ACTIVE FAULTS AND QUATERNARY GEO-HISTORY OF THE ALTIPLANO ON THE FOOT OF THE CORDILLERA REAL, BOLIVIA

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Abstract Active normal fault system and Quaternary geologic-history of the Bolivian Altiplano are represented in six figures. On the basis of total amount of fault displacements and the average fault slip rate shown in these figures, it is evident that the faulting had begun already ca. 13 Ma. Another significant issues such as distribution of fault trace and fault features are also illustrated in these figures.

Key words: Quaternary geo-history, active fault, glaciation, Altiplano, Bolivian Andes

1. Introduction

We carried out a research on the Quaternary geology in the Bolivian Andes which was financially supported by the Grant-in-Aid for Scientific Research (Oversea Scientific Survey) of the Japanese Ministry of Education, Science and Culture. Field survey led by Prof. Michio Nogami, Tokyo Metropolitan University was conducted from August to October in 1979.

The objects of the research were: 1) to discuss the glacial history of the Cordillera Real and related Quaternary geological and geomorphological developments, 2) to describe the active faults dislocating the Pliocene-Pleistocene sediments in the Altiplano and to evaluate them from the view of Quaternary geo-history, and 3) to investigate the lake-level fluctuation of Titicaca Lake and its cause. We have so far reported but important preliminary results in the following restricted occasions (*e.g.*, Nogami *et al.* 1980; Hirakawa *et al.* 1982). No research has submitted since then especially in terms of the active faults in the Altiplano. Therefore, it is still significant to introduce the field data, although the field observation had been conducted more than 20 years ago.

In this report, six figures with reference to active faulting along the southwestern foot of Cordillera Real in Bolivia will be presented, adding some interpreted remarks briefly.

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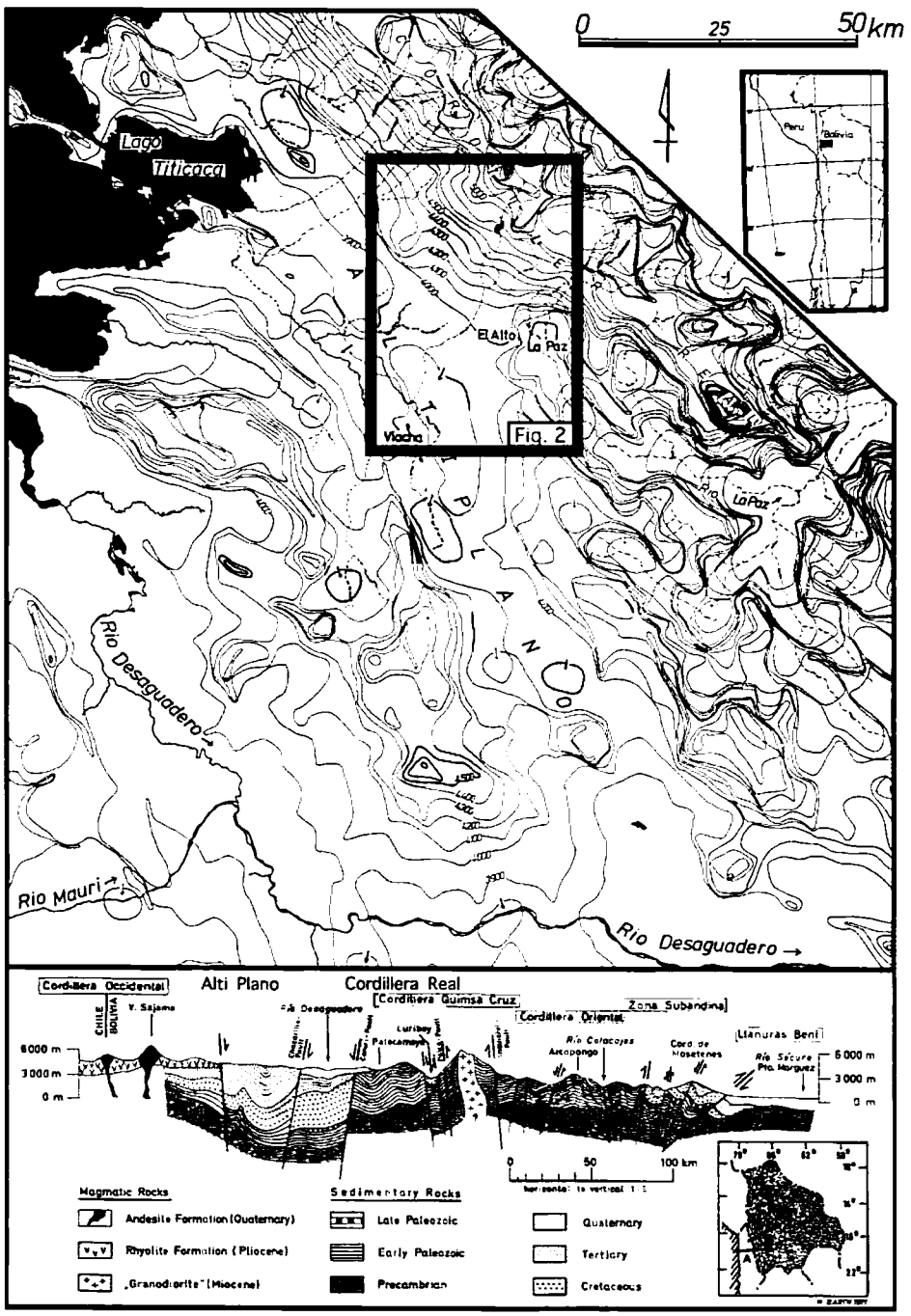

