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Clastic Dikes Of The Pasco Basin, Southeastern Washington

Final Report

Robert F. Black

**Prepared for the United States
Department of Energy
Under Contract DE-AC06-77RL01030**

Rockwell International

**Rockwell Hanford Operations
Energy Systems Group
Richland, WA 99352**

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Robert F. Black

January 19, 1979

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CLASTIC DIKES OF THE PASCO BASIN, SOUTHEASTERN WASHINGTON

ABSTRACT

Clastic dikes are planar features, commonly wedge shaped in cross section, with their apices mostly downward. They are filled with clastic sediments from clay to gravel in size.

Three days were spent in the Pasco Basin examining clastic dikes in 10 localities. It was clear from the field observations, summarized in the text, that the features called clastic dikes are multigenetic. Previously proposed theories of origin of the initial fractures, involving earthquakes, desiccation, deep frost cracking, thermal contraction cracking of permafrost, and upward injection of groundwater are not considered primary modes of formation of most initial cracks observed. However, the mechanism of cracking is not yet fully understood. The bulk of material filling most observed fractures came from above during aperiodic and repeated widening and concurrent filling (under an aqueous environment). No evidence for horizontal compression of the dikes or their margins was observed, as from thermal changes or wetting and drying. A loading hypothesis from catastrophic scabland floods is outlined as a possible cause for many typical clastic dikes.

Clearly, much more work needs to be done, not just to test the above concept, but to provide field information in three dimensions on the spatial distribution and characteristics of the clastic dikes. Mineralogic and chemical studies of components of the dikes should be undertaken to compare the infilled material with that of the host, the overlying material, and deposits from the catastrophic flooding of the Pasco Basin during the late Quaternary.

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INTRODUCTION

Clastic dikes in southeastern Washington consist of vertical to irregularly dipping fissure fillings of sand, silt, clay, and some gravel, cobbles, or rubble. The fillings generally are planar features normally wedge shaped in cross section, with their apices mostly downward. Highly irregular forms are present and some taper upwards. The host of many dikes is the unconsolidated glaciofluvial sand and gravel locally referred to as the Pasco Gravels and the fine-grained Touchet Beds. The host material immediately adjacent commonly differs markedly in texture, fabric, or lithology from the fillings in the dikes.

Clastic dikes have been recognized in eastern Washington for more than a half century.⁽¹⁾ They were described in considerable detail by Lupher.⁽²⁾ Other authors discussed the clastic dikes in the Ringold Formation⁽³⁾ and in the Touchet Beds.⁽⁴⁻⁷⁾ The Ringold clastic sediments are lacustrine-fluvial in origin,⁽⁶⁾ rest stratigraphically on the Saddle Mountains Basalt, and are Pliocene in age.⁽⁸⁾ The Touchet Beds, rhythmically bedded silt and fine sand with some clay and pebbles, were laid down in low-energy slackwater environments during Pleistocene catastrophic flooding.⁽⁶⁾ Descriptions of the host materials and the geologic setting are provided by Grolier and Bingham,⁽⁶⁾ Newcomb, Strand, and Frank,⁽⁹⁾ Bretz,⁽¹⁰⁾ Baker,⁽¹¹⁾ Baker and Nummedal,⁽¹²⁾ Patton and Baker,⁽¹³⁾ and others cited in those papers. As a part of this study, wedges and dike-like forms were exposed by trenching in unconsolidated sands near the Richland Sanitary Landfill where polygonal patterns are exposed at the surface. The sands are believed to be related to the last major scabland flood about 13,000 years ago.⁽¹⁴⁾ Stratigraphic nomenclature in this report follows that of Ledgerwood, Myers, and Cross.⁽¹⁵⁾

Origin of the fractures that led to the formation of the clastic dikes has been attributed to earthquakes,^(1,3,7) melting of buried ice and frozen sediments,⁽²⁾ upward injections of groundwater,⁽⁴⁾ thermal contraction of permafrost,⁽⁵⁾ desiccation cracks or deep frost cracks,⁽⁶⁾ and extension fracturing from the loading of turbidites on

unstable underlying sediments.⁽¹¹⁾ Origin of the fillings in the cracks is attributed to overlying materials by all authors cited except Newcomb⁽⁴⁾ who called for injection from below.

The writer was asked to examine representative clastic dikes in the field, discuss and document their possible origin, and recommend further studies. Ten sites (Figure 1) with one or more dikes were examined on July 31 and August 1 and 2, 1978 in the company of J. A. Caggiano, G. V. Last, J. T. Lillie, and A. M. Tallman of Rockwell Hanford Operations. A summary of the observations at each site, with discussion, is given. A review of some possible origins of the clastic dikes is followed by some suggestions for future work. G. V. Last took the photographs used in this report.

It was clear from the field observations alone that the features called clastic dikes are multigenetic. Earthquakes, desiccation, deep frost cracking, thermal contraction cracking of permafrost, and upward injection of groundwater are eliminated as primary modes of formation of most initial cracks. However, the mechanism of cracking is not clearly understood. It may result from complex processes. A loading hypothesis from catastrophic scabland floods is outlined as a possible cause for many typical clastic dikes.

