# STRUCTURAL STYLES IN THE SANTIAGO FOLD AND THRUST BELT, PERU :A SALT RELATED OROGENIC BELT

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## RESUMEN

Inestabilidades gravitacionales, inmediatamente después de la depositación de evaporitas, inició los primeros movimientos de sal en la faja plegada del Santiago. Estos movimientos y el desplazamiento lateral de la sal está manifestado en los cambios bruscos de espesores de las secuencias posteriores a la deposición de sal. Este estilo de deformación fué interrumpido durante las fases Quechua de la Orogenia Andina, la cual se caracterizó por deformación de escamas en la cual la sal jugó un papel muy importante como nivel de despegue. Los pliegues y las fallas no tienen una vergencia preferida y la intrusión de diapiros de sal ha dado como resultado la formación de estructuras periclinales. Análisis de huellas de fisión en apatita ha confirmado una edad de 10 Ma para el fallamiento y plegamiento de esta cadena.

## GEOLOGICAL SETTING OF THE SUBANDEAN FOLD AND THRUST BELT (SFTB)

The Subandean Fold and Thrust Belt, adjacent to the Marañon Foreland Basin, is a zone of mainly easterly verging steep to shallow reverse faults and asymmetric folds developed from Late Cretaceous (Peruvian phase) to Pliocene (Quechua-3) phases of the Andean Orogeny (Megard, 1984). The evolution of this FTB is linked in space and time to the presence and interaction of the arc-trench system. Along strike variations in the styles of deformation and width, however, are mainly controlled by the facies, anisotropy and thickness of the sedimentary wedge rather than by the angle of subduction (Jordan et al, 1983). Present day tectonic activity in this belt is documented by tilting of fluvial terraces and by a large number of earthquakes (Suarez et al, 1983).

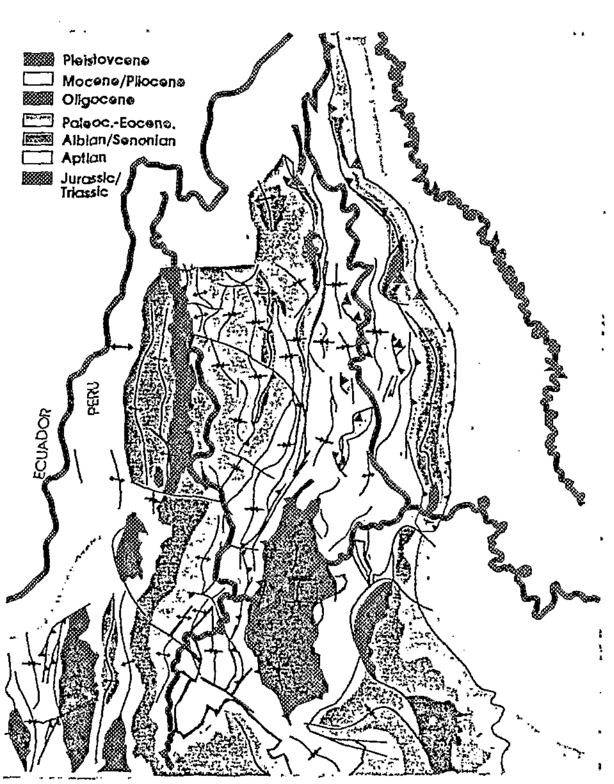


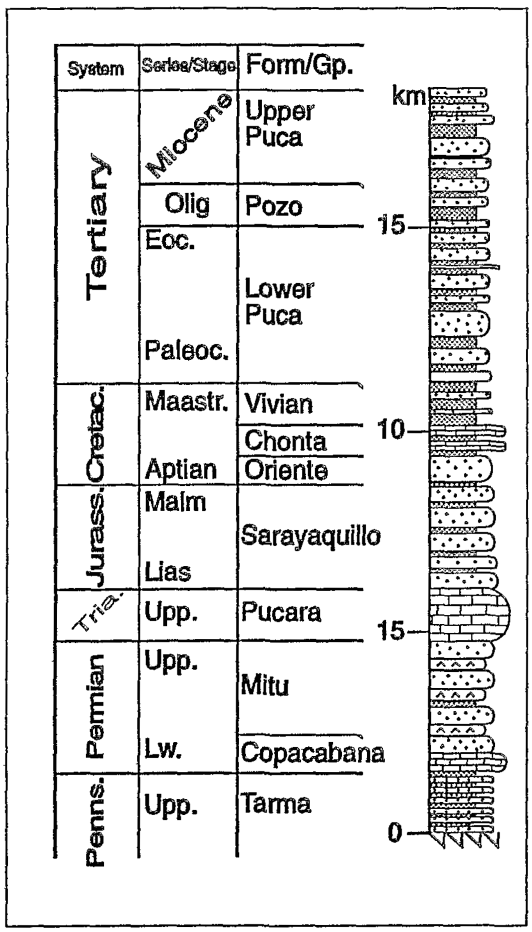
FIG. 1 Geological Map of the Santiago Basin.

The hinterland, known as the Marañon Geanticline (Benavides, 1956), is made up of Precambrian to Late Paleozoic rocks. This structural element was always positive during Cenozoic deformation and often was a submerged high during Mesozoic sedimentation. The SFTB is made up of Mesozoic and Cenozoic clastic and carbonate sequences with folds and faults subparallel to the arc. The Marañon Foreland Basin is a west dipping monocline in which Pre-Cretaceous rocks have been truncated following moderate tilting during the Late Jurassic (Araucanian) movements. This basin consists of up to seven kilometers of Mesozoic and Cenozoic rocks characterized by broad to gentle structures formed during Late Cretaceous to Cenozoic inversion of Jurassic grabens. Intrabasinal highs such as the

Loreto High and the Contamana Hills were active during Cretaceous and Tertiary deposition and are thought to reflect reactivation of pre-existing highs.

## SANTIAGO FTB STRATIGRAPHY.

The rocks outcropping in this orogenic belt range in age from Triassic to Pleistocene, and the presence of Paleozoic rocks as old as Ordovician is suspected in this belt in the subsurface as documented in some foreland wells (Fig. 1 and 2). Two distinctive tectono-stratigraphic sequences are present in the Santiago F.T.B. A pre-orogenic sequence, older than Santonian, is represented by the Triassic to Late Jurassic shallow water limestones and bituminous shales of the Pucará Formation (Rodriguez,1982) which are overlain by the red, varicolored sandstones and shales of the Jurassic Sarayaquillo Formation. Cretaceous sedimentation was initiated in the Aptian with the deposition of cross-bedded sandstones of the Cushabatay Formation and , after several transgressive-regressive pulses, terminated with the Senonian (Santonian ?) shales of the Cachiyacu Formation (fig.2).




The synorogenic sequence in the Santiago FTB began with the Late Cretaceous molasse sandstones and shales of the Huchpayacu Formation, which have not been differentiated in this belt and are probably included in the Lower Tertiary red sandstones and shales of the Lower Puca Formation (Fig.2). A period of relative tectonic quiescence was recorded during the Oligocene with deposition of marine shales, sandstones and tuffs of the Pozo Formation. A new pulse of molasse deposition was triggered in the Miocene with deposition of the Upper Puca Formation which probably continued throughout the Pliocene and Pleistocene with subtle breaks in sedimentation (Neiva and Corrientes Formation). Different pulses of molasse deposition are correlated to known phases of the Andean Orogeny which involved supracrustal thrusting and uplifting of the hinterland.

## AGE AND ROLE OF THE EVAPORITES

Benavides (1968), in his detailed analysis of the Huallaga diapirs, was the first to address the problem of the age of the evaporites in the Sub-Andean Basins of Peru. Because of the poorly defined structural and stratigraphical relationship of the salt source, he concluded that the age of the salt could be either Permian, Triassic and/or Jurassic. However, he did not rule out the possibility of multiple sources for some of the salt domes.