Fig. 1 Outline of topography of the northern Bolivian Altiplano (above), and its geologic section through the Bolivian Andes (below, according to Barth, 1972 redrawn from Zeil, 1979). Altiplano is a wide plateau region located at the west side of the Cordillera Oriental (Sub Andean) foreland thrust belts.

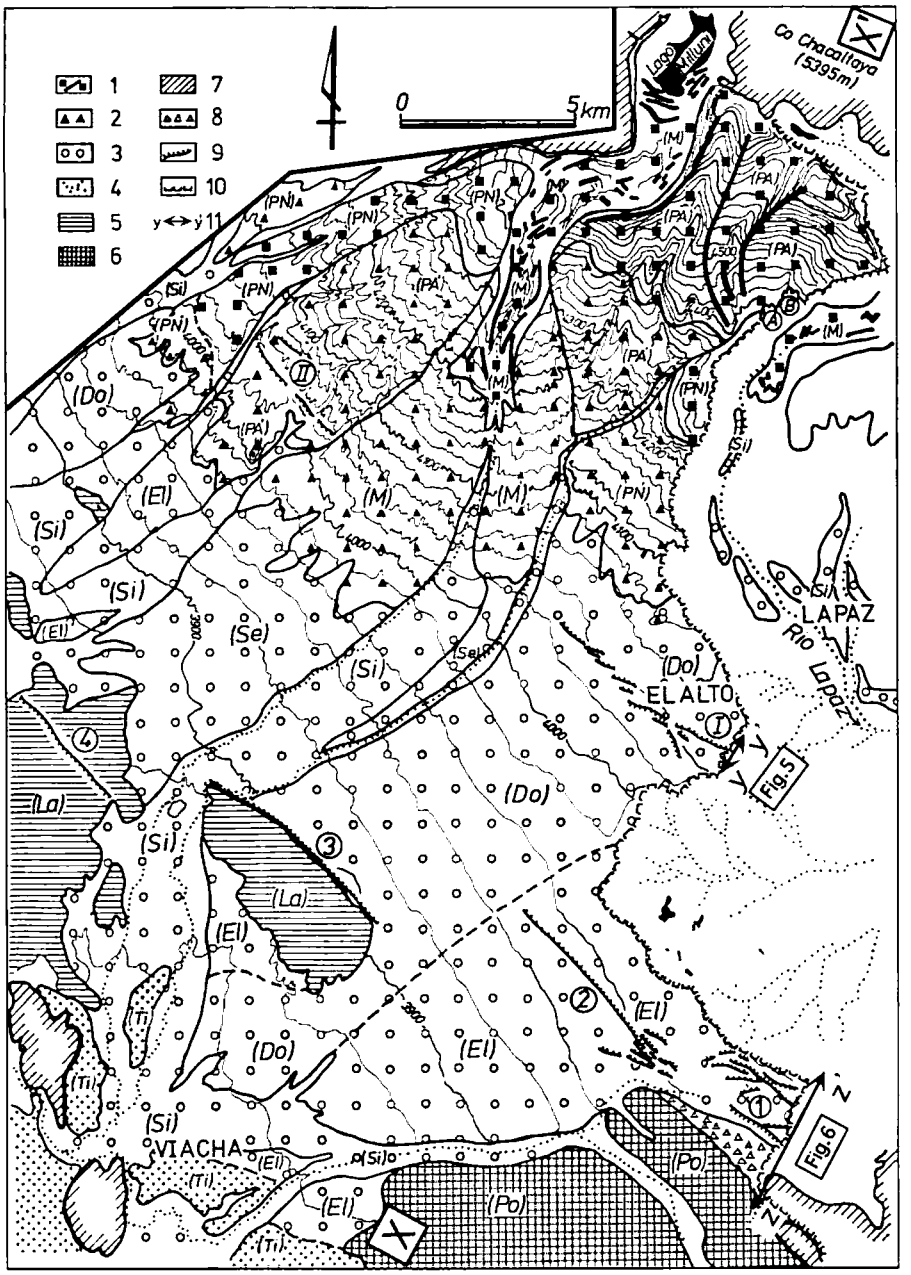

Fig. 2 Map showing distribution of topographic surfaces on the Altiplano and on the southwest foot of the Mt. Chacaltaya in the Cordillera Real (see Fig. 1 for location). 1: moraine and moraine ridge, 2: reworked till, 3: fan gravel, 4: river bed, 5: upland, 6: hill, 7: mountain, 8: talus, 9: active fault (1~4: El Alto fault, ①~④: Viacha fault), 10: Scarp on the edge of the Altiplano near La Paz, 11: geologic sections of X-X', Y-Y' and Z-Z' (see Figs. 5 and 6). (Si): Sique, (M): Milluni, (Se): Rio Seco, (PN): Pata Nueva, (PA): Pata Antigua, (El): El Alto, (La): La Paz, (Po): Pocojota.