FIELD DESCRIPTIONS OF CLASTIC DIKES

SITE 1

Site 1 is a sand pit in glacial fluvial sediments, informally named the Hanford formation, at the southeast end of Gable Mountain. The pit is in the SE $\frac{1}{4}$, Sec. 28, T13N, R27E. At the time of visit, three outcrops a few meters in extent in the pit contained clastic dikes. Thick talus of sand and some gravel hid the relationships of structures from one outcrop to another. The limited exposures contained roughly horizontal beds of fine to coarse sand and some gravel. Foreset beds, crossbeds, and other structures common in fluvial sediments are present. Bedding is weakly developed in more massive units. The sand is cut by a series of roughly parallel clastic dikes ranging from a few millimeters to a meter wide, which extend the full width and depth of the largest exposure--

FIGURE 1. Location Map.

about 5 m (Figure 2). The dikes are mostly sand that is similar in texture to the host overall, but locally distinct (Figure 3). The dikes are complex structures in which planar and irregular units of clay, sand of various sizes, and pebbles to cobbles locally show intricate cross-cutting relationships. Most planar units are vertical to steeply inclined, but small units are at any orientation. Clay-silt coatings (commonly referred to in this paper simply as clay coatings or clay skins) are confined typically to the walls of the host and each of the filling units (Figure 4). They may bound a dikelet of only a few millimeters to as many as several decimeters wide. Slump and flow bodies and rip-up clasts of the clay coatings are also found in some of the fillings. Fabric of the dike fillings is mostly that produced by modest current in water, perhaps less than 20 cm/sec. Sorting and stratification are poor to excellent. Dips of the stratification are in places much steeper than the normal angle of repose of sandy sediments (Figure 3).

Blocks of sediments up to several decimeters in width seem to have been rotated and cut by other dikes. The lack or paucity of deformation of the sand units cut by dikes and the rotation of blocks within dikes suggest open tension fractures in sediments that locally may have been frozen when emplaced. At least the host sediments needed to have had more cohesion than they do now. The clay skins preceded the main sand filling of the cracks as shown by their local disruption and inclusion in the filling. The fabric of the filling, the slump structures, and the irregularly tapering cracks themselves are readily explicable by infilling from above, mostly by flowing water.

No pressure effects such as upturned or compressed strata at the margin of the host are seen along the walls of dikes. The forces that opened the fractures aperiodically were tensional only. The fractures and fillings are not single events, except in a few cases. Most opposing walls of a dikelet within a larger dike do not have matching texture and fabric that can be traced across. Again, settlement of irregular blocks, filling around them, and fracture have seemingly produced the complex array of structure. Fragments of wood collected from one clastic dike at this site were dated at 18,705 radiocarbon years before present (+1515

FIGURE 2. In the Sand Pit at Gable Mountain Site Showing Clastic Dikes in the Northeastern Outcrop.

FIGURE 3. Detail of Sand in a Clastic Dike at Gable Mountain Site.
Scale is 17 cm long. Vertical face.

FIGURE 4. Clastic Dike at Gable Mountain Site, Showing Clay Skins Bounding a Sand Unit within the Dike. Scale is 15.2 cm long.

and -1275 Carbon-14 years; GX-5530). This places a maximum age on the dike filling at this locality.

SITE 2

This site is directly north of Goose Egg Hill, in Sec. 28, T12N, R26E. The Pasco Gravels grade into the Touchet Beds near the site. The principal dike seen is about 1 m wide and crops out at the road in the Pasco Gravels deposits. Only 2 m of the dike were exposed vertically. Another smaller dike was seen about 40 m east of the first, and in similar sediments. The larger dike clearly shows the distinct age relationships of an earlier sand dikelet within the main dike, which is cut by later dikelets (Figure 5). Clay-silt coatings on the earlier dikelet are also cut off by the later dikelets. Multiple dikelets a few millimeters to several centimeters wide make up the main dike. Each has its borders of clay-silt. The sand filling varies from very fine to coarse in individual dikelets within the main dike. Several caliche layers, 1 to 2 mm thick, are horizontal in the upper part of the dike, and cut all structures.

The smaller dike is largely in the bedding plane of sand deposits in which stratification in part is much steeper than the normal angle of repose of sediments. Small normal faults (Figure 6) and associated slump structures (Figure 7) are common. A third dike seems to join the second, but does not cut it; they appear to have formed contemporaneously.

The larger dike is similar in appearance, structure, fabric, and texture to those in Site 1. The smaller dike, with its contemporaneous branch, differs only in that it seems to have more normal faults. Water currents removed material, leaving a rippled surface on which additional similar beds were laid down. Some of the current structures cut the small faults, indicating that movement, erosion, and deposition were going on together. Clay coatings are involved as at Site 1.

SITE 3

The Badlands Locality, on the Old Inland Empire Highway, is in Sec. 9, T9N, R25E. The cross-bedded sand and gravel is considered to be the Rattlesnake Ridge interbed and is overlain by the Elephant Mountain

FIGURE 5. Part of Clastic Dike at Goose Egg Hill Site, Showing Clay Skins on Individual Units of the Dike and Cross-Cutting Relationships of Some Units. (Below the right end of the scale which is 15.2 cm long.)

