ALLUVIAL FAN DEPOSITS OF THE TODOS SANTOS FORMATION OF CENTRAL CHIAPAS, MEXICO

by

TERENCE CLETUS BLAIR

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PREFACE

The purpose of this thesis is to provide a better understanding of the depositional history of the Todos Santos Formation of central Chiapas, Mexico.

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ABSTRACT

ALLUVIAL FAN DEPOSITS OF THE TODOS SANTOS FORMATION
OF CENTRAL CHIAPAS, MEXICO

Terence Cletus Blair, M.S.
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Supervising Professor: Burke Burkart

The Todos Santos Formation at Jerico was deposited as an alluvial fan system by high gradient, short duration ephemeral streams which transported gravel, sand, and mud northeastward through a feeder canyon which opened out onto an alluvial plain. This alluvial fan system is composed of streamflood, debris flow, and braided stream deposits.

Three distinct alluvial fan environments were distinguished at Jerico: proximal fan facies, mid-fan facies, and distal fan facies. Analysis of the vertical succession of these depositional facies reveals two proximal to distal alluvial fan transitions separated by a distal to proximal transition. This suggests that a period of alluvial fan progradation separates two periods of alluvial fan recession.

The Todos Santos sandstone compositions and conglomerate clast assemblages can be attributed to four source rock units: the metamorphic-igneous basement rocks now exposed as the Chiapas massif; the Santa Rosa Group, a late Paleozoic sequence of predominantly marine sedimentary rocks; unnamed volcanic rocks found at the base, and interbedded with, the Todos Santos Formation; and the Todos Santos Formation itself. The lowermost conglomerate clast assemblage suggests that the channel network had already exposed the granitic batholith rocks of the Chiapas massif. Clasts from the debris flow sequence, which composes the central part of the Jerico section, indicate that source rock includes the meta-igneous complex, the Santa Rosa Group, and the unnamed volcanic rocks. Sandstone composition and conglomerate clasts from the upper portion of the Jerico section suggest that diminution of Santa Rosa outcrops in the source area had occurred by that time.

An abundance of debris flows, the presence of pedogenic carbonate nodule horizons, red coloration, and its lateral transition into evaporite deposits suggest that the Todos Santos Formation was deposited under arid to semi-arid climatic conditions. Palynologic evidence points to a Neocomian time of deposition.

The vertical succession of facies at Jerico combined with regional evidence suggest that deposition of the Todos Santos Formation was tectonically controlled. These sedimentary rocks were eroded off horst blocks and deposited in adjacent subsiding grabens or half-grabens. Graben formation may be associated with rifting and later subsidence of the Gulf of Mexico basin.

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Sample T-158 Claystone

Greenish-grey; greasy-feel; waxy; unresistant; discoidal weathering; contains muscovite flakes.

Sample T-163b Siltstone

Greenish-brown; orange and black stain; thickly laminated; contains muscovite flakes and carbonized plant fragments.

Sample T-162 Claystone

Greenish-grey; stained orange-brown; unresistant; discoidal weathering; contains muscovite flakes and carbonized plant remains.

Sample T-168 Siltstone

Greenish-grey; weathers dark brown; ripple casts on bottom; indurated; massive looking; muscovite flakes present.

Sample T-167 Mudstone

Greenish-grey; orange-brown and black stain; subgreasy; unresistant; discoidal weathering; contains muscovite and carbonized plant fragments.

Sample T-166 Siltstone

Greenish-brown; weathers dark-brown; orange-brown stain; indurated thinly laminated; parting lineations; abundant muscovite flakes; carbonized plant remains present.

Sample T-165 Claystone

Greenish-grey; waxy-looking; greasy feel; conchoidal fracture; contains muscovite flakes.

Sample T-164 Medium-grained sandy siltstone.

Greenish-grey; indurated; massive looking; contains some muscovite flakes.

Thin Section Description:
Compact; mainly linear grain contacts, some concavo-convex and tangential; angular, corroded grains. Quartz (45%): straight to slightly undulose extinction (26.5%), semi-composite, abundant vacuoles (5%), polycrystalline composite (13.5%). Feldspar (20%): sericitized orthoclase (19%), plagioclase (1%). Lithic fragments (21%): SRF's: chert (1%), intraformational mudstone fragments (14.5%); MRF's: biotite-muscovite-quartz schist (3.5%); VRF's: porphyritic rhyolite (2%). Other: biotite, muscovite, chlorite (trace); matrix (2%) chert cement (7%), garnet, opaque heavy minerals (1%).

Sample T-10 Granule-pebble conglomerate

Highly weathered; forming soil horizon; pebbles rounded, consist mainly of quartz, quartzite, and granite; clast-supported; sand matrix not identifiable.

Sample T-9 Granular, poorly-sorted, fine- to coarse-grained sandstone: lithic feldsarenite

Extremely weathered dark-brown to black; angular to subrounded grains; mode: coarse sand; composed of quartz, orthoclase, lithic fragments (siltstone), heavy minerals, chlorite, biotite, muscovite; granules composed mainly of quartz.

Grain Size Analysis: p: 11%, gr: 4%, vcs: 7%, cs: 23%, ms: 34%, fs: 11%, vfs: 2%, cz: 2%, mfz: 2%, c: 4%, mode = 1 ϕ

Sample T-8 Granular, moderately-sorted, medium to coarse-grained sandstone: lithic feldsarenite

Light-brown, weathers black; friable; mode = coarse-sand; grains subangular to rounded; composed of quartz, feldspar, lithic fragments, chlorite, muscovite, heavy minerals; quartzite fragments especially rounded.

Sample T-7 Pebbly, granular, moderately-sorted very-coarse to coarse sandstone: calcite cemented feldspathic litharenite

Light brown; weathers dark brown; friable; pebbles of quartz, quartzite, rhyolite, limestone, and granite; rounded to well-rounded; sand grains subangular to subrounded; composed of quartz, lithic fragments, feldspar, biotite.

Sample T-1 Coarse-sandy granule pebble conglomerate

Extremely weathered, stained yellow-brown to black; ferruginous; friable; pebbles and cobbles of milky quartz, quartzite, and granite; well-rounded; clast supported; matrix a well-sorted coarse-grained sandstone; grains subangular to subrounded; composed of quartz, orthoclase, rock fragments, and chlorite.

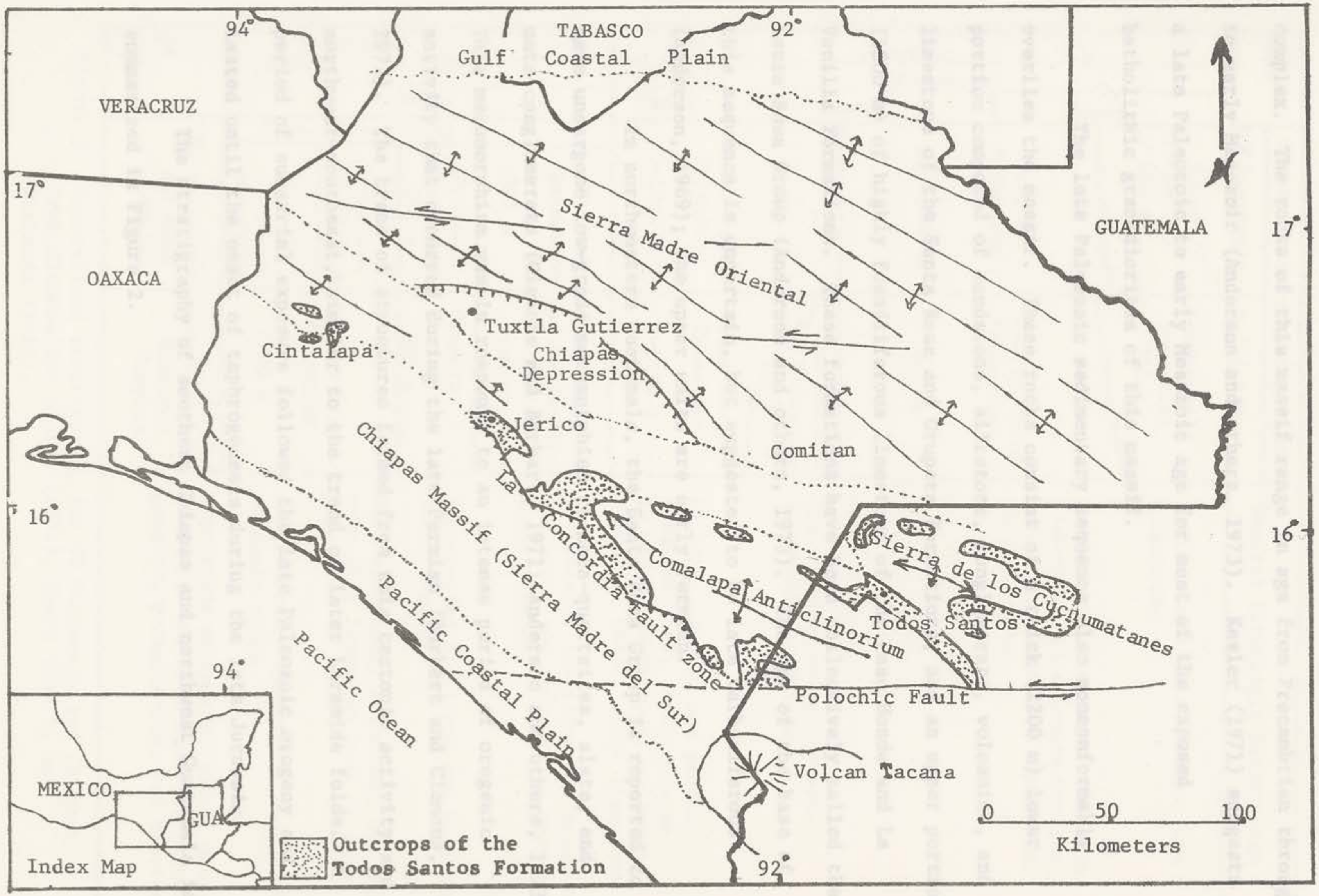


Figure 1. Outcrops of the Todos Santos Formation, Chiapas and northwestern Guatemala.

is composed of fine to medium sand sized grains. Figures 9c and 9d show a characteristic grain size distribution of two samples from this lithofacies.

Laminated Very-Fine Sandstone, Siltstone, Mudstone and Claystone (Fl)

This lithofacies is composed of laminated fine-grained deposits. The common alternation of such beds on a small scale and their persistant laminated nature justifies aggregating these units of varying grain size into one category. In the Jerico section the claystone is commonly gray-colored while the siltstone and very fine sandstone are typically brown. Lacy, carbonaceous leaf fragments as well as aligned muscovite flakes are abundant on the parting planes.

Age			General Statigraphic Column: NW Guatemala	General Statigraphic Column: S Chiapas	General Lithologic Description
Mesozoic	Cretaceous	Upper	Sepur Formation 250 m	Ocozocuatla Formation 300 m	marine sandstones, shales, and limestones
Mesozoic	Cretaceous	Upper / Lower	Ixcoy Formation 500-3000 m	Sierra Madre Formation 1610 m	interbedded limestone, dolomite, limestone and dolomite breccia, minor shale and fine sandstone, fossiliferous
Mesozoic	Cretaceous / Jurassic	Lower / Upper		San Ricardo Formation 0-375 m	tan to brown shale, gypsum, limestone, sandstone
Mesozoic	Jurassic	Upper	Todos Santos Formation 3-1200 m	Todos Santos Formation 0-1220 m	boulder, cobble, and pebble conglomerates, pebbly coarse to medium sandstones, siltsone, mudstone, shale, minor limestone
Paleozoic	Permian	Lower	Santa Rosa Group: Chochal Formation 1000 m	Paso Hondo and La Vanilla Formations 660 m	interbedded limestone and dolomite, sandstone and mudstone in upper part fossiliferous
Paleozoic	Permian	Lower	Santa Rosa Group: Esperanza Formation 500 m	Grupera Formation 500 m	interbedded limestone and mudstone, fossiliferous
Paleozoic	Permian / Carb	?	Santa Rosa Group: Tactic Formation 500-1000 m	Santa Rosa Formation 2700 m	fine sandstone, siltstone, and shale some thin limestone beds in upper part
Paleozoic	Carb	?	Santa Rosa Group: Chicol Formation 800-1200m		conglomerate, sandstone, tuffaceous volcanic rocks
Pre C			Meta-Igneous Basement Complex	Meta-Igneous Basement Complex	high-grade metamorhic rocks: meta-sediments and meta-igneous, plutonic granite, granodiorite, and diorite

Figure 2. Generalized stratigraphy for NW Guatemala and Chiapas, from Clemons and others (1974), Chubb (1957), and Richards (1963).

Previous Work

The first published mention of the Todos Santos Formation was by Sapper (1894), who named this rock unit after the village of Todos Santos de las Cuchumatan, Department of Huehuetenango, Guatemala; where he described good outcrop exposures of red conglomerate, sandstone, and shale. Vinson (1962) proposed the La Ventosa section of the Todos Santos Formation, located near La Ventosa, a small village a few kilometers southeast of Todos Santos, as the type section.

Early workers of the Todos Santos Formation concentrated on establishing the time of deposition of the unit, a problem still not solved precisely due to the sparse distribution of fossils. Burckhardt (1930) and Mülleried (1936) reported finding _Idoceras_ sp., _Waagenia_ sp., and _Halobra_ sp., late Jurassic fauna, from the middle of the Todos Santos Formation in western Chiapas. Ver Wiebe (1925) noted _Isatrean_ sp. and _Nerineopsis goyzuetae_, life forms indicative of late Jurassic to early Cretaceous time. Roberts and Irving (1957) found Neocomian fossils in the upper Todos Santos at the type locality, and Mülleried (1936) and Chubb (1959) also found Neocomian fossils in the upper Todos Santos in Chiapas.

A late Jurassic-early Cretaceous age range for the Todos Santos was obtained by later workers as well. Vinson (1962) noted the presence of the late Jurassic-early Cretaceous foraminifera _Anchispirocyclina hambesti_ (Jordan and Appin) from a basal conglomerate as well as an upper limestone lens of the Todos Santos in Guatemala. Blount (1967) found _Cayeuxia piae_, an upper Jurassic or lower Cretaceous calcareous algae, in a limestone bed near the top of the Todos Santos in the Chiantla quadrangle of northwestern Guatemala. Castro Mora and others (1975) dated, by radiometric K/Ar methods, andesitic and dacitic volcanic rocks found at the base of the Todos Santos Formation near Cintalapa, Chiapas, resulting in an age of 148 ± 6 m.y. (Oxfordian). They also noted that similar volcanic rocks are interbedded with the Todos Santos in that vicinity.

Later workers of the Todos Santos Formation focused on describing the lithology, examining the contacts, and determining the unit's thickness. The location of published detailed measured sections are shown in Figure 3. Lattimore (1962) measured 209 m of red conglomerate, sandstone, claystone, and minor dolomite in a section near Painconap in the Sierra de las Cuchumatanes. Richards (1963) measured 1240 m of red conglomerate, sandstone, siltstone, and shale at the type section at La Ventosa. Anderson (1969) observed 1120 m of Todos Santos in the San Sebastian Huehuetenango Quadrangle. Litke (1975) measured between 500-600 m of Todos Santos clastics near Barillas on the north flank of Altos Cuchumatanes.

Other workers in northwestern Guatemala have estimated the thickness of Todos Santos rocks in their respective study areas, further illustrating the great variability in thickness of this formation. Boyd (1966), approximated 640 m in the western part of the La Democracia Quadrangle, while Davis (1966) estimated 290 m in the eastern part. Blount (1967) suggested 700 m of Todos Santos rocks near Chiantla, just north of Huehuetenango. Burkart and Clemons (1972) report that the

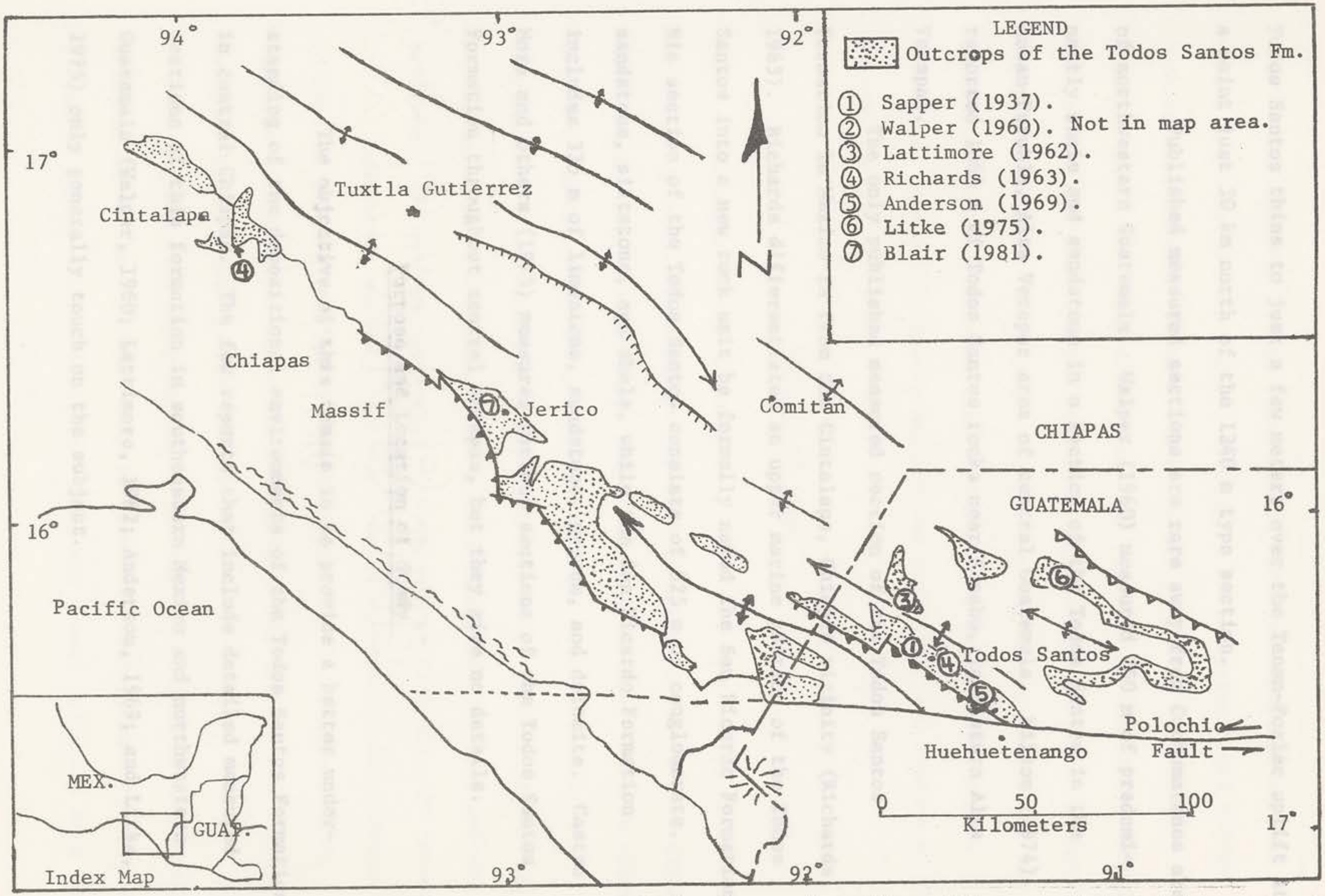


Figure 3. Measured sections of the Todos Santos Formation, Chiapas and Guatemala

Todos Santos thins to just a few meters over the Tenam-Poxlac uplift at a point just 30 km north of the 1240 m type section.

Published measured sections are rare away from Cuchumatanes area of northwestern Guatemala. Walper (1960) measured 750 m of predominantly shale and sandstone in a section of the Todos Santos in the Coban-Puruhla, Alta Verapaz area of central Guatemala. Wilson (1974) reported 1060 m of Todos Santos rocks near Senahu, in eastern Alta Verapaz.

The only published measured section of the Todos Santos Formation in Mexico is from the Cintalapa, Chiapas vicinity (Richards, 1963). Richards differentiated an upper marine portion of the Todos Santos into a new rock unit be formally named the San Ricardo Formation. His section of the Todos Santos consists of 825 m of conglomerate, sandstone, siltstone, and shale, while the San Ricardo Formation includes 375 m of limestone, sandstone, gypsum, and dolomite. Castro Mora and others (1975) measured various sections of the Todos Santos Formation throughout central Chiapas, but they give no details.

Purpose and Location of Study

The objective of this thesis is to provide a better understanding of the depositional environments of the Todos Santos Formation in central Chiapas. The few reports that include detailed measured sections of this formation in southeastern Mexico and northwestern Guatemala (Walper, 1960; Lattimore, 1962; Anderson, 1969; and Litke, 1975) only generally touch on the subject.

The outcrops of the Todos Santos Formation examined in this report are located near Jerico, Chiapas, a small agricultural colony located approximately 80 km south-southeast of Tuxtla Gutierrez (Figures 1 and 4). This study area lies between the measured Guatemala outcrops of the Todos Santos Formation and the only published measured section in Mexico. The Jerico outcrop area was chosen because of its geographic position between the studied areas, because of its good exposures, because a complete section was available, and because of its accessibility.

Methods of Study

Ten weeks during the summer of 1980 were spent doing field work in the study area. This work began with geologic reconnaissance aimed at obtaining the best exposures and a complete section. Section thickness was determined by using a jacob staff and Brunton compass. Conglomerate clast size and composition statistics were determined on the basis of 100 clasts at 10 m intervals throughout the conglomerate horizons. The maximum clast size of conglomerate beds was also noted.

Laboratory analysis involved a detailed petrographic examination of most of the 250 samples collected (Appendix II). Sixty-one thin sections were examined under the petrographic microscope, and a modal analysis made on twenty-seven samples.

A grain size study on twenty-one samples characterized the major lithofacies of the section. Samples were first disaggregated, then wet sieved to remove the mud fraction. Sand and gravel fractions were then

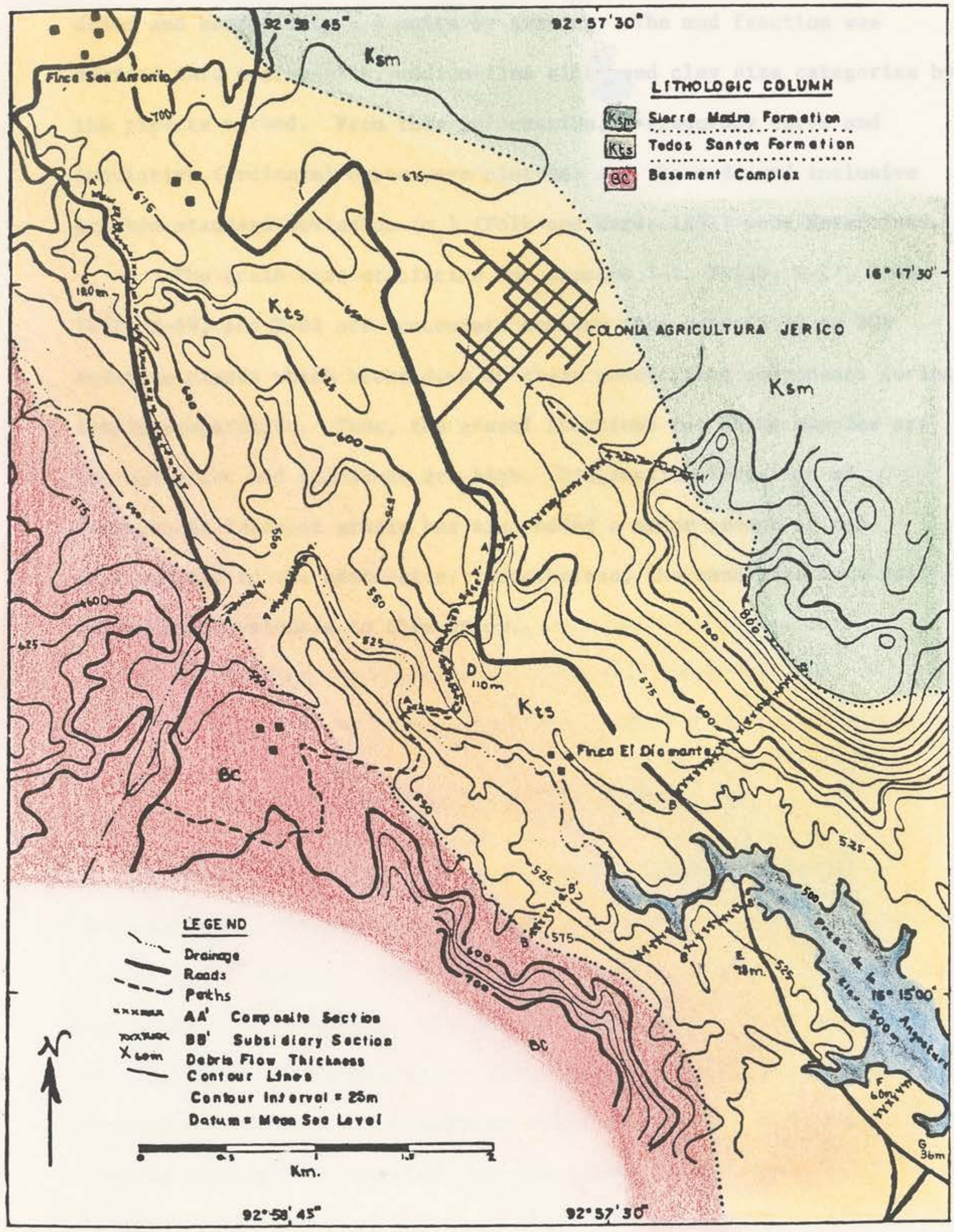


Figure 4. Generalized geologic and topographic map of the study area, Jerico vicinity, Chiapas.

dried and sorted into ¼ ϕ units by sieving. The mud fraction was divided into coarse-silt, medium-fine silt, and clay size categories by the pipette method. From this information, a frequency curve and cumulative (ordinate) curve were plotted, and the mode and inclusive graphic standard deviation (σ_I) (Folk and Ward, 1957) were determined.

The grain size statistics for samples T-9, T-13b, T-17, T-45, T-52, T-69, and T-82 are inaccurate because they contain 10 to 20% mudstone clasts which broke down to their constituent components during sample preparation. Thus, the gravel fractions for these samples are low while the mud fractions are high. Diagenetic alteration of constituent feldspar grains has also added a minor amount of non-detrital mud to the statistics. Nonetheless, the sand-size data are accurate and valuable to this study.

LITHOFACIES

The Jerico section of the Todos Santos Formation can be conveniently subdivided into lithofacies distinguished on the basis of grain size, sedimentary structures, sorting, and geometry. These subdivisions are valuable because each represents the result of different hydrodynamic conditions and thus aids in interpreting the depositional environment. The lithofacies described here are those of Miall (1977), with later additions from Rust (1978). They include: massive or crudely-bedded conglomerate (Gm), matrix-supported conglomerate (Gms), trough cross-bedded conglomerate (Gt), trough cross-bedded sandstone (St), planar or tabular cross-bedded sandstone (Sp), horizontally-bedded sandstone (Sh), scour-fill sandstone (Ss), and laminated siltstone, mudstone, claystone, and very fine sandstone (Fl).

Massive or Crudely-Bedded Conglomerate (Gm)

This lithofacies consists of pebble, cobble, and boulder conglomerates. Two types of Gm, based on grain size, were distinguished in the Jerico section: one comprised of a mixture of pebbles, cobbles, and boulders; the other of fine pebble-size clasts. Crude horizontal stratification of the gravel was discerned by grading, imbrication, and by interbedded horizontal sandstone units (Plate 1a). Both normal and inverse grading were observed, but the latter is uncommon. Particularly blocky clasts show an alignment of their long axis perpendicular to the

Plate 1a. Massive to crudely-bedded conglomerate lithofacies (Gm) of the Jerico section of the Todos Santos Formation.

Plate 1b. Massive, matrix-supported conglomerate lithofacies (Gms) of the Jerico section of the Todos Santos Formation.

flow direction. Bedding thickness range from 0.5 to 1.0 m. These conglomerates are clast-supported except where they grade into interbedded sandstone. The matrix is commonly a very coarse sandstone, similar in size to the sandstone interbeds. The matrix filtered into the interstices following gravel deposition. Clasts are most commonly rounded, and composed of granite, porphyritic rhyolite, quartzite, and milky quartz. All four of these lithic types are present in the pebble fraction; however, milky quartz and purple quartzite predominate. The cobble and boulder fractions are composed almost exclusively of granite and porphyritic rhyolite.

Massive, Matrix-Supported Conglomerate (Gms)

Rust (1978) characterized this lithofacies as one in which angular megaclasts are supported by a poorly-sorted matrix ranging in size from pebbles to mud. Other diagnostic attributes are its lack of bedding and lack of imbrication.

Gms was readily recognized in the Jerico section by its (a) poorly-sorted nature; (b) muddy-sandy matrix; (c) inclusion of angular clasts of a very fragile nature along with rounded clasts; (d) horizontal sheet geometry 0.3 to 1 m thick; (e) nonerosive base; (f) erosive top capped by a thin (10-20 cm) layer of poorly-sorted muddy sand similar in grain size to the matrix; and (g) by its red color (Plate 1b). Figures 5a, 5b, and 5c demonstrate the very poor sorting of these rocks.

