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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

SEP 20 1985

MEMORANDUM FOR: Phil Justus, Leader
Geology - Geophysics Section, WMGT, NMSS

FROM: Stephan J. Brocoum, Leader
Geology Section, GSB, DE

SUBJECT: TRANSMITTAL OF HANFORD AREA CLASTIC DIKE INFORMATION

As per telephone request by Richard Lee to Ina Alterman on September 12, 1985, we are forwarding information from the WNP-2 Operating License file on the clastic dikes of the Hanford region. The excerpted section is from the WNP-2 study of Quaternary sediments of the Pasco Basin and Adjacent Areas. It includes a list of references of primary sources of information as well.

Please direct any questions to Dr. Alterman. She may be reached on x27856.

Stephan Brocoum

Stephan Brocoum, Leader
Geology Section
Geosciences Branch, DE

Attachments:
As stated

cc: w/o attachments
L. Reiter
I. Alterman

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# TASK D3
# QUATERNARY SEDIMENTS STUDY OF THE PASCO BASIN AND ADJACENT AREAS

Prepared for

Washington Public Power Supply System

Under the Direction of

United Engineers & Constructors, Inc.
Philadelphia, Pennsylvania

July, 1981

**Woodward-Clyde Consultants**
Three Embarcadero Center, Suite 700, San Francisco, CA 94111

# 5. CLASTIC DIKES

A clastic dike is a tabular sedimentary body that cuts across the structure or bedding of pre-existing rock or sedimentary deposits. The dike is formed by the infilling of a crack or fissure, either from below, above, or laterally. The infilling may result from either forcible injection or from simple gravity infilling of sediments. The width of clastic dikes ranges from over one millimeter to several meters; height ranges from a few centimeters to many meters; length ranges from a few decimeters to many tens even hundreds of meters.

Clastic dikes may be found in any type of host rock or soil, provided that the following conditions are met:

1. There is a source of material available to fill the crack or fissure.
2. There is a mechanism for creating a crack of fissure into which the dike-forming material can penetrate.
3. There is a mechanism for getting the dike-forming material into the crack or fissure.

## 5.1 Previous Investigations of the Genesis of Clastic Dikes

Clastic dikes have been reported in the geologic literature at least since Jenkins (1925a) reported their occurrence in eastern Washington. Since that date, many workers have contributed to our general understanding of clastic dikes, their occurrence, and the mechanisms of emplacement.

Dionne and Shilts (1974) reported the existence of a single clastic dike of Pleistocene age in Quebec, Canada. The dike was 2 m high and 40 cm wide and consisted of glacial till that was forced into a crack that may have been produced when the frozen ground was overridden by glacial ice. The length of the dike was reported to be perpendicular to the direction of flow of the glacier.

Elson (1975) proposed a different mode of origin for a clastic dike also found in Quebec, Canada. Normally consolidated or unconsolidated sub-glacial lake deposits, in which pure water is confined by aquitard layers, were compressed from above either by sediment or ice. This pressure created positive pore water pressure and dilation of the sand layers. Negative pore water pressure developed downstream from the zone of compression, causing the overlying material to be sucked in to fill the negative-pore-water-pressure zone. The dike described, however, was a single dike, not a complex one such as those widely seen in the Touchet beds.

Dionne (1976) described miniature mud volcanoes and clastic dikes that are being created today in tidal sand- and mud-flats in Quebec, Canada. These clastic dikes occur in 4- to 6-sided polygons that have sides that range in length from 30 to 125 cm. Dionne proposed that the mechanism of formation involved lenses of buried ice that had been covered by recent sediment. When the ice thawed, the layers became fluid, the density of the overlying bay mud became greater than that of the now fluid layer, and the "ice lens" rose to the surface, thus creating the clastic dikes. Dionne notes that in James Bay, where the dikes occur, seismic shock is extremely unlikely to occur while the dikes are forming. He also measured the gradients of the surface of the mud flats and found them to be in the range of 1:400 to 1:800 (0.14 to 0.07 degrees. He concluded, therefore, that slumping was an unlikely mechanism for creating tension cracks into which sediment could fill.

Winslow (1977) reported the existence of a swarm of over 300 clastic dikes in southern Chile. The dikes, ranging up to 150 m in length, are possibly of Mesozoic age and consist of silty sandstone to boulder conglomerate. The dikes were all emplaced at high angles to both the fold axes and fracture cleavage of the host rock, and they are thought to have been emplaced during early phases of folding.

Bruhn (1979), also working in the southern tip of South America, reported clastic dikes that were emplaced parallel to the main-phase fold axes in the sedimentary rocks of Tierra del Fuego. Folding is believed to have occurred during the late Cretaceous, with emplacement of the dikes following closely after.