Indeed, the Late Permian red sandstones, shales and conglomerates of the Mitu Group contain significant amounts of gypsum and salt (Newell et al, 1953). The salt in the San Blas dome, in the central Andes, has been assigned to this unit by Benavides (1968). He also described some beds and lenses of gypsum with a maximum thickness of 8 meters in the Mitu Group near to the Pongo the Rentema (about 80 Km west of the Santiago Basin). Further evidence for a Permian and/or Triassic age for the salt is found in the Huallaga Basin where the salt in the Yuramarca dome contains limestones fragments that are interpreted to be from the Triassic/Jurassic Pucara Group. Furthermore, salt flowage in the Pilluana dome has brought up limestones containing *Myophoria pascoensis* of Late Triassic age and an Early Jurassic ammonite *Arietites sp.* (Benavides, 1968).

Rodriguez and Chalco (1975), based on $S^{32}/S^{34}$ ratio in some of the evaporites in the Huallaga Basin, have suggested a Permian age for the salt domes in the Huallaga Basin; unfortunately, they did not elaborate on their analysis. Therefore, the age of the salt in the Santiago and Huallaga FTB is Early Jurassic or older.

Recently, some wells (Loreto-1), drilled on the Marañon Foreland Basin, cored crystalline anhydrite interbedded with red and varicolored sandstones and limestones in the upper part of the Jurassic/Triassic Pucara Formation. Sabkha type limestones and dolomites are found in the Upper Ucayali Basin while Benavides (1968) has described some massive dolomites and limestones of Triassic age which rest upon gypsum beds that appear to be also of the same age in the Utcubamba valley of northern Peru. He also describes the overlying Middle Jurassic (Bajocian) beds near the Yeso locality which contain anhydrite and gypsum correlateing with the gypsiferous Chambará Formation near Tarma, in central Peru (Megard, 1978). In the central Andes, at Morococha, Benavides (1968) also describes a body of 150 meters thick of anhydrite unit with shale and limestone interbeds interpreted to be Middle Jurassic in age.

The Pucará Group is transitionally overlain by the Sarayaquillo Formation of Middle to Late Jurassic age which, in central Peru near La Merced, contains beds of salt near Cerros de la Sal. North of this locality, the Oxapampa-7-1 well contains 1720 meters of clear to white salt and anhydrite below Cretaceous beds and above rhyolites and conglomerates of the Permian Mitu Group. Benavides (1968) interpreted two of these salt intervals to be Jurassic in age. In northern Peru, in the Utcubamba region, the red beds of the Sarayaquillo Formation contain several beds of gypsum, some reaching several tens of meters in thickness (Benavides, 1968).

Although the cores of most salt diapirs in the Huallaga Basin are surrounded by the Sarayaquillo Formation, the age of the salt is still unknown. According to Benavides(1968) the source was a pre-Late Jurassic unit. Distribution of different thicknesses of salt bearing units along the foreland fold and FTB seems to have played a very important role, not only in the in the structural style but also in variations in the width of the S.A.F.T.B. Distribution of the Late Permian Mitu Group was controlled by the preservation of grabens and half-grabens formed during Late Permian extension (Megard, 1978) which has not been recognized in Ecuador. On other hand, the Triassic/Jurassic Pucara Group continues to the north in Ecuador where it is Known as the Santiago Formation. No evaporites have been described in this unit however. The Pucara Group seems to thin out southward near the Sira Mountains. Finally, the Jurassic Sarayaquillo Formation, which reaches significant thickness in northern Peru and southern Ecuador, contains only thin evaporites in the Cutucu Mountains where it is known as the Chapiza Formation (Tschopp, 1953), also thins out southward and disappears near the Sira Mountains.