Individual units are separated on the basis of interbedded finer-grained horizons (Plate 1b). Typical transitions are from matrix-

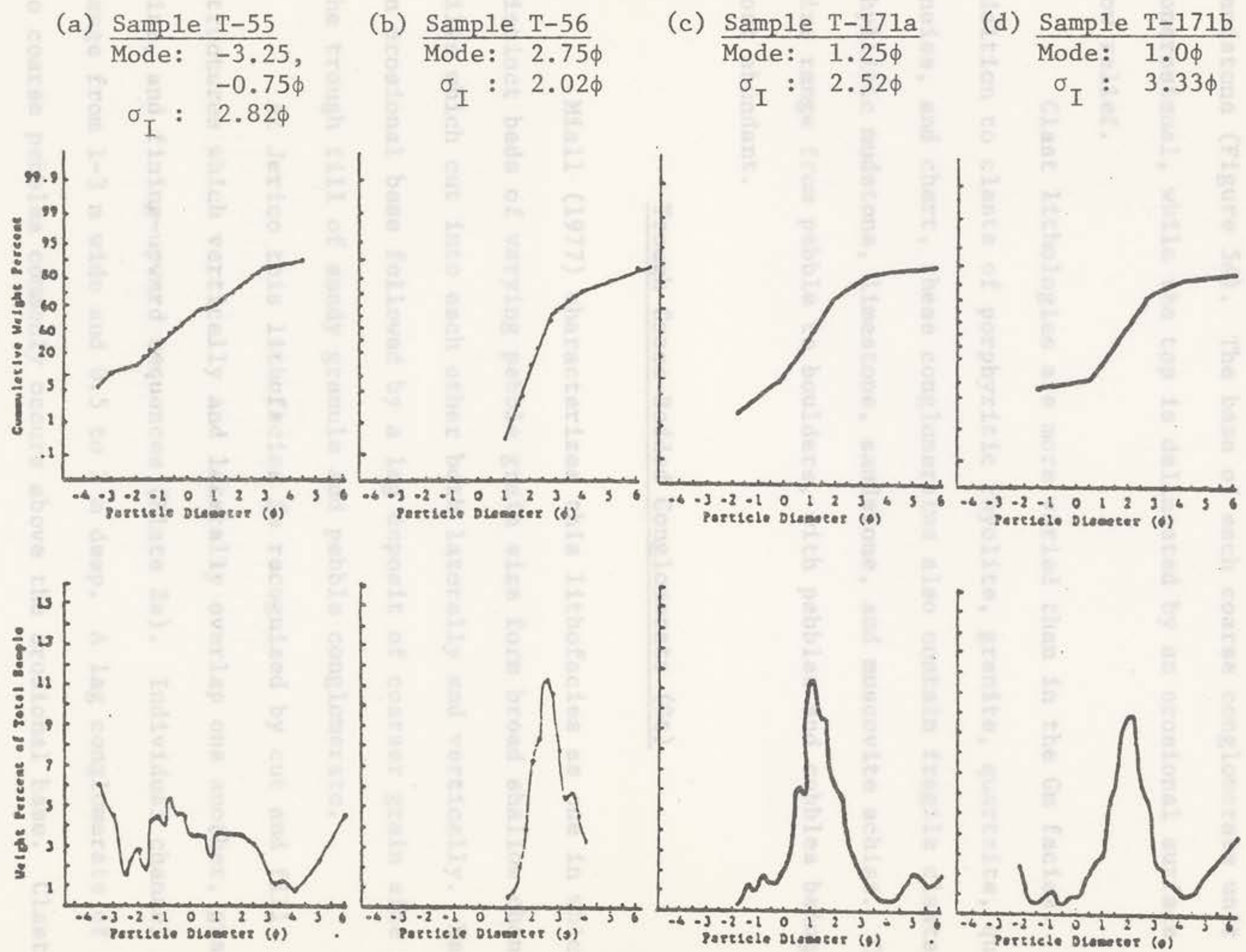


Figure 5. Cumulative and frequency curves for (a) sample T-55, (b) T-56, (c) T-171a, and (d) T-171b.

supported pebble-cobble conglomerates to a capping of muddy matrix-supported fine pebble conglomerates, or a muddy sandstone unit. Less commonly, the coarse conglomerates are overlain by a better-sorted sandstone (Figure 5d). The base of each coarse conglomerate unit is nonerosional, while the top is delineated by an erosional surface of low relief.

Clast lithologies are more varied than in the Gm facies. In addition to clasts of porphyritic rhyolite, granite, quartzite, quartz, gneiss, and chert, these conglomerates also contain fragile clasts of phyllitic mudstone, limestone, sandstone, and muscovite schist. Clast size range from pebble to boulders, with pebbles and cobbles being most abundant.

Trough Cross-Bedded Conglomerate (Gt)

Miall (1977) characterizes this lithofacies as one in which distinct beds of varying pebble grain size form broad shallow channel fills which cut into each other both laterally and vertically. Each has an erosional base followed by a lag deposit of coarser grain size than the trough fill of sandy granule and pebble conglomerate.

At Jerico this lithofacies is recognized by cut and fill structures which vertically and laterally overlap one another, grain size, and fining-upward sequences (Plate 2a). Individual channel cuts range from 1-3 m wide and 0.5 to 2 m deep. A lag conglomerate of fine to coarse pebbles commonly occurs above the erosional base. Clasts are composed of quartz, quartzite, and granite. Minor mudstone clasts and

Plate 2a. Trough cross-bedded conglomerate lithofacies (Gt) of the Jerico section of the Todos Santos Formation.

Plate 2b. Trough cross-bedded sandstone lithofacies (St) of the Jerico section of the Todos Santos Formation.

mudstone drapes are also common. Carbonized and calciticized tree fragments 8-20 cm in diameter and up to 8 m in length are also present in this lithofacies. Log axes trend subperpendicular to the direction of cross-bedding.

These deposits are poorly sorted, but better sorted than the Gms gravels. Figure 6 gives the grain size statistics for four samples from this lithofacies. The cumulative curve generally reveals three grain size populations, which represent the gravel, sand, and mud of the bed-load and suspended load.

Trough Cross-Bedded Sandstone (St)

This lithofacies is characterized by sets of mutually cross-cutting troughs of pebbly medium to coarse sandstone (Miall, 1977). At Jerico, this lithofacies consists of fining-upwards trough cross-bedded sequences 0.5 to 1 m thick and 1 to 3 m wide (Plate 2b). Erosional bases are commonly delineated by a pebble-lag conglomerate. These deposits are composed of pebbly coarse- to very coarse-grained sandstones. The sand fraction contains abundant angular quartz and feldspar grains; the gravel fraction is composed mainly of rounded quartz and granite rock fragments with minor rounded quartzite and mudstone clasts.

Figures 7a, 7b, 7c, 7d, and 7e are the grain size results of five samples from this lithofacies. All the samples show a break between bed load and suspended load, and the coarse sand modes are clearly defined.

(a) Sample T-45 Mode: -2.25ϕ, 1.25ϕ σ_I : 2.98ϕ

(b) Sample T-52 Mode: 0.25ϕ σ_I : 1.90ϕ

(c) Sample T-61 Mode: -2.0ϕ σ_I : 1.51ϕ

(d) Sample T-63 Mode: 2.0ϕ σ_I : 1.95ϕ

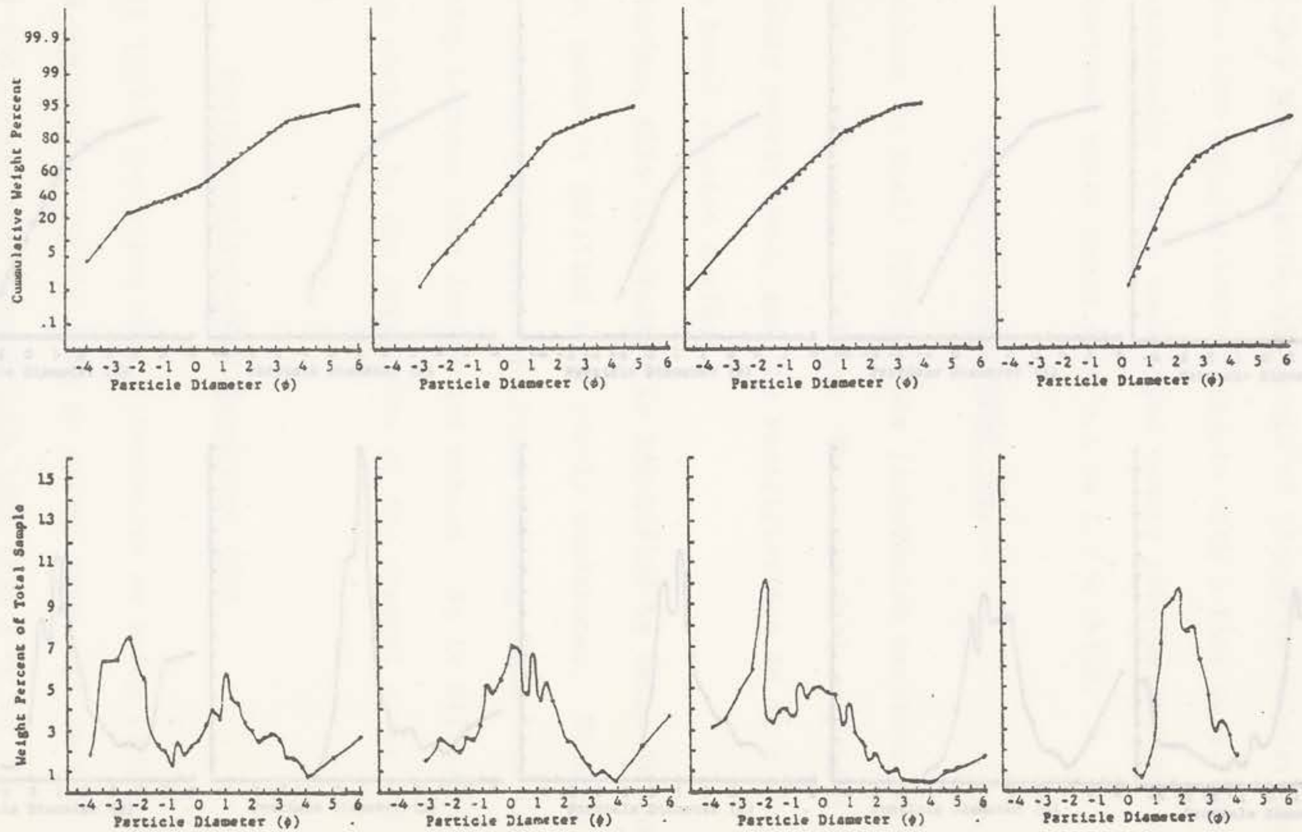


Figure 6. Cumulative and frequency curves for (a) sample T-45, (b) sample T-52, (c) sample T-61, and (d) sample T-63.

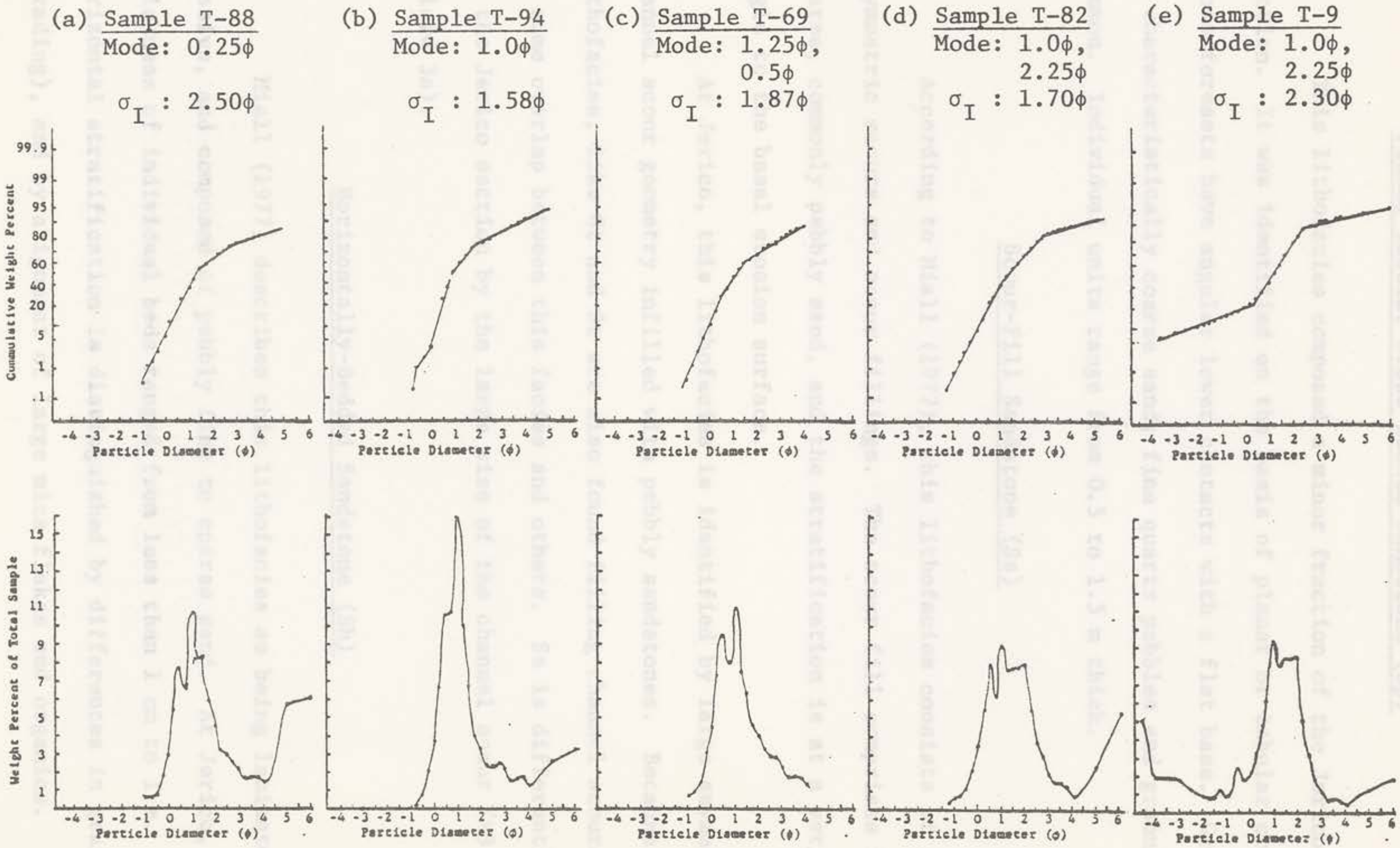


Figure 7. Cumulative and frequency curves for (a) sample T-88, (b) sample T-94, (c) sample T-69, (d) sample T-82, and (e) sample T-9.

Planar-Tabular Cross-Bedded Sandstone (Sp)

This lithofacies composed a minor fraction of the Jerico section. It was identified on the basis of planar or tabular crossbeds whose foresets have angular lower contacts with a flat base. Grain size is characteristically coarse sand; fine quartz pebbles and granules are common. Individual units range from 0.5 to 1.5 m thick.

Scour-Fill Sandstone (Ss)

According to Miall (1977), this lithofacies consists of large asymmetric scours and scour fillings. The scour fill comprises fine to coarse, commonly pebbly sand, and the stratification is at a very low angle to the basal erosion surface.

At Jerico, this lithofacies is identified by large asymmetric channel scour geometry infilled with pebbly sandstones. Because other lithofacies, like Gt and St are also found filling channel scours, there is some overlap between this facies and others. Ss is differentiated in the Jerico section by the large size of the channel scour (>3 m) (Plate 3a).

Horizontally-Bedded Sandstone (Sh)

Miall (1977) describes this lithofacies as being laminated to massive, and composed of pebbly fine to coarse sand. At Jerico, the thickness of individual beds ranged from less than 1 cm to 1 m. Horizontal stratification is distinguished by differences in grain size (grading), and by alignment of large mica flakes and organics.

Plate 3a. Large-scale channel scour and fill sandstone lithofacies (Ss) of the Jerico section of the Todos Santos Formation.

Plate 3b. Horizontally-bedded sandstone lithofacies (Sh) of the Jerico section of the Todos Santos Formation.

Two types of Sh deposits were distinguished in the Jerico section on the basis of grain size. One consists of moderately sorted fine and very fine sandstones with thinly-laminated bedding. Segregation of micas and organics is common on the bedding surfaces. The more common type of Sh deposit consists of moderately sorted coarse to very coarse sandstone with individual units that range from 0.5 to 1 m thick (Plate 3b). They, like the finer Sh units, show aligned micas on the parting planes. Another distinguishing feature of this type of Sh deposit is its pebbly character. The pebbles, which rarely exceed 2 cm in diameter, are composed predominantly of quartz with minor quartzite. This lithofacies becomes more pebbly as it grades into Gm.

Figures 8a, 8b, 8c, 8d, 8e, and 9a are grain size statistics of six samples from this lithofacies. Samples 8a through 8d are from the coarse Sh sublithofacies described above, while samples 8e and 9a are from the finer Sh sublithofacies. All six samples exhibit a sharp, unimodal sand fraction. Figures 9b and 9c are also grain size analysis of Sh deposits, however, these samples consist of alternating layers up to 1 cm thick of medium-coarse sandstone and coarse-very coarse sandstone. Thus, the results show the stratification bimodality.

Ripple Cross-Laminated Sandstone (Sr)

A variety of asymmetric ripple types generated by ripple migration characterize lithofacies Sr: solitary ripple trains, small scale (<5 cm) trough and planar cross-bedding, and climbing ripples (Miall, 1977). In the Jerico section, this lithofacies most commonly

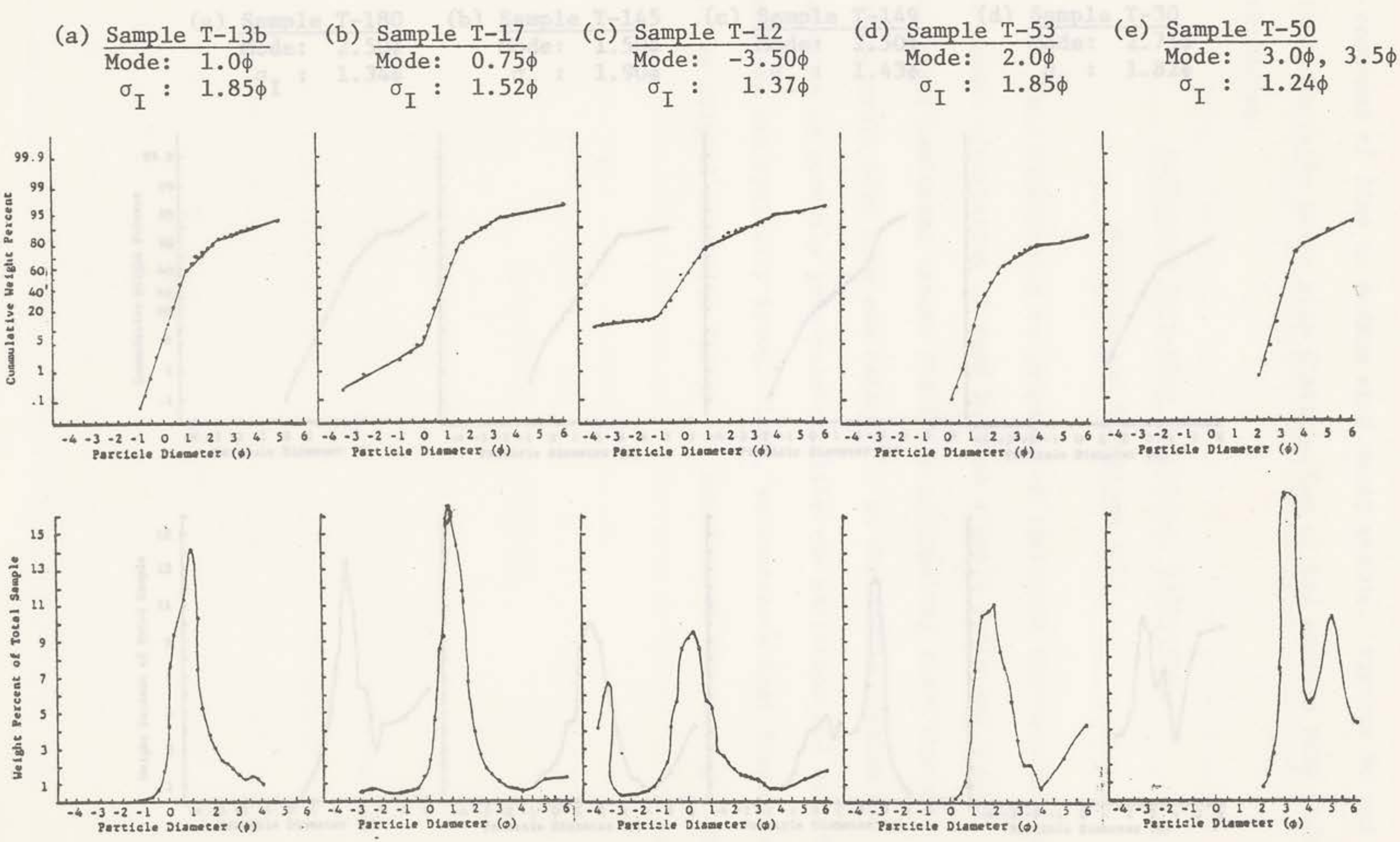


Figure 8. Cumulative and frequency curves for (a) sample T-13b, (b) sample T-17, (c) sample T-12, (d) sample T-53, and (e) sample T-50.

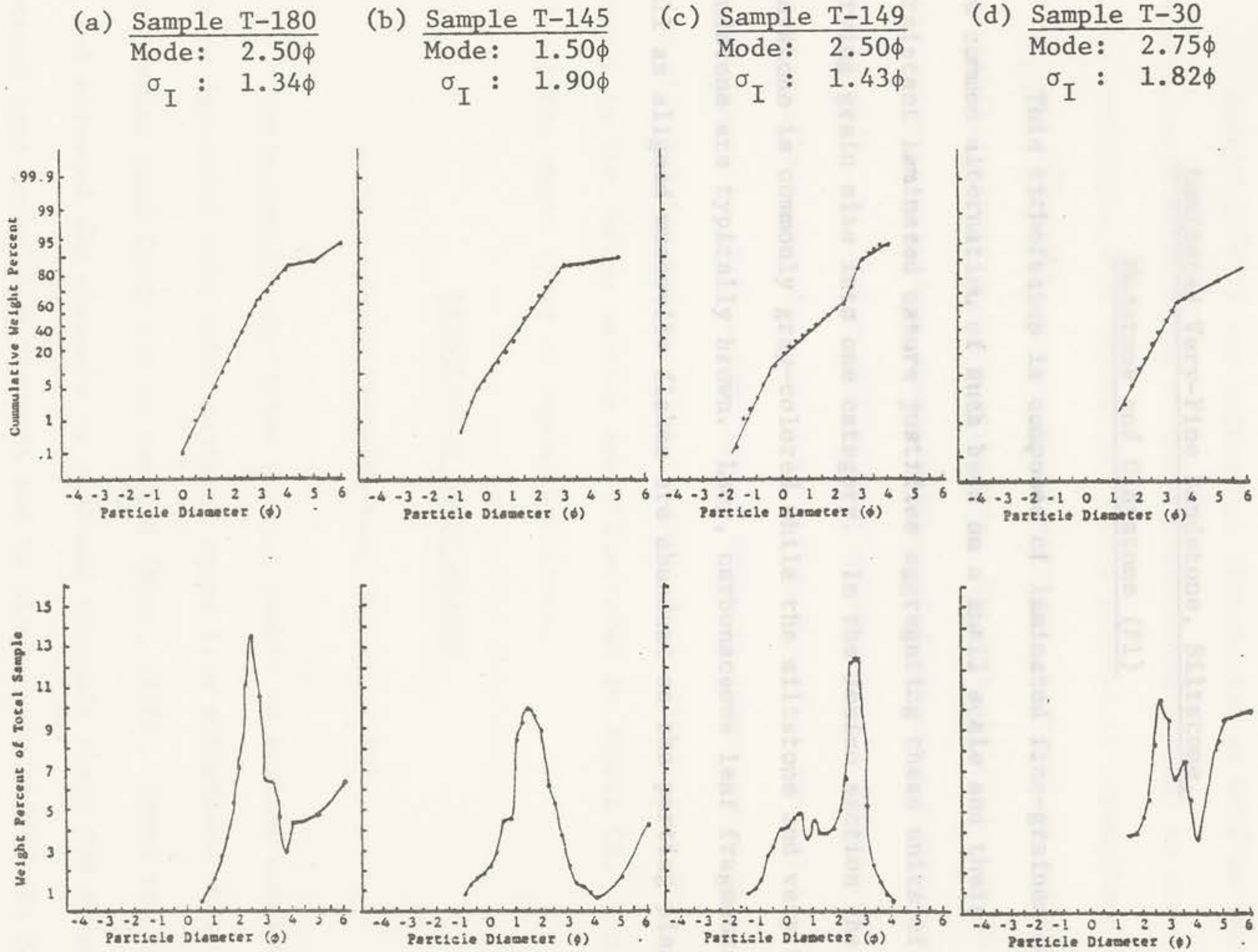


Figure 9. Cumulative and frequency curves for (a) sample T-180, (b) sample T-145, (c) sample T-149, and (d) sample T-30.

is composed of fine to medium sand sized grains. Figures 9c and 9d show a characteristic grain size distribution of two samples from this lithofacies.

Laminated Very-Fine Sandstone, Siltstone, Mudstone and Claystone (Fl)

This lithofacies is composed of laminated fine-grained deposits. The common alternation of such beds on a small scale and their persistant laminated nature justifies aggregating these units of varying grain size into one category. In the Jerico section the claystone is commonly gray-colored while the siltstone and very fine sandstone are typically brown. Lacy, carbonaceous leaf fragments as well as aligned muscovite flakes are abundant on the parting planes.

LITHOFACIES ASSOCIATIONS AND DEPOSITIONAL ENVIRONMENTS

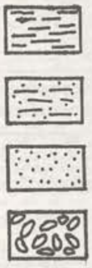
Examination of the individual lithofacies as well as the characteristic association of these lithofacies invokes an understanding of the environments of deposition. This process is strengthened by comparison with other stratigraphic sections, both modern and ancient, with similar lithofacies associations. By this operation, three main lithofacies associations characteristic of distinct environments were identified in the Jerico section of the Todos Santos Formation: (a) streamflood deposits; (b) debris flow deposits; and (c) braided stream deposits. This assemblage of deposits commonly occurs together in an alluvial fan system. The characteristic lithofacies associations present in the Jerico section are illustrated in Figure 10. A discussion of the three types of deposits follows.

Lithofacies Associations

Streamflood Deposits (Gm, Sh, minor St)

Horizontally stratified massive pebble to boulder conglomerates can be deposited only under confined rapid flow situations where upper flow regime conditions can be reached (Rust, 1978). These are typical of (a) alluvial fan channels or pediment channels where the stream is incised into underlying deposits and in which storm waters are concentrated from the drainage area into a surge flood; (b) of interfan streams which concentrate the runoff from adjacent fans; and (c) of

<u>LITHOLOGIC SYMBOLS</u>



Claystone

Siltstone

Sandstone

Conglomerate

<u>COLOR</u>

R Reddish-brown

G Gray

B Buff

<u>OTHER</u>

P Pedogenic carbonate nodules

L Carbonized leaf fragments

C Carbonized wood

T Tree fragments

<u>LITHOFACIES</u>

Gm Massive to crudely-bedded conglomerate

Gms Matrix-supported conglomerates

Gt Trough cross-bedded conglomerates

St Trough cross-bedded sandstones

Sp Planar cross-bedded Sandstones

Ss Scour-fill sandstones

Sh Horizontally-bedded sandstones

Sr Ripple cross-laminated sandstones

Fl Laminated fine-grained deposits

Figure 10a. Symbols used in Figures 10b, 10c, 10d, and 10e.

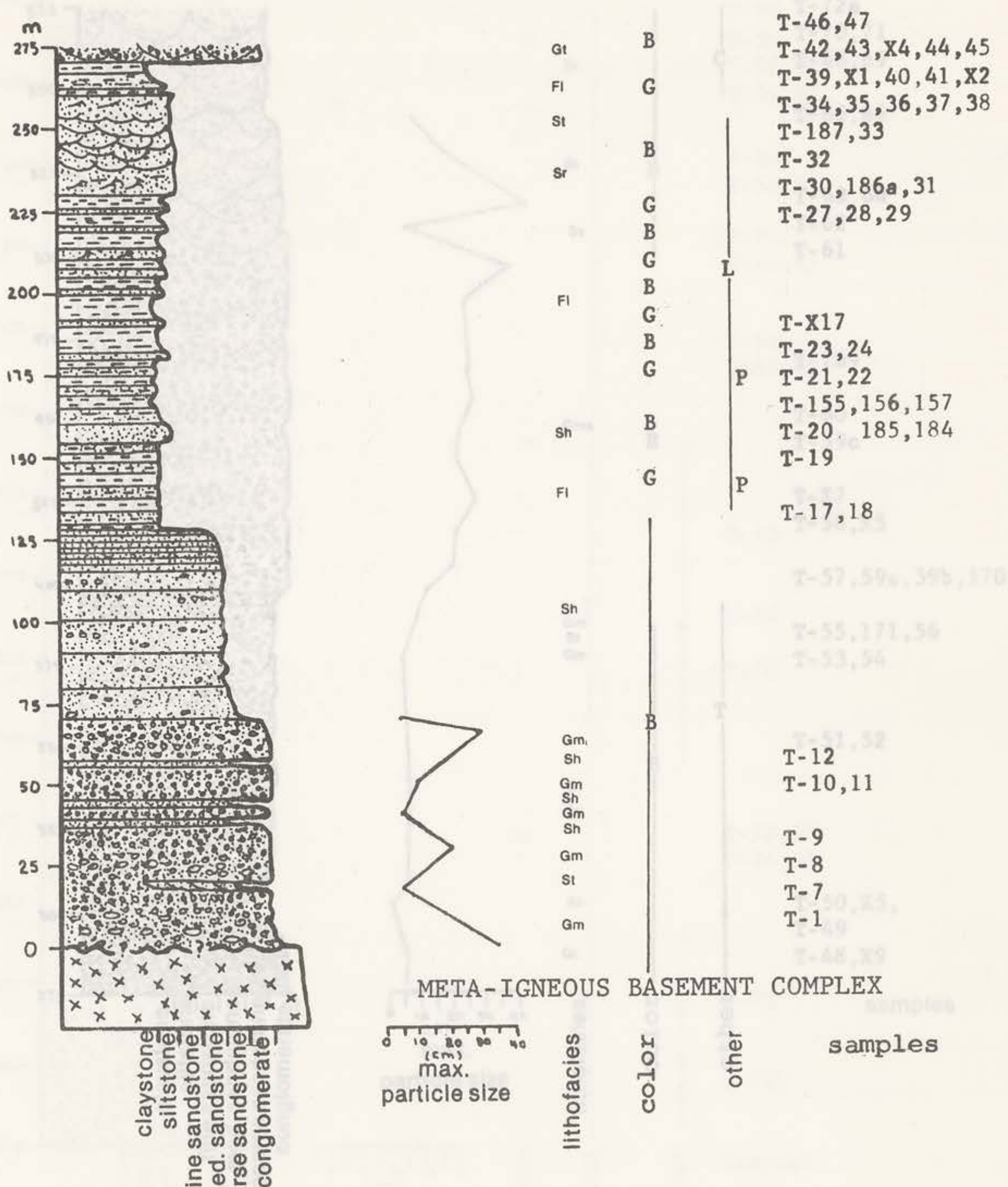


Figure 10b. Composite stratigraphic section of the Todos Santos Formation, Jerico, Chiapas.
Interval: 0-275 m above base.

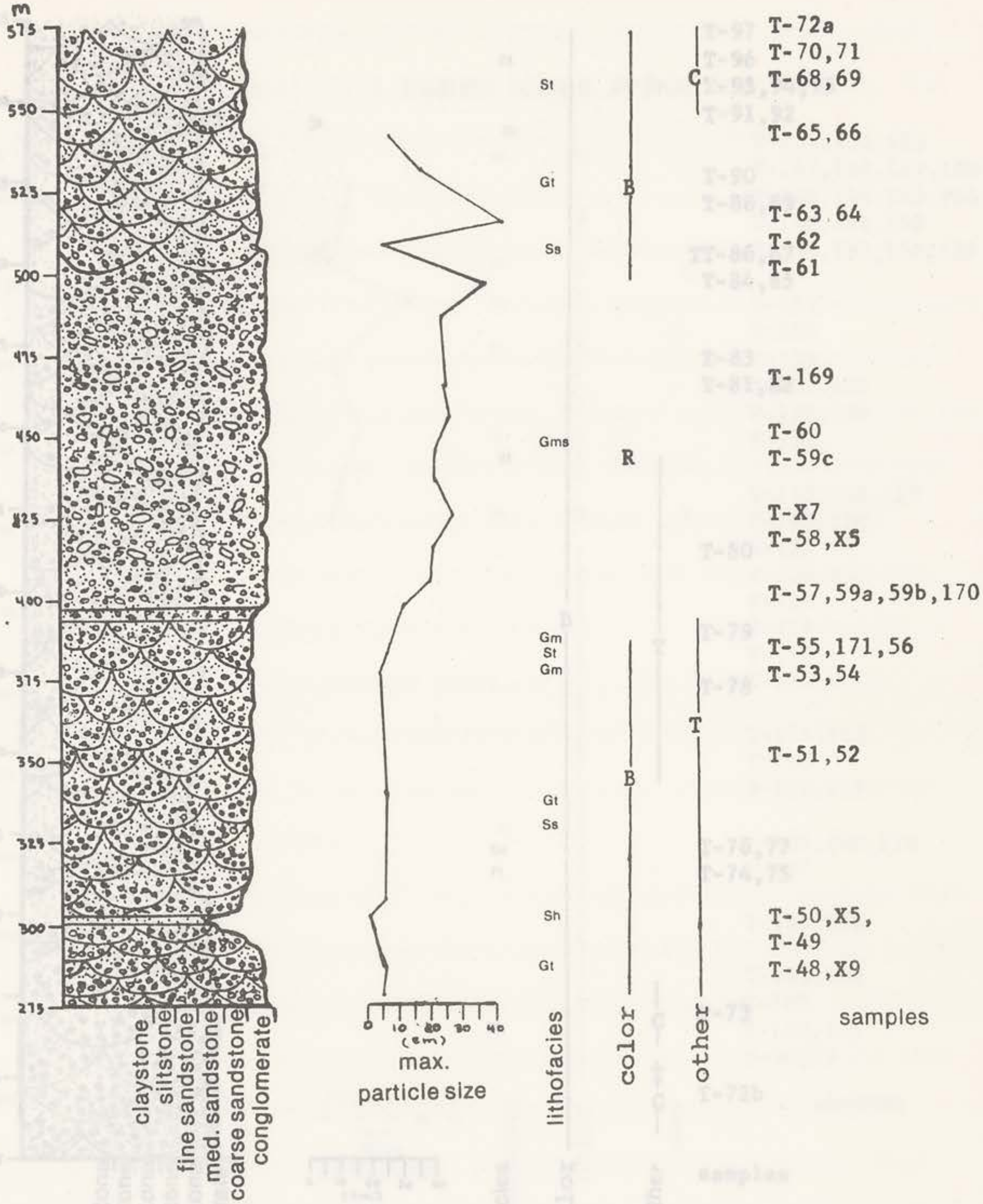


Figure 10c. Composite stratigraphic section of the Todos Santos Formation, Jerico, Chiapas.
Interval: 275-575 m above base.

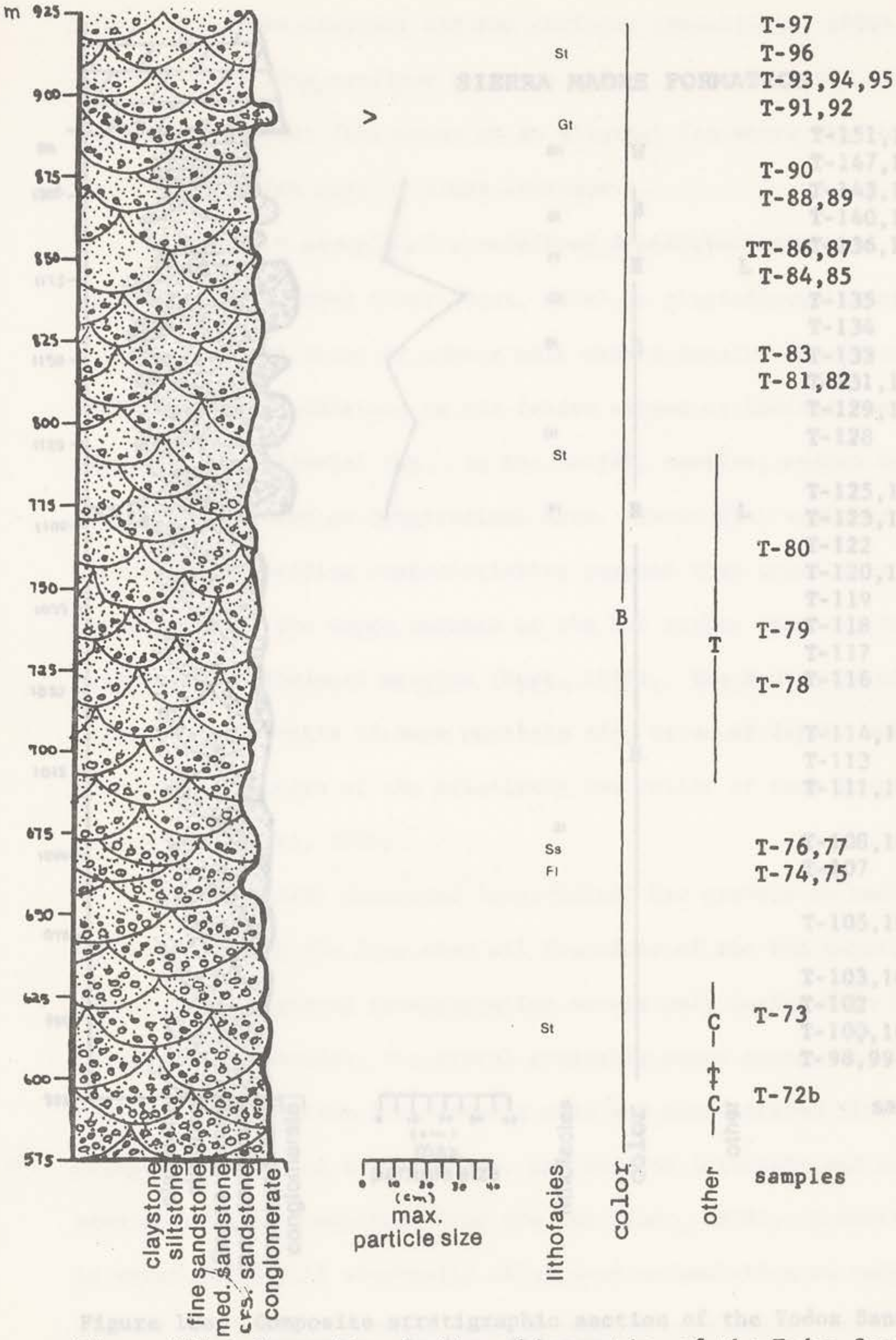


Figure 10d. Composite stratigraphic section of the Todos Santos Formation, Jerico, Chiapas.
Interval: 575-925 m above base.

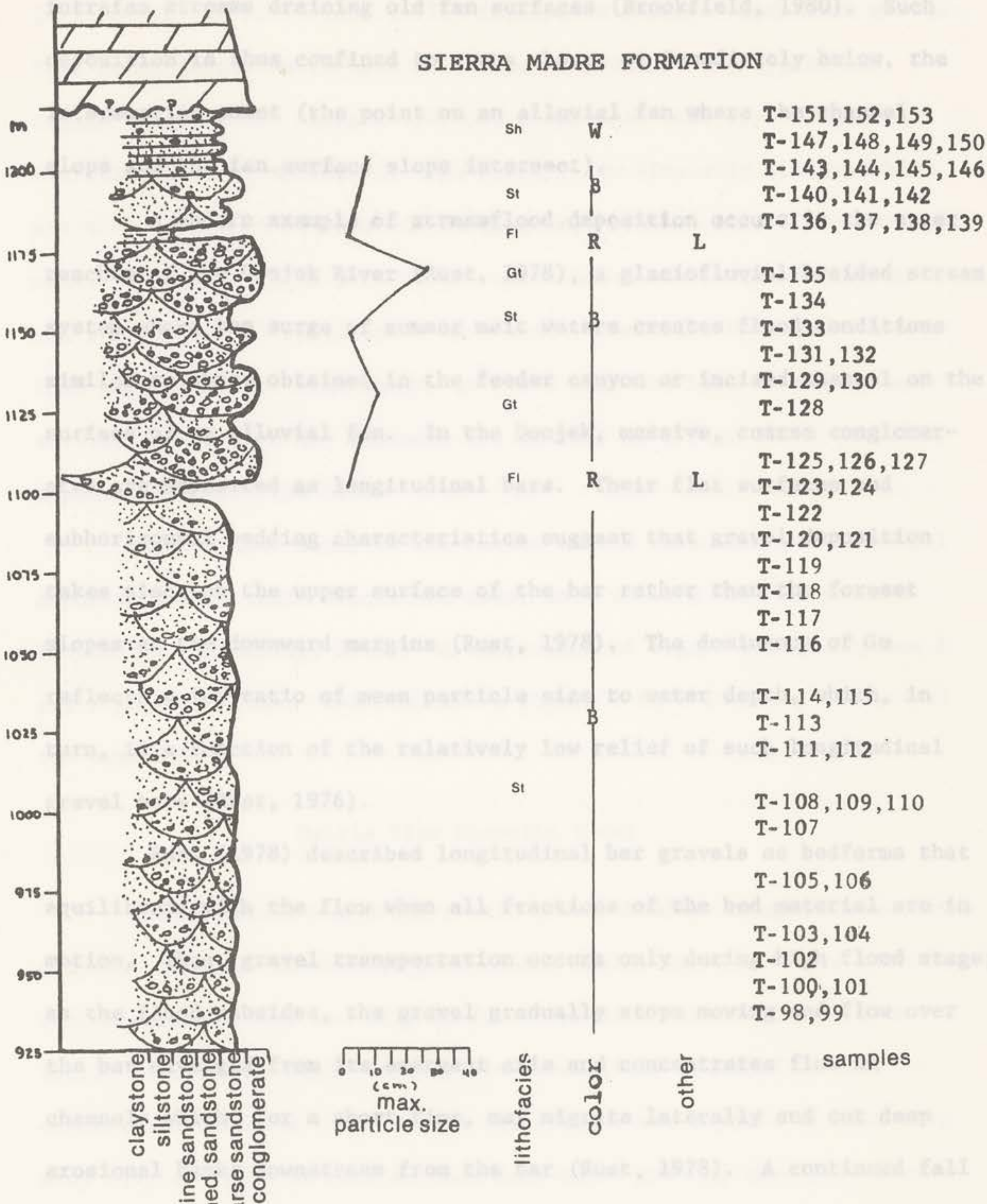


Figure 10e. Composite stratigraphic section of the Todos Santos
Formation, Jerico, Chiapas.
Interval: 925-1218 m above base.

intrafan streams draining old fan surfaces (Brookfield, 1980). Such deposition is thus confined to areas above, or immediately below, the intersection point (the point on an alluvial fan where the channel slope and the fan surface slope intersect).

A modern example of streamflood deposition occurs in the upper reaches of the Donjek River (Rust, 1978), a glaciofluvial braided stream system where the surge of summer melt waters creates flood conditions similar to those obtained in the feeder canyon or incised channel on the surface of an alluvial fan. In the Donjek, massive, coarse conglomerates are deposited as longitudinal bars. Their flat surfaces and subhorizontal bedding characteristics suggest that gravel deposition takes place on the upper surface of the bar rather than the foreset slopes at the downward margins (Rust, 1978). The dominance of Gm reflects a low ratio of mean particle size to water depth, which, in turn, is a function of the relatively low relief of such longitudinal gravel bars (Rust, 1976).

Rust (1978) described longitudinal bar gravels as bedforms that equilibrate with the flow when all fractions of the bed material are in motion. Thus, gravel transportation occurs only during high flood stage; as the flood subsides, the gravel gradually stops moving and flow over the bar diverges from its emergent axis and concentrates flow in channels which, for a short time, may migrate laterally and cut deep erosional banks downstream from the bar (Rust, 1978). A continued fall in water level will eventually allow sand accumulation as wedges to bar margins which build outward to form sets of high angle cross-stratification, or as upper flow regime horizontal sand beds (Rust, 1978; Miall, 1973). Miall (1973) interprets massive sandstones of the Peel Sound Formation to have been deposited under such upper flow regime conditions. Allen (1970) has shown that this type of flow is characteristic of relatively high energy, low sinuosity streams which are most likely to be found in the proximal reaches of a river environment. Consequently, a lithofacies association of Gm with St and Sh can result from a depositional environment conducive to streamfloods. This association of lithofacies is found near the base of the Jerico section (units 1 to 15, Appendix I), as well as 375 to 385 m (unit 25, Appendix I) above the base.

Streamflood deposits are better sorted than most other fluvial deposits due to their deposition under more uniform flow conditions (Boothroyd and Ashley, 1975). A comparison of Figure 8 with Figures 6 and 7 supports this. The samples in Figure 8 have lower σ_I values and are unimodal.

Debris Flow Deposits (Gms)

Muddy matrix-supported pebble-cobble-boulder conglomerates (Gms) comprise 120 m of the middle part (units 26-30, Appendix I) of the Jerico section. Gms can only be deposited as a viscous debris flow (Bull, 1972). The high velocity flow conditions required to move cobbles and boulders in a fluvial environment are capable of winnowing away clay and silt as well as most sand-sized grains, thus producing a Gm deposit instead. Supportive evidence from the Jerico outcrops of debris flow deposition for Gms units includes: the presence of angular brittle clasts of mudstone, schist, and limestone, which would not have survived fluvial transportation; the lack of oriented clasts; the presence of randomly aligned muscovite flakes; the nonerosional base of individual Gms deposits, and their characteristic red color which is indicative of a highly oxidizing subaerial environment.

The coarse Gms deposits in the Jerico section are commonly 30 cm to 1 m thick. Adjacent flows are separated by thin (10-20 cm) beds of red muddy matrix-supported fine pebble conglomerates, red muddy sandstones, and white nonmuddy sandstones. While the coarse debris flows overlie beds without an erosional scour, a pronounced erosional scour is commonly apparent between the coarse debris flow and its overlying units (Plate 1b). This relationship has been observed in other debris flow deposits (Sharp and Nobles, 1953; Miall, 1970). Sharp and Nobles (1953) described these minor sandstone interbeds as being deposited by less violent waters at the tail end of a flood or by occasional noncatastrophic floods over alluvial fan surfaces that were probably devoid of surface run-off most of the time.

Bull (1972) suggests three factors which promote debris flows: (a) abundant water supply over a short period of time, (b) steep slopes having insufficient vegetative cover to prevent erosion, and (c) a source material that provides a muddy matrix. Hewald (1978) further suggests a fresh build-up of debris on the feeder canyon floor, resulting from landsliding, slumping, and rain and rill wash. The most common setting capable of fulfilling these requirements is a semi-arid region of high relief. Debris flows build-up in the proximal portion of the alluvial fan, above or just below the intersection point (Hooke, 1967).

Hooke (1967) demonstrated the importance of source rock lithology on debris flow generation by comparing deposits from the Trollheim fan, which are predominantly of debris flow origin, to those of the Shadow Rock fan, which contain no debris flows. These two fans are located very close together in the Deep Springs Valley of California. Both have similar relief and were deposited under the same climatic conditions. The only difference between the two is source rock. The Shadow Rock fan, which has a resistant quartzite source, contains no debris flows. In contrast, the Trollheim fan, whose source is a sandy dolomite, is composed predominantly of debris flows.

Miall (1973) suggests that Bull's (1972) third criterion, the presence of mud-sized grains in the source area, is not a rigid requirement. The Devonian alluvial fan debris flows he studied contained less than 1% mud. Lustig (1965) reports less than 10% mud in the debris flow deposits he studied in California. Bull (1964) reports 30% mud in the debris flows near Fresno, California. In comparison, grain size analysis of four debris flow samples from the Jerico section contain 27%, 17%, 18%, and 12% mud respectively.

Braided Stream Deposits (Gt, St, Sp, Ss, Fl)

Braided stream deposits are formed by low sinuosity alluvial channels through the process of lateral and vertical accretion along with channel cutting and abandonment (Brookfield, 1980). Characteristics of braided stream deposits are: (a) cut and fill structures; (b) abundance of large-scale cross stratification; (c) rapid lateral variations in texture; (d) abundant fining-upward sequences; and (e) pebble to coarse sand grain size range. The most common lithofacies of the braided stream deposits of the Jerico section include channel fill deposits (Ss); trough cross-bedded sandy fine pebble conglomerates (Gt); trough cross-bedded pebbly sandstones (St); planar cross-bedded pebbly sandstones (Sp); and laminated fine-grained (sandstone, siltstone and mudstone) overbank deposits (Fl).

Most preserved braided stream deposits occur below the intersection point of an alluvial fan where hydraulic conditions become less conducive to transporting materials (Collinson, 1978). Collinson (1978) suggests that cut and fill deposition is initiated here by lateral expansion and shallowing which leads to a fall in shear stress and to lower stream competency and capacity. Deposition occurs on longitudinal bars, in channel scours, as migrating transverse bars, and in overbank areas. Longitudinal bars and large-scale channel scours are indicative of higher gradient streams, while transverse bars and overbank deposits occur farther downstream from the source area where the gradient lessens. This change downstream is also generally accompanied by a change in grain size from pebbles and granules to sand.

Thick, preserved Fl overbank deposits are characterized by climbing ripple lamination, small-scale cross-bedding, graded fine sand to silt, finely laminated mudstones, and an abundance of plant debris (Reineck and Singh, 1975). The critical factor in preserving overbank sediments in a vertical section is the nature and frequency of channel migration over a particular point on the alluvial plain in relation to the overall subsidence rates (Collinson, 1978). Thus, the best chance for overbank Fl preservation is when the overall rate of subsidence exceeds sedimentation.

Braided stream deposits comprise most of the Todos Santos Formation at Jerico. A 125 m portion near the base of the section (units 16 to 21, Appendix I) is composed of Fl and fine-grained St and Ss. It contains abundant fining-upwards sequences of very fine sandstone, siltstone, and mudstone. The sandstones and siltstones are brown and the mudstones are gray. Carbonized plant fragments are abundant on parting planes. Two horizons of pedogenic carbonate nodules are present within this unit, suggesting long periods of nondeposition in a semi-arid environment.

A 100 m portion in the lower part of the Jerico section (units 22 to 24, Appendix I), as well as the entire upper half of the section (units 31 to 34, Appendix I), are composed of predominantly pebble-granule conglomerates and pebbly coarse sandstones of braided stream origin. Abundant trough cross-bedding and channel fills are recognized.

A large portion of the Jerico section (upper 500 m) is poorly exposed. Where seen, the sedimentary structures consisted of trough cross-bedded sandstones with grain size similar to the St units immediately below. The uppermost 20 m of the section appears to be horizontally bedded with thin (1 cm) alternating layers of medium-coarse, and coarse-very coarse sandstone. The mineral composition and grain-size parameters of this unit suggest it to be also of braided stream origin.

Depositional Environments

The Todos Santos Formation at Jerico was deposited as an arid alluvial fan system by high-gradient, short-duration ephemeral streams which transported gravel, sand, and mud through a feeder canyon which opened out onto an alluvial plain. The alluvial fan system can be divided into three facies: proximal, mid-fan, and distal (McGowen and Groat, 1971). The proximal facies consists of rocks deposited within the high-gradient channels of the feeder canyon and upper alluvial fan above the intersection point; the mid-fan facies comprises rocks deposited at or immediately below the intersection point where the gradient is still high, but much less so than in the proximal reaches; the distal facies is composed of rocks deposited at the toe of the fan where the gradient is much lower than that of the mid-fan facies. Distinct lithofacies associations form in the different parts of the alluvial fan system as a consequence of these hydrodynamic differences. They are diagnosed on the basis of grain size, sedimentary structures, and geometry.

Proximal Fan Facies

The proximal fan facies is characterized by debris flows, streamflood deposits, and large-scale channel scours. Deposition occurs mainly within the feeder canyon and incised channels of the upper alluvial fan. Deposition is in response to torrential precipitation, where debris flows are initiated or flood surges occur, resulting in coarse gravel deposition and large-scale channel erosion. This facies consists mainly of conglomerates, with minor amounts of sandstone. The sandstone takes the form of trough crossbeds accreted onto the side of longitudinal gravel bars as the flood wanes, as horizontally bedded coarse upper regime deposits, or as channel fill.

Mid-Fan Facies

The mid-fan facies is characterized by sandy streamflood deposits, cut and fill sandy pebble and granule trough cross-bedded conglomerates of braided stream origin, and pebble conglomerate and coarse sandstone channel fill deposits. Deposition of this facies occurs at, or immediately below the intersection point where incised channels open up to a laterally extensive braided stream system. Because a stream loses its competency upon emergence at the intersection point, cobbles, and boulders are rare in the mid-fan facies. Sandy pebbly and granular conglomerates predominate.

Deposition in the mid-fan area occurs as longitudinal bars, in channel scours, and as tranverse migrating dunes. Pebbly conglomerates are deposited as longitudinal bars. As the bars are accreted, stream flow is diverted, and scouring occurs along the side of the bar (McGowen and Groat, 1971). During the waning stages of a flood, sand is deposited as horizontal sheets or as channel fills. Migrating transverse dunes are deposited under quieter flood conditions.

Distal Fan Facies

The distal fan facies of the Todos Santos Formation can be divided into two subfacies: (a) main braided channel and (b) braided distributary. This facies is distinguished from the others by the general lack of gravel and by thinner sets, suggestive of shallow, lower-gradient streams.

The main braided channel subfacies is characterized by pebbly-granular coarse to very coarse sandstones, which are either trough- or planar cross-bedded in sets 20 cm to 1 m thick. They represent lower energy deposits than those found in the higher reaches of the fan.

The braided distributary subfacies is composed of fine to very fine, thin trough cross-bedded and ripple-laminated sandstones interbedded with laminated siltstone, mudstone, and claystone. The trough cross-bedded sandstones represent the sluggish, but active tract of the distributary channel, while the mud-sized sedimentary rocks are indicative of overbank deposition. According to McGowen and Groat (1971), the braided stream distributary system begins where the slopes of the fan and the main braided channel become equal; at this point the flow breaks into numerous small braided channels that radiate outward across the toe of the fan.

SUCCESSION OF DEPOSITIONAL ENVIRONMENTS

Analysis of the succession of depositional environments of a vertical sequence of strata elucidates information leading to an understanding of the paleogeography as well as the tectonic setting at the time of deposition of that sequence. In this chapter, the succession of depositional environments of the Jerico section of the Todos Santos Formation, as well as the contacts that confine the unit, will be examined. The generalized succession of depositional environments for the composite section (AA'), as well as for an important subsidiary section (BB') are illustrated in Figure 11.

Lower Contact

The base of the Todos Santos Formation was not seen in the Jerico section. The lowermost exposures of the unit, consisting of coarse clast-supported conglomerate (Gm) are located in a stream bed near the main road that connects Tuxtla Gutierrez and Revolucion Americana (base of section AA', Figure 3). Immediately upstream are a great quantity of granite cobbles, pebbles, and boulders; further upstream are granite outcrops. The lower contact is either a fault between granitic massif rocks and the Todos Santos (Lopez Ramos, 1975), or it is a nonconformity.

The lowermost 220 m of the composite section are absent in a subsidary section 3 km southeast along strike from the stream bed where

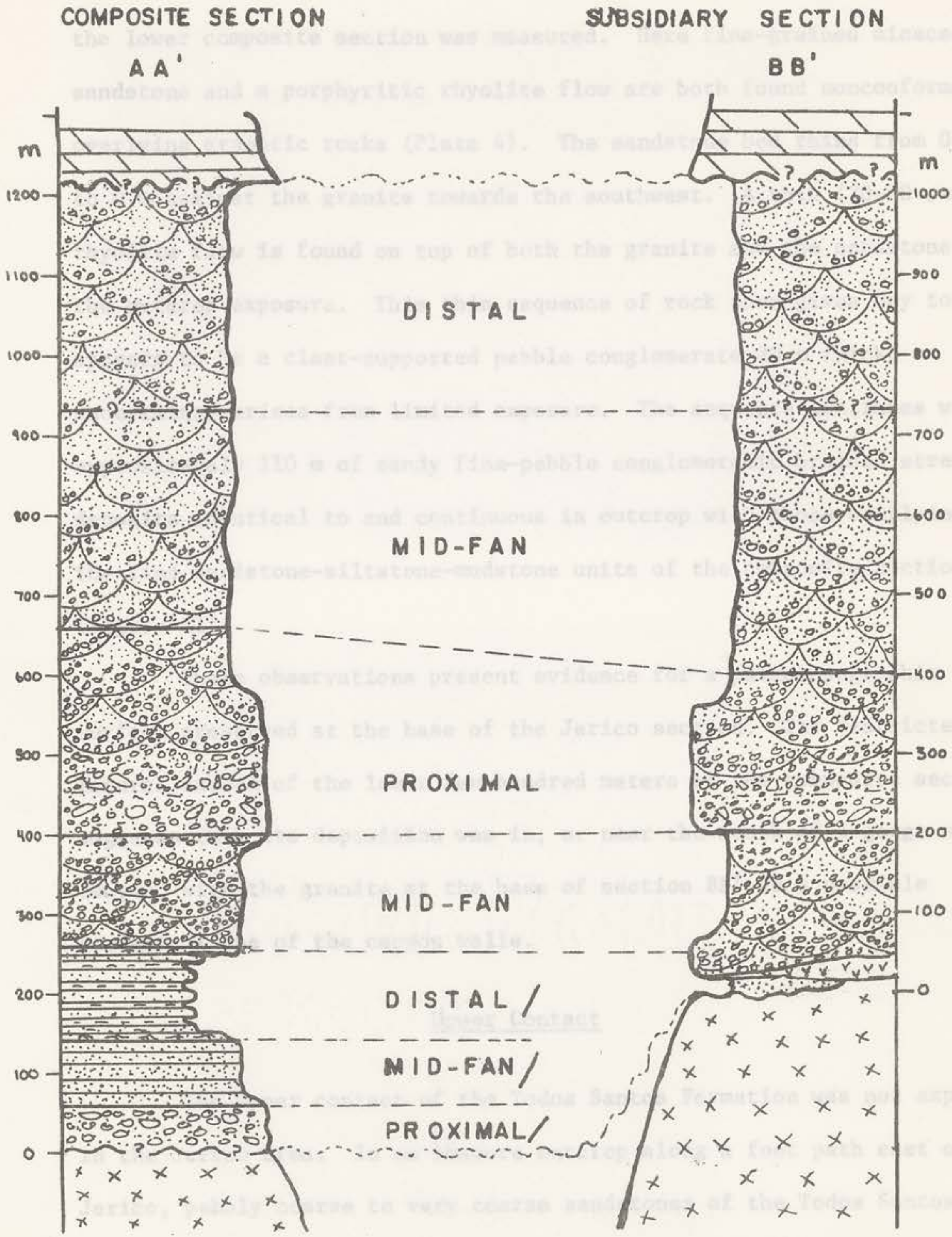


Figure 11. Facies succession in the composite section (AA'), and a subsidiary section (BB') of the Todos Santos Formation, Jerico, Chiapas.

the lower composite section was measured. Here fine-grained micaceous sandstone and a porphyritic rhyolite flow are both found nonconformably overlying granitic rocks (Plate 4). The sandstone bed thins from 0.5 m to 0 m against the granite towards the southwest. A thin (20-30 cm) rhyolite flow is found on top of both the granite and the sandstone in the outcrop exposure. This thin sequence of rock then gives way to what appears to be a clast-supported pebble conglomerate 20 m thick; uncertainty arises from limited exposure. The sequence continues with approximately 110 m of sandy fine-pebble conglomeratic braided stream deposits identical to and continuous in outcrop with those overlying the fine sandstone-siltstone-mudstone units of the composite section (Figure 11).

These observations present evidence for a paleotopographic surface preserved at the base of the Jerico section. The restricted lateral extent of the lower few hundred meters of the composite section suggests that its deposition was in, or near the mouth of a gorge or canyon, with the granite at the base of section BB' as a possible remnant of one of the canyon walls.

Upper Contact

The upper contact of the Todos Santos Formation was not exposed in the Jerico area. In an obscure outcrop along a foot path east of Jerico, pebbly coarse to very coarse sandstones of the Todos Santos Formation were separated from a dolomite breccia of the overlying Sierra Madre Formation by less than 1 m. This breccia is the lowermost unit of the Sierra Madre Formation throughout the study area.

Plate 4a. Nonconformable contact between granite of the Chiapas massif and fine-grained sandstone of the Todos Santos Formation. Located at base of subsidiary section BB' (Figures 3 and 11).

Plate 4b. Nonconformable contact between granite of the Chiapas massif and a porphyritic rhyolite flow. Located at the base of subsidiary section BB' (Figures 3 and 11). In this same vicinity, the granite and porphyritic rhyolite flow are separated by a fine-grained sandstone (Plate 4a).

Succession of Depositional Environments

Analysis of the vertical succession of depositional facies of the Todos Santos Formation in the study area reveals two proximal to distal alluvial fan transitions (Figure 11). They are separated by a distal to proximal transition.

The lower proximal to distal transition shows a gradual change from cobble-boulder conglomerates through coarse, horizontally bedded pebbly sandstones, to the distal main braided channel subfacies, and finally to a relatively thick (100 m) section of braided distributary subfacies. This lowermost mega-fining-upwards sequence has a limited lateral extent in the southeast direction. The lateral extent to the northwest is uncertain due to lack of exposure.

Immediately overlying the distal facies in the composite section, and above the granite/thin sandstone/volcanics in the subsidary section, is a thick (110 m) sequence of coarse sandy granule pebbly conglomerate of mid-fan facies. This sequence grades vertically upwards into proximal streamflood (10 m) and then into a thick (110 m) unit of debris flow deposits. This mega-coarsening-upwards sequence indicates fan progradation. Above the debris flows are extremely large channel scours (Plate 3a) and gravel channel fills also of the proximal facies. This sequence suggests erosion by the channel into the debris flow deposits in order to lower the steep debris flow gradient.

Six hundred meters of braided stream deposits of mid-fan and distal facies overlie these proximal debris flows and channel fills. The change in predominant grain size from pebbles and granules to coarse sand, accompanied by a higher quartz to feldspar ratio is evidence for the facies change from mid-fan to distal fan within this interval. This mega-fining-upwards sequence indicates fan recession. The Sierra Madre Formation unconformably(?) overlies this succession.

PALEOCURRENTS

Paleocurrent Data

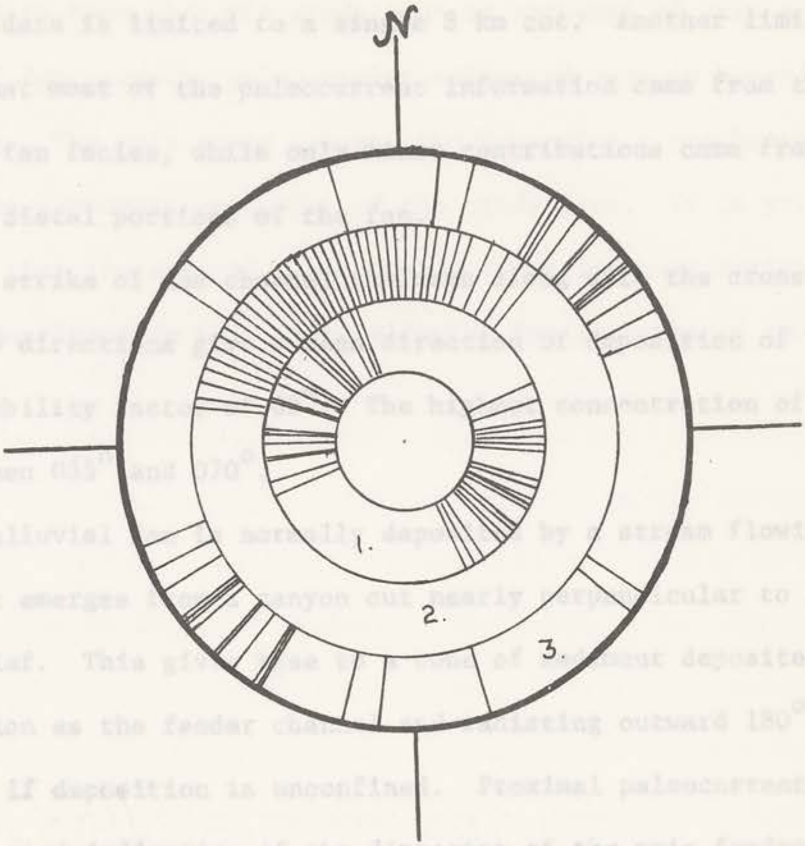
Paleocurrent information from the Jerico section of the Todos Santos Formation was obtained from (a) the orientation of the thalweg of medium to large channel scours (greater than 2 m in width and 1 m in depth), (b) large-scale cross-bedding, and (c) from the orientation of the long axes of detrital logs. The most reliable source of paleocurrent directions came from measuring the strike of the thalweg of channel cuts (Figure 12, ring 3).

Although large-scale crossbedding is abundant in the Jerico section, only apparent paleocurrent directions were obtained due to poor exposure. However, this data is of value because it determines an azimuth value for the thalweg strikes (Figure 12, ring 2). The density and orientation of these readings in Figure 12 largely reflects outcrop orientation.

Paleocurrent information obtained from the orientation of log fragments, which were abundant in the lower braided stream deposits, indicates that they align subperpendicular to the thalweg strikes, or subperpendicular to the direction of flow (Figure 12, ring 1).

Interpretation

Although the number of paleocurrent readings taken at Jerico are enough to make generalizations about alluvial fan deposition, the



1. Log orientations (19)
2. Crossbed directions (40)
3. Channel thalweg orientations (17)

Figure 12. Paleocurrent data from the Todos Santos Formation, Jerico, Chiapas.

limits to the data should first be clarified. The biggest limiting factor is that the paleocurrent data were obtained from a limited lateral outcrop area. No "down-fan" data could be obtained, and "cross-fan" data is limited to a single 8 km cut. Another limiting factor is that most of the paleocurrent information came from the braided mid-fan facies, while only minor contributions came from the proximal or distal portions of the fan.

The strike of the channel thalwegs along with the cross-bed apparent dip directions give a mean direction of deposition of 060°, with a variability factor of 60°. The highest concentration of data occurs between 035° and 070°.

An alluvial fan is normally deposited by a stream flowing in a channel that emerges from a canyon cut nearly perpendicular to a scarp of high relief. This gives rise to a cone of sediment deposited in the same direction as the feeder channel and radiating outward 180° in a semi-circle if deposition is unconfined. Proximal paleocurrent data will give a good indication of the direction of the main feeder channel. Data from the proximal facies of the Todos Santos at Jerico gives a range of 008° to 070°, suggesting that the strike of the scarp was northwest-southeast. This trend is similar to that of the Chiapas massif.

Normally mid-fan and distal fan paleocurrents should show greater variability than that of the Todos Santos at Jerico. A possible explanation for this is that the data are limited in number and aerial extent. This contention is strengthened by examination of the lateral variation in thickness of the debris flow unit of the section (Figure 4).

The trend of the cross-section is approximately parallel to the proposed strike of the scarp, making this a "cross-fan" section. A thinning trend from 120 m to 36 m over a distance of 8 km is apparent. This is interpreted to mean that the study area is composed of only a part of an alluvial fan, and the paleocurrent collected here is biased accordingly. The only three channel thalwegs with a northwest trend are from the northwest extremity of the study area. It is probable, therefore, that the exposed Todos Santos Formation near Jerico represents the southeastern half of an alluvial fan at least 16 km wide.

MINERALOGY AND PROVENANCE

Mineralogy

The mineralogy of the Todos Santos Formation was determined by examination of conglomerate clasts in the field, and by modal analysis of sandstones in thin sections. Conglomerate clast lithologies fell into three main assemblages, based on the mode of deposition and the stratigraphic position of the conglomerate. The lower fluvial conglomerate sequence contains pebbles and cobbles of granite, porphyritic rhyolite, milky quartz, and purple quartzite (Figure 13). In the upper fluvial conglomerates, pebbles of milky quartz and granite are most abundant. The debris flow conglomerates show the most variety of lithologic types. Pebbles and cobbles of granite, porphyritic rholite, milky quartz, and purple quartzite predominate, but phyllitic mudstone, gneiss, limestone, schist, chert, and sandstone are abundant locally (Figure 13).

A thin section modal analysis of 27 representative sandstone samples from the Jerico section was obtained by point-counting 700-900 counts per slide (Table 1).

Quartz (30-86%) is the most abundant mineral present in all samples. The majority of the quartz fragments are semi-composite polycrystalline grains. Smaller monocrystalline grains with straight to slightly undulose extinction are also common. Inclusions of zircon, tourmaline, rutile, and gas bubbles are abundant. All quartz grains are angular.

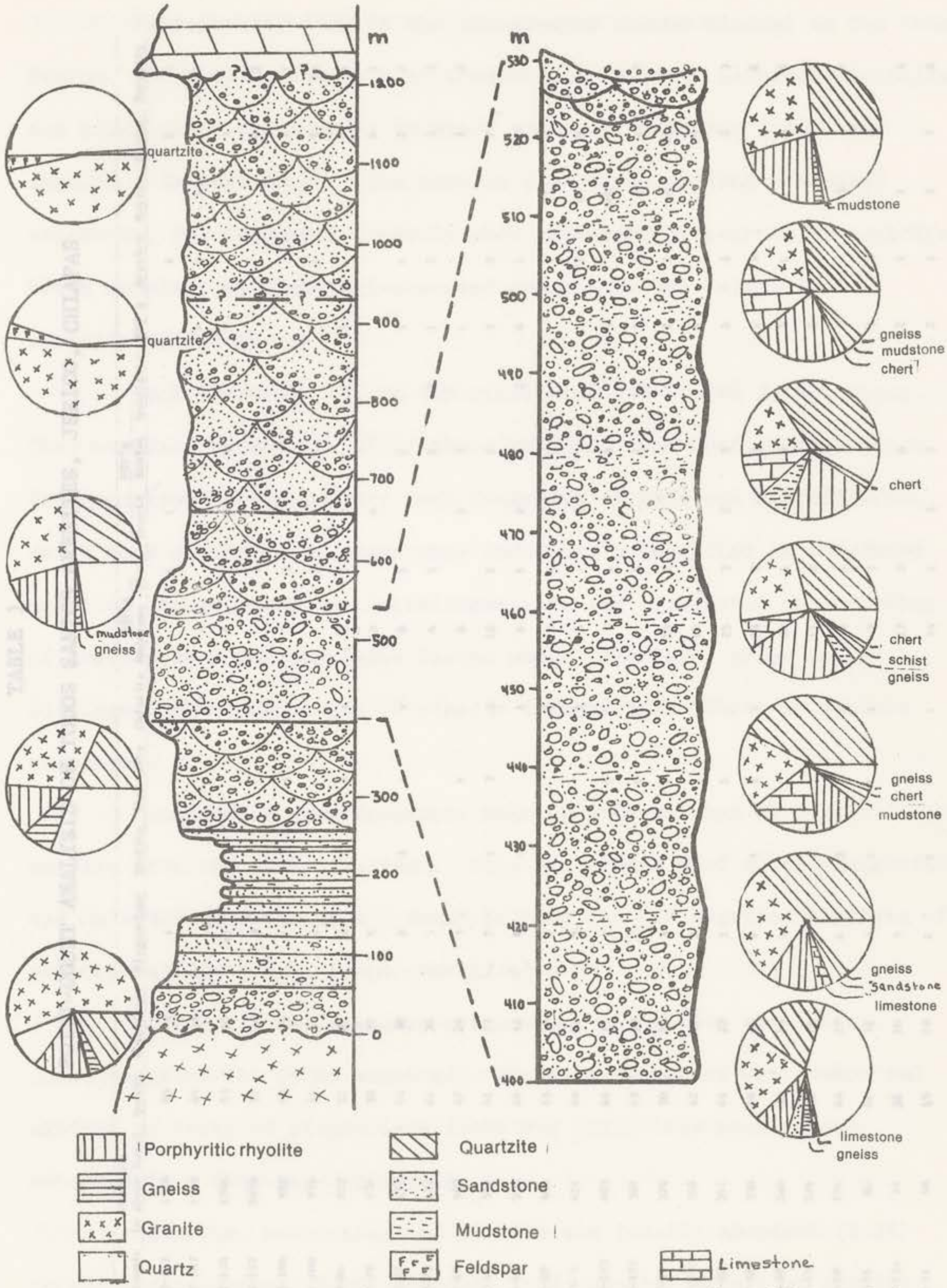


Figure 13. Conglomerate clast lithology versus stratigraphic position of the composite section of the Todos Santos Formation, Jerico, Chiapas.

TABLE 1

POINT-COUNT ANALYSIS OF TODOS SANTOS ARENITES, JERICO, CHIAPAS

Sample	Position (m above base)	Quartz	K-feldspar	Plagioclase	Biotite	Muscovite	Chlorite	SRF's Mudstone	SRF's Chert	MRF's Quartz	MRF's Schist	MRF's Quartzite	VRF's	Heavies	Matrix	Cement	Porosity
T-151	1216	86	4	1					1	1				1		2	5
T-147	1204	65	14					2		1			1	1	5		11
T-124	1106	53	10	15	1			4	1	2	8		3			3	
T-112	1030	55	30	2					1	1						9	2
T-106	988	58	25	t		t		3	3	1						3	7
T-100	946	54	19	1					2		2			t		9	11
T-86	852	52	22	1	1	1	t	6	1	3			2			7	4
T-79	734	38	27	5				15		4						6	5
T-77	672	46	30	1	1	t	t	8	2		2		1	t		2	7
T-73	622	41	36	3				6	1		3	2	1	1		3	3
T-69	560	47	26	3		t		8		1	3		t			7	5
T-64	522	41	27	2	t	3	2	12	1		3		1	1		7	
T-62	504	44	18	4	t		t	4	1	1	4	2	6	1		15	
T-60	446	45	9	1			1	6	t	1	5			1	23	8	
TX-5	424	40	21	2			1	6	1	6			3	2	10	8	
T-170	403	44	17	1		t		5	1		3		3		26		
T-171	388	49	19	2		t	t	11	2		5		2	t	5	2	3
T-54	374	30	20	3		t		10	1			2	7	1	2	24	
T-53	368	42	22	2		t		10	4				1	1		19	
T-52	351	46	12	1		1		25	3	1	3		1	1		3	3
T-51	350	49	16	1	t	1	t	18	2		6		2	1			4
T-48	280	54	13	1		t		12	1		9		2	t		3	5
T-43	274	43	16	1	t			11	2		6		2			11	3
T-18	124	40	27	4	2	t	t	12	1		3		2		5		4
T-14	86	44	31	3	t	1	t	9	1		3		2	2		4	
T-13a	74	36	20	3				17	2		8		2	1	7		4
T-11	58	45	19	1	t	t	t	14	1	1	3		2	1	2	7	4

Feldspar (10-39%) is the second-most common mineral in the Todos Santos. Orthoclase is the most predominant feldspar although microcline and plagioclase are present in minor amounts. Feldspar grains are angular. Because many of the samples are collected from weathered exposures, the feldspars commonly show extensive alteration to sericite. Fresh samples, as with well-cemented ones, show only slightly sericitized feldspars.

Rock fragments are an important fraction of the Jerico rocks. They comprise between 5-35% of these samples. The most abundant rock fragment type is sedimentary rock fragments of mudstone and siltstone. While many of these fragments were undoubtedly deposited as indurated detrital clasts, many are intraformational and originated by reworking of previously deposited Todos Santos muds. The later group is distinguished on the basis of plastic deformation. Chert is a minor component.

Metamorphic rock fragments make up greater than 5% of most samples from the Jerico section. They are composed of quartz-muscovite and chlorite schist, while a small part of the MRF fraction consists of polycrystalline quartz (meta-quartzite).

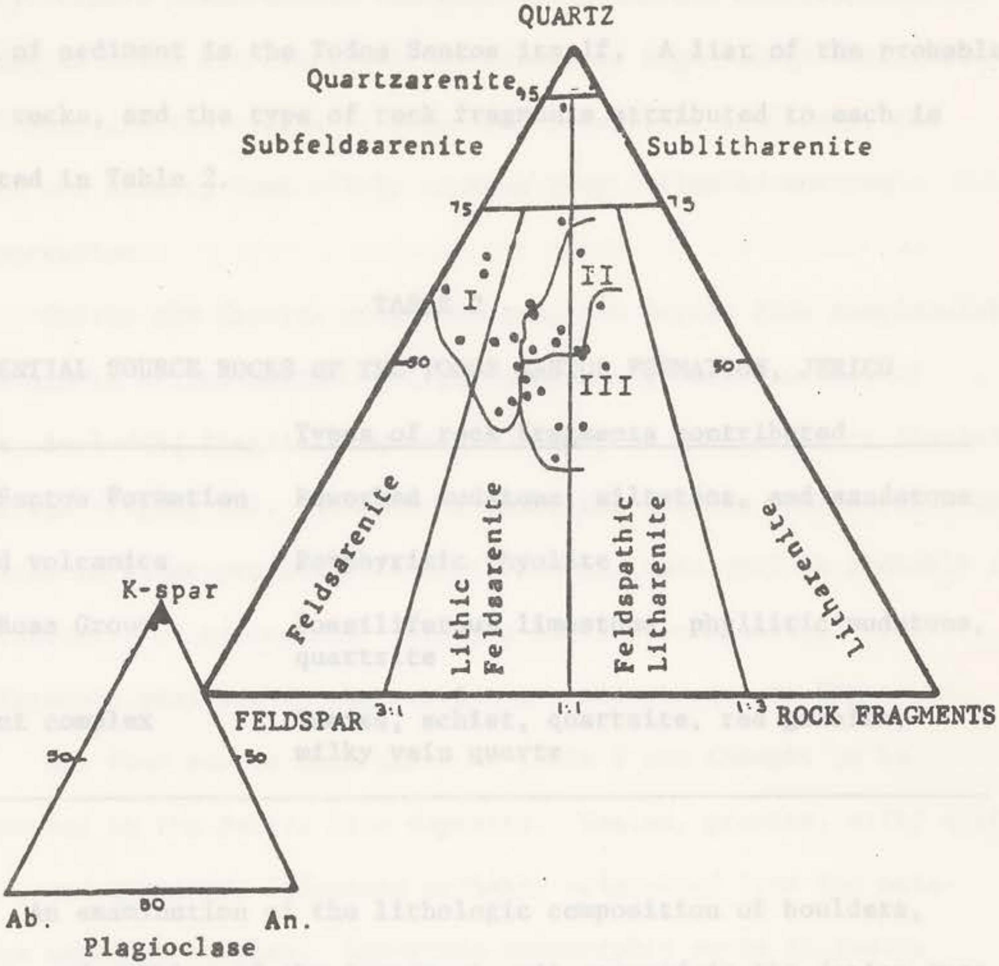
Volcanic rock fragments are a minor (1-7%) but persistent constituent of the rocks examined. Rhyolite fragments are common and exhibit an array of plagioclase laths and orthoclase phenocrysts embedded in a fine-grained matrix.

Chlorite, muscovite, and biotite are locally abundant (1-2%) in the Todos Santos. Heavy minerals (<1%) consist mainly of angular zircon and euhedral tourmaline. Garnet, rutile, hematite, and magnetite are also common.

The sandstone modal analysis presented in Table 1 was used to calculate the relative proportions of quartz, feldspar, and rock fragments, following the procedure of Folk, Andrews, and Lewis (1971). The results are illustrated on a quartz-feldspar-rock fragment ternary diagram (Figure 14). The bulk of the sandstones of the Jerico section fall into the lithic feldsarenite, feldspathic litharenite, and feldsarenite categories. The upper part of the section, above the debris flow sequence (Group III of Figure 14), is more feldspathic, and the lower part (Group I and II of Figure 14) is more lithic-rich.

Provenance

Provenance information for the Todos Santos at Jerico can be determined by combining paleocurrent information with the compositional data from sandstones and conglomerates. The Todos Santos in the Jerico area was transported from south-southwest by channels which emerged from the highlands onto an alluvial plain. The source area is in the direction of the now exposed plutonic and metamorphic rocks of the Chiapas massif. Although now uncovered in central Chiapas, the meta-igneous complex comprising the Chiapas massif is covered and flanked by the late Paleozoic Santa Rosa Group in the Comalapa anticlinorium of southeastern Chiapas. The anticlinorium plunges to the northeast from there. This rock group, along with the meta-igneous basement complex, are considered as probable sediment sources for the Todos



Group I   Arenites from above the debris flow sequence
Group II   Arenites from the debris flow sequence
Group III Arenites from below the debris flow sequence

Figure 14. Mineralogic composition of arenites from the Todos Santos Formation, Jerico, Chiapas.

Santos. An additional source is volcanic rocks (rhyolite) which precede, and are interbedded with the Todos Santos Formation. Another source of sediment is the Todos Santos itself. A list of the probable source rocks, and the type of rock fragments attributed to each is presented in Table 2.

TABLE 2

POTENTIAL SOURCE ROCKS OF THE TODOS SANTOS FORMATION, JERICO

Source	Types of rock fragments contributed
Todos Santos Formation	Reworked mudstone, siltstone, and sandstone
unnamed volcanics	Porphyritic rhyolite
Santa Rosa Group	Fossiliferous limestone, phyllitic mudstone, quartzite
Basement complex	Gneiss, schist, quartzite, red granite, milky vein quartz

An examination of the lithologic composition of boulders, cobbles, and pebbles of the lowermost unit exposed in the Jerico area (Figure 13) suggests that the channel network had already exposed the granitic batholith rocks of the Chiapas massif. This is evidenced by an abundance of granite and milky quartz fragments within this conglomerate. An abundance of porphyritic rhyolite clasts indicates the presence of volcanics in the source area also. Quartzite, possibly from the Santa Rosa Group or from the meta-igneous basement complex, is the other major clast component in this conglomerate.

As would be expected from the suggested fluvial transport history, clasts found in the lowermost conglomerate are composed of lithologies which are relatively resistant to high energy transportation. Nonresistant clasts of mudstone, limestone, sandstone, and schists are absent, most likely because they failed to survive transportation.

Unlike the fluvial conglomerates, the debris flow conglomerates in the middle of the Jerico section contain a greater variety of clasts, including fragile fragments unlikely to persist under fluvial conditions (Figure 13). Because of this, and because debris flows are deposited in close proximity to their source, this unit is probably the best indicator of provenance. Changes in clast composition with stratigraphic position in the section are illustrated in Figure 13.

All four source rock units of Table 2 are thought to be represented in the debris flow deposits. Gneiss, granite, milky quartz, schist, and quartzite fragments probably originated from the meta-igneous basement complex. Low-grade metamorphic rocks including phyllitic mudstone and possibly quartzite fragments, suggest Santa Rosa provenance.

Fossiliferous limestone clasts were found which contain fusulinids, brachiopods, and bryozoans. They are probably derived from the Chochal Formation of the Santa Rosa Group. Dr. Merlynd K. Nestell of the University of Texas at Arlington supported this conclusion by identifying silicified specimens of the genus Parafusulina sapperi (Staff), a Permian (Leonardian) fusuline, in one of the clasts.

Curiously, this species was originally described from the Chochal Formation of Guatemala (Dunbar, 1939), but was not found by Thompson and Miller (1944), who studied the fusulinid fauna of southernmost Chiapas.

Porphyritic rhyolite similar to that interbedded in the Todos Santos of Jerico is also a common constituent of the debris flow conglomerates. Minor amounts of intraformational red beds were also identified in thin sections of the sand fraction of the debris flow sands.

A plot of position above the base of the debris flow unit versus clast lithology is presented in Figure 15. This graph illustrates the availability of the different clasts with time. The middle area of the graph shows that all four potential source rock

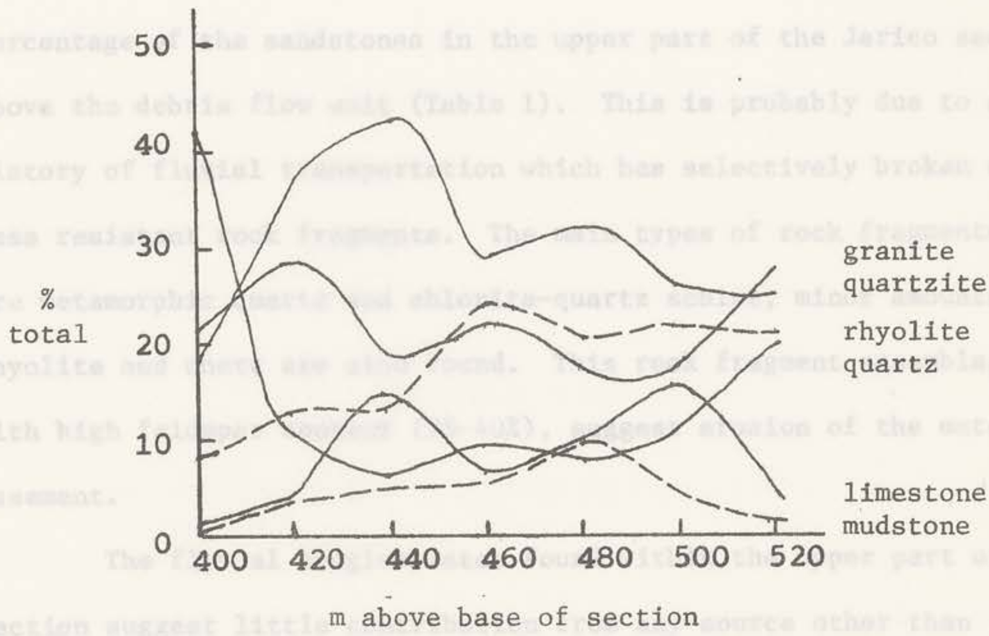


Figure 15. Conglomerate clast lithology versus stratigraphic position within the debris flow sequence of the Todos Santos Formation, Jerico, Chiapas.

units were probably present during deposition of these debris flows. A gradual decrease of limestone, phyllitic mudstone, and quartzite, along with an increase in granite and milky quartz fragments towards the top of the debris flow unit, suggests that the exposures of the Santa Rosa Group in the source area were diminishing as the drainage basin became more and more entrenched into the massif.

The diminution of mudstone outcrops in the source area may have played a part in the termination of debris flow deposits on the alluvial fan. Within the Santa Rosa Group are thick horizons of mudstones (Tactic Formation) (Clemons and others, 1974). A build-up of weathered Tactic mudstone in a position of high relief under semi-arid climatic conditions must have been an ideal setting for generating debris flows after torrential rainfalls.

Except for mudstone clasts, rock fragments make up only a small percentage of the sandstones in the upper part of the Jerico section, above the debris flow unit (Table 1). This is probably due to a longer history of fluvial transportation which has selectively broken down the less resistant rock fragments. The main types of rock fragments present are metamorphic quartz and chlorite-quartz schist; minor amounts of rhyolite and chert are also found. This rock fragment assemblage, along with high feldspar content (25-40%), suggest erosion of the meta-igneous basement.

The fluvial conglomerates found within the upper part of the section suggest little contribution from any source other than the massif (Figure 13). The clasts are composed almost entirely of granite and quartz pebbles. Complete uncovering of the Chiapas massif had occurred by the time of deposition of the upper portion of the Jerico section.

DIAGENESIS

The cements in many of the samples collected are absent because of extensive surface weathering of the outcrops investigated. When present, the cementing agent is one of three types: clay, clay-chert, or calcite.

Clay Cement

Most clay present in the rocks examined is detrital in origin, but a small amount may have been added by diagenetic alteration of feldspar minerals. The clay was deposited in two forms: as intraformational mudstone clasts, and as individual particles originally suspended in the stream water. Both modes of clay are responsible for binding large parts of the Jerico section as a result of compaction, which squeezed the mud into intergranular areas where it then hardened, bonding the sediment together in a fashion similar to concrete. Intraformational mudstone clasts are common in the braided stream deposits at Jerico; matrix mud is common to the debris flows.

Clay-Chert Cement

Chert cement occurs primarily as intergrowths in small patches within the detrital clay fraction of muddy braided stream and debris flow deposits from the Jerico section. It is commonly associated with strained monocrystalline and polycrystalline quartz grains that exhibit corroded edges (Plate 5a).

Plate 5a. Photomicrograph illustrating chert intergrowths within detrital clay matrix of sample T-11 from the Jerico section of the Todos Santos Formation. Note corroded quartz grain margins. Magnification: 12X

Plate 5b. Photomicrograph illustrating typical calcite cementation of arenites from the Jerico section of the Todos Santos Formation. Magnification: 3X

Dapples (1972) suggests two possible sources for chert cement. One is from partial dissolution of strained quartz. Because chert has a lower free energy than strained quartz, it is the more stable form of SiO_2. Migration of the SiO_2 from the surface of the detrital quartz grains results in a corroded appearance. Crystallization of chert within the matrix expands the clay, welding it to the quartz grain. The other possible source for chert cement comes from recrystallization of detrital clay minerals with a resultant release of SiO_2. Under these conditions, the matrix is not expanded, and the quartz is not corroded.

Because corroded quartz grains are common in the chert-cemented samples from Jerico, it appears that the source of at least some of the SiO_2 composing the chert cement came from dissolution of the nearby detrital quartz grains.

Calcite Cement

Calcite fills pores and replaced matrix muds, feldspars, and, less commonly, polycrystalline and strained quartz grains (Plate 5b). In all thin sections studied, calcite cementation was secondary. Calcite is a common cement in unweathered samples from Jerico, but has been removed from the weathered samples of similar horizons. It is probably a more common cement in the Todos Santos Formation than the samples from Jerico would indicate. A very likely source for calcite cement is the limestone and dolomite of the overlying Sierra Madre Formation.

Hematite and Limonite

The samples collected from Jerico are commonly colored red from hematite or yellowish brown from limonite. Only in very localized occurrences are either of these two iron minerals found as cements. Hematite-stained rocks are mainly restricted to the debris flow sequence at Jerico, where the hematite occurs intimately with the mud fraction of these sediments. Most of the braided stream deposits are stained yellowish-brown with limonite. The limonite occurs as an inconsistent stain over the outcrops. Whereas the hematite stain originated soon after the time of deposition of the debris flows, the limonitic stain is probably a result of weathering after the Todos Santos was uplifted and exposed.

Magnetite, illmenite, pyrite, chlorite, and biotite, all present in the plutonic and metamorphic source rocks, are a probable source of iron responsible for the coloration of Todos Santos Formation. Magnetite, ilmenite, chlorite, and biotite are also detrital constituents of the Todos Santos. Whether the iron minerals coloring these sediments resulted from the <u>in situ</u> breakdown of unstable iron silicates (Walker, 1967), or from the aging of detrital iron hydroxides (Van Houten, 1968), could not be determined. Possibly both mechanisms were active.

Diagenetic Quartz Frosting

The uppermost 20 m of the Jerico section consisted of frosted, sugary, quartz-rich sandstones. Grains from some samples of this unit were examined with the Scanning Electron Microscope (SEM) to determine the cause of frosting. The SEM revealed surfaces that were interpreted as being the result of chemical etching. This chemical attack on the quartz was probably caused by weak basic solutions acting over a long period of time, which entered the Todos Santos Formation from the Sierra Madre Formation immediately above.

PALEOGEOGRAPHY

Age of Deposition

Fossil material is sparse in the Todos Santos Formation at Jerico. Carbonized leaf remains are present on parting planes in the F1 lithofacies, and carbonized-calcified, and silicified tree fragments are present in parts of the braided stream deposits, however, none are preserved well enough for identification.

Better results came from a palynologic investigation of some gray mudstones and claystones from the F1 lithofacies. Seven samples (T-165, T-158, T-156, T-23, T-27, T-35, and T-41) from the 125 to 265 m interval above the base of the Jerico section were examined by R. A. Christopher of the United States Geological Survey for palynomorphic remains. The lowermost sample (T-165) and the uppermost sample (T-41) were barren. Thirty-five different genera were recovered from the intervening samples. The list of palynomorphs identified by Dr. Christopher, as well as their stratigraphis position and range within the Jerico section, are presented in Figure 16.

According to Dr. Christopher:

> All five palynologic assemblages from the Todos Santos Formation are similar in both their composition (see Figure 1(1b)) and their dominant forms, with Corollina torosus, Monosulcites spp., Equisetosporites spp. and trilete spores with verrucae or wart-like sculptural elements (e.g., Verrucosisporites spp., Rubinella, spp., Converrucosisporites spp., Leptolepidites spp.) as common elements. None of these are biostratigraphically important in identifying strata of either Jurassic or Cretaceous age.

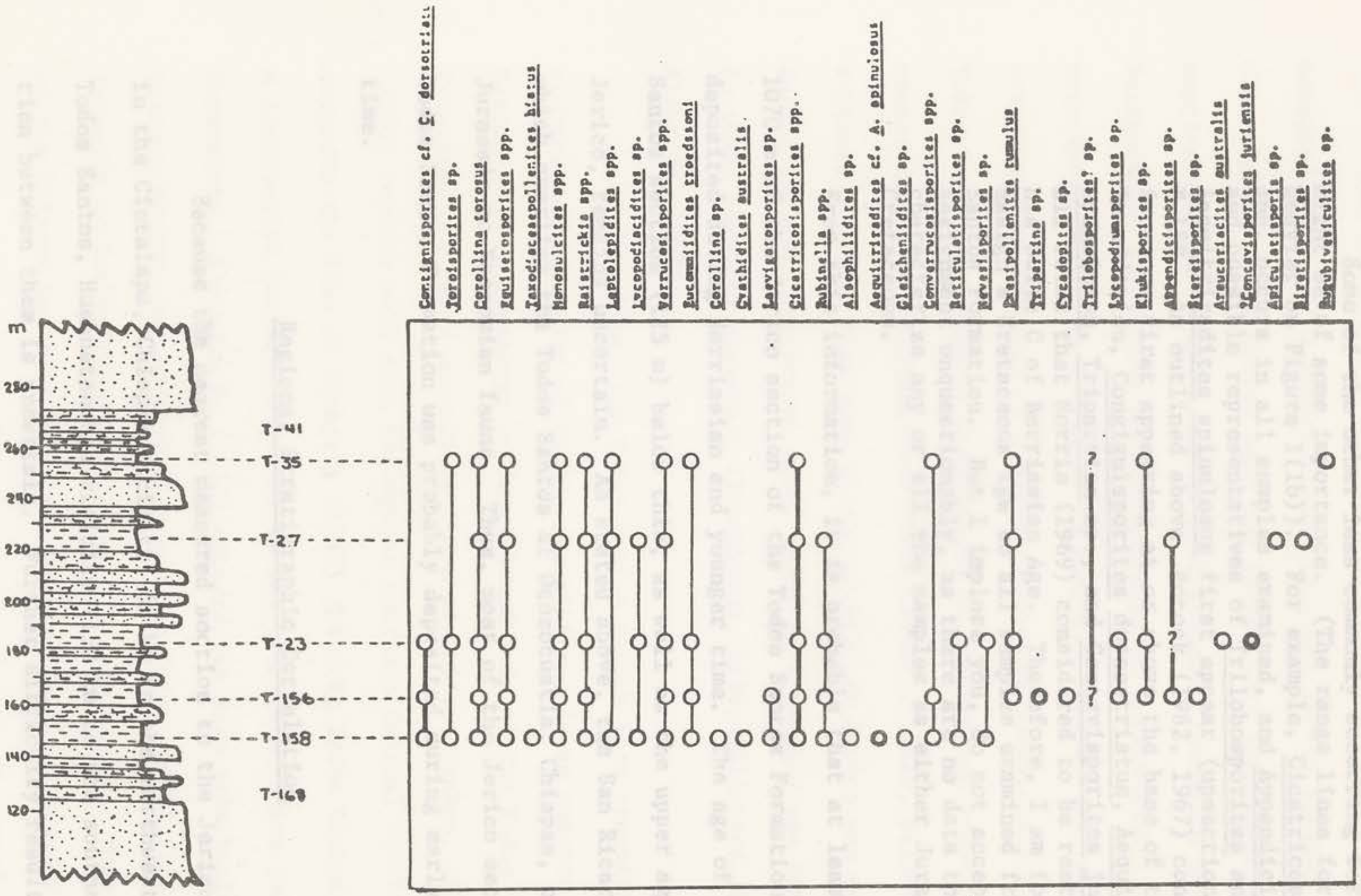


Figure 16. Palynomorphs from the braided distributary subfacies of the Todos Santos Formation, Jerico, Chiapas.

Some of the other less commonly occurring forms, however, might be of some importance. (The range lines for these are heavier on Figure 1(1b)). For example, Cicatricosisporites spp. occurs in all samples examined, and Appendicisporites sp., and possible representatives of Trilobosporites and Aequitriradites spinulosus first appear (upsection) in sample T-158. As outlined above, Pocock (1962, 1967) considered these forms as first appearing at or above the base of the Cretaceous. In addition, Congignisporites dorsostriatus, Aequitrira spinulosus, Tripartina sp., and Concavisporites juriensis are all forms that Norris (1969) considered to be restricted to his Suite C of Berriasian Age. Therefore, I am forced to assign a Cretaceous age to all samples examined from the Todos Santos Formation. But I implore you, do not accept this age assignment unquestionably, as there are no data that positively characterize any or all the samples as either Jurassic or Cretaceous.

From this information, it is probable that at least the upper 1070 m of the Jerico section of the Todos Santos Formation were deposited during Berriasian and younger time. The age of the Todos Santos section (125 m) below this, as well as the upper age limit at Jerico, remains uncertain. As stated above, the San Ricardo Formation, which overlies the Todos Santos at Ocozocuatla, Chiapas, contains Jurassic to Neocomian fauna. Thus, most of the Jerico section of the Todos Santos Formation was probably deposited during early Neocomian time.

Regional Stratigraphic Correlation

Because the nearest measured section to the Jerico section is in the Cintalapa, Chiapas vicinity (65 km to the northwest) and the Todos Santos, Huehuetenango vicinity (150 km to the southeast), correlation between them is uncertain. Further difficulty results from the lack of marker beds or time constraints between these sections.

The Todos Santos Formation at Jerico differs from these other measured sections in several respects. The Jerico section is composed almost entirely of coarse sand and larger detritus, while the other sections record an abundance of fine-grained floodplain deposits. Furthermore, the Jerico section contains no interbedded limestone or near-shore marine deposits; it is composed entirely of continental detritus (the presence of a dolomite breccia immediately overlying the Todos Santos may suggest dissolution of intervening evaporites in the manner discussed by Blount and Moore (1969)). Also, palynological evidence suggests that most of the section at Jerico was deposited during earliest Cretaceous time, which is a younger age than is applied to these deposits elsewhere (Burckhardt, 1936; Mülleried, 1930; Richards, 1963).

At Cintalapa, the Todos Santos grades into transitional marine evaporites suggestive of sabkha deposition. In an outcrop near Magone, Oaxaca (300 km northwest of Jerico) red beds of the Todos Santos Formation are found underlying 200 m of halite (Bishop, 1980). Bishop (1980) reports well data throughout northern Central America that supports the idea of Richards (1963) that the Todos Santos Formation is a continental facies equivalent to the evaporite Salina and San Ricardo Formations. Viniegra O. (1971) reports two main salt basins from south-eastern Mexico, one Oxfordian in age (Isthmian basin), and one Late Jurassic to Early Cretaceous in age (Chiapas basin). However, the age of the Chiapas basin is based on the fact that it is underlain by red beds of the Todos Santos Formation. As already discussed, the age of the Todos Santos is variable. The Todos Santos appears to be older basinward, and younger at the basin edge.

Paleoclimate

Several paleoclimatic indicators in the Jerico section of the Todos Santos Formation suggest that it was deposited in an arid to semi-arid environment. Horizons of pedogenic carbonate nodules within the Fl lithofacies are good evidence for semi-arid climatic conditions (Blatt, Middleton, and Murray, 1972). Red coloration due to hematite suggests a strong oxidizing environment characteristic of the semi-arid alluvial fan setting (Bull, 1972). A thick horizon of debris flows also infers this type of environmental setting. Although exact time correlation is uncertain, gypsum, anhydrite, and halite found interbedded with the Todos Santos throughout northern Chiapas and Guatemala (Wilson, 1974; Bishop, 1980), indicate a hot, dry climate where the evaporation rate was high.

Tectonic Setting

Thick, coarse-grained sequences of alluvial fan deposits usually signify contemporary rapid basin subsidence because only by maintained source uplift can such quantities of coarse-grained debris be eroded, transported, and preserved (Steel and Wilson, 1975). The most typical modern setting for deposition of thick deposits of alluvial fan detritus is a region of horst-graben topography where movement along normal faults causes continued subsidence of the trough-like grabens relative to the uplifted horsts. A modern analog to this setting is the Basin and Range province of southwestern United States and northwestern Mexico.

Anderson (1969) suggested that the Todos Santos Formation in northwestern Guatemala was deposited in subsiding grabens. Burkart and Clemons (1972) delineate two northwest-southeast trending grabens in northwestern Guatemala through an isopach of the Todos Santos Formation (Figure 17). These grabens, one 40 km wide and filled with over 1200 m of sediment at its thickest point, bound the Tenam-Poxlac uplift. The Todos Santos thins to 3 m in thickness over the axis of this uplift, which is located just 30 km north of the 1240 m thick type section at La Ventosa (Burkart and Clemons, 1972).

The Todos Santos Formation at Jerico is probably also deposited in a graben or half graben whose scarp trended northwest-southeast. Evidence for tectonism within the Jerico section comes from the succession of fan facies. The first proximal to distal fining-upwards sequence is abruptly halted by mid-fan, then proximal facies rapidly building up over the distal braided distributary deposits of the alluvial fan. From then on, nearly 900 m of coarse-grained braided stream detritus suggests that subsidence of the graben basin was continuous.

Another piece of evidence for tectonism within the Jerico section is the subsidary section (BB') of Figure 11. Deposition of braided stream channel deposits on what previously was a highland adjacent to a canyon suggests that back-faulting of the scarp may have occurred at that time.

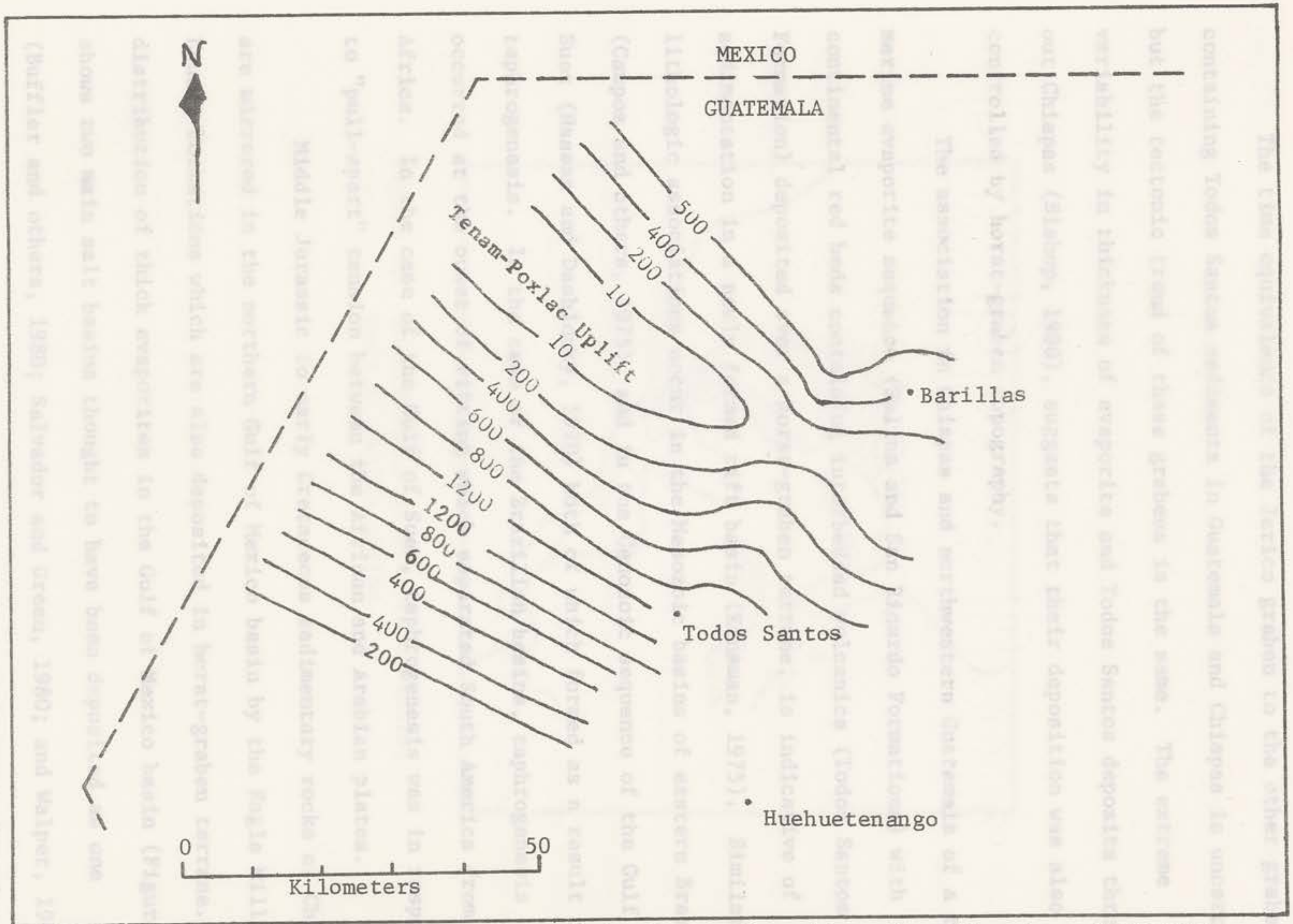


Figure 17. Generalized Isopach map of the Todos Santos Formation of northwestern Guatemala (after Burkart and Clemons, 1972). Contours given in meters.

The time equivalence of the Jerico graben to the other grabens containing Todos Santos sediments in Guatemala and Chiapas is uncertain, but the tectonic trend of these grabens is the same. The extreme variability in thickness of evaporite and Todos Santos deposits throughout Chiapas (Bishop, 1980), suggests that their deposition was also controlled by horst-graben topography.

The association in Chiapas and northwestern Guatemala of a thick marine evaporite sequence (Salina and San Ricardo Formations) with continental red beds containing interbedded volcanics (Todos Santos Formation) deposited over a horst-graben terrane, is indicative of sedimentation in a newly formed rift basin (Kinsman, 1975). Similar lithologic associations occur in the Mesozoic basins of eastern Brazil (Campos and others, 1975), and in the Cenozoic sequence of the Gulf of Suez (Hassan and Dashlouty, 1970) both of which formed as a result of taphrogenesis. In the case of the Brazilian basins, taphrogenesis occurred at the onset of rifting which separated South America from Africa. In the case of the Gulf of Suez, taphrogenesis was in response to "pull-apart" tension between the African and Arabian plates.

Middle Jurassic to early Cretaceous sedimentary rocks of Chiapas are mirrored in the northern Gulf of Mexico basin by the Eagle Mills and Louann Formations which are also deposited in horst-graben terrane. The distribution of thick evaporites in the Gulf of Mexico basin (Figure 18) shows two main salt basins thought to have been deposited as one (Buffler and others, 1980; Salvador and Green, 1980; and Walper, 1980). This salt basin represents a restricted marine environment deposited over attenuated, block faulted continental crust which subsided below

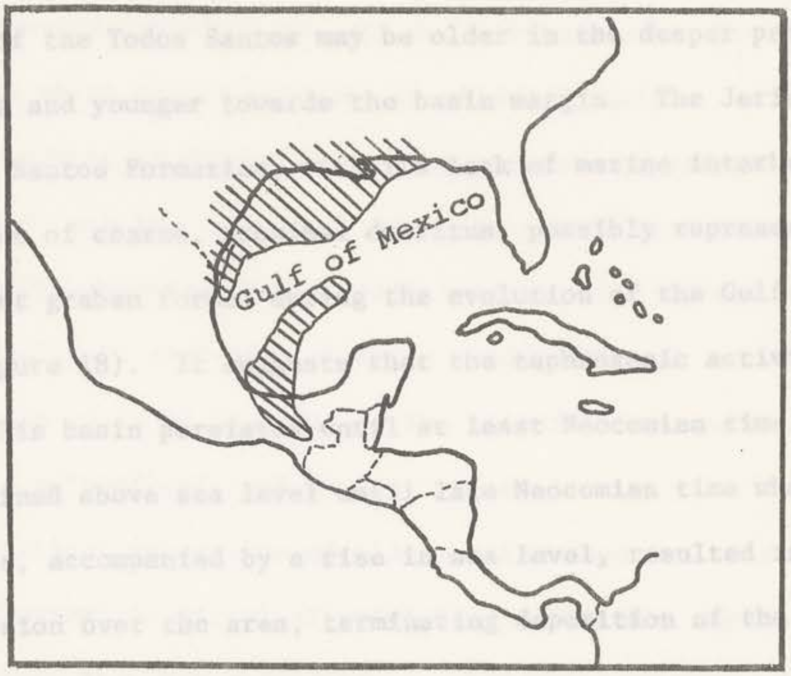


Figure 18. Distribution of evaporite basins, Gulf of Mexico region.

sea level. Continued subsidence of the mid-basin crust, accompanied by back-faulting at the basin margins gradually increased the area of the basin.

The Todos Santos Formation may represent the continental infilling of these taphrogenic basins in the southern Gulf of Mexico. Deposits of the Todos Santos may be older in the deeper parts of the salt basin and younger towards the basin margin. The Jerico section of the Todos Santos Formation, with its lack of marine interbeds and composition of coarse, proximal detritus, possibly represents the southermost graben formed during the evolution of the Gulf of Mexico basin (Figure 18). It suggests that the taphrogenic activity that created this basin persisted until at least Neocomian time. The graben area remained above sea level until late Neocomian time when continued subsidence, accompanied by a rise in sea level, resulted in a marine transgression over the area, terminating deposition of the Todos Santos Formation.

CONCLUSIONS

(1) The Todos Santos Formation at Jerico was deposited as an alluvial fan system by high gradient, short duration ephemeral streams which transported gravel, sand, and mud northeastward through a feeder canyon which opened out onto an alluvial plain.

(2) An abundance of debris flows, the presence of pedogenic carbonate nodules, and the fact that the Todos Santos is interbedded with evaporite deposits to the north suggests that it was deposited under arid to semi-arid climatic conditions.

(3) The main types of deposits of the alluvial fan system are debris flows, streamflood, and braided stream.

(4) The vertical succession of alluvial fan deposits at Jerico shows two proximal to distal alluvial fan transitions separated by a distal to proximal transition.

(5) Paleocurrent information suggests that the Jerico alluvial fan built out towards the northeast from a scarp trending northwest-southeast.

(6) Provenance studies indicate that the source for the Todos Santos deposits were the meta-igneous basement complex, the Santa Rosa Group, contemporary volcanic rocks, and the Todos Santos itself.

(7) Meta-igneous basement rocks of the Chiapas massif were exposed by the time deposition of the Jerico section began.

(8) The Todos Santos has a varied assemblage of rock fragments in the lower part, but the upper part contains only fragments of the

basement complex, suggesting that diminution of all source rocks except the Chiapas massif occurred by this time.

(9) Palynologic evidence suggests that most of the Jerico section was deposited during Neocomian time.

(10) The Jerico section of the Todos Santos differs from other studied sections in that it contains little floodplain deposits and no interbedded marine deposits.

(11) The Todos Santos at Jerico was deposited in a subsiding graben or half graben associated with early rifting of the nascent Gulf of Mexico basin.

APPENDIX I

FIELD DESCRIPTION OF THE TODOS SANTOS FORMATION, JERICO, CHIAPAS

COMPOSITE SECTION, TODOS SANTOS FORMATION, JERICO, CHIAPAS

Section measured in the Jerico, Chiapas vicinity. Location of measured outcrops are illustrated in Figure 4. Section begins in a stream valley along the main road connecting Tuxtla Gutierrez and Revolución Americana, elevation: 540 m. Section ends atop a cliff southeast of Jerico, elevation: 800 m. Measured with jacob staff and Brunton compass.

UNIT	UNIT DESCRIPTION, SAMPLES, SAMPLE LOCATION, SAMPLE LITHOLOGY	UNIT THICKNESS	CUMULATIVE THICKNESS
	UPPER PEBBLY COARSE SANDSTONE UNITS (675 m)	18	1218
34	Sandstone: white; frosted; sugary; friable to indurated where cemented with calcite; composed of predominantly angular quartz grains (90%) and weathered feldspar (10%); feldspar not as abundant as in Units 33 and 34; these sands are stratified into horizontal layers 1-3 cm thick of medium- to coarse-grained sandstone alternating with coarse- to very coarse-grained sandstone; these individual horizons range from moderate- to well-sorted; scattered within this unit are rounded quartz pebbles 1-3 cm in diameter. Sample T-153 m1218 coarse sandstone Sample T-152 m1216 medium sandstone Sample T-151 m1215 coarse sandstone Sample T-150 m1213 coarse sandstone Sample T-149 m1211 coarse sandstone Sample T-148 m1209 coarse sandstone Sample T-147 m1207 coarse sandstone Sample T-146 m1206 coarse sandstone Sample T-146 m1204 medium sandstone Sample T-144 m1202 coarse sandstone - contact covered -		
33	Sandstone and conglomerate: buff-colored; stained yellow-brown by goethite and often is weathered brown to black; most of the unit was seen in weathered exposures; where seen, the rocks were trough cross-bedded; composed of moderately-sorted pebbly coarse- to very coarse-grained sandstones; pebbles rarely exceeded 2-3 cm and are composed of angular to rounded quartz and granite fragments, and angular orthoclase fragments; sand grains are composed of angular quartz, weathered feldspars, and minor amounts of mudstone clasts (probably intraformational); in the 710 to 810 m interval (above the base) of this section well-preserved silicified log fragments 8-10 cm in diameter and up to 20 cm long are present; a 4 m thick lens of trough cross-bedded pebble conglomerate composed the 886 to 890 m interval; it consisted of well-rounded clasts 2-5 cm in diameter of quartz and granite; a thin reddish-brown sandy siltstone 1 m thick was found at m 1116; another pebble conglomerate was found at m 1190. Sample T-143 m1198 coarse sandstone Sample T-142 m1196 very coarse sandstone Sample T-141 m1195 granule conglomerate Sample T-140 m1190 coarse sandstone Sample T-139 m1187 granule conglomerate	542	1200

Sample T-138	m1184	sandy siltstone
Sample T-137	m1181	granule conglomerate
Sample T-136	m1180	very coarse sandstone
Sample T-135	m1172	very coarse sandstone
Sample T-134	m1166	very coarse sandstone
Sample T-133	m1148	pebble conglomerate
Sample T-132	m1146	very coarse sandstone
Sample T-131	m1136	coarse sandstone
Sample T-130	m1133	medium sandstone
Sample T-129	m1130	very coarse sandstone
Sample T-128	m1127	very coarse sandstone
Sample T-127	m1122	very coarse sandstone
Sample T-126	m1116	fine sandstone
Sample T-125	m1114	pebble conglomerate
Sample T-124	m1107	fine sandstone
Sample T-123	m1104	coarse sandstone
Sample T-122	m1098	medium sandstone
Sample T-121	m1091	very coarse sandstone
Sample T-120	m1086	pebble conglomerate
Sample T-119	m1078	very coarse sandstone
Sample T-118	m1071	coarse sandstone
Sample T-117	m1065	pebble conglomerate
Sample T-116	m1053	very coarse sandstone
Sample T-115	m1048	granule conglomerate
Sample T-114	m1042	very coarse sandstone
Sample T-113	m1036	very coarse sandstone
Sample T-112	m1029	coarse sandstone
Sample T-111	m1021	coarse sandstone
Sample T-110	m1015	coarse sandstone
Sample T-109	m1009	granule conglomerate
Sample T-108	m1000	granule conglomerate
Sample T-107	m 993	granule conglomerate
Sample T-106	m 988	granule conglomerate
Sample T-105	m 979	granule conglomerate
Sample T-104	m 970	coarse sandstone
Sample T-103	m 964	granule conglomerate
Sample T-102	m 956	medium sandstone
Sample T-101	m 948	coarse sandstone
Sample T-100	m 940	medium sandstone
Sample T- 99	m 938	granule conglomerate
Sample T- 98	m 926	granule conglomerate
Sample T- 97	m 920	coarse sandstone
Sample T- 96	m 913	coarse sandstone
Sample T- 95	m 908	conglomerate
Sample T- 94	m 902	coarse sandstone
Sample T- 93	m 896	coarse sandstone
Sample T- 92	m 888	coarse sandstone
Sample T- 91	m 886	conglomerate
Sample T- 90	m 872	very coarse sandstone
Sample T- 89	m 866	very coarse sandstone
Sample T- 88	m 862	coarse sandstone
Sample T- 87	m 856	conglomerate
Sample T- 86	m 850	coarse sandstone
Sample T- 85	m 839	coarse sandstone
Sample T- 84	m 835	coarse sandstone
Sample T- 83	m 815	conglomerate

Sample T- 82 m 807 coarse sandstone
Sample T- 81 m 805 silicified wood
Sample T- 80 m 760 coarse sandstone
Sample T- 79 m 730 conglomerate
Sample T- 78 m 716 conglomerate
Sample T- 77 m 669 coarse sandstone
Sample T- 76 m 668 conglomerate

- gradational -

32 Sandstone and conglomerate: composed of moderately sorted coarse- to very coarse-grained sandstones mainly; sequence is trough and planar cross-bedded in sets about 1 m thick; sandstones are subangular; commonly contain basal lag conglomerates of pebble-sized rounded quartz and quartzite 1-8 cm thick; occasionally clasts of 20 cm thick are found near the base; this unit contains abundant horizons of carbonized plant material commonly deposited as thin (1-3 cm) layers on avalanche faces; a yellow sulfur stain is locally present around these plant remains; overall the color is buff; commonly it is stained a goethitic yellow-brown; a minor (2 cm) lense of grey claystone was also present. 115 658

Sample T-75 m 658 coarse sandstone
Sample T-74 m 656 mudstone
Sample T-73 m 623 conglomerate
Sample T-72b m 586 coarse sandstone
Sample T-72a m 575 coarse sandstone
Sample T-71 m 568 conglomerate
Sample T-70 m 563 carbonized wood
Sample T-69 m 559 coarse sandstone
Sample T-68 m 555 granule conglomerate
Sample T-66 m 543 coarse sandstone with carbonized wood
Sample T-65 m 542 coarse sandstone

- gradational -

<u>UPPER PEBBLY COARSE SANDSTONE UNITS</u> (675 m)

<u>UPPER CLAST-SUPPORTED SANDY CONGLOMERATE UNIT</u> (43 m)

31 Conglomerate and sandstone: buff-colored (10YR8/2) conglomerates and sandstones; stained, in part, reddish orange (10YR6/6) on weathered surfaces; in spots black from desert varnish; trough cross-bedded; abundant cut and fill structures; gravel fills; one channel cross-section was 2 m thick at the center and pinched out over a distance of 7 m; conglomerates consist of clasts 2-15 cm in diameter; most commonly 5-10 cm; well-rounded; composed of red granite (28%), purple quartzite (26%), porphyritic rhyolite (22%), quartz (21%), and gneiss (3%); clast-supported; matrix composed of coarse-grained to granular angular sandstone. Sandstone in trough-bedded layers and is composed of angular quartz, feldspar, and rock fragments; also contains pebbles (1-2 cm in diameter) of well-rounded quartz and quartzite. 43 543

Sample T-64 m 519 medium sandstone
Sample T-63 m 518 conglomerate
Sample T-62 m 505 conglomerate

- sharp, erosional in part with up to 1 m of relief -

UPPER CLAST-SUPPORTED SANDY CONGLOMERATE UNIT (43 m)

RED MATRIX-SUPPORTED CONGLOMERATE UNITS (121 m)

30 Conglomerate and sandstone: pale red to reddish brown, weathers black; matrix-supported conglomerate similar to unit 28 and 30 below except for the following: clast sizes increase erradically to fragments up to 50 cm in diameter; intervening sandy layers become thicker (up to 20-25 cm) and are buff-colored in part; show indistinct cross-beds. 6 500

Sample T-61 m 497 conglomerate

- gradational -

29 Conglomerate and sandstone: similar to unit 28 below except for the following clast lithology and size information: clast composition: rounded purple quartzite (27-33%), rounded coarsely-crystalline red granite (16-23%) angular to rounded purple porphyritic rhyolite (21-24%), rounded milky quartz (8-11%), limestone (6-17%), slate (3-10%), gneiss (2-3%), muscovite-quartz schist (0-1%), chert (1%). Clast size: ranges from 5 to 25 cm, mode: 7-8 cm. 51 494

Sample T-169 m 470 pebbly mudstone
Sample T-60 m 446 conglomerate

- gradational -

28 Sandstone and conglomerate: grayish-red color; predominantly poorly-sorted coarse-grained sandstones; trough cross-bedded; beds up to 1.5 m thick but pinch out laterally usually less than 7-8 m distance; cut and fill structures, pinches out laterally into conglomerates similar to unit below. 5 443

Sample T-59c m 438 conglomerate

- erosional surface -

27 Conglomerate and sandstone: grayish red (10R4/2); weathers to black; some sandy areas are white; conglomerates are poorly sorted, matrix-supported, in layers 15 cm to 1 m thick; separated by pebbly sandstone layers 3-5 cm thick; conglomerate clasts composed of rounded purple quartzite (37%), rounded coarsely-crystalline red granite (28%), purple porphyritic rhyolite (13%), rounded milky quartz (12%), angular dark gray slate clasts (5%), limestone (3%), quartz-orthoclase gneiss (1%), and meta-sediment (1%); clast size coarsens from 3-18 cm (mode: 5 cm) 47 438

in the lower part of the unit to 6-30 cm (mode: 12 cm) in the upper part of the unit; lithologic composition dependent on mode, quartzite, granite, and milky quartz comprise most of the clasts that are less than 5 cm in diameter, clasts larger than this contain the rock fragments listed above; the largest clasts found (20-30 cm) are predominantly of granite and porphyritic rhyolite. The matrix to the conglomerates is a poorly-sorted muddy sandstone. Sandstone layers intervening between conglomerates are poorly- to moderately-sorted angular to subangular fine to coarse sandstones; composed of quartz, feldspar, rock fragments, and minor amounts of muscovite; these sandstones overlie the conglomerate beds with an erosional unconformity; appears to be graded in part, composed of pebbly beds 1-2 cm thick intervening between sandier beds; are horizontal.

Sample T-X7 m 424 conglomerate
Sample T-X5 m 422 pebbly sandstone
Sample T-58 m 420 conglomerate
Sample T-170 m 405 pebbly coarse sandstone
Sample T-59b m 400 pebbly coarse sandstone
Sample T-59a m 400 fine sandstone
Sample T-57 m 396 conglomerate clasts

- gradational -

26 Conglomerate and sandstone: mottled irregularly white and grayish red (10R4/2); sandstones appear in horizontal beds 5-6 cm thick in between conglomeratic beds 10-20 cm thick. Conglomerates poorly sorted; clasts well-rounded; size range 1-10 cm in diameters; mode = 3.5 cm; composed of milky quartz (42%), coarse-grained red granite (22%), purple quartzite (19%), and porphyritic rhyolite (8%); most conglomerate is matrix-supported; matrix composed of a poor- to moderately-sorted medium to coarse sandstone. Sandstone (matrix and beds): white areas granular coarse-grained sandstone, moderately sorted; composed of quartz, feldspar, and rock fragments. Red areas are finer grained, predominantly poorly-sorted, muddy fine- to medium-grained sandstone; friable. 10 389

Sample T-56 m 388 fine sandstone
Sample T-171 m 386 coarse sandstone
Sample T-55 m 380 pebble conglomerate

- sharp erosional contact with up to 15 cm relief -

<u>RED MATRIX SUPPORTED CONGLOMERATE UNITS</u> (121 m)

LOWER PEBBLY COARSE SANDSTONE UNITS (109 m)

25 Sandstone and conglomerate: buff (10R8/2) and reddish-brown (5R6/2) colored; mottled; some cut and fill structures, but not as prevalent as low units; composed of sandy pebble-granule conglomerate that grades upward into a poorly sorted medium to sandy pebble-granule conglomerate that grades upward into a poorly sorted medium to very coarse sandstone. Conglomerates contain clasts of rounded granules and pebbles 0.5 to 2 cm in diameter; quartz most prevalent composition. Sandstone is angular to subangular; friable; composed of quartz, feldspar, and rock fragments; some mica. 13 379

Sample T-54 m 373 coarse sandstone
Sample T-53 m 371 conglomerate

- gradational -

24 Conglomerate and sandstone: buff colored; stained yellow- to reddish-orange; weathers gray; unit composed of sandy pebbly conglomerates and pebbly coarse-sandstones that intergrade; some medium-coarse sandstone lenses also present; unit contains abundant cut and fill structures characterized by sandy conglomerates grading upwards into pebbly coarse sandstones; some coarsening upward sequences also; lag conglomerate of pebbles 1-3 cm in diameter common at base of scour; trough cross-beds in sets 10 to 50 cm thick; commonly can be seen pinching out laterally over 5 to 8 m; foreset beds consist of sandy conglomerate intergrading to pebbly sandstone over a range of 0.5 to 3 cm; horizons of mudstone intraformational conglomerate clasts present; preserved carbonized-calcified log fragments are abundant; range in size from 6-15 cm in diameter and up to 3 m long; one shows a distinct trunk; cross-beds were deposited over and around these logs. Conglomerates: clasts range from granule to pebbles 5 cm in diameter; rounded; composed of predominantly milky quartz, granite, porphyritic rhyolite, quartzite, and sedimentary rock fragments; comprise 10-50% of various beds; sand matrix angular to subangular; abundant quartz. Sandstones: pebbly, granular, moderately sorted very coarse to coarse; angular to subangular; friable. Outcrop massive; resistant. 64 366

Sample T-52 m 350 coarse sandstone
Sample T-51 m 346 coarse sandstone
Samples T-X5 -X10 m 302-344 carbonized-calcified tree fragments

- sharp contact -

23 Sandstone: light-brown; weathers darker; moderately-sorted; silty, fine-grained sandstone; thickly laminated in horizontal beds; micaceous (biotite mainly) with flakes aligned in bedding plane and causing the laminated appearance; blocky cleavage; resistant. 1 302

Sample T-50 m 301 fine sandstone

- sharp contact -

22	Sandstone and conglomerate: buff colored, stained yellowish-orange in part; consists of pebble conglomerates that fine upwards into pebbly coarse sandstones; trough cross-bedded in sets 20 cm to 1 m thick, exhibit abundant cut and fill structures; thin (2-5 cm) layers of mudstone also present. Conglomerate: contains clasts of well-rounded granules and pebbles up to 2 cm in diameter of milky quartz, quartzite, coarse-grained granite, gneiss, porphyritic rhyolite, and some sedimentary rock fragments; matrix a quartrz-rich coarse sandstone, subangular to subrounded. Pebbly sandstone units are of similar lithology. Sandstones are moderately-sorted, some silty fine-grained, others medium-coarse grained; brown colored; micaceous (muscovite and biotite); weathers dark gray. Mudstone: brownish-gray in coloring; massive; contains muscovite; weathers discordally. Rip-up clasts of mudstone pseudo-nodules 5-15 cm in diameter are commonly found horizontally aligned above erosional surfaces. Carbonized-calcified logs 5-30 cm in diameter ans up to 2 m in length where exposed. A halo of yellowish-orange goethitic stain commonly surrounds these biologic remains. Outcrops massive and resistant.	31	301

Samples T-X-9	m 278- m 300	carbonized-calcified tree fragments
Sample T-49	m 284	medium-fine sandstone
Sample T-48	m 278	coarse sandstone
Sample T-47	m 274	claystone
Sample T-46	m 273	fine sandstone
Sample T-45	m 273	sandy conglomerate
Sample T-44	m 272	carbonized-calcified tree fragments
Sample T-X4	m 272	fine-medium sandstone
Sample T-43	m 270	coarse sandstone
Sample T-42	m 270	coarse sandstone

- sharp erosional contact -

LOWER PEBBLY COARSE SANDSTONE UNITS (109 m)

SILTSTONE-CLAYSTONE-FINE SANDSTONE UNITS (143 m)

21	Claystone-mudstone-siltstone-sandstone: interbedded siltstones and sandstones in beds 5-10 cm thick; become more abundant in the upper 6 m; claystone-mudstones in beds 0.5 to 1 m thick; aligned muscovite flakes and carbonized plant fragments are abundant throughout this unit. Sandstone: tan; weathers orange-brown; abundant quartz; poorly sorted silty to fine grained; thinly bedded; abundant sole markings at its base above the mudstones. Siltstones: Bluish-gray to dark brown; muddy; thickly laminated. Mudstones and claystones: greenish-gray to dark brown; weather discoidally.	27	280

Sample T-X2	m 269	silty fine sandstonee
Sample T-41	m 267	claystone
Sample T-40	m 266	sandy siltstone
Sample T-X1	m 266	silty fine sandstone

	Sample T-39 m 263 mudstone Sample T-38 m 262 mudstone Sample T-37 m 260 fine sandstone Sample T-36 m 255 fine sandstone Sample T-35 m 254 mudstone		
	- gradational -		
20	Sandstone: tan (5YR7/2) to grayish-orange (10YR7/4); weathers dark brown; medium- to coarse-grained; moderately- to poorly-sorted; grains subangular to subrounded; composed of quartz, feldspar, and lithic fragments; beds 10 cm to 1 m thick; flaggy in part; parting planes contain abundant aligned muscovite flakes and carbonized plant remains; horizontal beddings; splits into massive beds; resistant; the upper half of this unit contains thin lenses of claystone; the claystone is greenish gray to light brown; contains carbonized plant material; micaceous; 5-20 cm thick; sole markings apparent on bottoms of sandstone that overlie these claystone lenses; some slump structures present; also claystone appear lensoidal concave downward, trough cross-bedded; vertical and lateral variability.	21	253
	Sample T-34 m 252 Medium-fine sandstone Sample T-33 m 248 fine sandtone Sample T-187 m 247 sandy siltstone Sample T-32 m 234 Silty fine sandstone Sample T-31 m 233 medium-coarse sandstone Sample T-186a m 232 fine sandstone Sample T-30 m 232 fine sandstone		
	- sharp contact (erosional) -		
19	Sandstone-mudstone-claystone: silty very fine sandstone interbedded with mudstone and claystone; erosional contact where sandstone overlies claystone/mudstone, mudstone/claystone gradational over sandstone; sandstone units 0.5 to 3 m thick; claystone-mudstone units 0.5 to 9 m thick. Silty sandstone: yellowish-gray (5Y7/2) to light grayish brown; flaggy; thinly bedded; contains abundant carbonized plant material and aligned micas on parting planes; some weathers discoidally. Claystone/mudstone: greenish-gray; weathers dark brown to black; not fissile; thickly laminated to thinly bedded; micaceous; contains disseminated carbonized plant material; discoidal weathering, unresistant.	54	232
	Sample T-29 m 226 fine sandstone Sample T-28 m 223 sandy siltstone Sample T-27 m 220 mudstone Sample T-X17 m 190 silty sandstone Sample T-26 m 187 claystone Sample T-25 m 185 claystone Sample T-24 m 183 fine sandstone Sample T-23 m 181 mudstone		
	- sharp contact -		

18 Siltstone-claystone-silty sandstone: (interbedded 1-7 m thick). 17 178
Claystone: grey; weathers orange-red to black; discoidal weathering; very recessive. Siltstone: beds 1-2 m thick; brown (5Y6/4); weathers grayish-green (5GY6/1) finely laminated to thinly bedded; carbonized plant material and aligned mica flakes abundant on parting planes. Silty sandstone: yellowish grey (5Y7/2) finely laminated to thin bedded; carbonized plant material on parting planes.

Sample T-22 m 175 siltstone
Sample T-21 m 171 mudstone
Sample T-157 m 170 siltstone
Sample T-156 m 166 claystone
Sample T-155 m 162 muddy fine sandstone

- gradational -

17 Sandstone: greenish-gray color (10Y6/2); poorly-sorted, muddy 3 161
very fine sandstone; grains composed of quartz (75%), feldspar (4%), rock fragments (3%) and clay; contains some carbonized plant remains both on parting surfaces and disseminated; very micaceous (both muscovite and biotite); massive bedded; resistant; grades laterally into poorly sorted muddy fine-grained laminated sandstone.

Sample T-20 m 160 silty, very-fine sandstone
Sample T-185 m 159 muddy, very-fine sandstone
Sample T-184 m 158 silty, very-fine sandstone

- sharp to gradational contact -

16 Claystone-siltstone-mudstone: alternating beds of each 0.1 to 31 158
1 m thick; Claystones: bluish-gray to greenish gray; waxy; some micaceous (muscovite); some with carbonized plant material, weathers discoidally; Mudstone: greenish-brown to greenish-gray; some with cross-ripple lamination; muscovite flakes; carbonized plant material; thin-bedded. Siltstone: greenish brown; massive bedded; micaceous (muscovite); carbonized plant remains; some sole markings at base of siltstone where it overlies claystones; unit as a whole is very unresistant.

Sample T-161 m 156 sandy siltstone
Sample T-160 m 155 claystone
Sample T-159 m 152 mudstone
Sample T-158 m 148 claystone
Sample T-163b m 142 siltstone
Sample T-162 m 140 claystone
Sample T-168 m 136 siltstone
Sample T-167 m 135 mudstone
Sample T-166 m 133 siltstone
Sample T-165 m 132 claystone
Sample T-164 m 128 claystone
Sample T-163a m 127 claystone

- contact covered -

SILTSTONE-CLAYSTONE-FINE SANDSTONE UNITS (143 m)

MASSIVE SANDSTONE UNITS (58 m)

15	Sandstone: tan; weathers reddish brown to black; well-sorted medium-grained; very thin to thin bedded (1-10 cm); flaggy appearance; indistinct parting lineation; grains composed of quartz, feldspar; and lithic fragments; also micaceous with flakes parallel to the bedding plane.	5	127

Sample T-19 coarse sandstone

Sample T-18 m 121.5 medium sandstone

- gradational -

14	Sandstone; tan colored; weathers dark brown to black; poorly sorted medium to very coarse grains; subrounded; consist of quartz, feldspar, lithic fragments; massive beds 0.5 to 1 m thick; not as resistant as unit 13; contains abundant pebbles of well-rounded quartz and porphyritic rhyolite 1-3 cm in diameter.	12	122

Sample T-17 m 120 poorly sorted medium to very coarse sandstone

- gradational -

13	Sandstone: yellowish gray (5Y7/2); weathers dark brown to black; moderately sorted coarse to very coarse grained; composed of quartz, feldspar, and lithic fragments; subangular to subrounded; thin to thick horizontal beds; massive splitting beds 0.25 to 1.5 m thick; resistant; slightly pebbly in parts; pebbles 0.5 to 2 cm in diameter; mainly well-rounded quartz and quartzite.	41	110

Sample T-16 m 109 coarse sandstone
Sample T-15 m 107 coarse sandstone
Sample T-14 m 85 coarse sandstone
Sample T-13b m 70 coarse sandstone
Sample T-13a m 70 pebbly coarse sandstone

- sharp erosional contact -

MASSIVE SANDSTONE UNITS (58 m)

LOWER CLAST-SUPPORTED SANDY CONGLOMERATE UNITS (69 m)

12	Conglomerate: similar to unit 11 except that it contains no clasts larger than pebbles; becomes more sandy; weathers recessively.	4	69

- gradational -

11	Conglomerate: tan colored; weathers black; horizontal bedding; clasts poorly sorted; granule to pebble size; clasts composed of milky quartz, porphyritic rhyolite, purple quartzite, and red granite; all are well-rounded except the granite fragments which are subangular to subrounded; larger cobbles and boulders are infrequently present up to 20 cm and composed mainly of subangular to angular red coarsely-crystalline granite fragments; a zone 0.5 m thick was composed almost solely of granules; outcrop highly weathered. Sample T-12 m 62 granule pebble conglomerate	6	65
	- erosional surface -		
10	Conglomerate and pebbly sandstone: similar to below except that it contains a higher percentage of coarse sand and granules and abundant well rounded mulky quartz pebbles 0.5-3 cm in diameter; less resistant. Sample T-11 m 57 coarse sandstone Sample T-10 m 53 pebble conglomerate	9	59
	- gradational -		
9	Conglomerate: tan, weathers black; horizontal bedding; clast supported; consists of coarsening upward sequences approximately 2/3 m thick; coarsens from a coarse sandy granule conglomerate to a pebble conglomerate with clasts 1-4 cm being most abundant; well-rounded; composed of red granite, milky quartz, and purple quartzite; matrix of coarse poorly-sorted sandstone; adjacent coarsening upward units are gradational over 6 cm; resistant.	10	50
	- gradational -		
8	Conglomerate and interbedded sandstone: conglomerate similar to Unit 7 except it is interbedded with discrete sandstone beds 10-20 cm thick; these sandstones are granule-very coarse to coarse; composed of quartz, feldspar, and lithic fragments; bounded on the bottom by an erosional surface and on top grade into conglomerate; tan colored; horizontal bedding; resistant.	2	40
	- erosional surface -		
7	Conglomerate: tan, weathers black; poorly-sorted pebbles, cobbles, and boulders; boulders up to 40 cm in diameter primarily subangular fragments of coarsely crystalline granite; cobbles mainly granite and porphyritic rhyolite; pebbles (4-6 cm common) mainly well-rounded to rounded clasts of milky quartz, granites and purple quartzite; Matrix: granular to coarse poorly sorted sandstone.	6	38
	- gradational -		

6	Sandy conglomerate: grayish orange (5YR7/2) color; weathers black; slightly cobbly sandy pebble conglomerate; moderately sorted; cobbles modal at 10 cm; composed mainly of granite and andesite; pebbles abun-ant (60%); ½-3 cm in diameter; composed of milky quartz, red coarsely crystalline granite, and purple quartzite; rounded to well-rounded; crude horizontal bedding; matrix: poorly sorted granular very coarse to coarse sandstone; composed of angular to subangular clasts of quartz, feldspar, and lithic fragments; sand exists within conglomerate as a matrix support, no distinct sandstone lenses. Sample T-9 m 31 pebbly coarse sandstone - gradational -	6.0	32.6
5	Conglomerate: clast supported; crude horizontal bedding as a result of more sandy layers, resistant; moderately sorted clasts of pebbles, some cobbles; pebbles (60%) rounded to well-rounded; 4-6 cm diameter; composed of purple quartzite, milky quartz, porphyritic rhyolite, red coarsely crystalline granite, and gneiss; matrix (40%) granular very coarse to coarse sandstone; composed of subangular to subrounded grains of quartz, rock fragments, and feldspar; exists as lenses 6-10 cm thick and as inter-clast fills; lenses of sandstone are separated from underlying conglomerates by an erosional surface. - gradational -	5.5	26.0
4	Sandstone: yellowish gray (5Y7/2), very coarse- to coarse-grained with granules and pebbles up to 1 cm in diameter; poorly sorted; composed of fragments of quartz, feldspar, and lithic fragments; angular to subrounded; vague cross-bedding outlined by pebbles; sand lenses 1 m thick separated by stringers of conglomerate (similar to Unit 3) that range from 10-40 cm thick; very resistant. Sample T-8 m 19.5 coarse sandstone - erosional surface -	2.5	20.5
3	Conglomerate; similar to Unit 1. - gradational -	3.5	18.0
2	Conglomerate: clast supported; crude horizontal bedding due to grading; resistant; moderately sorted clasts of pebbles and cobbles; cobbles (5%) mainly coarsely crystalline granite; largest up to 15 cm; pebbles (55%) of purple quartzite, milky quartz, granite, porphyritic rhyolite, and gneiss; clasts rounded to well-rounded; modal size 2-3 cm; matrix (40%) poorly sorted granular-very coarse to coarse sandstone, exists in inter-clast areas as well as in more discrete lenses 6-8 cm thick with about 20% pebbles approx. 1 cm in diameter; sandy lenses are tan; coarser areas are reddish gray due to an abundance of red clasts. - gradational -	5.0	14.5

1	Conglomerate: clast supported; crude horizontal bedding; normal grading; resistant; poorly sorted clasts of pebble, cobble, and boulder size; boulders (5%) and cobbles (15%) mainly subangular to subrounded of coarsely crystalline granite and porphyritic rhyolite; slight imbrication N 8 W; pebbles (50%) mainly rounded to well-rounded purple quartzite, milky quartz, coarsely crystalline red granite; purple porphyritic rhyolite, and biotite-orthoclase-quartz gneiss; matrix (25%) of poorly sorted, granular, very coarse to coarse sandstone; subangular to subrounded, occurring as inter-clast fills and thin (2-10 cm) lenses; matrix tan colored but overall exposure red (10R4/6) due to an abundance of red clasts. Sample T-7 m 9 coarse sandstone Sample T-1 m 2 pebbly coarse sandstone	9.5	9.5
	- base of section covered, either it lies disconformably over, or is in fault contact with, rocks of the Chiapas massif. -	0	0

LOWER CLAST-SUPPORTED SANDY CONGLOMERATE UNITS (69 m)

APPENDIX II

PETROGRAPHIC DESCRIPTIONS OF SAMPLES FROM THE

TODOS SANTOS FORMATION, JERICO, CHIAPAS

Note: Refer to Figure 10 and Appendix I for the stratigraphic position of each sample.

Sample T-153 Moderately-sorted medium- to coarse-grained sandstone calcite-cemented subfeldsarenite

White (9Y); frosted; sugary; weathers yellowish-brown to black; thinly bedded in horizontal layers 1 cm thick; indurated; calcite cemented; composed of angular quartz and weathered feldspars.

Sample T-152 Moderately-sorted fine- to medium-grained sandstone: calcite-cemented subfeldsarenite.

White to pale orange (10YR8/2); frosted; sugary; weathers yellowish-brown to black; thinly-bedded in horizontal layers 1 cm thick; some granules and pebbles present which appear to be segregated into horizonal layers; sand grains composed of angular quartz and weathered feldspar; granules composed of angular to subrounded quartz.

Sample T-151 Moderately sorted medium- to coarse-grained sandstone: calcite-cemented quartzarenite.

White (9Y); frosted; sugary; weathers yellowish-brown; horizontally stratified into thin beds 1-2 cm thick as a result of grain size differences; consists of interbedded layers of moderately-sorted medium/coarse sandstone and moderately-sorted coarse- to very coarse-grained sandstone 0.25-0.5 cm thick.

Thin Section Description:

Bimodal (75% fine sand, 25% coarse sand), angular to subangular; compact; predominantly linear grain contacts. Quartz: polycrystalline composite (15%), mainly restricted to coarse sand fraction, monocrystalline grains (70.5%) with straight to slightly undulose extinction, inclusions of euhedral tourmaline, acicular zircon, and gas bubbles common. Feldspar: predominantly orthoclase (4%), plagioclase (trace). Lithic fragments (2.5%): All modal in coarse sand fraction; SRF's chert (1.5%); MRF's: quartz-muscovite schist (1%). Heavy minerals: (0.5%) euhedral tourmaline, angular zircon, garnet. Patchy calcite cement (1.5%); porosity 5.5%.

Sample T-150 Moderately-sorted medium- to coarse-sandstone: quartz arenite

White; sugary; extremely weathered to yellowish-brown and black; very friable, composed of angular quartz which is segregated into bands of medium/coarse sand grains 1 cm thick divided by layers of coarse- to very coarse-grained sand 0.25-0.5 cm thick.

Sample T-149 Moderately-sorted medium- to coarse-grained sandstone: quartz arenite

Light brown; frosted; sugary; very weathered and friable; composed of angular grains of quartz; horizontal stratification based on grain size; the medium/coarse sands are divided by layers of coarse- to very coarse-grained sands 0.25 to 0.5 cm thick.

Grain Size Analysis: gr: 4%, vcs: 14%, cs: 18%, ms: 17%, fs: 37%, vfs: 4%, z+c: 10%, mode = 2.75 ϕ.

<u>Sample T-148</u> Moderately-sorted bimodal fine- to medium-grained and medium- to coarse-grained sandstone: subfeldsarenite

White; frosted; sugary; weathered; very friable; composed of angular quartz with some weathered feldspars; shows alternating horizontal layers of differing grain size: medium/fine and medium/coarse about 1 cm thick.

<u>Sample T-147</u> Moderately-sorted medium- to coarse-grained sandstone: subfeldsarenite

White; frosted; sugary; extremely weathered; very friable; composed of angular quartz and weathered feldspars.

Thin Section Description:

Inhomogeneous; loosely-packed; friable, tangential and linear grain contacts; medium sand: 50%, coarse sand: 25%; sand angular to subangular. Quartz: (64.5%), straight to slightly undulose extinction, abundant vacuoles (56%), semi-composite (0.5%), polycrystalline composite (8%). Feldspar (13.5%): orthoclase (13%), microcline (0.5%), sericitized. Lithic fragments (4%) restricted to coarse sand fraction, MRF's: meta-quartz (1.5%); SRF's: mudstone fragments (1%), chert (1%); VRF's: porphyritic rhyolite (0.5%). Heavy minerals: angular zircon, euhedral tourmaline, garnet.

<u>Sample T-146</u> Well-sorted coarse-grained sandstone: subfeldsarenite

White; frosted; sugary; very friable, weathered; composed of angular quartz and altered feldspars.

<u>Sample T-145</u> Moderately-sorted coarse- to medium-grained sandstone: subfeldsarenite

White; frosted; sugary; highly altered; very friable; composed of angular quartz grains and weathered feldspars.

Grain Size Analysis: vcs: 8%, cs: 20%, ms: 39%, fs: 17%, vfs: 4%, cz: 2%; fmz: 4%, c: 6%, mode - 1.5 ϕ.

<u>Sample T-144</u> Moderately-sorted very coarse- to coarse-grained sandstone: feldsarenite.

White; extremely weathered; very friable; composed of angular quartz and weathered feldspar.

<u>Sample T-143</u> Moderately-sorted granular very coarse- to coarse-grained sandstone: feldsarenite

Light brown; weathered; friable; composed of angular quartz and weathered feldspar; granules composed of angular to subangular quartz and pink granite, and angular pink and white orthoclase.

<u>Sample T-142</u> Moderately-sorted pebbly, granular very coarse-grained sandstone: feldsarenite

Light brown; extremely weathered; some goethitic stain; very friable; composed of angular quartz and weathered feldspars; granules composed of angular to subangular quartz and angular pink orthoclase; pebbles (up to 2 cm in diameter) composed of rounded quartz and pink granite.

<u>Sample T-141</u> Moderately-sorted very coarse-grained sandy granule conglomerate: feldsrudite

Light brown; weathered; friable; composed of angular grains of quartz and pink orthoclase, and of weathered feldspar.

<u>Sample T-140</u> Moderately-sorted pebbly, granular medium- to coarse-grained sandstone: feldsarenite

Light brown; indurated; weathered; composed of angular quartz and weathered feldspar; granules are composed of angular quartz and pink orthoclase; pebbles (up to 4 cm in diameter) are composed of rounded pink granite fragments.

<u>Sample T-139</u> Very coarse-grained sandy granule conglomerate: feldsrudite

Weathered; buff; friable; granules are composed of angular to subrounded quartz and angular, subequant, blocky, pink orthoclase.

<u>Sample T-138</u> Slightly granular fine sandy silistone.

Reddish-brown; indurated; composed of quartz and feldspars; granules composed of angular to subrounded grains of quartz and pink granite; these grains show a hematitic coating; also muscovite flakes are present.

<u>Sample T-137</u> Very coarse-grained sandy pebbly granule conglomerate: feldsrudite

Light brown; weathered; friable; composed of angular to subrounded quartz and pink granite fragments, and blocky pink orthoclase; sand component composed of angular quartz and weathered feldspar.

<u>Sample T-136</u> Moderately-sorted pebbly coarse- to very coarse-grained sandstone: feldsarenite

Light brown; weathered; friable; composed of angular quartz and orthoclase, and weathered feldspar.

<u>Sample T-135</u> Well-sorted granular very coarse-grained sandstone: feldsarenite

Light-brown; weathered; friable; composed of angular quartz and pink orthoclase; and weathered feldspar.

Sample T-134 Moderately-sorted granular coarse- to very coarse-grained sandstone: feldsarenite

Weathered; stained with goethite; friable; composed of angular quartz and weathered feldspar; granules angular to subround quartz and granite grains.

Sample T-133 Very coarse-grained sandy granule pebble conglomerate: feldsrudite

Weathered; brown; indurated; pebbles up to 1.5 cm and composed of angular to subrounded quartz and pink granite; sand fraction composed of angular quartz and weathered feldspars.

Sample T-132 Moderately-sorted coarse- to very coarse-grained sandstone: feldsarenite

Weathered; brown; indurated; composed of angular to subrounded grains of quartz and granite, blocky pink orthoclase, and weathered feldspar.

Sample T-131 Moderately-sorted granular very coarse- to coarse-grained sandstone: feldsarenite

Weathered; light-brown; indurated; composed of angular quartz and weathered feldspars; granules composed of subrounded quartz and pink granite, and angular pink orthoclase.

Sample T-130 Moderately-sorted granule coarse- to medium-grained sandstone: feldsarenite

Weathered; yellow-orange; indurated; composed of angular quartz and weathered feldspar; granules are of subangular to subrounded quartz.

Sample T-129 Moderately-sorted coarse to very coarse-grained sandstone: feldsarenite

Weathered; light-brown; very friable; composed of angular quartz and weathered feldspars.

Sample T-128 Moderately-sorted granular very coarse-grained sandstone: feldsarenite

Weathered; yellowish brown; indurated; composed of angular quartz and weathered feldspar grains; granules are of angular to subrounded quartz and angular pink orthoclase and pink granite.

Sample T-127 Moderately-sorted pebbly coarse- to very coarse-grained sandstone: feldsarenite

Weathered; light brown; composed of angular quartz and weathered feldspar; gravel (up to 1 cm in diameter) is composed of angular to subrounded clasts of quartz, pink granite, and pink orthoclase, with minor amounts of porphyritic rhyolite and mudstone.

Sample T-126 Moderately-sorted medium- to fine-grained sandstone: feldsarenite

Brown; weathers to dark brown and black; friable; composed of angular quartz and feldspar grains.

Sample T-125 Moderately-sorted coarse-grained sandy granular pebble conglomerate: lithic feldsrudite

Weathered; friable; light-brown; composed of angular to subrounded quartz, angular fresh and weathered feldspars, and weathered mudstone fragments.

Sample T-124 Moderately-sorted very fine- to fine-grained sandstone: chert cemented lithic feldsarenite

Brown; well indurated; contains some horizontal laminations of aligned micas; composed of angular grains of quartz, feldspars, and rock fragments.

Thin Section Description:

Compact; abundant linear grain contacts; fine sand (50%), very fine sand (30%), silt (20%); sand grains angular. Quartz (53%): straight to slightly undulose extinction, abundant vacuoles (28%); semi-composite, undulose extinction (15%). Feldspar (25%): orthoclase (10%), microcline (trace), plagioclase (15%) An_{28}, altered. Micas (1%) chlorite, muscovite, biotite. Lithic fragments: SRF's: chert (1%), mudstone (4%), VRF's: porphyritic rhyolite (3%), MRF's: muscovite-quartz schist (10%). Chert cement (3%). Heavy minerals (trace): zircon.

Sample T-123 Moderately-sorted, granular medium-to coarse-grained sandstone: feldsarenite

Weathered; light brown; composed of angular quartz, angular pink orthoclase, and weathered feldspar.

Sample T-122 Moderately-sorted granular coarse- to medium-grained sandstone: feldsarenite

Buff; very well indurated; composed of angular quartz, angular pink orthoclase, and weathered feldspars.

Sample T-121 Well-sorted granular very coarse-grained sandstone: feldsarenite

Pale orange, very indurated; composed of grains of angular quartz, angular, blocky pink orthoclase, weathered feldspar, and minor mudstone fragments.

Sample T-120 Moderately-sorted coarse-grained sandy pebbly granule conglomerate: lithic feldsrudite

Weathered to yellowish-brown; indurated; granules and pebbles (up to 1 cm in diameter) of rounded mudstone fragments, angular to subrounded quartz; weathered angular granite, and blocky pink orthoclase, sand grains composed of angular quartz and weathered feldspar.

Sample T-119 Moderately-sorted pebbly granular very coarse-grained sandstone: feldsarenite

Weathered; light brown; composed of angular quartz and weathered feldspar; granules and pebbles (up to 1 cm in diameter) composed of rounded quartzite, angular quartz, and blocky pink orthoclase.

Sample T-118 Moderately-sorted granular very coarse- to coarse-grained sandstone: feldsarenite

Buff; indurated; composed of angular quartz and weathered feldspar; granules are of angular quartz and blocky pink orthoclase.

Sample T-117 Moderately-sorted very coarse-grained sandy granule conglomerate: feldsrudite

Weathered; light brown; friable; granules composed of angular quartz and blocky pink orthoclase; sand grains of weathered feldspar and angular quartz.

Sample T-116 Moderately-sorted granular coarse- to very coarse-grained sandstone: feldsarenite

Weathered; buff; friable; granules of angular quartz and blocky pink orthoclase; sand grains are of angular quartz and weathered feldspar.

Sample T-115 Moderately-sorted very coarse-grained sandy granule conglomerate: feldsrudite

Weathered to white; friable; granules composed of angular quartz and blocky pink orthoclase; sand grains are of angular quartz and weathered feldspar.

Sample T-114 Moderately-sorted slightly pebbly, granular, very coarse-grained sandstone: feldsarenite

Buff; indurated; granules and pebbles (up to 1.5 cm) composed of angular quartz and blocky pink orthoclase; sand grains are of angular quartz and weathered feldspars.

Sample T-113 Moderately-sorted granular very coarse-grained sandstone: feldsarenite

Buff; indurated; granules composed of angular quartz and blocky pink orthoclase; sand grains are of weathered feldspar and angular quartz.

Sample T-112 Moderately-sorted very coarse- to coarse-grained sandstone: chert-cemented orthoclase feldsarenite

Buff; indurated; composed of angular quartz and weathered feldspars.

Thin Section Description:

Compact; abundant linear and concavo-convex grain contacts; granules (20%), very coarse sand (60%), coarse sand (20%), angular. Quartz (55%); monocrystalline, straight to slightly undulose extinction (42%), polycrystalline, composite (13%). Feldspar (29.5%): orthoclase (28%), microcline (1.5%), plagioclase (2.5%). Lithic fragments (1.5%). MRF's: meta-quartz (1.0%), SRF's: chert (0.5%), VRF's: porphyritic rhyolite (trace). Chert cement (9%); porosity (1.5%).

Sample T-111 Moderately-sorted very coarse- to coarse-grained sandstone: feldsarenite

Buff; indurated; composed of angular quartz and weathered feldspar.

Sample T-110 Well-sorted coarse-grained sandstone: feldsarenite

Buff; indurated; composed of angular quartz and weathered feldspar.

Sample T-109 Moderately-sorted very coarse sandy granule conglomerate: feldsrudite

Weathered; indurated; composed of angular quartz and weathered feldspar.

Sample T-108 Moderately-sorted very coarse-grained sandy granule conglomerate: feldsrudite

Weathered; indurated; composed of angular quartz and weathered feldspar.

Sample T-107 Moderately-sorted very coarse sandy granule conglomerate: feldsrudite

Buff; indurated; composed of angular quartz and pink orthoclase.

Sample T-106 Coarse-grained sandy, pebbly granule conglomerate: chert cemented orthoclase feldsarenite

Buff; indurated; granules composed of angular to rounded milky quartz and blocky, equant, pink orthoclase; pebbles of rounded quartz up to 2 cm in diameter; sand of angular quartz and weathered feldspar.

Thin Section Description:

Subcompact; tangential and linear grain contacts; grains angular. Quartz (57.5%): straight to slightly undulose extinction; vacuoles common (39%), semi-composite extinction (1.5%), polycrystalline composite (17%). Feldspar (25.5%): orthoclase (24%), microcline (1.5%), plagioclase muscovite (trace). Cement (2.5%). Porosity: (7%).

Sample T-105 Coarse-grained sandy granule conglomerate: feldsrudite

Buff; indurated; granules composed of angular quartz and pink orthoclase; sand grains of angular quartz and weathered feldspar.

Sample T-104 Moderately-sorted medium- to coarse-grained sandstone: feldsarenite

Buff; friable; composed of angular quartz and orthoclase, also weathered feldspars.

Sample T-103 Coarse-grained sandy pebbly granule conglomerate: feldsarenite

Weathered; light-brown; indurated; granules of angular quartz, some of mudstone; sand grains of angular quartz and weathered feldspar.

Sample T-102 Moderately-sorted fine- to medium-grained sandstone: feldsarenite

Weathered to brown; indurated; composed of angular quartz and orthoclase; and weathered feldspar.

Sample T-101 Moderately-sorted granular medium to coarse-grained sandstone: feldsarenite

Weathered to light brown; indurated; composed of angular quartz and weathered feldspar; granules are of angular to subrounded quartz and blocky pink orthoclase.

Sample T-100 Moderately-sorted granular coarse- to medium-grained sandstone: chert-clay cemented orthoclase feldsarenite

Weathered; stained yellowish-brown, indurated; sand grains of angular quartz and weathered feldspar; granules are of angular to rounded milky quartz and blocky pink orthoclase.

Thin Section Description:

Compact; concavo-convex grain contacts; medium sand: 40%, coarse sand: 30%, very coarse sand: 20%, fine sand and silt: 20%, angular. Quartz (53.5%); straight to slightly undulose extinction, abundant vacuoles (38.5%), semi-composite (1%), polycrystalline composite (14%). Feldspar (20.5%): orthoclase (19%), microcline (trace), plagioclase (1.5%). Lithic fragments (3.5%): MRF's: metaquartz (1.5%), VRF's: porphyritic rhyolite (trace), SRF's: chert (1%), mudstone (1%). Cement: (9%). Porosity: (13%).

Sample T-99 Moderately-sorted coarse-grained sandy, pebbly granule conglomerate: felds rüdite.

Weathered; light brown; friable; granules composed of rounded quartz and blocky, fresh orthoclase; pebbles are 1-2 cm in diameter clasts of rounded quartz; sand grains are of angular quartz and weathered feldspar.

Sample T-98 Moderately-sorted very coarse-grained sandy granule conglomerate: feldsarenite

Weathered; buff; friable; composed of angular quartz and weathered feldspar.

Sample T-97 Granular coarse- to very coarse-grained sandstone: feldsarenite

Weathered; yellowish-brown; sand grains angular and composed of quartz and fresh and weathered feldspar; fresh feldspar grains are orthoclase; granules composed of rounded quartz and angular orthoclase.

Sample T-96 Granular coarse- to very coarse-grained sandstone: feldsarenite

Weathered; buff-colored; consists of angular grains of quartz and altered feldspar; granules composed mainly of rounded quartz, but also of angular, blocky orthoclase; indurated.

Sample T-95 Medium- to coarse-grained sandy pebble conglomerate: feldsrudite

Weathered; indurated; pebbles from granule size to 2 cm in diameter; subangular to rounded; composed of coarse-crystalline pink granite, milky quartz, and mudstone fragments, matrix composed of angular quartz and altered feldspar: probably cemented by compressed mudstone fragments.

Sample T-94 Moderately-sorted medium- to coarse-grained sandstone: feldsarenite

Weathered; buff; composed of angular grains of quartz and feldspar.

Grain Size Analysis: vcs: 7%, cs: 44%, ms: 24%, fs: 9%, vfs: 6%, cz:2%, mfz: 4%, mode: 1ϕ

Sample T-93 Moderately-sorted coarse- to very coarse-grained sandstone: feldsarenite

Weathered; stained with goethite; consists of angular grains of quartz and weathered feldspar; some muscovite; indurated; friable.

Sample T-92 Moderately-sorted granular very coarse- to coarse-grained sandstone: feldsarenite

Weathered dark brown; indurated; consists of angular quartz and altered feldspar grains; granules composed of angular quartz and altered and fresh orthoclase grains.

Sample T-91 Coarse-grained sandy pebble conglomerate: feldsrudite

Clast supported; pebbles rounded and range from 1-5 cm in diameter; composed only of pink granite and milky quartz; matrix is an angular coarse-grained sand composed of quartz and weathered feldspar; some of the feldspar is very fresh pink orthoclase; this rock is part of a trough cross-bedded sequence.

Sample T-90 Moderately-sorted granular coarse- to very coarse-grained sandstone: feldsarenite

Weathered light brown; sand grains composed of angular quartz and weathered feldspar; granules of angular to subangular quartz; indurated.

Sample T-89 Moderately-sorted, pebbly granular coarse- to very coarse-grained sandstone: feldsarenite

Weathered; friable; gravel composed of rounded quartz and fresh angular pink orthoclase; sand grains angular quartz and weathered feldspar.

Sample T-88 Moderately-sorted medium- to coarse-grained sandstone: feldsarenite

Extremely weathered; very friable, buff-colored; composed of angular grains of quartz and altered feldspar.

Grain Size Analysis: vcs: 7%, cs: 30%, ms: 27%, fs: 11%, vfs: 6%, cz: 6%, mfz: 6%, c: 7%, mode: 1 ϕ.

Sample T-87 Very coarse-grained sandy, pebbly granule conglomerate: felds rudite.

Extremely weathered; goethitic stain; clast supported; pebbles up to 2 cm; clasts composed of angular quartz, granite, and mudstone fragments, sand grains of angular quartz and weathered feldspar.

Sample T-86 Moderately-sorted granular, coarse- to very coarse-grained sandstone: sparse chert cemented lithic feldsarenite

Weathered dark brown; partial goethitic stain; very friable; sand grains angular, mode = 1 mm; composed of quartz and feldspar, also fragments of porphyritic rhyolite and mudstone; granules of granite and quartz.

Thin Section Description:

Compact; abundant linear and concavo-convex grain contacts, grains angular, coarse-very coarse sand grains mainly quartz, very-coarse sand and granules composed of lithic fragments. Quartz (51.5%); semi-composite, undulose extinction (3%), straight to slightly undulose extinction (29%), composite, undulose extinction (19.5%). Feldspar (23.5%); orthoclase (21%), SRF's: intraformational mudstone (6%), chert (1%), VRF's: rhyolite (1.5%). Muscovite and chlorite (0.5%), biotite (1%), cement (7%), porosity (4.5%).

Sample T-85 Moderately-sorted, granular coarse- to very coarse-grained sandstone: feldsarenite

Weathered dark-brown; indurated; composed of angular fragments of quartz and weathered feldspar; also minor amounts of mudstone fragments.

Sample T-84 Slightly granular, moderately-sorted very coarse to coarse-grained sandstone: feldsarenite

Light-brown; weathers darker; very friable; composed of angular quartz grains and weathered feldspars; granules are subrounded and composed of quartz and granite.

Sample T-83 Clast-supported moderately-sorted very coarse-grained sandy, granule conglomerate: feldsarenite

Weathered; goethite stained; indurated; probably chert cement; granules are angular to subround grains of quartz and feldspar; sand grains are angular quartz and weathered feldspar.

Sample T-82 Slightly granular moderately-sorted medium- to coarse-grained sandstone: feldsarenite

Buff; weathered to dark brown; stained in part with goethite; friable; planar cross-bedded, granules angular to subrounded and composed of quartz mainly, some fresh feldspar (orthoclase) also; sand grains are angular quartz and altered feldspar; this unit contains silicified wood fragments.

Grain Size Analysis: vcs: 8%, cs: 29%, ms: 31%, fs: 14%, vfs: 6%, cz: 2%, mfz: 5%, c: 5%, mode = 1 ϕ.

Sample T-81 Silicified wood fragments

Light-brown fragments; show well-preserved wood structure; pieces are 10-20 cm in diameter and 20 cm long; are probably conifers.

Sample T-80 Poorly-sorted silty, pebbly, fine- to medium-grained sandstone: feldsarenite

Extremely weathered; stained orange-brown and black; composed of angular grains of quartz and weathered feldspar; pebbles consist of quartz, chert, and granite; are subangular.

Sample T-79 Clast-supported coarse-grained sandy granule-pebble conglomerate: hematite-chert cemented lithic feldsarenite

Tan; stained with yellow-brown goethite; pebbles up to 5 cm in diameter, angular to subrounded, composed of porphyritic rhyolite, granite, quartz, and chert-cemented sandstone; granules mainly of angular, equant grains of quartz; sand angular to very angular and composed of quartz and weathered feldspar.

Thin Section Description:
Compact, concavo-convex grain contacts; angular. Quartz (53%) semi-composite, undulose extinction, abundant vacuoles (25%), straight to slightly undulose extinction (23%), composite, undulose extinction (5%). Feldspar (17%): orthoclase (15%), plagioclase (2%). Lithic fragments (15%): SRF's: intraformational mudstone (10%), MRF's: meta-quartz (5%). Cement (5%).

Sample T-78 Very coarse-grained sandy, pebbly granule conglomerate: feldsrudite

Extremely weathered; stained with goethite; granules angular to subrounded; consist of quartz, feldspar, and porphyritic rhyolite; sand grains consist of angular quartz and weathered feldspar; this unit contains silicified wood fragments.

Sample T-77 Moderately-sorted coarse- to very coarse-grained sandstone: chert cemented lithic feldsarenite

Extremely weathered; coated with white clay film from altered feldspars and stained black in part; compact; well cemented; indurated; grains are very angular to angular; subequant; composed of quartz, feldspar, and lithic fragments.

Thin Section Description:
Compact; angular; 60% coarse sand, 30% very coarse sand. Quartz (46%): straight to slightly undulose extinction, vacuoles, tourmaline inclusions (34.5%), semi-composite, segmented undulose extinction (1.5%), composite, undulose extinction (10%). Feldspar (31.5%): microcline (1%), orthoclase (29.5%), plagioclase (1%). Lithic fragments (12%): MRF's: quartz-muscovite schist (2%), SRF's: chert (2%), introformational mudstone (8%), VRF's: rhyolite (0.5%). Cement: (1.5%), porosity: 6.5%, detrital hematite: (0.5%), biotite, chlorite, muscovite (0.5%).

Sample T-76 Moderately-sorted granular coarse- to very coarse-grained sandstone: feldsarenite

Very weathered, stained yellow brown from goethite; granules rounded and composed of quartz and granite; sand grains are angular to subangular and consist of quartz and weathered feldspar; indurated.

Sample T-75 Moderately-sorted granular very coarse-grained sandstone: lithic feldsarenite

Buff, weathers to dark brown; consists of angular grains of quartz, weathered feldspar, and mudstone grains; small amounts of muscovite and carbonized wood fragments also present; small limonitic concretions 1-2 cm in diameter; probably cemented by compacted mudstone fragments; indurated; resistant.

Sample T-74 Mudstone

Greenish-brown; greasy; forms a trough-shaped lens 10-20 cm thick; weathers discoidally; stained with goethite; contains carbonized plant fragments and muscovite.

Sample T-73 Moderately sorted coarse-grained sandy granite conglomerate: patchy calcite cemented lithic feldsarenite

Buff, weathers to dark brown; indurated; resistant; granules angular to rounded and composed of quartz, granite, and porphyritic rhyolite; sand grains angular and composed of the same; detrital carbonized wood fragments also present.

Thin Section Description:
Linear grain contacts; 30% granules, 40% coarse sand, 20% medium sand; angular. Quartz (41%): straight to slightly undulose extinction, abundant vacuoles (23%), composite, undulose extinction (13%), monocrystalline strongly undulose extinction (4%), semi-composite undulose extinction (1%). Feldspar (38.5%): orthoclase (34%), microcline (1.5%), plagioclase, An_{35} (3%). Lithic fragments (13%): Chert (1%), claystone (6%), MRF's: meta-quartz (2%), muscovite-quartz schist (1%), VRF's: rhyolite (1%). Other: muscovite (trace), cement (3%), porosity (3%), heavy minerals: garnet, zircon.

Sample T-72b Moderately sorted medium- to coarse-grained sandstone: feldsarenite

Buff, weathers to black; stained with goethite; composed of angular grains of quartz and weathered feldspar.

Sample T-72a Moderately-sorted medium- to coarse-grained sandstone: feldsarenite

Buff; weathers to dark brown, goethitic stain in part; composed of angular grains of quartz and feldspar; with a small amount of sedimentary rock fragments and muscovite; feldspars mainly weathered; very friable; trough cross-bedded.

Sample T-71 Moderately-sorted very coarse-grained sandy, pebbly granule conglomerate: feldsrudite

Extremely weathered and stained goethitic yellowish-brown; consists of angular to rounded clasts of quartz, granite, porphyritic rhyolite, and chlorite schist; sand grains angular and composed mainly of quartz and feldspar; also contains detrital carbonized wood fragments.

Sample T-70 Moderately-sorted fine-grained sandy siltstone

Light-brown; stained yellow by sulfur; contains abundant detrital carbonized wood fragments; also abundant muscovite flakes.

Sample T-69 Moderately-sorted, slightly granular medium- to coarse-grained sandstone: calcite cemented lithic feldsarenite

Buff, stained yellowish-brown with goethite; cross-bedded; very friable; grains angular and composed of quartz, orthoclase, and rock fragments; feldspars range from fresh to predominantly altered.

Thin Section Description:

Compact; linear grain contacts angular-subangular. Quartz (47%); straight to slightly undulose extinction, abundant vacuoles (30%), semi-composite, undulose extinction (3%), composite, undulose extinction (14%). Feldspar (29%): orthoclase (25%), microcline (1%), plagioclase (3%). Lithic fragments (12%): MRF's: bimodal, elongate polycrystalline quartz (2%), quartz-muscovite schist (2%); SRF's: intraformational mudstones (8%), VRF's: rhyolite (trace). Other: muscovite (trace), calcite cement (7%), porosity (5%).

Grain Size Analysis: vcs: 10%, cs: 36%, ms: 23%, fs: 11%, vfs: 7%, cz: 3%, mfz: 5%, c: 5%, mode = 1 ϕ.

Sample T-68 Clast-supported, well-sorted granule conglomerate: feldsrudite

Buff; very porous and friable; composed of angular, subequant grains of quartz and orthoclase; orthoclase ranges from very fresh to extremely altered; minor fragments of porphyritic rhyolite and ubiquitous muscovite.

Sample T-67 Clasts collected from cobble conglomerate:

(a) gray chert
(b) coarsely-crystalline red granite
(c) quartz-orthoclase muscovite schist

Sample T-66 Moderately-sorted slightly granular coarse- to very coarse-grained sandstone: feldsarenite

White; composed of very angular to angular subequant grains of quartz and altered feldspar; contains abundant charcoal wood remains; has a sulfur stain; planar cross-bedded; very friable.

Sample T-65 Moderately-sorted very coarse-grained sandy conglomerate: feldsarenite

Buff; sample extremely weathered to orange-brown; grains very angular to angular and composed of quartz and very altered feldspars; contains some charcoal wood fragments; stained with goethite; possibly ferruginous cement.

Sample T-64 Moderately-sorted medium- to fine-grained sandstone: clay-chert cemented lithic feldsarenite

Light-brown; indurated; resistant; cross-bedded, composed of angular to subangular grains of quartz, feldspar, rock fragments, muscovite, and chlorite.

Thin Section Description:
Compact; corroded concavo-convex grain contacts; 60% fine sand, 30% medium sand; angular to subangular; many quartz grains elongated. Quartz (38.5%): straight to slightly undulose extinction, vacuoles (34.5%), semi-composite, segmented undulosity (t), composite, undulose extinction (4%). Feldspar (29%): orthoclase (27%), weathered to sericite, microcline (trace), plagioclase: An_{55} (2%). Lithic fragments (16.5%): SRF's: chert (2%), intraformational mudstone (11%); MRF's: muscovite-quartz schist (3%), VRF's (0.5%). Other: muscovite: abundant (3%), biotite (0.5%), chlorite (2.5%); chert cement (7%), heavy minerals (1%); garnet, opaques, zircon.

Sample T-63 Moderately sorted coarse- to very coarse-grained sandy pebble granule conglomerate: ferruginous cemented feldspathic lithrudite

Reddish-gray; clasts angular, composed mainly of quartz, also porphyritic rhyolite, granite, and chert; sand grains angular and composed of quartz, feldspar (weathered and fresh) and rock fragments; friable; resistant; trough cross-bedded.

Grain Size Analysis: cs: 7%, ms: 35%, fs: 20%, vfs: 11%, cz: 4%, mfz: 7%, c: 10%, mode = 2 ϕ.

Sample T-62 Moderately-sorted, coarse- to very coarse sandy, pebble granule conglomerate: ferruginous cemented lithic feldsrudite

Light-brown, weathers darker; granules subangular to subrounded, composed of quartz, granite, and quartzite; sand fraction composed of quartz, feldspar, and rock fragments, indurated; resistant; cross-bedded; grades into a pebble conglomerate (coarsens upward) rich in fragments of quartz, granite, porphyritic rhyolite, and quartzite.

Thin Section Description:
Loosely packed, angular to subangular sand, granules subrounded; 60% coarse sand, 40% very coarse sand and granules. Quartz (40%: straight to slightly undulose extinction, vacuoles and microlites common (26%), polycrystalline composite (9.5%), semi-composite, undulose extinction (4.5%). Feldspar (22%): orthoclase (18%), plagioclase (4%). Other: biotite (trace), chlorite (trace), ferruginous cement (15.5%), detrital hematite (1%). Lithic fragments (16%): MRF's: meta-quartz and quartz-muscovite schist (6%), SRF's chert (1%), mudstone (3%), VRF's: porphyritic rhyolite (6%).

Sample T-61 Moderately-sorted coarse- to very coarse-grained sandy granule-pebble conglomerate: calcite cemented feldspathic lithrudite

Reddish-gray; weathers to black; extremely friable; pebbles subrounded to rounded and consist of coarse-crystalline red granite, mudstone, quartz, chlorite schist, and porphyritic rhyolite; sand grains angular to subangular and composed of quartz and feldspar.

Grain Size Analysis: gr: 28%, gn: 14%, vcs: 22%, cs: 17%, ms: 9%, fs: 3%, vfs: 1.5%, cz: 0.5%, mfz: 2%, c: 3%, mode = 2 ϕ

Sample T-169 Poorly-sorted pebbly, muddy very fine-grained sandstone

Mottled reddish-brown and greenish gray; blocky cleavage; indurated; sand grains very angular and quartz-rich; abundant unaligned muscovite and biotite flakes; disseminated coarse sand grains of quartz throughout the sample; gray areas contain less mud than the reddish brown portions.

Sample T-60 Matrix-supported, very poorly-sorted muddy, fine- to very coarse-grained sandy, granule pebble conglomerate: clay-hematite-patchy calite cemented feldspathic lithrudite

Red; weathers to gray; clasts subangular to rounded grains of porphyritic rhyolite, chlorite-epidote-orthoclase-quartz gneiss, coarsely-crystalline red granite, siltstone, quartzite, and milky quartz, clasts range in size from 4 mm to 4 cm; sand grains angular; composed of quartz, weathered feldspar, and rock fragments; modal coarse-grained; friable; resistant.

Thin Section Description:

Mud matrix-supported; inhomogeneous; angular. Quartz (45%): straight to slightly undulose extinction, abundant vacuoles (29%), composite, straight extinction (13%), semi-composite, undulose extinction (3%). Feldspar (9.5%): orthoclase (8.5%), plagioclase (1%). Lithic fragments (12%) SRF's: chert (1%), mudstone and siltstone (5%); MRF's: quartz-muscovite schist, chlorite-quartz schist (6%). Other: chlorite (1%), opaque heavy minerals, garnet (2%); calcite replacement (8.5%); hematite-stained clay matrix (23%).

Sample T-59 Matrix-supported, poorly-sorted muddy fine- to coarse-grained sandy pebble conglomerate: feldsrudite

Extremely-weathered to black; pebbles rounded and range in size from 1-5 cm; composed of granite, quartz, quartzite, and gneiss; sandy matrix composed grains of angular quartz and extremely weathered feldspar and biotite.

Sample T-X7 Clast-supported pebble conglomerate: calcite-cemented litharenite

Lignt -brown; composed of subangular to rounded pebbles ranging in size from 1-4 cm in diameter; consist of abundant porphyritic rhyolite, biotite-chlorite-quartz-orthoclase gneiss, coarsely crystalline biotite-quartz-orthoclase granite, milky quartz, purple quartzite, red siltstone, and purple phyllite; matrix is moderately-sorted medium- to coarse sandy; mainly angular quartz; well-cemented; indurated; resistant.

Sample T-X6 Moderately sorted medium- to coarse-grained sandy granule-pebble conglomerate: hematite-calcite cemented feldspathic lithrudite.

Red; indurated; resistant; pebbles up to 10 cm in diameter; rounded; composed of limestone, quartzite, milky quartz, porphyritic rhyolite, purple phyllite, and granite; matrix is medium- to coarse-grained angular sand, composed mainly of quartz; well-cemented by calcite.

Sample T-X5 Granular, pebbly, poorly-sorted medium- to very coarse-grained sandstone: clay-hematite-calcite cemented lithic feldsarenite

Red; very friable; resistant; sand grains angular; composed of quartz, feldspar, and rock fragments; granules and pebbles angular to subrounded; composed of quartz, quartzite, granite, muscovite-chlorite schist, gneiss; volcanic rock fragments, sedimentary rock fragments: limestone, chert, and mudstone; sample represents a non-conglomeratic unit 10-15 cm thick in between matrix-supported conglomerates.

Thin Section Description:
Linear grain contacts, others within mud matrix; grains very-angular to angular. Quartz (40%): straight extinction, abundant vacuoles (25%), semi-composite, segmented extinction (trace), composite, undulose extinction (15%). Feldspar (23%): orthoclase (20%), microcline (1%), plagioclase (2%). Lithic fragments (14.5%): VRF's: plagioclase laths, quartz phenocrysts, embayed quartz grains (2%); MRF's: polycrystalline quartz with crenulated boundaries (5.5%), SRF's: chert (1%), mudstone (some detrital lithified fragments, others are intraformational (6%). Other: chlorite (1%), calcite cement and replacement (8%), hematitic stained mud matrix (10.5%).

Sample T-58 Matrix-supported, poorly-sorted slightly muddy, fine- to very coarse-grained sandy, pebble cobble, granule conglomerate: clay-hematite-calcite cemented lithic feldsrudite

Red; pebbles up to 4 cm in diameter; rounded; composed of quartz, granite, quartzite, and chlorite schist; granules sub-angular and composed mainly of quartz; sandy matrix angular and composed of quartz, feldspar, and lithic fragments; friable; resistant; cobbles up to 6 cm and composed of granite, quartzite, porphyritic rhyolite, limestone, phyllitic mudstone, and quartz.

Sample T-170 Very poorly-sorted muddy, granule fine- to very coarse-grained sandstone: clay-hematite-calcite cemented feldsarenite

Reddish brown; some areas are white; weathers black; very friable; sand grains composed mainly of angular quartz and altered feldspar grains; also present are rock fragments of purple quartzite, red granite, and chlorite schist; muscovite, chlorite, and biotite also present, granules consist mainly of angular to subangular quartz grains.

Thin Section Description:
Mud matrix-supported; angular grains. Quartz (43%): straight to slightly undulose extinction, contains vacuoles (33.5%), semi-composite, undulose extinction (9%), composite polycrystalline quartz (0.5%). Feldspar (18%): weathered orthoclase (17%), microcline (trace), plagioclase (1%). Lithic fragments (11.5%): chert (1%), intraformational mudstone (4.5%); MRF's: muscovite-quartz schist (3%); VRF's: porphyritic rhyolite: (3%). Other: muscovite (trace), opaque heavies (1%), hematite-stained clay matrix (26%).

Sample T-59b Very poorly-sorted, granular, muddy, fine- to very coarse-grained sandstone: clay-hematite cemented lithic feldsarenite.

Reddish brown; very friable; composed of angular quartz, feldspar, and lithic fragments; feldspar mostly altered although some is fresh; pebbles rounded and consist mainly of quartz and granite; some muscovite schist fragments present.

Sample T-59a Very poorly-sorted, granular muddy fine- to coarse-grained sandy, pebble cobble conglomerate: clay-chert cemented lithic feldsrudite

Reddish-brown, very friable; composed of angular grains of quartz, feldspar, and rock fragments; most feldspar is extremely weathered but some fresh grains of orthoclase are noted; muscovite is conspicuously present and is unaligned; granules composed of subrounded quartzite; pebbles and cobbles rounded and composed of quartz, quartzite; porphyritic rhyolite, granite, gneiss, and meta-sediment.

Sample T-56 Poorly-sorted muddy fine- to very fine-grained sandstone: clay-hematite-chert cemented feldspathic litharenite

Reddish-brown; very friable; sand grains angular; composed of quartz, rock fragments, feldspar, and muscovite, massive bedding; musvovite flakes show no alignment.

Grain Size Analysis: ms: 14%, fs: 38%, vfs: 19%, cz: 8%, mfz: 9%, c: 10%, mode = 2.5 ϕ

Sample T-171 Very poorly-sorted granular muddy fine- to very coarse-grained sandstone: clay-hematite cemented lithic feldsarenite

Red, white in part, lacking mud; sand grains angular; consist of quartz; extremely altered feldspars, rock fragments, muscovite, chlorite, and biotite; granules rounded and composed mainly of quartz; friable; inhomogeneous.

Thin Section Description:
Muddy matrix supported; angular; inhomogeneous. Quartz (49%): straight to slightly undulose extinction (3.6%), polycrystalline composite (10%), semi-composite, undulose extinction (3%). Feldspar (20.5%): orthoclase (19%), plagioclase (1.5%). Lithic fragments (19.5%); Muscovite-quartz schist (4.5%); MRF's: rhyolite porphyry (2%); SRF's: chert (2%), mudstone (11%). Other: chlorite (0.5%), tourmaline, garnet (0.5%), hematite-stained clay matrix (7%), porosity (3%).

Grain Size Analysis: (T-171 white): p: 2%, gn: 4%, vcs: 6%, cs: 27%, ms:32%, fs: 10%, vfs: 2%, cz: 2%, mfz: 7%, c: 8%, mode = 1 ϕ
(T-171 red): p: 7%, gn: 1%, vcs: 3%, cs: 10%, ms: 34%, fs: 22%, vfs: 5%, cz: 3%, mfz: 8%, c: 7%, mode = 2 ϕ

Sample T-55 Matrix-supported, very poorly-sorted muddy fine- to very coarse-grained sandy, granule pebble conglomerate: clay-hematite-calcite cemented lithic feldsarenite-rudite.

Red; some non-muddy areas are white; clasts 1-10 cm in diameter, consist of quartz, quartzite, granite, limestone, porphyrite rhyolite, gneiss, and red sandstone; subrounded to rounded; matrix: angular grains of quartz, feldspar, and lithic fragments.

Grain Size Analysis: p: 15%, gn: 15%, vcs: 17%, cs: 13%, ms: 14%, fs: 10%, vfs: 4%, cz: 2%, mfz: 4%, c: 6%, mode = 1.25 ϕ

Sample T-54 Muddy, moderately-sorted fine- to medium-grained sandstone: hematite-clay-calcite cemented lithic feldsarenite

Mottled white/red-brown; white areas don't contain mud; trough cross-bedded; grains angular to subangular; composed of quartz, feldspar, and lithic fragments.

Thin Section Description:
Tangential and linear grain contacts, angular. Quartz (30%) straight to slightly undulose, abundant vacuoles (20%), polycrystalline, undulose extinction (8%); semi-composite, undulose extinction (2%). Feldspar (22.5%): Orthoclase (20%), microcline (t), plagioclase (2.5%). Lithic fragments (19.5%): SRF's: intraformational mudstone (10.5%); MRF's: meta-quartz (2.5%); VRF's: rhyolite (6.5%). Other: muscovite: (trace); calcite cement and replacement (23%); hematite-stained matrix (2%); garnet and opaque heavy minerals (2.5%).

Grain Size Analysis: cs: 6%, ms: 40%, fs: 25%, vfs: 7%, cz: 2.5%, mfz: 5%, c: 13.5%, mode = 2 ϕ

Sample T-53 Coarse sandy granule conglomerate: hematite-calcite cemented lithic feldsrudite.

Red-brown; clast-supported; indurated; resistant; trough cross-bedded; granules and sand subangular to subrounded; composed of quartz, orthoclase, and lithic fragments.

Thin Section Description:
Loosely packed; 50% granules, 30% very coarse sand; angular to rounded. Quartz (42%) straight to slightly undulose extinction, abundant vacuoles (22.5%), polycrystalline composite (16.5%); semi-composite, undulose extinction (3%). Feldspar (24%): orthoclase (22%), plagioclase (2%). Lithic fragments (14%): SRF's: intraformational siltstone (10%); MRF's: meta-quartz (4%), VRF's: rhyolite (trace). Other: muscovite (trace); calcite cement (19%); opaque heavy minerals (1%).

Sample T-52 Pebbly, granular, moderately-sorted very coarse- to coarse-grained sandstone: patchy ferruginous cemented feldspathic litharenite

Sample weathered; tan, weathered to yellowish-brown; cross-bedded; friable; sand grains angular to subangular and composed of quartz, feldspar, and lithic fragments; coarse grains rounded and composed of quartz, quartzite, and granite.

Thin Section Description:
Compact; inhomogeneous; linear grain boundaries; angular to subangular. Quartz (46%): straight to slightly undulose extinction (23%), polycrystalline, composite (20%); semi-composite, undulose extinction (3%). Feldspar (12.5%): orthoclase (11.5%), microcline (trace), plagioclase (1%). Lithic fragments (33%): SRF's: chert (3%), intraformational siltstone (25%); VRF's: rhyolite (1%); MRF's: quartz-muscovite-schist and meta-quartz (4%). Other: muscovite (1%), garnet, zircon (0.5%), porosity (4%), hematite-stained clay (3%).

Grain Size Analysis: p: 7%, gn: 10%, vcs: 22%, cs: 25%, ms: 18%, fs: 8%, vfs: 3%, z+c: 7%, mode = 0.25 ϕ

Sample T-51 Granular-pebbly, moderately-sorted medium- to coarse-grained sandstone: clay-chert cemented feldspathic litharenite

Tan colored; weathers to dark brown; cross-bedded; friable; sand grains angular to subangular; composed of quartz, feldspar, and rock fragments; granules and pebbles well rounded and consist of quartz and quartzite.

Thin Section Description:
Compact; abundant plastically deformed intraformational muds; coarse sand (50%), medium sand (25%), fine sand and finer (25%); angular. Quartz (47.5%): straight to slightly undulose extinction (40%), semi-composite, segmented extinction (1.5%), polycrystalline composite (6%). Feldspar (17.5%): orthoclase (16%), microcline (0.5%), plagioclase (1%). Lithic fragments (27.5%): SRF's: chert (2%), intraformational mudstone (18%); MRF's: quartz-muscovite schist, garnet-muscovite schist (6.5%); VRF's: rhyolite (1%). Other: biotite, muscovite, chlorite (1%); clay-chert cement (2.5%); porosity (4%); opaque heavy minerals (0.5%).

Sample T-X10 Calcified-carbonized tree fragments

Tree remains of branches and trunks; range in size up to 20 cm in diameter and 6 m in length.

Sample T-50 Well-sorted very fine-grained sandstone: lithic feldsarenite

Light brown; thinly laminated; friable; breaks readily along bedding planes; grains subangular to subrounded; composed of quartz, altered feldspar, chlorite schist fragments, and biotite; blocky cleavage; resistant.

Grain Size Analysis: fs: 30%, vfs: 46%, cz: 11%, mfz: 4%, clay: 9%, mode = 3 ϕ

Sample T-X9 Calcified-carbonized tree fragments

Tree remains of branches and trunks; range in size up to 20 cm in diameter and 6 m in length.

Sample T-49 Moderately-sorted fine- to medium-grained sandstone: feldsarenite

Greenish-brown; weathers to dark brown; resistant; indurated; cross-bedded; angular grains of quartz and altered feldspar; abundant muscovite and biotite, aligned along horizontal planes.

Sample T-48 Pebbly, granular, moderately-sorted coarse- to very-coarse sandstone: calcite-cemented feldspathic litharenite

Buff-colored; weathers to black; limonitic stain; friable; cross-bedded; sand grains angular to subrounded; composed of quartz, feldspar, rock fragments; granules and clasts of quartz, quartzite, granite, and gneiss.

Thin Section Description:

Semi-compact, linear grain boundaries; 40% granules, 50% very coarse sand, 10% coarse sand; granules subrounded, sand angular to subangular. Quartz (52%): polycrystalline composite (34%), straight extinction, abundant vacuoles (18%). Feldspar (14%): orthoclase (9%), microcline (1%), plagioclase (1%). Lithic fragments (22%); SRF's: chert (2%), intraformational mudstone (11%), MRF's: muscovite-quartz schist (9%). Other: patchy calcite cement (3%); porosity (5%).

Sample T-47 Claystone

Greenish-grey; discoidal weathering; from a layer 2-5 cm thick.

Sample T-46 Moderately-sorted very fine- to fine-grained sandstone: mudstone arenite

Light brown; weathers to a dark brown; indurated; blocky cleavage; grains very angular to angular; composed of quartz and mudstone fragments.

Sample T-45 Matrix-supported pebble conglomerate: lithic feldsrudite

Buff colored; weathers to a yellow-brown; friable; pebbles 1-2.5 cm most common; are well-rounded; composed of quartz, granite, and quartzite; also some porphyritic rhyolite; matrix is moderately-sorted medium- to coarse-grained sand; angular to subangular; composed of quartz, feldspar, and muscovite schist fragments; some of the grains are coated with hematite, much of which is now altered to goethite.

Grain Size Analysis: p: 27%, gr: 7%, vcs: 9%, cs: 16%, ms: 15%, fs: 11%, vfs: 6%, cz: 2%, mfz: 3%, c: 4%, mode = $-2.5\ \phi$

Sample T-44 Calcified - carbonized tree fragments

Black; woody structure of tree fragments readily seen (all structures flattened); fragments vary from small branch segments 4-6 cm in diameter and 10 cm long to trunks 20 cm in diameter and up to 6 m long.

Sample T-X4 Slightly granular, moderately-sorted medium- to coarse-grained sandstone; lithic feldsarenite

Brownish-grey; weathers darker; angular grains composed of quartz, feldspar, and chlorite schist fragments; some pebbles of rhyolite porphyry, quartzite, and granite also present; undurated.

Sample T-43 Moderately-sorted medium- to coarse-grained sandstone: calcite cemented feldspathic litharenite

Buff-colored; weathers dark brown; subangular to subrounded grains fo quartz, orthoclase, sedimentary rock fragments and biotite; indurated; resistant.

Thin Section Description:

Subcompact; very coarse sand (20%), coarse sand (55%), medium sand (25%); angular to subangular grains. Quartz: (43.5%): chalcedony (trace); straight to slightly undulose extinction, abundant vacuoles, some inclusions of tourmaline, rutile, and muscovite (38%), semi-composite undulose extinction (0.5%), polycrystalline composite (5%). Feldspar (18%): orthoclase (16%), microcline (0.5%), plagioclase (1.5%). Lithic fragments (22.5%): SRF's: chert (1.5%), mudstone (13%); MRF's: muscovite-quartz schist (6%); VRF's: porphyritic rhyolite (2%). Other: biotite (trace); calcite cement (pore fillings and replacement (11%), porosity (3%); heavy minerals (1%), tourmaline, zircon.

Sample T-42 Poorly-sorted pebbly granular very coarse- to coarse-grained sandstone: lithic feldsarenite

Light-brown; stained yellowish-brown; sand grains angular to subrounded and composed of quartz, feldspar, heavy minerals, and some lithic fragments; granules subrounded and composed of muscovite schist, quartz, quartzite, claystone, and orthoclase; friable; blocky cleavage.

Sample T-X2 Moderately-sorted very fine-grained sandy siltstone: subfeldsarenite

Brown and black horizontal streaks; weathers to dark grey; finely laminated into alternating organic-rich and organic-poor horizons; organics consist of carbonized, compressed plant fragments (detrital); grains subangular and composed of quartz and feldspar, muscovite also present.

Sample T-41 Claystone

Greenish-grey; weathers black; waxy; conchoidal fracture, discoidal weathering; abundant muscovite flakes; no palynomorphs.

Sample T-40 Moderately-sorted fine-grained sandy siltstone: feldsarenite

Light-brown; weathers with an orange-brown tint; thin wispy lamination; indurated; irregular cleavage; contains quartz, feldspar, and abundant biotite and muscovite; also present are limonitic concretions 1 cm in diameter.

Sample T-X1 Moderately-sorted very fine- to fine-grained sandstone: feldsarenite

Greenish-brown; weathers to black; friable; thickly laminated; composed of angular grains of quartz and feldspar; abundant biotite and muscovite; aligned on bedding planes.

Sample T-39 Claystone

Tan; yellowish-brown stain; unresistant; discoidal weathering; contains muscovite flakes and carbonized plant remains.

Sample T-38 Claystone

Greenish-grey; thinly laminated; blocky cleavage; contains abundant muscovite flakes and carbonized plant remains along bedding planes; discoidal weathering.

Sample T-37 Moderately-sorted silty, very fine-grained sandstone: calcite cemented feldsarenite

Greenish-grey; weathers to black; thickly laminated; indurated; blocky cleavage; consists of angular quartz and feldspar (weathered) grains; also muscovite and biotite align bedding plains.

Sample T-36 Moderately-sorted very fine- to fine-grained sandstone: calcite-cemented feldsarenite

Grayish orange pink; weathers dark brown; indurated; thickly bedded; composed of angular to subangular grains of quartz, feldspar; also biotite and muscovite schist flakes present.

Sample T-35 Mudstone

Greenish-grey; waxy; discoidal weathering; contains muscovite flakes and carbonized plant remains.

Sample T-34 Moderately-sorted silty very fine-grained sandstone

Light-brown; weathers dark-brown to black; thinly laminated; flaggy; contains abundant carbonized plant fragments, muscovite, and biotite on bedding planes; resistant.

Sample T-33 Moderately-sorted very fine- to fine-grained sandstone: feldsarenite

Greyish-brown; weathers black; resistant; massive, indurated; blocky cleavage; compact; angular grains of quartz, altered feldspar, muscovite.

Sample T-187 Moderately-sorted very fine-grained sandy siltstone

Brown, wispy horizontal thin laminations; rip-up clasts of claystone 5 mm in diameter at base; composed of angular quartz, feldspar, and dispersed, but abundant biotite flakes; resistant, blocky cleavage.

Sample T-32 Moderately-sorted silty very-fine grained sandstone: feldsarenite

Greenish-brown; weathers greenish-black; compact; indurated; resistant; massive-bedded; composed of angular grains of quartz and feldspar with small amounts of biotite, muscovite, and heavy minerals.

Sample T-31 Moderately-sorted fine- to medium-grained sandstone: feldsarenite

Light-grey; weathers dark-grey; indurated; resistant; contains angular to subangular grains of quartz, feldspar, chlorite, heavy minerals, and biotite; compact.

Sample T-186a Moderately-sorted, silty very fine-grained sandstone: subfeldsarenite

Light-grey, streaked with biotite horizons; thin ripple cross-lamination; flaggy; splits along bedding planes of biotite; contains angular quartz and feldspar grains; abundant biotite (flakes ¼ to ½ mm in diameter), some muscovite.

Sample T-30 Moderately-sorted fine- to very fine-grained sandstone: subfeldsarenite

Buff; weathers dark-brown; massive-bedded; flaggy; resistant; grains subangular; composed of quartz, feldspar, heavy minerals, biotite, muscovite, and detrital carbonized plant material; contains some limonitic concretions 1-2 mm in diameter.

Grain Size Analysis: ms: 13%, fs: 33%, vfs: 24%, cz: 9%, mfz 10%, c: 11%, mode = 3 ϕ

Sample T-29 Moderately-sorted very fine- to fine-grained sandstone: feldsarenite

Greenish-brown; weathers black; contains angular grains of quartz, feldspar, biotite, and muscovite; indurated; very resistant.

Sample T-28 Moderately-sorted very fine sandy siltstone

Grey; massive-bedded; irregular fracture; micaceous.

Sample T-27 Mudstone

Greenish-brown; unresistant; discoidal weathering; muscovite flakes present.

Sample T-X17 Siltstone

Greenish-brown; weathers to dark brown; thinly laminated; flaggy; abundant aligned muscovite flakes and carbonized plant remains on bedding plane surfaces.

Sample T-26 Claystone

Greenish-grey; yellowish-green stain; thinly laminated; unresistant; conchoidal fracture; discoidal weathering; some carbonized plant remains on bedding planes.

Sample T-25 Claystone

Greenish-grey; unresistant; discoidal weathering; some carbonized plant remains.

Sample T-24 Moderately-sorted silty very fine-grained sandstone

Greenish grey; weathers to orange-brown and dark grey; thinly laminated; flaggy; contains abundant carbonized plant material on bedding planes.

Sample T-23 Mudstone

Greenish-grey; thinly bedded; somewhat fissile; unresistant; discoidal weathering; muscovite flakes and carbonized plant material present.

Sample T-22 Siltstone

Greenish brown; weathers to black; orange stained in part; thinly-bedded; indurated; parting lineation; discoidal weathering, contains muscovite flakes and carbonized plant remains.

Sample T-21 Mudstone: subfeldsarenite

Greenish brown; weathers to greenish black; thickly laminated; indurated; discoidal weathering; contains aligned muscovite flakes and carbonized organic material.

Sample T-157 Siltstone

Brown; weathers to black; finely-laminated; indurated; massive appearance; resistant; contains aligned muscovite flakes and carbonized plant fragments.

Sample T-156 Mudstone

Greenish-grey; yellow-brown stain; subwaxy; resistant; discoidal weathering; contains muscovite flakes.

Sample T-155 Poorly sorted muddy very fine-grained sandstone

Light-brown; weathers to dark-brown; some orange stain; massive; discoidal weathering; contains muscovite flakes and carbonized plant remains.

Sample T-20 Moderately-sorted silty very fine-grained sandstone: subfeldsarenite

Greenish-brown; weathers darker; massive; beds 3/4 m thick; indurated; resistant to weathering; grains angular; muscovite-rich.

Sample T-185 Moderately-sorted muddy very fine-grained sandstone

Buff; weathers to dark-brown and black; thickly laminated (½ to 1 cm); friable; composed of abundant quartz, also feldspar, muscovite, biotite, and carbonized plant material; micas and plant material aligned along bedding planes.

Sample T-X25 Carbonate nodules

Dark grey with irregular black stringers; irregular, rough outer surface; radially concentric inward from the top and bottom for the first 1-2 cm; crystalline; distribution irregular with shale horizons in this part of the section.

Sample T-184 Poorly-sorted silty fine- to very fine-grained sandstone

Brown; weathers black; subparting lineations; indurated; resistant; massively bedded (0.75 m) contains muscovite flakes and carbonized plant fragments.

Sample T-161 Medium-sandy siltstone

Light-brown; weathers black; indurated; thickly laminated; contains muscovite flakes and carbonized plant fragments.

Sample T-160 Claystone

Greyish-green; subgreasy; resistant; discoidal weathering; contains muscovite flakes and carbonized plant remains.

Sample T-159 Mudstone

Greenish-grey; orange and black stain; thin cross-ripple lamination; current ripple mold on bottom; parting lineation, abundant muscovite flakes and carbonized plant remains.

Sample T-158 Claystone

Greenish-grey; greasy-feel; waxy; unresistant; discoidal weathering; contains muscovite flakes.

Sample T-163b Siltstone

Greenish-brown; orange and black stain; thickly laminated; contains muscovite flakes and carbonized plant fragments.

Sample T-162 Claystone

Greenish-grey; stained orange-brown; unresistant; discoidal weathering; contains muscovite flakes and carbonized plant remains.

Sample T-168 Siltstone

Greenish-grey; weathers dark brown; ripple casts on bottom; indurated; massive looking; muscovite flakes present.

Sample T-167 Mudstone

Greenish-grey; orange-brown and black stain; subgreasy; unresistant; discoidal weathering; contains muscovite and carbonized plant fragments.

Sample T-166 Siltstone

Greenish-brown; weathers dark-brown; orange-brown stain; indurated thinly laminated; parting lineations; abundant muscovite flakes; carbonized plant remains present.

Sample T-165 Claystone

Greenish-grey; waxy-looking; greasy feel; conchoidal fracture; contains muscovite flakes.

Sample T-164 Medium-grained sandy siltstone.

Greenish-grey; indurated; massive looking; contains some muscovite flakes.

Sample T-163a Claystone

Light greenish-gray; orange-brown stain; weathers discoidally.

Sample T-19 Moderately-sorted medium- to coarse-sandstone: feldsarenite

Light-brown; weathered to dark-brown and black; indurated (possibly chert cement); grains angular to subangular; composed of quartz, feldspar, biotite, muscovite, heavy minerals.

Sample T-18 Moderately-sorted fine- to medium sandstone: chert-clay cemented lithic feldsarenite

Light-brown; weathers dark-brown to black; thinly-bedded, horizontal, parting lineations; flaggy; indurated; grains angular to subangular; composed of quartz, feldspar, rock fragments, heavy minerals, and abundant muscovite and biotite with (001) face aligned along bedding planes.

Thin Section Description:

Compact; linear and tangential grain boundaries; medium-fine sand size; angular grains. Quartz (40%): straight to slightly undulose extinction, abundant vacuoles (36.5%), semi-composite undulose extinction (1.5%), polycrystalline composite (2%). Feldspar (30.5%): orthoclase (27%), microcline (trace), plagioclase (3.5%) An28. Lithic fragments (18%): SRF's: chert (2%), intraformational mudstone (11%); MRF's: muscovite-quartz gneiss, quartzite (3.5%); VRF's: porphyritic rhyolite (1.5%). Other: muscovite (1.5%), biotite (0.5%), chlorite (1%); clay matrix (5%), sparse chert cement (1%), porosity (4%), tourmaline, zircon, opaques, garnet, hematite (2%).

Sample T-17 Moderately-sorted medium- to coarse-grained sandstone: feldsarenite

Buff; ferruginous; weathers yellowish-brown; friable; grains angular to subangular; composed of quartz; altered feldspars, and chlorite.

Grain Size Analysis: gr: 1%, vcs: 5%, cs: 41%, ms: 37%, fs: 7%, vfs: 2%, cz: 1%, mfz: 1%, c: 5%, mode = 1 ϕ

Sample T-16 Moderately-sorted, medium- to coarse-grained sandstone: feldsarenite

Buff; weathers to yellowish-brown; friable; grains subangular to subrounded; composed of quartz, feldspar, and biotite.

Sample T-15 Moderately-sorted coarse- to medium-grained sandstone: lithic feldsarenite

Buff; weathers dark-brown to black; sample weathered; medium bedded; friable; grains subangular; composed of quartz, feldspar, lithic fragments.

Sample T-14 Moderately-sorted, coarse- to medium-grained sandstone: chert-cemented lithic feldsarenite

Buff; weathers to dark-brown; obdurate; medium-bedded; horizontal; grains angular; composed of quartz, orthoclase, rock fragments, mica.

Thin Section Description:

Compact; linear grain contacts; angular sand grains. Quartz (43.5%): straight to slightly undulose extinction, vacuoles common (32%), composite (8.5%), semi-composite, undulose extinction, some with rutile needles (3%). Feldspars (34.5%): orthoclase (sericitized) (31.5%), microcline (trace), plagioclase (3%). Lithic fragments (15%): chert (2%), intraformational siltstone (7.5%), MRF's: muscovite-quartz schist (3.5%), VRF's: porphyritic rhyolite (2%). Other: muscovite, chlorite, biotite (1%); chert cement (4%), rutile, zircon, hematite, opaques (3%).

Sample T-13b Moderately-sorted very coarse- to coarse grained sandstone: feldsarenite

Weathered to black; thickly-bedded; friable; composed of angular to subangular grains of quartz, feldspar, and sedimentary rock fragments; also chlorite, biotite, and heavy minerals.

Grain Size Analygis: vcs: 7%, cs: 51%, ms: 19%, fs: 8%, vfs: 5%, cz: 2%, mfz: 3%, c: 5%, mode = 0.5 ϕ

Sample T-13a Granular, pebbly, moderately-sorted coarse- to very coarse sandstone: chert cemented feldspathic litharenite

Light-brown; weathers dark brown to black; thickly bedded; obdurate; sand grains angular to subangular; composed of quartz, lithic fragments, feldspar, chlorite, biotite.

Thin Section Description:

Compact; most grain contacts are linear, some concavo-convex; grains are angular in shape. Quartz (36%): polycrystalline composite (8%), straight to slightly undulose, vacuoles common, inclusions of tourmaline and biotite present (21%), semi-composite, undulose extinction (7%). Feldspar (23%): orthoclase (20%), microcline (trace), plagioclase (weathered) 3%. Lithic fragments (28.5%): SRF's: mudstone, siltstone (17%), chert (2%); MRF's: muscovite-quartz gneiss (7.5%); VRF's: rhyolite porphyry (2%). Other: chlorite, biotite (trace); chert cement (7%); porosity (6%), zircon, garnets, opaques (0.5%).

Sample T-12 Cobbly, pebbly, granular, moderately-sorted; coarse- to very coarse-grained sandstone: feldsarenite

Extremely weathered dark-brown to black; very friable; sand grains angular to subrounded, but mainly subangular; consist of quartz and altered feldspar mainly; pebbles composed of granite, milky quartz, quartzite, and rhyolite; well-rounded.

Grain Size Analysis: p: 14%, gn: 5%, vcs: 28%, cs: 28%, ms: 10%, fs: 5%, vfs: 3%, cz: 2%, mfz: 1%, c: 4%, mode = 0.25 ϕ

Sample T-11 Granular, moderately-sorted, medium- to coarse-grained sandstone: clay-chert cemented feldspathic litharenite

Light-brown; weathers orange-brown to black; friable; angular to subrounded; composed of quartz, lithic fragments, feldspar; granules well-rounded grains of granite, quartz, and quartzite.

Thin Section Description:
Compact; mainly linear grain contacts, some concavo-convex and tangential; angular, corroded grains. Quartz (45%): straight to slightly undulose extinction (26.5%), semi-composite, abundant vacuoles (5%), polycrystalline composite (13.5%). Feldspar (20%): sericitized orthoclase (19%), plagioclase (1%). Lithic fragments (21%): SRF's: chert (1%), intraformational mudstone fragments (14.5%); MRF's: biotite-muscovite-quartz schist (3.5%); VRF's: porphyritic rhyolite (2%). Other: biotite, muscovite, chlorite (trace); matrix (2%) chert cement (7%), garnet, opaque heavy minerals (1%).

Sample T-10 Granule-pebble conglomerate

Highly weathered; forming soil horizon; pebbles rounded, consist mainly of quartz, quartzite, and granite; clast-supported; sand matrix not identifiable.

Sample T-9 Granular, poorly-sorted, fine- to coarse-grained sandstone: lithic feldsarenite

Extremely weathered dark-brown to black; angular to subrounded grains; mode: coarse sand; composed of quartz, orthoclase, lithic fragments (siltstone), heavy minerals, chlorite, biotite, muscovite; granules composed mainly of quartz.

Grain Size Analysis: p: 11%, gr: 4%, vcs: 7%, cs: 23%, ms: 34%, fs: 11%, vfs: 2%, cz: 2%, mfz: 2%, c: 4%, mode = 1 ϕ

Sample T-8 Granular, moderately-sorted, medium to coarse-grained sandstone: lithic feldsarenite

Light-brown, weathers black; friable; mode = coarse-sand; grains subangular to rounded; composed of quartz, feldspar, lithic fragments, chlorite, muscovite, heavy minerals; quartzite fragments especially rounded.

Sample T-7 Pebbly, granular, moderately-sorted very-coarse to coarse sandstone: calcite cemented feldspathic litharenite

Light brown; weathers dark brown; friable; pebbles of quartz, quartzite, rhyolite, limestone, and granite; rounded to well-rounded; sand grains subangular to subrounded; composed of quartz, lithic fragments, feldspar, biotite.

Sample T-1 Coarse-sandy granule pebble conglomerate

Extremely weathered, stained yellow-brown to black; ferruginous; friable; pebbles and cobbles of milky quartz, quartzite, and granite; well-rounded; clast supported; matrix a well-sorted coarse-grained sandstone; grains subangular to subrounded; composed of quartz, orthoclase, rock fragments, and chlorite.

SUBSIDIARY SECTION (See Figure 4 for location).

Sample T-182b Well-sorted medium-grained sandstone: feldsarenite

Reddish-brown; weathers to dark brown; composed of angular quartz and pink orthoclase, weathered feldspar, and subaligned muscovite and biotite, friable; weathered.

Sample T-182a Very coarsely crystalline red granite

Weathered; composed of crystals 1-2 mm in diameter of pink orthoclase, grey plagioclase (oligoclase) biotite and quartz.

Sample T-181B Moderately-sorted coarse- to medium-grained sandstone: feldsarenite

Weathered brown; friable, composed of angular, subequant grains of quartz and feldspar, and weathered feldspar; also biotite and muscovite.

Sample T-181a Porphyritic rhyolite

Weathered; phenocrysts of pink and grey feldspar 1-3 mm in diameter are embedded in a purple matrix; consists of a flow 0.5 m thick.

Sample T-180b Moderately-sorted very fine- to fine-grained sandstone feldsarenite

Reddish brown; friable; grains are angular, subequant; composed of quartz, feldspar, and aligned biotite and muscovite

Grain Size Analysis: cs: 4%, ms: 18%, fs: 43%, vfs: 18%, cz: 5%, mfz: 6%, c: 6%, mode = 2.5 ϕ

Sample T-180a: Very coarsely-crystalline granite

Weathered; composed of crystals 1-2 mm in diameter of pink orthoclase, white plagioclase, quartz, and biotite.

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