Pierce (1979) described clastic dikes emplaced in the fault breccia at Heart Mountain in northwest Wyoming. He suggests that movement on the Heart Mountain fault created a large volume of calcibreccia from the upper plate of the faulted block. The calcibreccia was immediately covered by Tertiary volcanics. As the weight of the overburden increased, the unstable, water-saturated calcibreccia became mobile and was injected upwards as clastic dikes into the overlying volcanic rocks.

Russ (1979) reports the existence of clastic dikes in the Reelfoot Lake area of northwest Tennessee. A trench excavated to investigate late Holocene faulting encountered 13 sand dikes adjacent to or near the fault plane. The Reelfoot Lake area was struck by large-magnitude earthquakes in 1811 and 1812. Russ suggests that the proximity of the sand dikes to the fault plane indicates that the clastic dikes were created when liquefaction occurred during the earthquakes.

Muir and Fritsche (1981) investigated a complex intrusive dike-like feature in the sediments of Kern Lake, California, and compared the feature to another that formed during the Imperial Valley, California, earthquake of 1979. They concluded that the intruding well-sorted fine sand came from below the water table and that there were confining clay layers both above and below the source bed. The intrusion included more than one event. The Kern Lake intrusion occurred along a wide dike zone, accompanied by the collapse of adjacent sediment into the dike, whereas the Imperial Valley intrusion was confined to a single, thin dike with no adjacent collapse features. The differences between them were postulated to result from the position of the sediments in relation to the water table. At Kern Lake all of the sediment overlying the source bed was below the water table, whereas at the Imperial Valley area most of the sediment overlying the source bed was above the water table and unsaturated.

## 5.2 Classification of Clastic Dikes

Hayashi (1966) proposed a classification of clastic dikes on the basis of reports of many clastic dikes observed in Japan. The classification proposed five categories to describe the morphology of clastic dikes:

1. Simple dikes - clastic material filled a single crack or gash

2. Multiple dikes - two or more gashes are filled with similar material

3. Composite dikes - a single gash was filled two or more times

4. En echelon dikes - clastic dikes consisting of several small-scale dikes composed of the same materi-

al are arranged <u>en echelon</u>

5. <u>Swarm of dikes</u> - a set of numerous parallel clastic dikes.

Subsequent classification of dikes was then made based on the time of origin:

1. <u>Primary</u>

   Clastic dikes having-- straight-wall (indicating shearing
   - rugged-wall (indicating tension)
   - obscurely-walled (indicating pre-consolidation emplacement)
   - branching (upwards, downwards, irregular)
   - tapering (upwards, downwards, lenticular)

2. <u>Secondary</u>

   Clastic dikes whose original shapes have been modified by diagenesis or movement that took place after formation of the dikes. These can be divided into two main groups:

   1. Penecontemporary deformed clastic dikes, in which deformation of both dike and host rock is occurring at the same time, as in folding.

   2. Later deformed clastic dikes, which may have been faulted.

Hayashi notes that lateral offset of (vertical) clastic dikes records bedding plane slippage and that possibly very large masses of sedimentary rocks may slip along bedding planes without any visible deformation or recognizable development of gouge or clay along the planes.

A means of classifying clastic dikes by genesis was also proposed:

1. Intrusive clastic dikes are those in which large fragments and solfataric muds are forced upwards into the fissures of the country rock during igneous activity.

2. Injection clastic dikes are those in which quicksand is injected into cracks or joints. The sediments of these dikes sometimes display laminae running nearly parallel with the walls.

3. Infilling clastic dikes are those in which clastic materials accumulate in cracks or joints under the influence of gravity. The sediments in dikes of this type frequently show horizontal stratification.

4. Squeezed-in clastic dikes are those in which unconsolidated or partially consolidated plastic layers are squeezed, under stress, into crevices, above or below, without destroying their internal structures. The dike-forming materials of such origin often show a symmetrically arranged layered structure parallel to the walls of the dike and display a pull-apart structure. Experiments by Jenkins (1925b) showed that such structures originate from the injection of strata rather than re-sorting from a mixture.

5. Diagenetic clastic dikes are those in which the existing clastic dike has been altered by diagenetic modifications.

## 5.3 Clastic Dikes of the Pasco Basin

### 5.3.1 Previous Work

Jenkins (1925a) believed that the clastic dikes of eastern Washington were produced when cracks resulting from earthquake disturbances were filled with sediment injected under pressure in an aqueous environment. He felt that the dikes could be filled from the top and that they would die out at depth.

Lupher (1944) presented a thorougn investigation of the occurrence and mode of formation of clastic dikes particularly associated with proglacial deposits in Washington and Idaho. He recognized that tne dikes were being produced concurrent with tne deposition of the host units into which they were emplaced. At least four processes were involved in the filling of the dikes, any or all of which may have been involved in the formation of any individual dike. All of the processes involved filling from above, or movement of sediment through groundwater.

Lupher (1944) noted that the open fissures into whicn clastic dikes were formed could be created in a number of ways. One of Lupher's principal conclusions was that the clastic dikes found in this area must be related to frozen ground or ice and are therefore Pleistocene in age. Three of Lupher's five proposed mechanisms for the creation of the fissures involved ice indirectly: (1) uneven settling of and ultimately cracking of blocks of sediment overlying layers of melting buried ice; (2) gravity sliding and faulting on inclined zones of subsurface melting; (3) formation of cavities where ice blocks and layers melted. The other two postulated mechanisms involved erosion by underground streams, and faulting and fissuring by landslides in the Columbia River basalts.

The possibility that clastic dikes were formed sub-aerially was examined but discarded as a general method of formation, because many dikes contain medium and even coarse sands that could not be transported aerially. Lupher (1944) likewise discounted injection from below because he could find no evidence of plastic or water-charged sediment being injected from below. He also noted that many dikes were traceable to overlying current-bedded sand.

The idea that clastic dikes might have formed cataclysmically at the time of deposition of the Touchet beds was rejected by Lupher, an antidiluvianist. A geologically instantaneous flood would not have provided enough time for the formation and subsequent melting of ice layers, which Lupher regarded as prerequisite for the creation of the fissures into which clastic dikes were emplaced. Lupher could neither believe that clastic dikes containing up to a maximum of 80 dikelets could be related, other than marginally, to earthquake activity in the Pasco area.

Newcomb (1962) investigated the dikes described by Lupher (1944) and added a number of observations pertaining to their mode of origin:

1. Some dikes occur in polygonal networks that have cell diameters ranging from 15 to 120 m.

2. The dikes are most profuse within the altitude range of 120 to 240 m and are scarce above 300 m.

3. Dikes are most numerous where the Touchet beds overlie highly permeable materials.

4. Dikes typically have "roots", a "trunk", and "branches" near the top.

5. The dikes cut all but the uppermost 3-6 m of the thickest sections of the Touchet beds.

6. The silt laminae on the walls, the "wall seams" of Lupher (1944) or "clay skins" of Black (1979), are filter cake, which attest to outward filtration of sediment-carrying fluids from each successive dike lamina.

Newcomb (1962) concluded that the above features indicate that the clastic dikes were formed by the upward injection of groundwater. Each "dikelet" was probably caused by bank storage when a pressure difference was produced by large drawdowns of Lake Lewis, the large body of water ponded upstream of Wallula Gap during the Missoula flood. Lowerings subsequent to the first one caused injection along preferential planes of weakness. Thus, the clastic dikes formed during the first lowering of Lake Lewis.

Alwin and Scott (1970) noted that clastic dikes in the Touchet beds penetrate downwards from a few centimeters to over 30 m with near vertical dips. They identified features of clastic dikes, such as composite nature, clay wall linings, cross-stratification, graded beds, and oriented grains. Alwin and Scott concluded that these features indicated a downward infilling of the dikes by silt and sand. They felt that the dikes represent infillings of permafrost-related crevices.

Black (1979) made a detailed study of clastic dikes in the Pasco Basin for Rockwell-Hanford Operations. He visited ten different sites and concluded that the dikes are multigenetic. He considered that previously suggested mechanisms, such as earthquakes, dessication, deep frost cracking, thermal contraction of permafrost, and upward injection of groundwater are not the primary modes of formation of most cracks. Neither did he discount the possibility that some or all of these mechanisms could have been used to produce some of the cracks. Black observed that the bulk of material filling most observed dikes came from above during aperiodic and repeated widening and concurrent filling of cracks in an aqueous environment. In seven of the ten observed localities, all of the dikes were composite (Hayashi, 1966) and were filled from above in a stress environment that indicated tension, not compression.

Black (1979) hypothesized that hydraulically dammed late Pleistocene floodwater, which repeatedly covered the area, was responsible for the formation of the fractures - for the aperiodic widening of these cracks - and was the primary source of material that filled the cracks. Sudden loading by floodwater on a ground surface whose ground-water level was not close to the surface produced stresses that were irregularly distributed. These stresses induced cracking of the ground, which would have allowed turbid water to enter. Sediment in the water would at first have been filter pressed against the walls of the crack, creating the "clay skins." Fractures could have been widened as the load increased or as shear resistance decreased with increasing pore pressure. