amotape pebbles of dark quartzites and black argillites. In their discussion of the oldest Tertiary rocks in the Talara basin, Liddings and Olsson (1928) implied that the Amotape Mountains may have been a source when they stated "...the Tertiary shoreline was finally established along the present base of the Amotape Mountains and the main Andean trend." A more recent study states that the Paleocene-Eocene rocks were derived from the Amotape Mountains (Feininger et al, 1980). In the Talara basin at least, the available data indicates an Amotape-Andean source rather than a west-flowing Amazon River derivation.

In the Santa Elena basin approximately 100 miles (161 km) north of the Talara basin (fig. 2), a stratigraphic section very similar to that of Talara is present (Marchant, 1961). In a detailed study of Santa Elena outcrops, well data, and 500 thin sections, Small (1962) found that the mineral composition of these rocks is essentially identical to the mineral composition of the metamorphic rocks comprising the Amotape Mountains. He also found that the directional properties of these rocks indicate a south-southeast derivation.

Disregarding the obvious correlation between Santa Elena, Talara, and the Amotape-Andes mountains, Small (1962) postulated that the Amotape-Andes was not the source for the Santa Elena Paleocene-Eocene. Locked into the tectonic-sedimentary analytic approach, he needed a closer source in order to explain the textual and mineralogical immaturity of the deposits. He concluded that the deposits were derived from "a rapidly rising landmass..." that, "lay to the southeast..." where, "streams eroded a terrain of high relief, dumped the load into the adjacent rapidly subsiding basin before much weathering, rounding or sorting occurred." He named this landmass "Amotapia." The name is appropriate, the landmass is not.

There is no evidence that a high relief landmass existed where Small suggested (eastern Gulf of Guayaquil). It seems unlikely such a landmass could have been totally eroded, especially while coeval and adjacent mountains are still present. Although I disagree with Small's interpretation, his basic petrological data is excellent. I reinterpret these data to indicate that the Paleocene-Eocene sediments of Santa Elena were derived from the same source as those of the Talara basin - the Amotape and ancestral Andes mountains. This interpretation is further supported when the unusual tectonic history of the region is considered.

**Tectonics.** The Talara basin is underlain by Paleozoic metamorphic, plutonic, and volcanic basement rocks - continental crust (Amotape Fm.). Overlying the basement are Cretaceous carbonates, marine shales, sandstones and volcaniclastics. The section is marked by several unconformities. The Tertiary section is comprised of Paleocene-Eocene shallow water marine sandstones and shales - shelf deposits.

In contrast to Talara, the basement rocks at Santa Elena are comprised of nonmetamorphosed diabase, basalt (often pillowved), basaltic agglomerate and tuff - oceanic crust (Pinon Fm.). This ocean crust is overlain by a thick sequence of Cretaceous deep water volcaniclastics, graywackes, and cherts - a eugeosynclinal island-arc association (Cayo, Guayaquil Fms.). These rocks are in turn followed by...
anomalous shallow water marine sandstones and shaleshelf deposits (Azucar and Ancon Groups).

A boundary between the continental crust of the South American plate, and the oceanic crust of a pre-Nazca plate is postulated for the area between Talara and Santa Elena. The precise nature of the boundary is speculative. Lonsdale (1978) concluded it is accretionary. Feininger et al (1980) make a case for transform faulting, and Shepard et al (1981) utilize a combination of accretion and shearing.

The presence of a plate boundary suggests a submarine gradient between the relatively buoyant and high standing South American plate, and the adjacent deep ocean floor to the north. Feininger et al (1980) noted that this gradient created an unstable shelf-edge. Upper Eocene tectonic movements resulting from subduction beneath the South American plate caused the Talara basin at shelf-edge to fail. Thousands of kilometers of sediment and rock were swept northward in a series of vast submarine gravity slides that came to rest on the oceanic plate at Santa Elena (fig. 7).

supported by the stratigraphic similarity of the Talara and Santa Elena Paleocene-Eocene sections, and by crude oil correlation studies (Feininger et al, 1980). The idea of allochthonous deposition at Santa Elena was first suggested by Brown (1938) and followed with detailed mapping of the allochthonous complexes by Coleman (1970). Slide plates have also been mapped in the subsurface at Talara oil fields (fig. 8).

Allochthon deposition explains why shallow water shelf deposits, sourced from the Amotape and Andes mountains, are found so far to the north of their depositional site, sitting on deep water eugeosynclinal volcaniclastics and oceanic crust at Santa Elena.

The Amazon River Theory has some additional flaws not addressed in the literature. How could a delta have been building out into the Gulf of Guayaquil at the Tumbes Megashear, and yet leave no stratigraphic record? As previously discussed, the Paleocene-Eocene rocks in that portion of the Gulf are allochthonous. Petrologic studies clearly indicate younger overlying rocks were derived from the western Andes and foothills (Small, 1962).

Perhaps the delta and portal were located at the Amazonas shear about 200 miles (320 km) to the south. Evidence is much stronger for the Amazonas than for the Tumbes, and the present-day Maranon River flows along its trend. In this case the delta should be reflected in the stratigraphic record at Sechura. For all practical purposes, none of the Paleocene-Eocene sandstones at Talara are present onshore at Sechura. The area has been tested with 28 wells (Travis et al, 1974).

The idea that a delta could have existed at the Amazonas shear, only to be destroyed and its sediment transported northward by coastal currents, is also unlikely. The only current available for such work is the Peru current - one of the ocean's weakest currents from a sediment transport perspective.

If the Amazon River - Portal Theory cannot explain the stratigraphic record at Talara and Santa Elena, what is the origin of the sediments?

This is the end of Part I of this paper. Part II will appear in the December Bulletin.