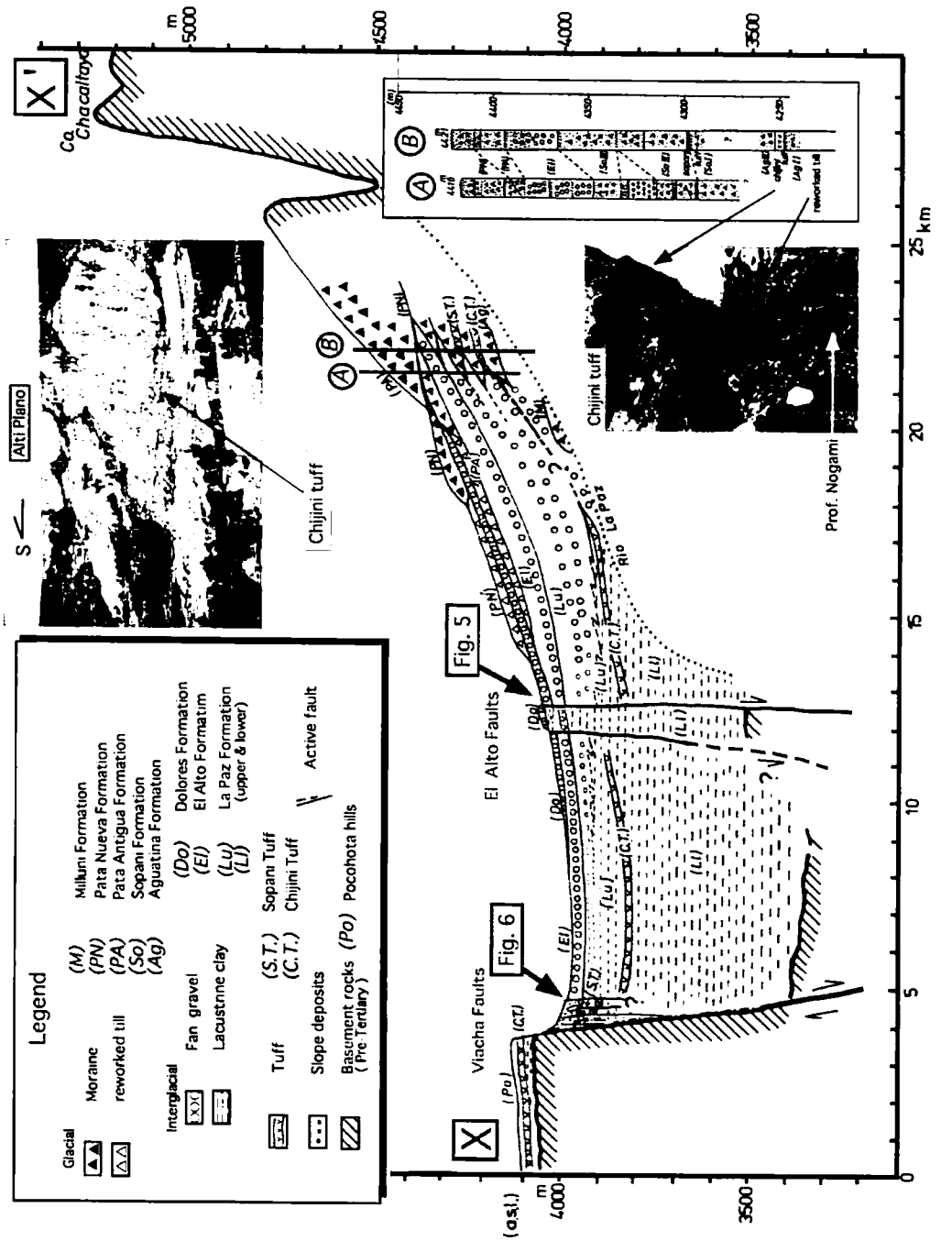

Fig. 3 Geologic and topographic sections showing the stratigraphy of sediments and dislocation by falting along the scarp of the Altiplano edge near La Paz, including two detailed columnar description (right lower part). Displacement and rate of Viacha faults can be provided by the pyroclastic flow deposits, Chijini Tuff (C.T) dated to 3.27 Ma.

