Petroleum Systems of Western South America Assessed from Oil Geochemistry and Basin Redefinitions

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The Sub-Andean basins of South America are among the most prolific oil-producing areas of the world. From western Venezuela to southern Argentina there are no fewer than sixteen separate oil productive basins which lie directly east of the Andes. Production is from formations ranging in age from Devonian to Tertiary and recoverable oil to date exceeds 80 billion barrels, of which approximately 50 billion barrels have already been produced. The sedimentary basins of South America that occur around the PreCambrian Guyana and Brazilian shield areas, along the Andean mountain chain, and offshore on the continental margins contain sedimentary rocks ranging from Paleozoic to Cenozoic age. These basins are described by their relationship to the Mesozoic Andean volcanic arc as forearc Coastal basins and backarc Sub-Andean and Intermontane basins.

The forearc basins are located on the oceanward side of the volcanic arc (Santa Elena and Coastal basins) and contain sediments that consist of shales and carbonates that are sometimes interbedded with volcanics. The backarc basins are relatively small borderland basins located on the cratonic side of the volcanic arc and commonly contain prograding wedges of Mesozoic and/or Cenozoic clastics, carbonate platform rocks, and abundant organic material. Many of the Sub-Andean basins (e.g., Llanos, Putumayo, Oriente, and Maranon basins) represent Mesozoic backarc settings that became foredeep in the Tertiary. Other Sub-Andean basins (e.g., Cuyo basin) have had a rift origin and were influenced by backarc sedimentation in the late Mesozoic, and later became foredeeps in their western parts. Intermontane basins (e.g., Maracaibo and Middle and Upper Magdalena basins) have had a Mesozoic backarc history but became separated from their Sub-Andean counterparts to the east by the Tertiary uplift of the Eastern Cordillera (e.g., Maracaibo/Barinas).

The foreland basins along the foothills of Sub-Andean Belt form a complex system of depositional troughs separated by transverse arches that share a similar geologic evolution but have a varied stratigraphic depositional history. The bulk of sedimentary fill is mainly Cretaceous and Cenozoic; however, Paleozoic sediments particularly south of the FitzCarrald Arch are important source and reservoir rocks. The structural framework, limits of the main depositional units and the Cretaceous basins boundaries are shown in Figures 1a, 1b and 1c, respectively. Stratigraphic correlations are provided in Figure 2. See Urien, 2001 (AAPG Memoir 74, p. 373-402) and references therein for more detailed descriptions of stratigraphy and structural elements.

In order to understand the petroleum systems active in the Sub-Andean basins, geochemical data of oils are interpreted in such a way that oil/oil correlations are made, and source rock inferences are proposed. This is possible since the geochemical characteristics of oil reveal information on source age and paleoenvironmental conditions of deposition. Similarities and/or differences in the geochemistry of crude oils relate to common or dissimilar source strata and have implications with regard to tectonic episodes that control source rock depositional environments. The Sub-Andean regional petroleum systems were evaluated by first determining the number of effective source units within a region by establishing the number of compositionally distinct oil families through the use of multivariate statistics. The chemical attributes of these oil families can also be used to determine the stratigraphic and aerial distribution of the source(s), source age, lithology, organic input, thermal maturity and depositional environment (Figure 3). This is possible because crude oils are the compositional derivatives of their source(s) and as such they carry important biological information about the source character and thermal history. For example, sterane distributions and stable carbon isotopic compositions for oils derived primarily from marine shales vary through time and often as a function of lithology and depositional environment. Consequently, differences can be used to distinguish Cretaceous sourced oils from those derived from older (Pre-Cretaceous) sequences (Figure 4). Through the use of a multi-parameter approach, additional data such as carbon isotopic compositions can be used to correlate oils from Peru and their likely sources as is demonstrated in Figure 5 and mapped in Figure 6. In this way, oils derived from Middle Cretaceous source rocks (e.g., Chonta, Vivian) can be readily distinguished from oils derived from different age source units such as the Miocene Heath, Jurassic Pucara, Permian Ene and Carboniferous Ambo. Areas of mixed provenance can also be identified.