## STRUCTURAL STYLES OF THE SANTIAGO FTB.

Gravitational instability triggered early salt movement soon after the first evaporite deposition and was manifested by major outward and lateral movement of salt toward the Campanquiz and Huaracayo Ranges. This event is documented by rapid changes in thickness and facies of the post-salt to Pelogene units. Indeed, Late Cretaceous to Paleogene loading by molasse deposition associated with the Peruvian and Incaic phases of the Andean Orogeny in the hinterland have merely enhanced the rate of salt movement, and thus the facies and thickness changes. A pulse of relative tectonic quiescence with little or no salt movement (Pozo Formation deposition) preceded the maximum paroxysm of the Quechua phase (Neogene) of the Andean Orogeny. In the Santiago Basin, this Quechua event has been dated with apatite fission track (AFT) methods and was characterized by thin skinned deformation and the formation of a salt related fold and thrust belt with a relatively moderate amount of shortening.

The Santiago FTB, formed by the complex interaction of gravitational instabilities of salt and compressional forces, is similar to other salt related thrust belts in the world which are characterized by low taper angle (Davis and Engelder, 1985). This orogenic belt consists of a complex in and out-of-sequence fold and thrust belt with low cross-sectional taper angle similar to the Huallaga FTB to the south. The folds are characterized by anticlinal thickening and synclinal thinning of the salt, with faulting dominated by high angle back thrusts and diffuse forward vergent thrusts (Fig.. 3 AND 4). In general, there is a lack of a preferred structural vergence of ramps and folds. Salt domes are often developed near the axis of synclines with common development of rim synclines by either salt withdrawal at the footwall of the listric faults or by normal listric faults formed by reactivation of pre-existing thrust faults. Salt

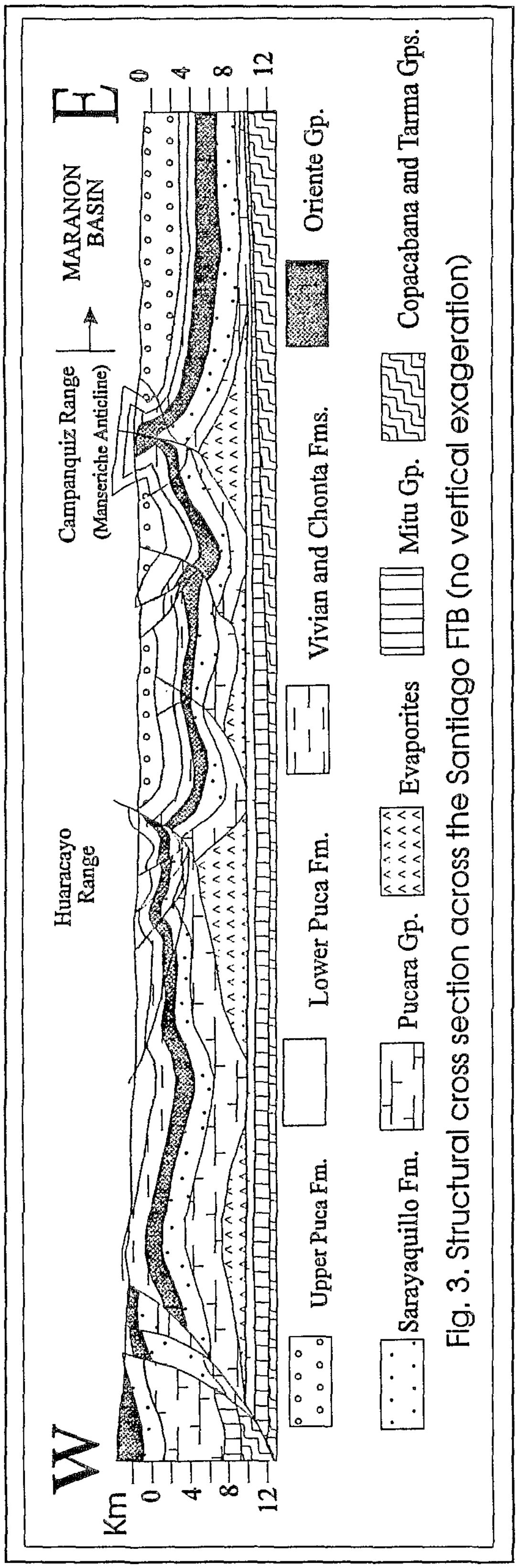


Fig. 3. Structural cross section across the Santiago FTB (no vertical exageration)

piercement accounts for narrow periclinal structures and the enlargement of pre-existing broad synclines. Most of the periclines are pierced by diapiric structures. Significant uplifts of the frontal thrust and in the
adjacent hinterland are related to pronounced salt thickening (Huaracayo and Campamquiz Ranges). The frontal thrust is usually characterized by the development of box-folds, overturned folds, or upright folds above a major salt core. Indeed forward and back thrusting at the mountain front are often propagated in several splays over a paleo high formed by early salt withdrawal.