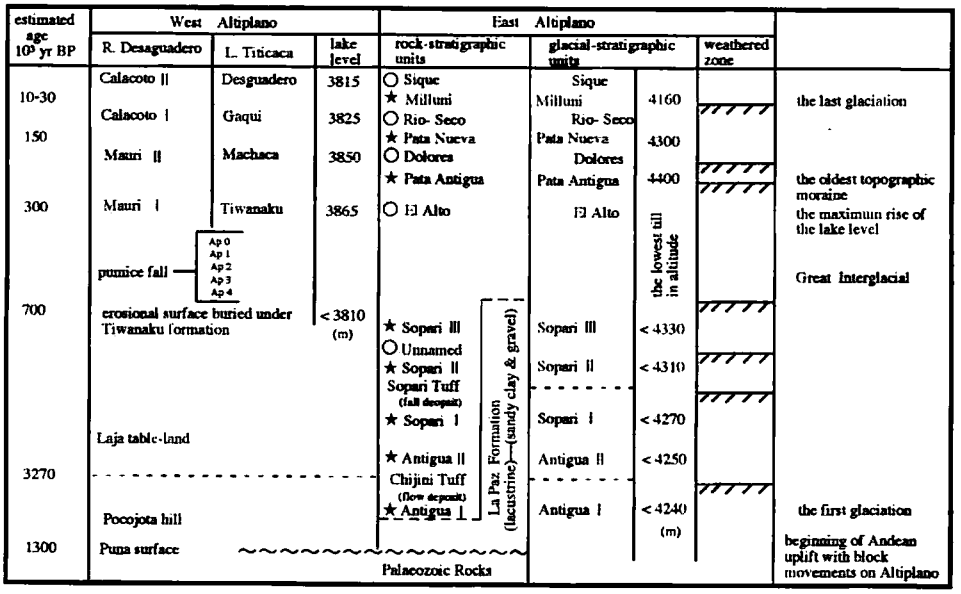

Fig. 4 Summarized diagram on Quaternary geo-history of the Altiplano near La Paz. (according to Nogam 1970, Nogami *et al.* 1980 and Hirakawa *et al.* 1982). Calacoto II, Mauri I etc. in the West Altiplano means the terrace surfaces associated with paleo-Titicaca Lake level. O and ★ in the colum of the rock-stratigraphic units for the East Altiplano indicate the interglacial well washed gravels and glacial till/reworked glacial till, respectively.

2. Outline of the Quaternary Geo-history in the Altiplano

The Bolivian Altiplano is a tectonic depression (Servicio Geologico de Bolivia. 1967: Lohmann 1970: Sempere *et al.* 1990) which extends northwest-southeast direction and is more than 200 km wide at the altitude of 3000~4000 m above sea level. It is bordered by the Cordillera Real (its eastern foot located foreland thrust belt) to the east and by the Cordillera Occidental with many volcanoes to the west, attaining to 6500 m above sea level, respectively. Quaternary geology and geomorphology of the southwestern foot of the Cordiella Real and the Altiplano around La Paz are presented here, referring to the Figs. 1, 2, 3 and 4. Major significant features as follows:

1) The oldest glaciation represented by till (Aguatina I Till in Fig. 4) should be prior to the fall of Chijini Tuff (remarkable ignimbrite) dated to 3.27 Ma. The Chijini Tuff intercalated in the lacustrine La Paz Formation is an important key bed for the correlation and the stratigraphy of the sediments.
2) Subsequently there were at least five glaciations indicated by glacial tills and related sediments (Aguatina II, Sopani I, Sopari II and Sopari III, respectively: see Fig. 4) until the Great Interglacial which is probably situated in the middle Pleistocene. These till deposits were strongly suffered from pedogenesis shown weathered horizons, indicating the occurrences of Interglacial period. The Great Interglacial Period is identified by the El

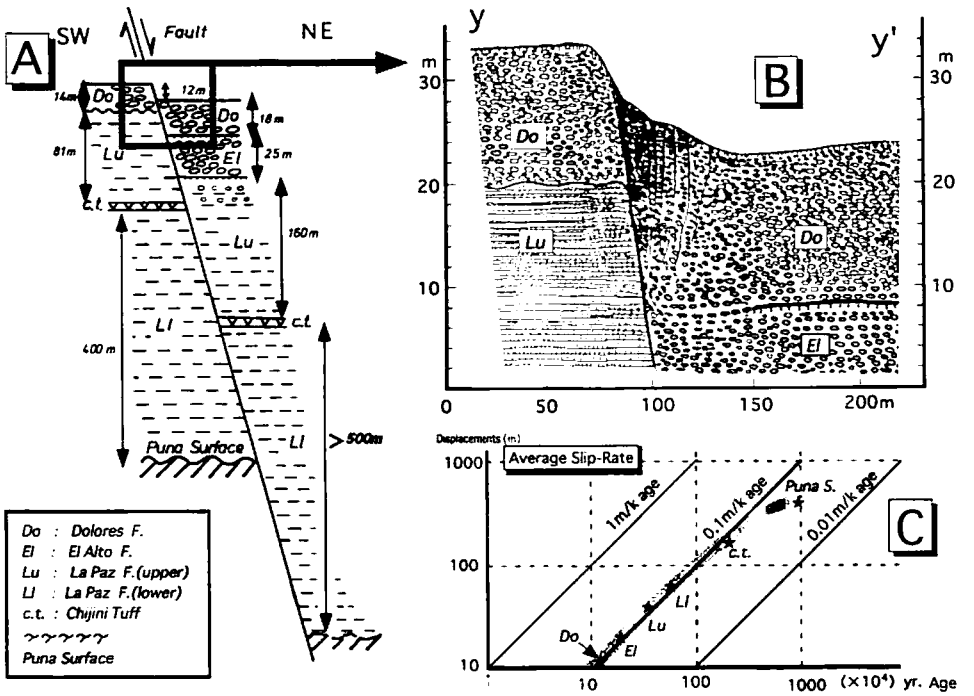

Fig. 5 Displacements of the El Alto faults. A: cross section of the fault (see Fig. 2 for location; Y-Y'), B: closed-up section near surface, C: estimation of average slip-rate of the El Alto faults.

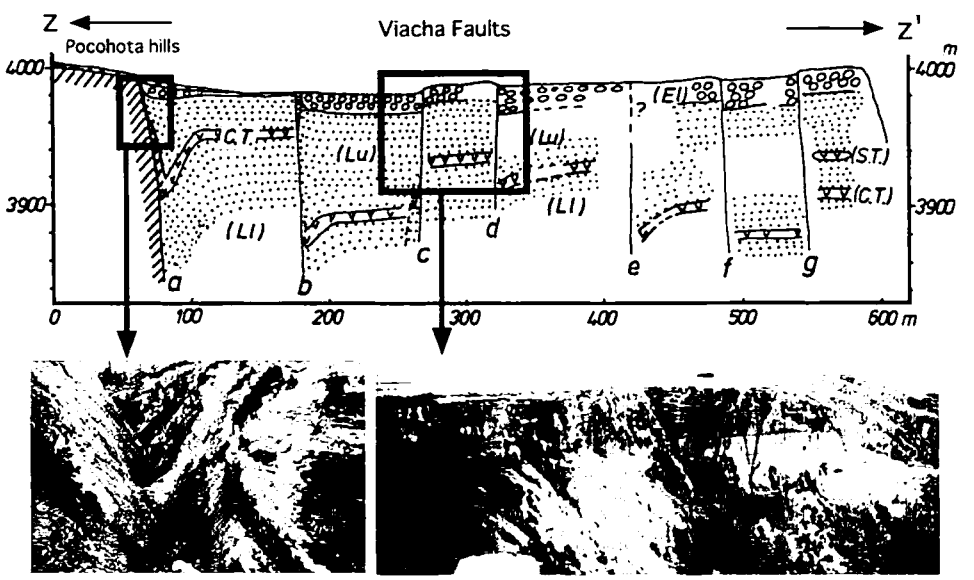

Fig. 6 Cross section along the Scarp of the Altiplano edge showing the Viacha fault and dislocated sediments near La Paz (see Fig. 2 for location; Z-Z'). Photos show typical fault outcrops.

Alto Formation which is characterized by the thick well washed fluvial gravels forming a widely developed alluvial fan.

3) Following the Great Interglacial, three glaciations such as Pata Antigua, Pata Nueva and Milluni in ascending order (Fig. 4) are clearly recognized on the basis of the terminal moraine landforms. Of these glaciations the Milluni should represent the Last Glaciation.
4) The proglacial landform of piedmont glaciers dose not show a outwash plain but a steeper plain consisting of reworked tills probably transported by mud-flow like processes, which is characterizes by the braided pattern of levees.
5) The upper La Paz valley dissecting the sequence of sediments mentioned above or the depositional surface of Altiplano began to drain crossing the Cordillera Oriental after the last glacial advance. However, the downcutting has already reached ca. 1000 m or more in depth.

3. Active Faults in the Bolivian Altiplano, near La Paz

Tow active faults (the Viacha faults system and the EL Alto faults, in Fig. 2) distributed in the Altiplano, near La Paz, run almost parallel in northwest-southeast direction along the Coniri structure (Dewey and Lamp 1992). Fault features, displacements, activities and slip rate of these two active faults are summarized as follows:

1) Total length of each active fault system, consisting of several short traces respectively, amounts to more than 20 km (Fig. 2).
2) Each active fault system is a normal fault type, mainly with northeast side down and subsidiarily with southwest side down (Fig. 2).
3) The El Alto faults system has dislocated the basement rock, (Puna Surface), lower part of the La Paz Formation (Ll in Fig. 3) , the Chijini tuff (C.T.), upper part of the La Paz Formation (Lu), El Alto Formation (EL), and alternated glacial and interglacial deposits. The depositional surface of Dolores Formation (Do) has also dislocated (see Figs. 3 and 5), but no scarp on the younger surface than the Last Glaciation surface of Milluni Formation (Mi) has dislocated.
4) The Viacha faults system is located corresponding to the eastern margin of Pocojota (Po) hills. The amount of displacement indicated by the surface of basement rock (Puna Surface) is more than 700 m, while that of Chijini tuff (C.T.) is 300 m (see Fig. 6).
5) Andean uplift accompanying normal faults began at the end of the Miocene (ca. 13 Ma) just after the formation of the low relief Puna Surface. Total amount of fault displacements has reached more than ca. 1000 m. According to the accumulation of each fault displacements, the average fault slip rate of these faults is estimated to be less than 0.1 m/ka (see Fig. 5C). Recurrence interval is referred to be 50 ka. Therefore, displacement of each faulting is assumed to be 3~5 m.

References

Barth, W. 1972. Das Permokarbon bei Zudanez (Bolivia) und eine Ubersicht des

Jungpalaozoikum im zentralen Teil der Anden. *Geol. Rdsch* **61**: 249-270.
Clapperton, C. M. 1979. Glaciation in Bolivia before 3.27 Myr. *Nature* **277**: 375-377.
Dewey, J. and Lamb, S. 1992. Active tectonics of the Andes. *Tectonophysics* **205**: 79-95.
Hirakawa, K., Nogami, M., Koaze, T. and Imaizumi, T. 1982. Terrace landform development and lake level fluctuation in the southern fringe of the lake Titicaca and the upper Desaguadero valley, Bolivian Altiplano. *Journal of Geography* **91**: 104-123. *
Lohmann, H. M. 1970. Outline of the tectonic history of Bolivian Andes. *Amer. Asoc. Petrol. Geol. Bull* **54**: 735-757.
Nogami, M. 1970. El retroceso de los glaciares en la Cordillera Real, Bolivia. *Geographical Review of Japan* **43**: 338-346. **
Nogami, M., Koaze, T., Hirakawa, K. and Imaizumi, T. 1980. Quaternary geo-history of Bolivian Andes. *24th I.G.C. Main session Abstracts* **1**: 98-99.
Sempere, T., Herail, G., Oller, J. and Bonhomme, M. G. 1990. Late Oligocene-early Miocene major tectonic crisis and related basins in Bolivia. *Geology* **18**: 946-949.
Servicio Geologico de Bolivia. 1967. *Mapa Geologico de Bolivia 1: 100,000*. HOJA No. 5941 Umala.
Zeil, W. 1979. *The Andes -a geological review*. Berlin: Gebruder Borntraeger.

(*: in Japanese with English abstract. **: in Japanese with Spanish abstract)