FIGURE 6. Part of Clastic Dike at Goose Egg Hill Site, Showing Small Normal Fault. Hammer is 31.5 cm long.

FIGURE 7. Part of Clastic Dike at Goose Egg Hill Site, Showing Slump Structures. Scale is 15.2 cm long.

Member of the Saddle Mountains Basalt, which is about 10.5 million years old.⁽¹⁵⁾ The sand and gravel unit contains irregular fragments of clay-silt laminae and is consolidated so it can stand with vertical or overhanging surfaces. Only two clastic dikes, about 1.0 to 1.5 m apart and parallel, appear in the outcrop that is about 50 m long (Figure 8). The dikes parallel and are normal to very small rectangular joints with caliche which occur at a spacing of 10 to 20 cm throughout the outcrop.

The clastic dikes at Site 3 differ in many important respects from the clastic dikes observed at most other localities in the Pasco Basin. The two dikes are narrow, a few millimeters to 10 cm wide, and die out upward near the top of the Rattlesnake Ridge interbed (Figures 9 and 10). The fractures themselves are gently curving and display minor structures that suggest slight oblique right lateral displacement. The filling in the upper part of the outcrop is till-like (diamicton). It is grey, poorly sorted, and contains rocks not seen in the host. The lower part of the filling consists of material which is in part like that of the sand host and in part clay-silt. The contact between the till-like material and the lower sand and silt is generally not a simple line, but a zone of interfingering units.

Clay skins are common along the walls of the fracture. Rip-up clasts are abundant in heterogeneous rubble and in rectangular fragments that are parallel to the sides of the fractures (Figure 11). Locally, blocks of the host are isolated within the fractures, and till-like material and rip-up clasts of clay surround them (Figure 12). In such instances the filling on one side of the included block differs from the filling on the other side. The till-like material came in later than the clay skins and contains rip-up clasts of the clay skins, indicating at least two filling sequences.

The site is on the west flank of the Chandler Narrows anticline that strikes 310 degrees. The clastic dikes trend about 80 degrees to the axis of that anticline, and the initial fractures may be related to it in origin. The small caliche-filled joints in rectangular array are also presumed to be part of the same tectonic system. Both appear to be ancient features according to the degree of soil development in the upper

FIGURE 8. Two Clastic Dikes in the Rattlesnake Ridge Interbed of the Saddle Mountain Basalt at the Badlands Locality. Hammer is 31.5 cm long.

FIGURE 9. Part of Eastern Dike at the Badlands Locality, Showing Clay Skins and Changes in Nature of Filling. Hammer is 31.5 cm long.

FIGURE 10. Uppermost Part of the Eastern Dike at the Badlands Locality, Showing Till-like Material Directly Under Host Rock.

FIGURE 11. Upper Part of the Eastern Dike at the Badlands Locality, Showing Till-Like Material and Broken Fragments of Clay Skins.

FIGURE 12. Lower Part of the Eastern Dike at the Badlands Locality, Showing an Inclusion of the Host Rock within the Dike. Lens cap is 5.3 cm across.

part of the clastic dikes and the great depth of the caliche. However, aperiodic movement of the fractures has permitted some intermittent filling and fracturing of previous fillings.

Whether the diamicton material is till remains to be determined. Moreover, its mode of emplacement and age are conjectural.

SITE 4

The east bluff of the Yakima River, near Benton City, Washington, at the northeast corner of Highway 12 and the old road to Richland is in Sec. 20, T9N, R27E. The bluff displays more than 20 clastic dikes of laminated silt and very fine sand in the Touchet Beds above road level. The dikes vary from a few millimeters to 1.5 m in width (Figures 13 and 14). Most extend from road level up to the base of the soil at the top of the bluff, 5 to 7 m high; a few of the smallest pinch out above and below within the exposure. Some of the largest dikes branch upward and become narrow in the soil zone. Irregular stringers filled with clay extend from some dikes several centimeters into the host before pinching out. It is not known to what depth below the road the larger dikes penetrate. The narrowest dikes are filled with clay and silt, but most dikes are filled with irregular vertical layers of clay, silt, sand, and some gravel. The layers are a few millimeters to several centimeters wide and are separated from each other generally by a thin layer of clay (Figure 15); most layers are 1 to 2 cm wide. The clay skins locally are disrupted and incorporated within some layers. Some layers cross other layers to show distinct sequential development; others are offset (Figure 15). Stratification in the fillings is locally vertical, but generally crudely horizontal to inclined below the angle of repose. Slump and flow structures are common in the layers. Details of the lowermost part of the dike in Figure 14 show some units curve to the horizontal (Figure 16).

No pressure effects along the walls of the host are visible. All fractures appear to be tensional. Offset displaces parts of some clastic dikes by up to several centimeters towards the Yakima River to the west. Abrupt offset of vertical fractures follows bedding planes in the laminated fine sand and silt of the Touchet Beds, and fillings may follow the tortuous route faithfully or be offset (Figure 17). Dikes join or

FIGURE 13. Part of an Upward Bifurcating Dike and Small Dikes at the Benton City Site. Trowel is 25 cm long.

FIGURE 14. Multiple Layering in a Clastic Dike at the Benton City Site.

FIGURE 15. Small Fault and Other Details of the Dike in Figure 14.

FIGURE 16. Details of the Lowermost Part of the Dike in Figure 14. Scale is 15.2 cm long.

FIGURE 17. Offset of a Small Clastic Dike about 1 cm Wide at the Benton City Site.

merge with each other, but none was observed to cut cleanly across another. A case can be made for a polygonal network of large dikes by extending the trends of dikes exposed along the base of the sloping bluff. Polygons so constructed are about 5 to 8 m across. These dikes are similar to those at Sites 1 and 2.

The fillings of the larger dikes, those that reach the soil, came distinctly from above and differ from the host beds. The coarse sand and gravel fill in many layers is not found in the host. Large blocks of the host have settled downward in the upward branching dikes. Narrowing of some dikes upward seems to be related to the absence of some of the layers filling the dike in the middle of the bluff. It could not be ascertained whether this is related to non-deposition of some layers at the top or whether the layers had been removed during episodic opening of the dikes. Clearly, the bulk of the material came from above.

The clay skins on the walls preceded the main filling, as rip-up clay is found in the fillings. Much stratification in individual layers is typical of that produced by flowing water and represents foreset beds, ripples, settling out of coarse particles in crudely horizontal layers, and flow and slump of clastics in water. The origin of the locally vertical fabric is unknown. Most normal faulting with displacements up to several centimeters seems related to slippage of the upper part of the bluff toward the Yakima River, across the road. Many dikes may have filled tension fractures produced in the Touchet Beds as they slide toward the river.

SITE 5

The Weber Canyon Road site is in an area of Touchet Beds dissected into ridges and gullies draining to the Yakima River. A road cut about 30 m long displayed clastic dikes 2 to 10 cm wide and at intervals of 1 to 2 m (Figure 18). Most dikes are roughly parallel to the crest of one of these ridges, but they do not change size or orientation from the axis outward. A few dikes intersect or join (Figure 18). The Touchet Beds are laminated fine to medium sand and silt and have a double layer of volcanic ash in the upper part of the exposure that is cut and locally offset by the clastic dikes (Figure 19). Fillings of the dikes differ

FIGURE 18. Upward Bifurcating Dike at Weber Canyon Road Site.

FIGURE 19. Volcanic Ash Beds Offset by Clastic Dike at the Weber Canyon Road Site.

from the host in that they are generally coarser and more variable (Figure 20). Locally, finer-textured fillings are seen. The dikes are nearly vertical to irregular with abrupt bends. Several branch upward or become narrower (Figures 18 and 19). Some of the smaller dikes are single units of sand bounded by clay layers separating them from the host (Figure 21). Most are multiple layers of sand of different sizes separated by clay skins from adjacent layers (Figure 20). Some layers cut across other layers. More layers are found in the lower parts of several dikes than in the upper part where they thin or branch. Some with multiple layers below are truncated and refilled and have a single unit above with a nearly horizontal contact between them. Some dikes are offset by small normal faults (Figure 22) that may have clastic fillings different from the host. The dikes are similar to those of Sites 1, 2, and 4.

Tension fractures with aperiodic opening in increments seem to be commonplace. Most filling was washed in by water aperiodically in narrow fractures in which clay skins were formed before coarser detritus was laid down. Much of the filling is within the normal angle of repose for sand, but locally strata within narrow layers are nearly vertical. The ash was not identified, but presumably came from Mount St. Helens.

SITE 6

This site, near the Richland City Landfill, is in the SE $\frac{1}{4}$, Sec. 20, T20N, R28E. Glacial-fluvial sediments are covered with sand dunes. On air photos, dark lines outline polygons that are 50 to 130 m across. The borders of the polygons are generally slight ridges or troughs or a break in surface level from one polygon to the adjacent of 5 to 20 cm. The borders are 0.5 to 1.0 m wide, and vegetation is more luxuriant than in the rest of each polygon. The borders are also the home of numerous burrowing rodents.

Two pits were opened at polygonal border junctions, using a backhoe. Each pit penetrated 2 to 3 m in an initial opening. After examination, the pits were widened 0.5 to 1.0 m to provide new faces for a better perspective of the third dimension of the clastic dikes exposed. These dikes differ significantly from those at the other sites observed in the

FIGURE 20. Detail of Stratification in a Clastic Dike at the Weber Canyon Road Site. Trowel is 25 cm long.

FIGURE 21. Detail of Stratification and Clay Skins in a Clastic Dike at the Weber Canyon Road Site. Coin is 2.1 cm across.

FIGURE 22. Offset of Clastic Dikes at the Weber Canyon Road Site above Gravel. Shovel is 52 cm long.

Pasco Basin. They are mostly silt and clay with some sand layers generally different from the medium-coarse sand of the host. The dikes are only 1.0 to 1.5 m high and in very loose sand.

Pit 1

The first pit excavated was about 30 m northeast of Washington State Highway 240. The excavation revealed four dikes up to 1 m wide and 1.5 m high that joined in the initial excavation (Figures 23 and 24). They merged rather than cross-cut each other. All dikes partly graded or feathered into horizontal beds about 2 m below the surface, which are only slightly disturbed directly below the dikes. Vertical and inclined sand layers of the dikes cut horizontal silty-sandy horizons locally (Figure 25). Clayey-silty stringers from above penetrate and die out in the horizontal sandy layers below the dikes. The material in the dikes came from above rather than from below, according to minor slump structures and discrete wedging out of stringers of the dikes, which curved into the horizontal layers. Some layers, though vertical, have graded beds. Beds in the horizontal layer below one dike were locally domed upward 10 to 20 cm (Figure 26).

A singular paucity or lack of clay skins bounding individual vertical layers 2 to 6 cm wide of silt or sand is strikingly different from most other dikes observed in the Pasco Basin (Figure 27). Horizontal caliche layers at various depths cut most structures (Figure 24), but locally follow stratification and more rarely are cut by parts of a dike (Figures 23 and 27). The top of one dike of mostly silty material was poorly defined because sand, like that of the host, is dispersed in vertical layers and small irregular bodies in the dike (Figure 24).

Pit 2

The second pit was opened on the extension of the polygonal border in Pit 1, and was about 80 m distant, where another intersection showed on aerial photographs. Two dikes about 0.5 and 0.8 m wide intersected at right angles in the pit. They are similar in all respects to those in Pit 1. Vertical layers flare outward and partly cut and merge into horizontally layered fine sediments (Figures 28 and 29). Minor slump

FIGURE 23. Pit Showing 2 of 4 Clastic Dikes in the Richland City Landfill Area.

FIGURE 24. Detail of the Dike on the Left in Figure 23.

FIGURE 25. Detail of the Dike on the Right in Figure 23, Showing Penetration of the Dike Material into Water-Table (?) Layering. Horizontal caliche layer at arrow.

FIGURE 26. Small Antiform in the Lower Part of a Clastic Dike in Pit 1, Richland City Landfill.

FIGURE 27. Detail of Sediments in a Clastic Dike in Pit 1, Richland City Landfill Area. Coin is 2.1 cm across.

FIGURE 28. Clastic Dike Penetrating Water-Table (?) Stratification in Pit 2, Richland City Landfill Area. Trowel is 10.5 cm long.

FIGURE 29. Clastic Dike in Pit 2, Richland City Landfill Area. Caliche Horizons at Arrows. Trowel handle is 25 cm long.

structures in the dikes and cross-cutting relationships show that the bulk of the dike material came from above. Caliche horizons cut parallel across most structures in the dikes (Figure 29). The lower horizontal silt-clay layers also cut across structures in the coarse sand host (Figures 30 and 31).

These dikes differ from others seen in the Pasco Basin in that they are limited in height, have little or no clay borders on vertical layers of different materials, are generally finer textured rather than coarser than their host, have wide and vague tops, and cut yet curve into and merge with horizontal layers of similar texture where they die out. They also show by a variety of structures that the bulk of the material came down from above. The dikes distinctly cut across some horizontal stratification in their host, and are made up of a multiplicity of layers of material of different textures.

SITE 7

The Railroad site is in the NE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 21, T9N, R28E. Touchet Beds in a gentle anticline are cut by numerous dikes (Figure 32) that form incomplete polygons 5 to 8 m across in the exposure. The dikes vary in width from a few millimeters wide (Figure 33) to complex forms more than 1 m wide for a single dike and more than 2 m wide at junctions of dikes. Some narrow dikes are less than 1 m high, tapering at top and bottom; most dikes continue below the floor of the excavation and are more than 5 m high. Dikes are straight, curved, and irregular. Some bend abruptly to follow bedding planes for a decimeter or so in the Touchet Beds. Most are widest at the top at the soil zone and taper downward, but a few widen and branch with depth (Figures 32 and 34). The branches also contain cross-cutting dikes through part of their width and into the Touchet Beds (Figure 34). The largest dikes pierce the Touchet Beds at the apices of gentle anticlines with relief up to 50 cm in horizontal distances of about 5 m.

Dike fillings are vertical to highly irregular layers of clay, silt, and sand, and some gravel (Figures 35 and 36). Most units are much coarser than the host, and are bounded by prominent clay skins. A variety of sedimentary structures from simple roughly horizontal beds to

FIGURE 30. Monoform Structure in Pit 2, Richland City Landfill Area.

FIGURE 31. Detail of Sediments in Lower Part of Figure 30.
Top of hammer handle is 4.5 cm across.

FIGURE 32. View North of Railroad Site, Showing Intersecting Clastic Dikes.

FIGURE 33. Small Clastic-Dike Joint in the Railroad Site.
Scale is 9 cm long.

FIGURE 34. Root-Like Extension of a Clastic Dike in the Railroad Site. Note dikelets below Scale. Scale is 9 cm long.

FIGURE 35. Detail of the Individual Units Bounded by Clay Skins in a Clastic Dike in the Railroad Site. Scale is 9 cm long.

FIGURE 36. Detail of the Individual Units Bounded by Clay Skins in a Clastic Dike in the Railroad Site. Scale is 9 cm long.

irregular vertical layers are present in perplexing array. Cross beds, cut and fill, and graded bedding are common. Many strata are steeper than the normal angle of repose of the material. The very narrow dikes are filled with clay and some silt like the clay layers bounding the units that make up the larger dikes. Stringers of the clay layers penetrate the host, especially along bedding planes. Individual units of the larger dikes vary in width from a few millimeters to at least 30 cm; most are 1 to 6 cm. Slump structures in the dikes are universal. These dikes are similar to those at Sites 1, 2, 4, and 5.

The main distinction is the large gentle anticline in the Touchet Beds and local anticline at several of the largest dikes. It is not known whether these anticlines are related to the stress field that produced the aperiodic opening of the fractures in which the dikes seemingly were produced by infilling from above, with some movement laterally of finer material in the smallest dikes. Field observations confirm that the material in the dikes did not come directly from the host--it is too coarse or too fine. Moreover, no compressional effects were seen on the sides of any dike. All structures in the dikes are interpreted as primary sedimentation units from flowing water or as slump structures in an aqueous medium.

SITE 8

One small dike-like form was seen in section along the Kennewick Irrigation Canal, in the SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 29, T9N, R27E. The dike form is as much as 30 cm wide and is exposed about 1.5 m. The apex was not seen, but the dike had tapered to about 10 cm. The dike is in fanglomerate from a gully crossing the canal and is composed of mud and rubble identical to that on the slope overlying it. It appears to be a recent colluvial filling of a tension fracture opened along the gully by gravity movements toward the gully. This dike seems to be unrelated to the others seen in the Pasco Basin.

SITE 9

A borrow pit in the SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 19, T9N, R27E (near Kiona) contained two clastic dikes and one caliche dike. However, the site was

not photographed until later when the exposed face revealed three clastic dikes and no caliche dike. Two dikes, close together (Figure 37), were in the approximate position of the east dike and caliche dike. The third was about 20 m to the west. The wall of the pit revealed about 2 m of basalt-rich gravel topped by 1 to 2 m of fine sand and silt of the Touchet Beds (Figure 37). Details of the two clastic dikes in Figure 37 are shown in Figures 38 and 39. Up to 10 cm of reworked gravel (without caliche) and sand and silt locally separated those units. Structures produced by colluviation and mass movement are present in the sand and silt unit. The basaltic gravel is solidly cemented in the upper part with caliche. The caliche dike, about 10 to 12 cm wide, was truncated on top by the reworked gravel. Its apex was hidden by talus.

At the time of visit the two clastic dikes of vertical layers of sand, silt, and clay extended from the surface soil down into the basaltic gravel. One on the east increased abruptly in width from about 8 cm in the upper sand to about 20 cm at the top of the basaltic gravel as did the one photographed later (Figure 40). It was pinched, but not lost, in the reworked zone separating the overlying sand from the lower gravel. The dike was still about 12 cm wide at the base where it disappeared under talus. The second dike, about 20 m to the west of the first, was about 10 cm wide at top (Figures 41 and 42). Where it entered the upper part of the basaltic gravel, the dike curved to the horizontal and split into a number of thin layers that gradually pinched out in a horizontal distance of 3 to 4 m. The two clastic dikes are composed mostly of layers 1 to 8 cm wide of fine to medium sand, and some coarse sand. The layers and host are bounded by clay skins with some silt. Silt and clay penetrate the basaltic gravel adjacent to the dikes. The sand units displayed locally sedimentary beds that are steeper than the normal angle of repose of the material. Slump structures were especially prominent in the upper part of the clastic dike in the basaltic gravel, above a pronounced bend in the dike. The two clastic dikes have many similarities with those in Sites 1, 2, 4, 5, and 7.

The caliche dike is the oldest, having been truncated by the reworked gravel. The clastic dike on the west is the youngest, cutting all the units uniformly. The eastern dike appeared to be intermediate in age.

FIGURE 37. Wall of the Kiona Pit, Showing Two Small Clastic Dikes in Basaltic Gravel and Mass-Moved Structures in Overlying Silt-Sand Unit. Photos taken after writer's visit.

FIGURE 38. Detail of the Two Clastic Dikes in Figure 37.

FIGURE 39. Detail of the Clastic Dike on the Right in Figure 38. Coin is 1.9 cm across.

FIGURE 40. Easterly Clastic Dike in the Kiona Pit that Penetrates Upward into the Silt-Sand Unit. Lens cap is 5.3 across.

FIGURE 41. Westernmost Clastic Dike in the Kiona Pit.
Lens cap is 5.3 cm across.

FIGURE 42. Detail of the Upper Part of the Clastic Dike in Figure 41. Coin is 1.9 cm across.

The uppermost part, in the sand, was narrower and lacked the prominent layered structure of the wider part in the basaltic gravel. It was also much narrower in the reworked gravel. The evidence suggests possibly that the dike had started in the basaltic gravel and continued to grow during the formation of the reworked gravel unit and the deposition of the overlying sand unit. Radiometric dates of caliche thought to be time stratigraphic equivalent indicate considerable antiquity--ca. 200,000 years B. P.⁽¹⁶⁾ However, the lack of caliche and the paucity of oxidation and iron staining in the clastic dikes indicate that they are much younger.

SITE 10

In the NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 11, T13N, R27E of the White Bluffs, the upper Ringold Formation crops out. From a distance, certain rubbles appear to be clastic dikes at various levels in the formation. On closer examination each of those seen can easily be shown to be a broken rock zone at the head of a slump block and to be a linear rather than a planar feature. As such, they differ completely from the clastic dikes of the Pasco Basin. This does not mean that clastic dikes do not form in the Ringold Formation. Clastic dikes in the Ringold have been discussed by Brown and Brown⁽³⁾ and Grolier and Bingham.⁽⁶⁾ Photographs of seemingly true clastic dikes from the SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 3, T14N, R26E in the Ringold Formation were sent to the author after his visit (Figures 43, 44, and 45) and show marked similarity to the clastic dikes in Sites 1, 2, 4, 5, 7, and 9.

SUMMARY

The clastic dikes in Sites 1, 2, 4, 5, 7, 9, and 10 are megascopically similar in their texture, fabric, and relation to their host. All display the pronounced vertical layers of sand and silt, and have thick clay and silt coatings separating them and lining the walls of the host. The bulk of the material came down from above aperiodically as openings were enlarged underwater. All evidence suggests tension and no compression.

FIGURE 43. Clastic Dike in the Ringold Formation at White Bluffs.

FIGURE 44. Clastic Dike in the Ringold Formation at White Bluffs. Trowel is 25 cm long.

FIGURE 45. Clastic Dike in the Ringold Formation at White Bluffs. Trowel is 25 cm long.

The two dikes in Site 3 have some features in common with those above, such as clay skins on the walls of the host. They have a paucity of vertical layers, and do not have the same aerial spacing. Hence, they must be treated separately.

The dikes at Site 6 are even more unlike the typical dikes of Sites 1, 2, 4, 5, 7, 9, and 10. The host is completely unconsolidated sand, clay skins are absent or rare, depth of penetration is slight, spacing is much wider, and dikes merge with, yet cut horizontal strata.

The dike of Site 8 is not considered a true clastic dike in the sense of those in the other sites, but is related to the simple collapse of overlying material into slump fracture.

ORIGIN OF CLASTIC DIKES

Origin of the fractures in which clastic dikes are now found has been attributed to earthquakes,^(1,3,7) melting of buried ice and frozen sediments,⁽²⁾ upward injections of groundwater,⁽⁴⁾ thermal contraction of permafrost,⁽⁵⁾ desiccation cracks or deep frost cracks,⁽⁶⁾ and extension fracturing from the loading of turbidites on unstable underlying sediments.⁽¹¹⁾ Source of the fillings in the fractures is attributed to materials from above by all authors except Newcomb⁽⁴⁾ who called for injection by groundwater from below. In part, then, the origin of the fractures is a separate problem from the fillings. They are connected by the same force, according to Newcomb,⁽⁴⁾ or may be involved in the same situation, as by loading of the surface with turbid water that provides a force for fracturing and a source for material.

SITES 1, 2, 4, 5, 7, 9, AND 10

It was clear from the field observations alone that the features called clastic dikes are multigenetic. However, those dikes in Sites 1, 2, 4, 5, 7, 9, and 10 have many features in common and are believed to have a common origin. A possible mechanism for producing those fractures and their infilling follows later. The origins of the dikes in the other areas are mentioned last.

Earthquakes, desiccation, deep frost cracking, thermal contraction cracking of permafrost, and upward injection of groundwater are eliminated by this writer as primary modes of formation of the initial cracks in Sites 1, 2, 4, 5, 7, 9, and 10. See Black^(17,18) for some of the requirements that need to be met for the formation of wedges by thermal and desiccation cracking. The precise mechanism of cracking in the Pasco Basin is not clearly understood and may be the result of complex processes. However, the dikes require aperiodic widening and infilling from above in a flood plain or lacustrine environment. Repeated movements almost instantaneously from a few millimeters to many centimeters must have widened some cracks according to the infilled structures, others probably opened more slowly. The filling could have been done in a few minutes, but may have taken many hours or even days as cracks widened. It is the author's opinion that the frequency and amount of movement in the widening of the fractures is not characteristic of earthquake movements, desiccation, deep frost cracking, thermal contraction cracking of permafrost, nor upward injection of groundwater. All these processes, except injection of groundwater, involve compression alternating with tension. Shrinkage by thermal means or by drying is followed by expansion on warming or wetting. The clastic dikes are singularly set apart in their absence of evidence for compression. Because of small coefficients of thermal expansion, thermal contraction rarely produces cracks more than 10 to 15 mm in width, yet many layers are 10 cm and more wide.

Earthquake vibrations, which involve alternating compression and tension, should produce a pattern of ground cracks related to the stress field, unless a supersaturated loose sediment is vibrated. Then, the change to close packing reduces the volume of sediment, and upward injection of water and sediment locally can occur in crudely polygonal patterns. This was not observed during the limited visit. More importantly, earthquakes would not be expected to occur with the frequency required to generate the small movements that permitted the vertical layers of the dikes to form aperiodically during the relatively short period when the sites were underwater. This does not mean that a fracture produced by earthquakes does not occur in the Pasco Basin, but

only that the dikes of all but possibly one of the observed sites do not indicate such an origin. The fractures in Site 3 possibly were produced by faulting related to the Chandler Narrows anticline.

The infilling by water-deposited sediments is demonstrably from above. Many of the sediments are clays, silts, and very fine sands such as are found in lakes. It is hypothesized that hydraulically dammed Pleistocene floodwater that repeatedly covered the Pasco Basin is primarily responsible for the initial fracturing, for the aperiodic widening, and for the primary source of sediments that filled the fractures. This concept incorporates many of the ideas of Jenkins⁽¹⁾ as well as others. Floodwaters were generated rapidly during the runoff of water in the channeled scabland to the east and northeast.^(6,9,10,11,12,13)

Immediately prior to the time of Quaternary flooding, it is anticipated that groundwater tables were not appreciably different from those of today. The almost instantaneous flooding would rapidly exert a load on the surface, because the soil above the groundwater table would not be able to be saturated as rapidly as the floodwaters entered the basin. The stress resulting from water loading would not be uniform because of the irregularities in topography, depth to resistant rock, and variability of existing joints and other structures in previously deposited sediments. The horizontal component of stress on slopes could generate tension fractures. Forceful entry of the surface water down into the zone of aeration would widen any pre-existing fractures, generate new ones, and fill cracks with turbid water. The turbid water would penetrate the fractures and enter the soil through the pores. Clay and silt in the water would be filter pressed out on the walls of any opening. Changing currents in floodwaters generated by the torrential discharges involved in the channeled scablands easily could have moved the sand and gravel seen in some of the fractures.

Sand could be deposited in layers steeper than the normal angle of repose if water were flowing more or less horizontally through the sediment and into the host at a fracture. The velocity determines the angle of repose, up to 90 degrees, which is steepened markedly at relatively low velocities by preventing individual grains of sand from rolling outward from the surface. Fractures could be widened as the load

increased or as resistance to shear was reduced by porewater pressure increase. Thus, through the span of time involved in the floods, and its repeated growth and demise, ample opportunity to produce the clastic dikes in Sites 1, 2, 4, 5, 7, and 9 seems possible. Clastic dikes with properties similar to those of Touchet Beds and Pasco Gravels apparently occur in the Ringold Formation, but since such dikes were not observed, the proposed hypothesis should be restricted to the clastic dikes in the Touchet Beds and Pasco Gravels.

If clastic dikes were produced in such a manner, it means that not all are the same age, necessarily, and that some may have been short-lived phenomena whereas others were of longer duration. It would also mean that similar dikes might be found at much greater depths, from earlier floods.⁽¹³⁾

SITE 3

The two dikes at Site 3, by their spacing and alignment, suggest a tectonic origin for the fractures related to the Chandler Narrows anticline. The fillings, with clay skins on their walls, suggest that infiltrating turbid water occurred early, possibly in pre-existing fractures. The till-like material filling part of the fracture suggests that repeated widening did not occur as often as in the sites above. The source of the till-like material is not known.

SITE 6

The polygonal patterns and dikes at Site 6 in part cross blowouts and in part are covered by sand dunes. Water loading of the loose porous sand could not develop fractures in irregular array with the observed large spacing, as tensional strength of the sediments is too low. Moreover, the shallow depth, lack of clay skins, and exceedingly high porosity of the material do not argue for such an origin. Nonetheless, very fine sand, with some clay and silt, has worked its way down from above, at least in part by water movement. Whether this occurred under a lake or in normal soil processes is not known. Vertical layers and stringers cut and merge with horizontal layers of similar material. The host sediment has little cohesiveness; and shrinking from drying should

not generate polygonal cracks on the scale observed. The cracks may be related to some aspects of the geology at depth, particularly fluctuations of the groundwater table, but information is lacking and further speculation unwarranted. The origin of the cracks is simply not known.

SITE 8

The dike of Site 8 is not considered a true clastic dike in the sense of the others described. It is considered a simple collapse of the host material in a fracture generated by slope movements.

SUMMARY

Likely, more detailed field work over a wider area would reveal clastic dikes of still different origins than those indicated above. A firm simple generalization for the origin of all clastic dikes is not probable. As more are seen, the more complex the situation is likely to be.

RECOMMENDATIONS FOR FURTHER STUDY

The dikes and polygonal patterns in Site 6 are the most intriguing, because no reasonable hypothesis for their origin comes to mind. Obviously, additional field evidence is required from other excavations in such polygons. The fillings of all dikes, not just those at Site 6, need to be studied by appropriate mineralogical and chemical means to see how they compare with the host, the Touchet Beds and Pasco Gravels, and also with the fillings in the clastic dikes in other areas in the basin. Subsurface exploration is required to determine details of the geology below the level of the pits.

A system of classification of clastic dikes needs to be prepared after detailed observation of more clastic dikes. A classification has been hinted at in this report. It is particularly important to work out the environment of each dike or group of related dikes during the time of formation. This necessitates the preparation of a map showing the

distribution of dikes and their relation to Pleistocene sedimentary environments and floodwater levels, and the sand and silt of the upper Ringold unit, depth to bedrock, major facies changes, and tectonic structures. Obviously, better dating of the fractures and fillings should be strived for.

The dikes in the Touchet Beds and Pasco Gravels sediments are important from the point of view of groundwater flow. Hence, it is necessary to determine the depth of penetration of the surface dikes and to find out whether similar dikes also exist at much greater depths, having been produced during early phases of lakes, or by other means.

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