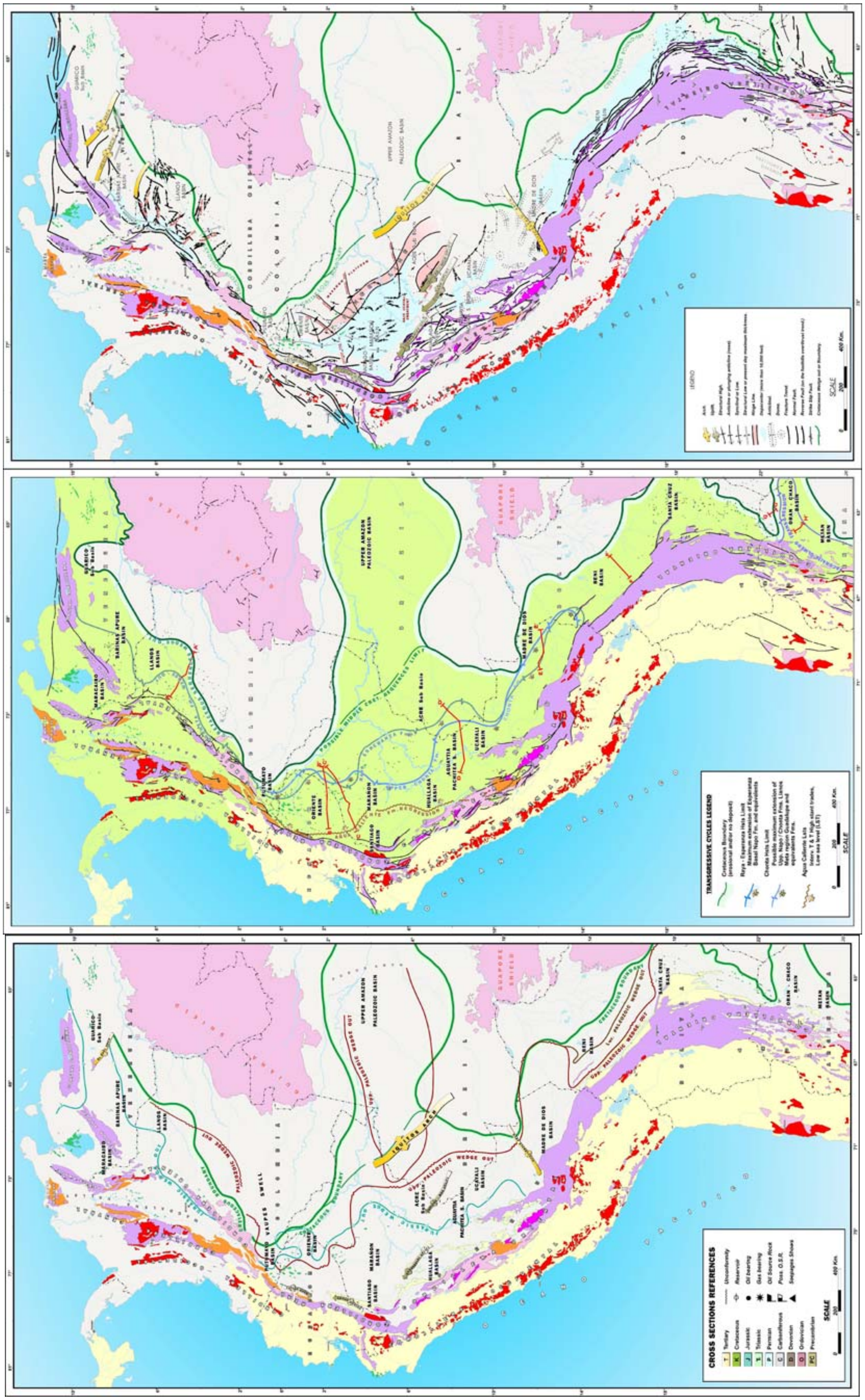

Figure 1. Sub-Andean structural framework (a); limits of main depositional units (b) and Cretaceous Basin boundaries (c).

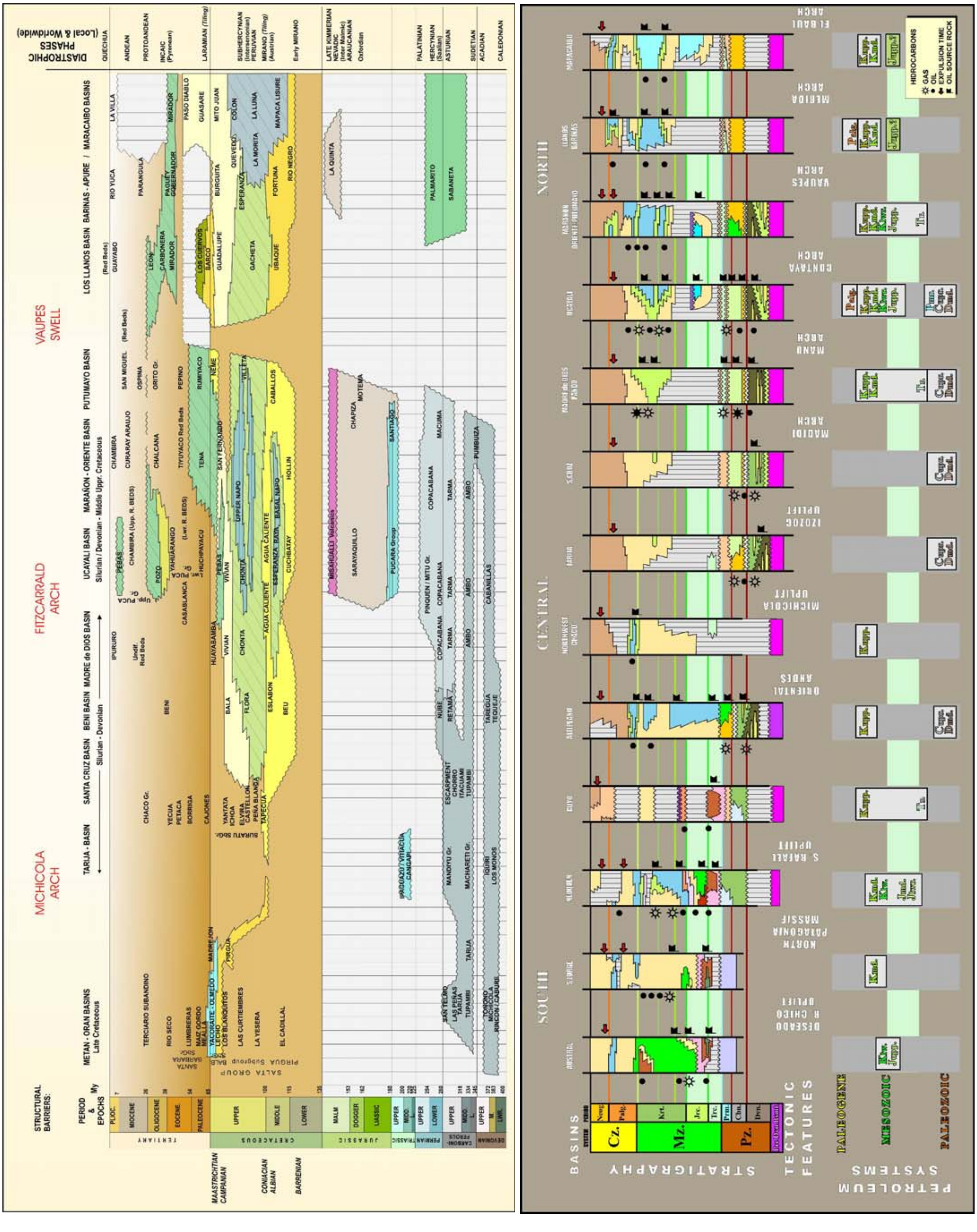

Figure 2. The Sub-Andean stratigraphic correlation chart.

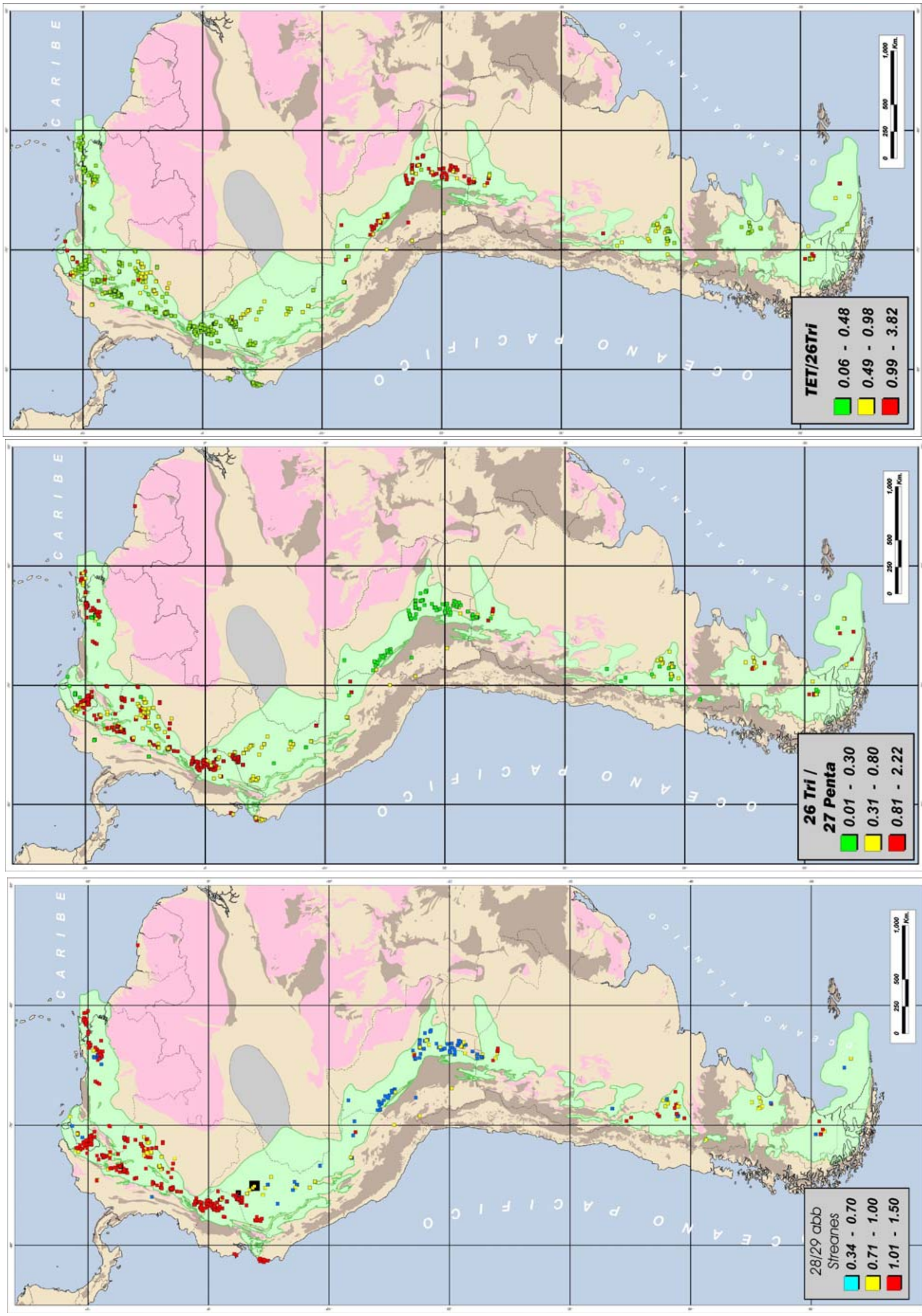

Figure 3. Variation of key biomarker parameters that vary as a function of lithofacies (C_{24} tetracyclic terpane/C_{26} tricyclic terpanes; values increase with increasing clastic input), anoxic conditions. (C_{26} tricyclic/C_{27} pentacyclic terpanes; values increase with anoxicity), and source age (C_{28}/C_{29} αββ sterane ratio; for oils derived from marine shales, values typically decrease with source age).

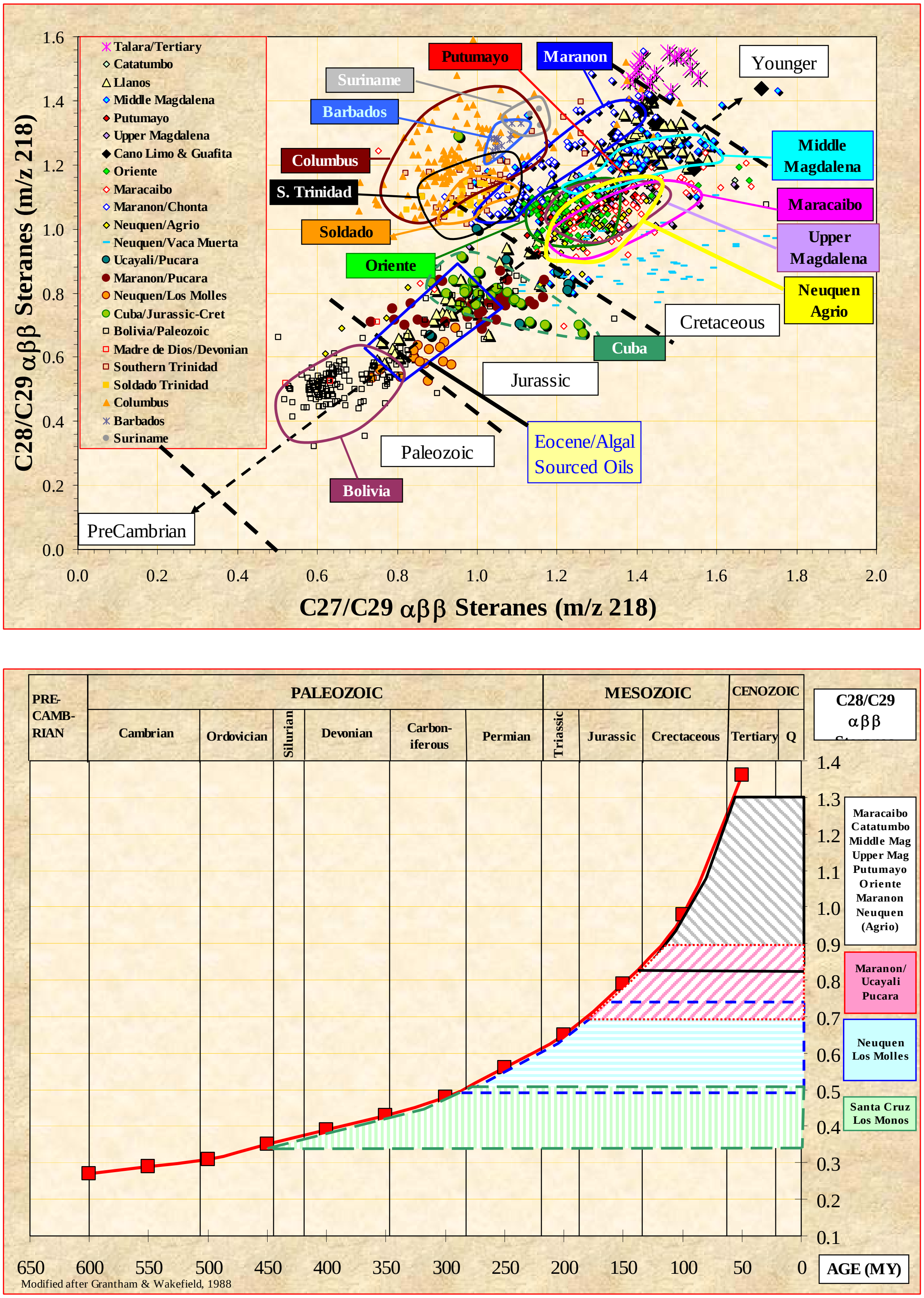

Figure 4. Variations of sterane αββ sterane compositions of Sub-Andean oils as a function of source age (mainly applicable for oils derived from marine shales).

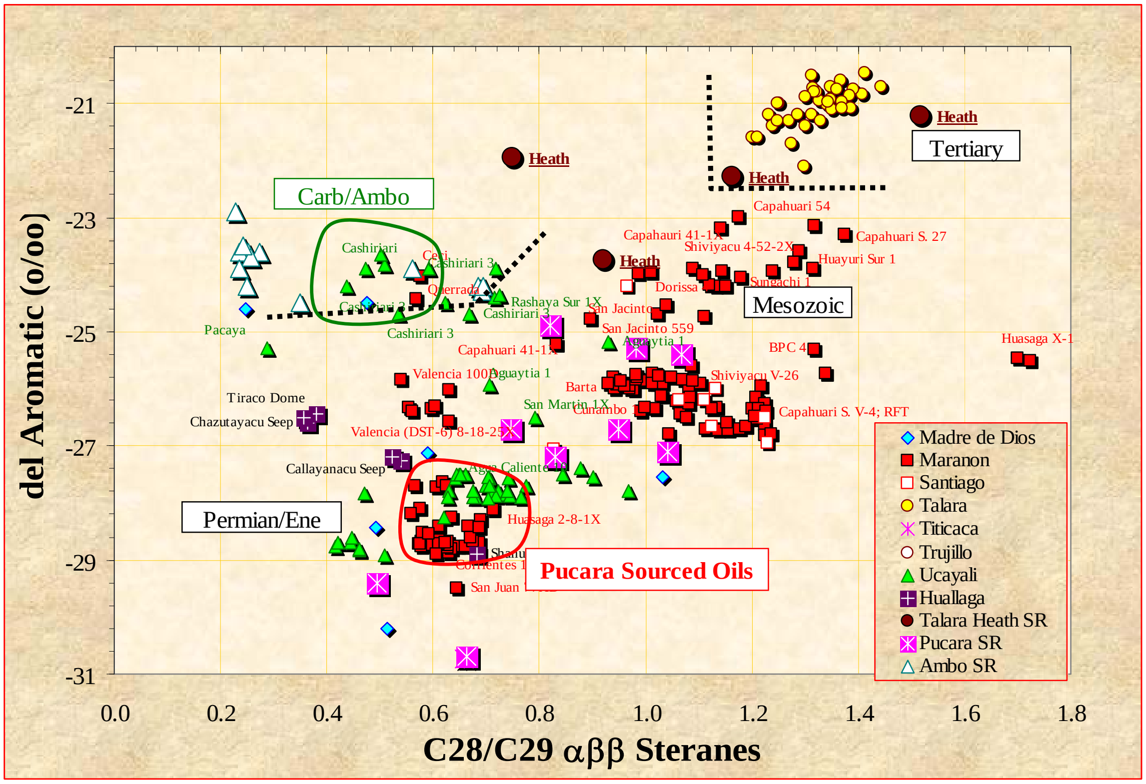

Figure 5. Variations of αββ sterane (m/z 218) and isotopic compositions of Peruvian oils and representative source rocks (Schiefelbein, et al., 2008; INGEPET, Lima Peru).

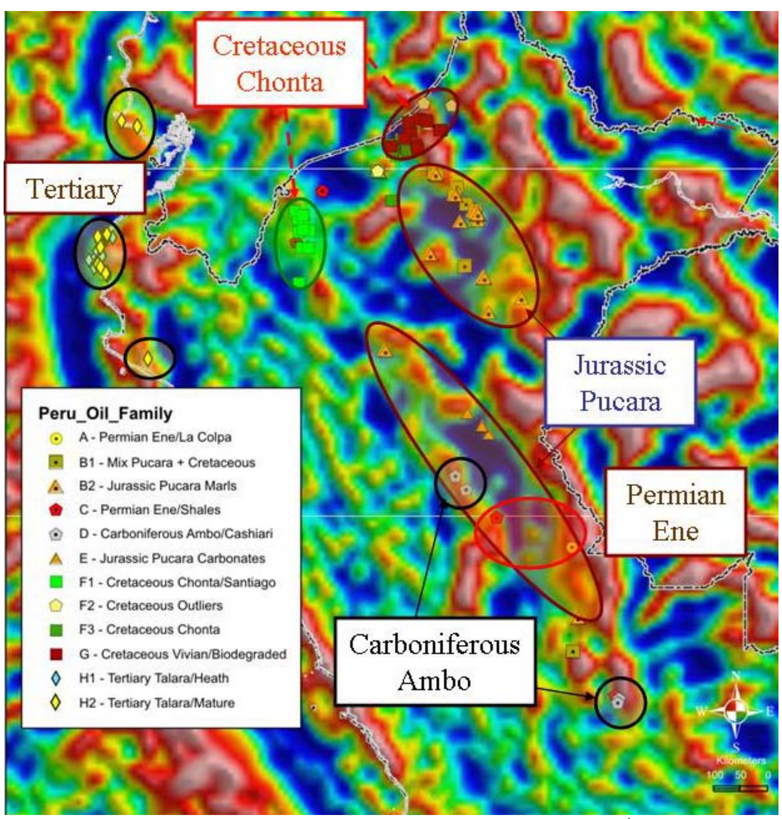

Figure 6. Distribution of Peruvian Oil Families on Gravity 1st vertical derivative.

More than 2000 oils from onshore and offshore South America were statistically evaluated using twenty source-dependent geochemical parameter. Results (Figures 7 and 8) are used to distinguish twelve different oil groups or types several of which mainly occur only in Brazil, Bolivia and/or Argentina (Figure 9). These include oils derived from source rocks deposited in hypersaline/transitional (J) and lacustrine (G, I, L2) environments as well as oils derived from Paleozoic (K) and Tertiary (L1) source rocks. Interestingly, lacustrine-derived oils from Reconcavo and several basins from Argentina are correlative and may have a common tectonic history related to early rifting events. Oils from the offshore Great Campos area have unique chemistries associated with an origin from lacustrine source rocks deposited in a brackish/saline environment related to Syn-rift II. Another unique set of oils distinguished by heavy carbon isotopes and abundant oleanane occur offshore Peru in the Talara basin.

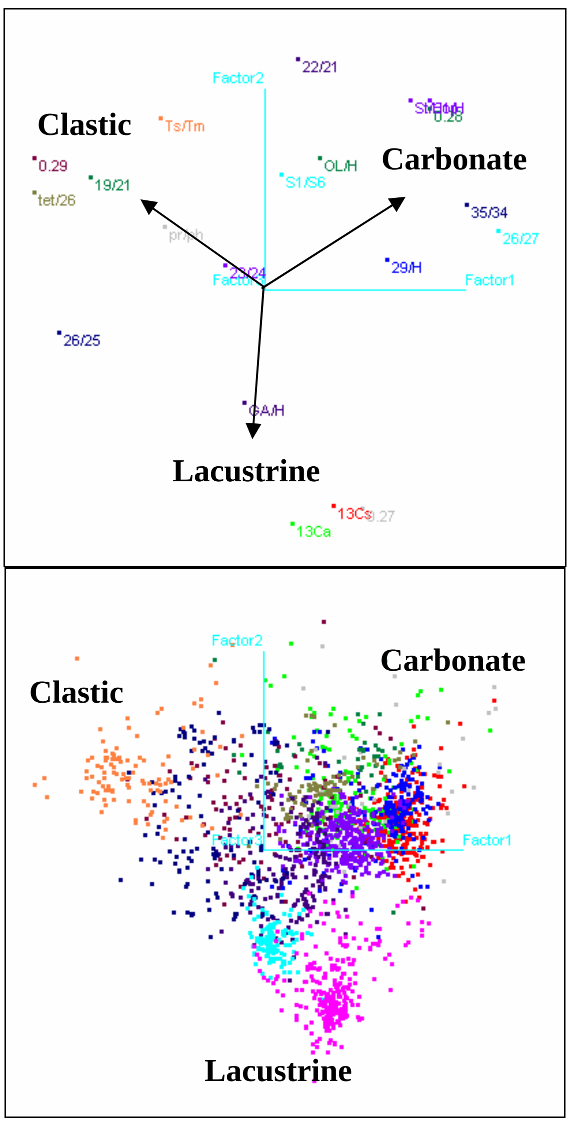

Figure 7. PCA loadings (top) and scores plots.

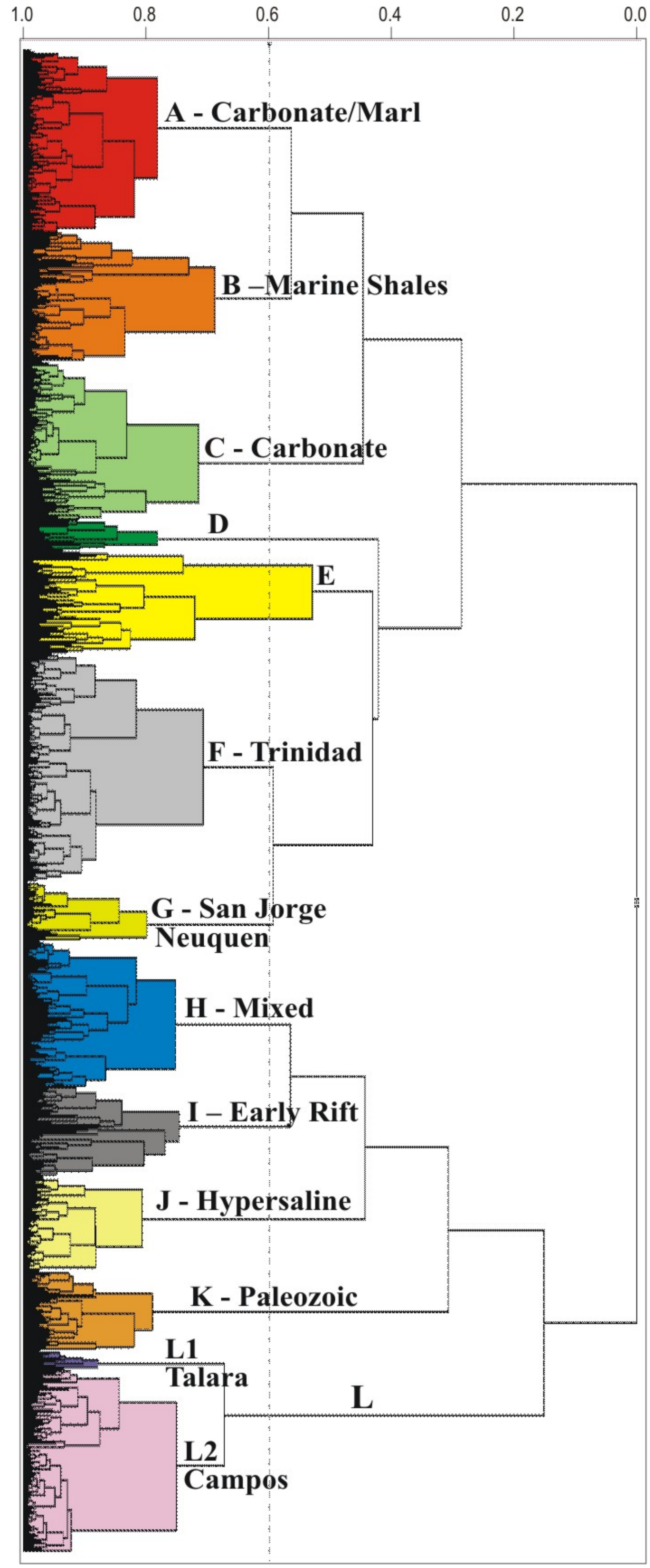

Figure 8. Cluster analysis dendrogram.

Figure 9. Oil types based on statistical evaluation of all South America Oils.

Based on the compilation, statistical analyses and visual comparison of literature and laboratory geochemical data pertaining to oils from Western South America (excluding Brazil), several different oil types are recognized in the Sub-Andean basins (Figure 10). These vary according to source age (Cenozoic, Mesozoic, & Paleozoic), depositional environment (marine, coastal, lagoonal, continental etc.) and/or lithofacies (carbonate, marls, shales, etc.). Oils of mixed provenance can also be identified. According to the distribution of these different oil types, source age increases from north to south (Figure 11).

Recognizing that the vast majority of hydrocarbons discovered to date in the northern Sub-Andean basins (Maracaibo, Oriente, Maranon, etc.) originated from prolific oil-prone Cretaceous source rocks (La Luna and age equivalents), it is also important to determine whether other younger and/or older sequences have contributed to reserves. Based on the available information, both in terms of data and sample coverage, Pre-Cretaceous oils can be confidently identified in several areas, including central/southern Peru (Maranon, Ucayali, Madre de Dios), Bolivia (Devonian) and Argentina. In this manner, and with support from ancillary data, important Jurassic source units have been identified in the Marañon and Ucayali (Pucara group) basins of Peru and the Neuquen (Vaca Muerta, Los Molles) and Austral (Springhill) basins of Argentina. To date, although Jurassic source units may be present in Colombia (Cano Limon area?) and Venezuela (Espino Graben area?), no direct evidence is available (to this study) to confirm their activity as a source of significant hydrocarbon accumulations.

In Argentina, the statistical results can be used to distinguish oils derived from different source rocks deposited in variable lacustrine and restricted marine environments that are active in the Cuyo (Cacheuta), Neuquén (Puesto Kauffman, Los Molles), San Jorge (D129) and Austral (Springhill, Tobifera) basins. Marine-derived oils from the Neuquén Basin can be easily differentiated according to source age and/or facies; oils in the Mendoza area originated from Lower Cretaceous Agrio source rocks and oils from the southern part of the basin originated from different source facies of the Upper Jurassic Vaca Muerta Formation.

Ongoing work includes mapping of different oil types or families together with gravity and magnetic data in an attempt to ascertain tectonic relationships among the different and varied oil-bearing source compartments. The combination of this detailed multi-disciplinary information can be used to improve the definition and limits of the main Paleozoic-Mesozoic-Cenozoic geologic settings.

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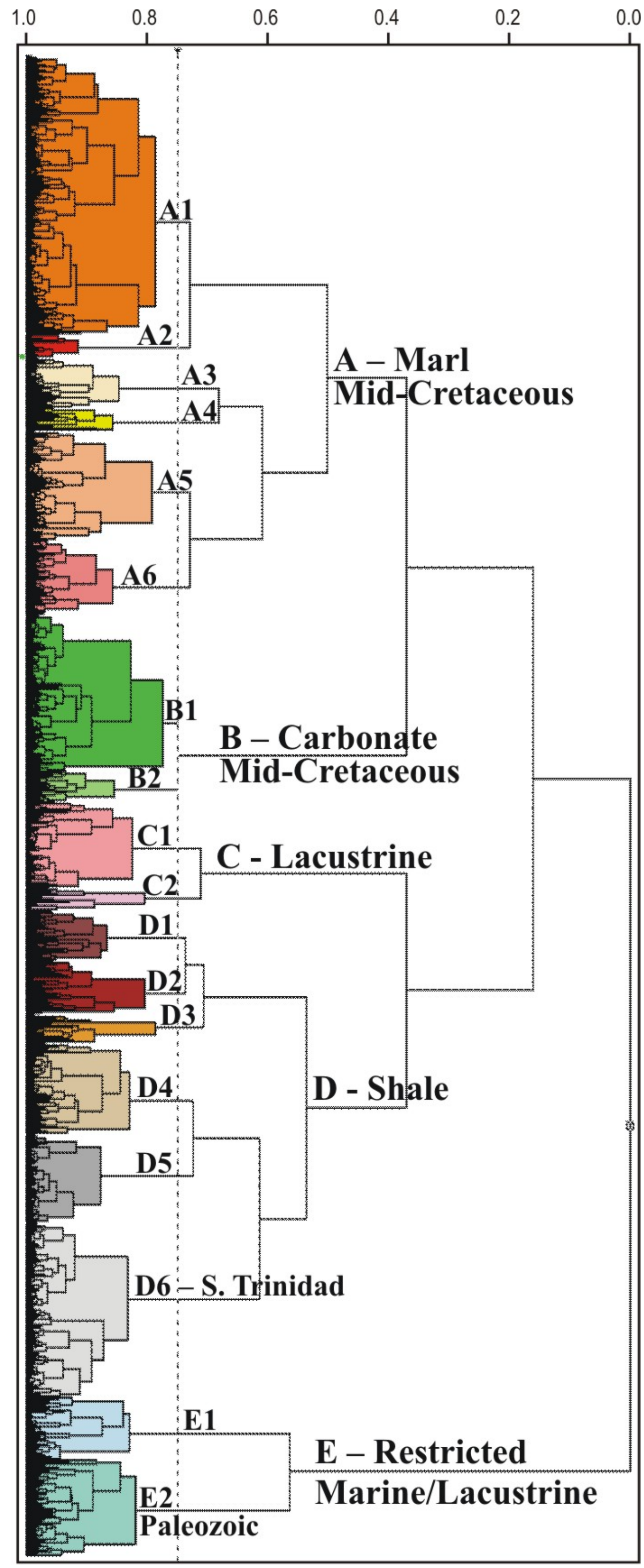

Figure 10. Hierarchal cluster analysis dendrogram: Sub-Andean Oil Families.

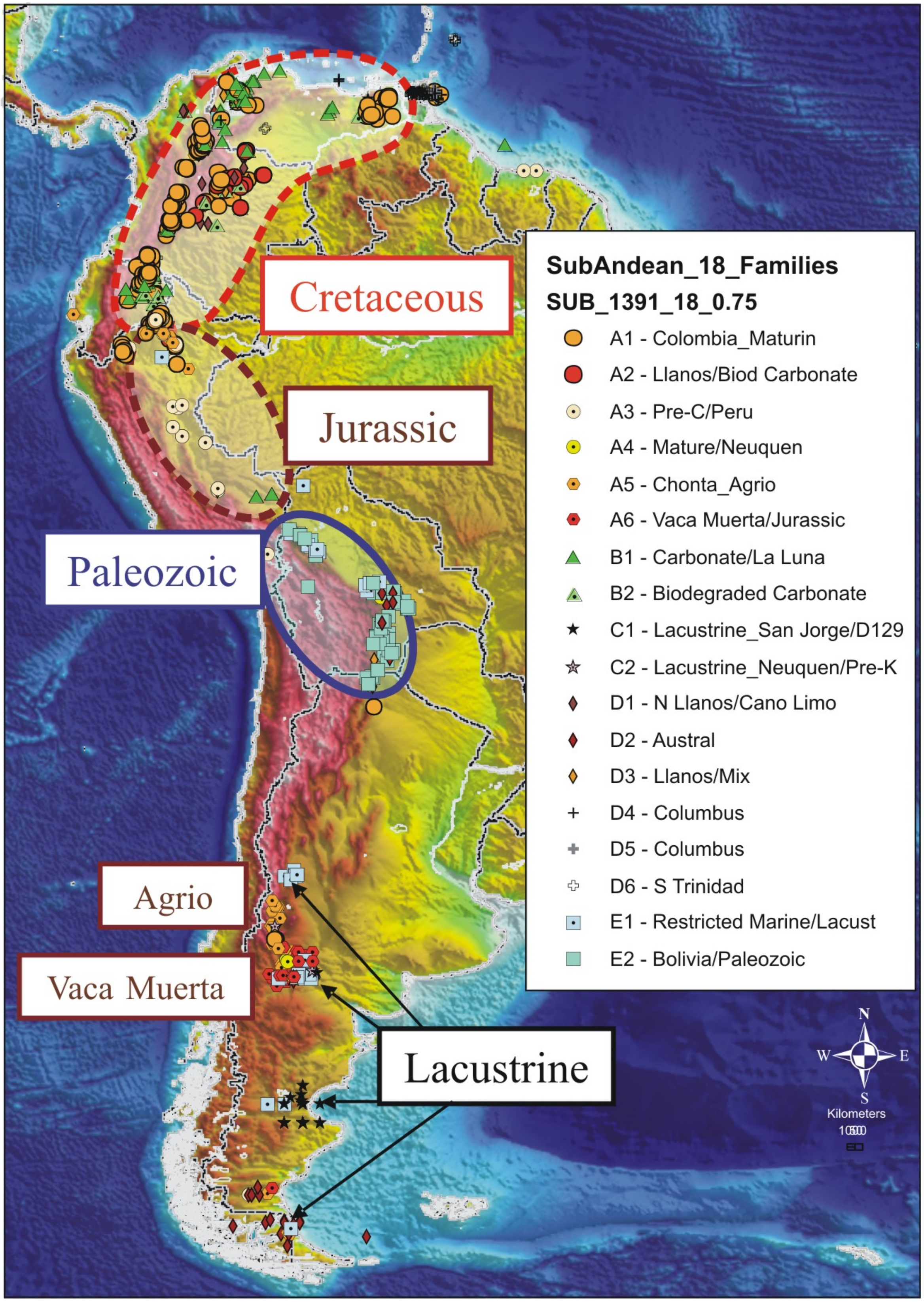

Figure 11. Distribution of Sub-Andean Oil Families.