The main orientation of the folds and thrusts changes from N-NE to NW near the latitude of the Marañon River, similar to changes reported in the Eastern Cordillera (Ham and Herrera, 1963). This oroclinal bending was initiated during Early Createaceous accretion of the Tahuin Terrane to the Peruvian margin and post-Oligocene clockwise and counterclockwise rotations respectively north and south of the Huancabamba deflection (Mitouard et al, 1990, Laj et al, 1992).

## EVOLUTIONARY STAGES OF THE SANTIAGO FTB

The Late Jurassic Araucan Orogeny is poorly defined in Peru and Ecuador and is represented in the S.A.F.T.B. by moderate tilting of the Sarayaquillo/Chapiza formations before the deposition of the Aptian Cushabatay/Hollin Formations. Several sismic lines in the area (Touzett and Sanz, 1985) provide strong evidence for at least Early Cretaceous salt withdrawal with coeval growth and variable sedimentation rates throughout the Late Miocene. The structural depression, along the Santiago River, was formed by pervasive thrusting accompanied by salt diapirism.

The evolution of the Santiago Basin seems to have undergone the following structural/ depositional stages since the Mesozoic.

STAGE I.- Once deposition of evaporite bearing units terminated, sedimentation and tectonic movements caused gravitational instabilities and triggered early movement of the evaporites. Evaporite withdrawal took place during the Araucan Orogeny (Late Jurassic) when the evaporites moved laterally and upward into the cores of the Campanquiz and Huaracayo Ranges. Sediment loading at the center of the basin caused the evaporites to move in a double end toothpaste tube fashion. Cretaceous sedimentation was thicker in the center of the basin (Santiago and Neiva Basins s.s.)

than on the flanks (ranges). This pronounced change in thickness was accompanied by significant changes in facies across the belt.

Sediment loading continued throughout the Paleogene with local intrabasinal salt movement within the Santiago depression as illustrated in the Apingrasa Structure in which some sort of growth faulting is recorded (Touzett and Sans, 1985). High rates of sedimentation associated with Late Cretaceous and Paleogene molasse of the Peruvian (Santonian) and Incaic (Middle Eocene) phases of the Andean Orogeny provided the mechanism for evaporite remobilization.

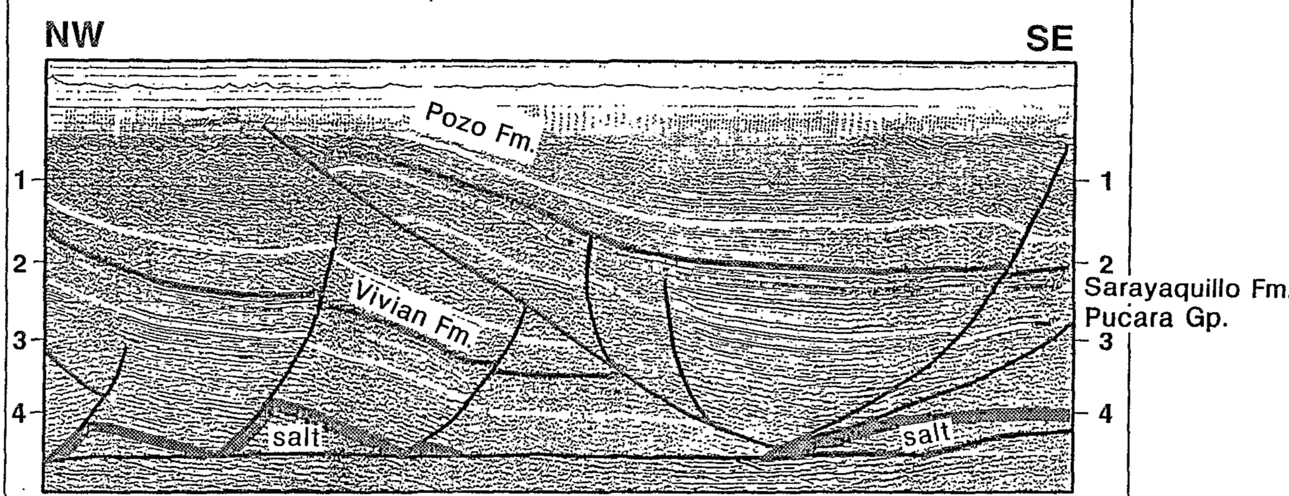



Fig.4

STAGE II.- The Oligocene was a period of tectonic quiescence with little or no salt movement. Sedimentation changed from fluviatile in the Lower Puca Formation to the shallow marine environment in the Pozo Formation (Rodriguez, 1982).

STAGE III.- Reactivation of salt movement during the Early and Middle Miocene was accompanied by a recurrence of the fluviatile Upper Puca Formation. Salt piercement accounted for narrow periclinal anticlines and the enlargement of pre-existing broad synclines.

STAGE IV.- The Late Miocene and Pliocene/Pleistocene movements of the Quechua phase of the Andean Orogeny were the result of horizontal compressional forces which reactived and modified the structural pattern established early in the evolution of the basin. Forward-vergent thrusting was rather diffuse while back thrusts were steeper and more localized. Most of the periclinal anticlines were broken by diapiric structures located above synclinal counterfolds.

## AFT ANALYSIS

Four outcrop samples of Campanian to Aptian age were analyzed for apatite fission tracks with the purpose of obtaining possible constraints on the thermal history, maximum depth of burial, and timing and rate of uplifts and exhumation (Table I). Two samples were from the Campanquiz Range (sample 1 and 2) and the other two were from the Huaracayo Range (samples 3 and 4). The analyses were conducted by Geotrack International.

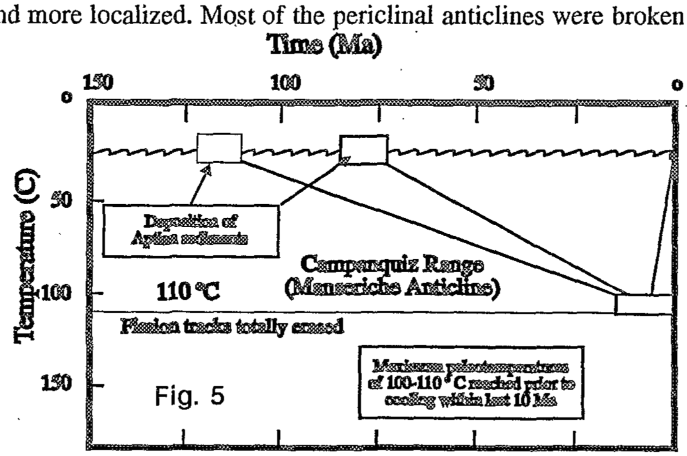



Fig. 5

The four samples show consistent evidence of elevated temperatures at some time since deposition. Indeed, mean fission track ages are significantly less than the respective Cretaceous stratigraphic ages, and the majority of individual grains give fission track ages which are very much less than the stratigraphic age. Furthermore, measured mean track lengths are all much less than the predicted values of of the mean length ( $l_p$=14.9 μm). This means that the great majority of tracks in these samples are shorter than would be expected if they had formed at the prevailing temperatures in each sample. The shorter tracks were the result of enhanced fission track annealing at elevated paleotemperatures at some time after deposition.

TABLE I. APATITE FISSION TRACK ANALYSIS

| Samp. | Formt. | # of grains | Standard track density $x10^6cm^{-2}$ | Fossil track density $x10^5cm^{-2}$ | Induced track density $x10^6cn^{-2}$ | Chi squar prob % | Fiss. track age (Ma) | U cont. ppm | Mean track length (μm) | σ μm |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Cush. | 20 | 1.221 | 0.904 | 2.323 | < 1 | 8.4 ± 1.2 | 25 | 10.76 ± 1.30 | 3.89 |
| | | | (1921) | (52) | (1336) | | 20.3 ± 10.5* | | (9) | |
| 2 | Cush. | 20 | 1.221 | 1.010 | 2.343 | 2.2 | 9.3 ± 1.1 | 25 | 13.14 ± 0.54 | 2.07 |
| | | | (1921) | (73) | (1693) | | 13.3 ± 3.6* | | (15) | |
| 3 | Vivian | 11 | 1.221 | 3.786 | 3.422 | < 1 | 23.8 ± 2.9 | 37 | 13.19 ± 0.03 | 0.04 |
| | | | (1921) | (76) | (697) | | 60.7 ± 43.2* | | (2) | |
| 4 | Cush. | 20 | 1.221 | 6.409 | 4.428 | < 1 | 31.1 ± 1.9 | 48 | 11.16 ± 0.46 | 2.39 |
| | | | (1921) | (363) | (2508) | | 39.0 ± 22.2* | | (27) | |

Brackets show number of tracks counted

Standard and induced track densities measured on mica external detectors (g =0.5, and fossil track densities on internal mineral surfaces

* Mean age used where pooled data fail $\chi^2$test at 5%. Errors quoted at ± 1σ

Ages for samples calculated using $\zeta$ = 3.527using (Analysis P.O. Sulivan) for dosimeter glass SRM612 (Hurford and Green, 1983).

All four samples show clear evidence of having undergone paleotemperatures in the range of 100° to 110° C reached prior to a Late Tertiary cooling event (within the last 10 Ma). Two samples from the Campanquiz Range (samples 1 and 2) reached a maximum post depositional paleotemperatures during the Neogene heating episode (Fig. 5). However, the two from the western Huaracayo Range (samples 3 and 4) show evidence to have experienced even higher paleo-temperatures at some other time prior to the Neogene (Fig. 6 ).

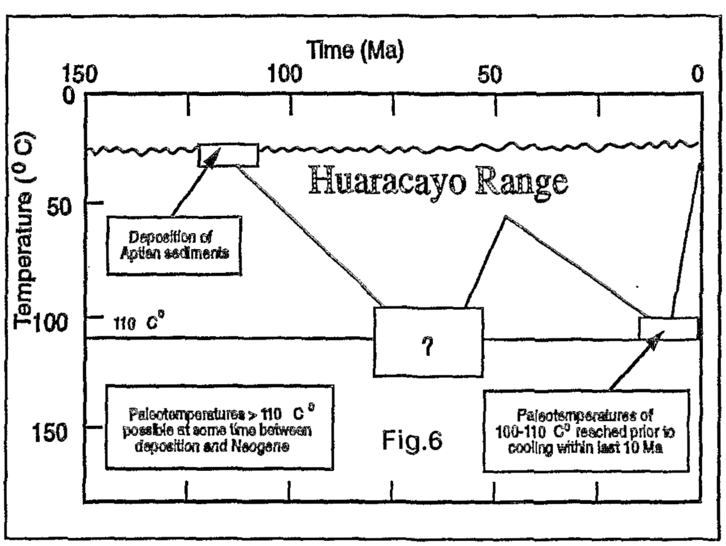


Fig.6

Cooling was rapid with up to 3.5 to 4.5 km of section removed from both areas since cooling begun assuming that the present day gradient is 1.15 °F/100 ft (21°C/km) and the present day surface temperature of 80°F (27 °C) prevailed at the time of uplift. The data do not allow accurate assessment of the active exhumation rate, but a minimum average rate of 350 to 400 m/Ma, is estimated assuming continuous uplift since 10 Ma to the present.

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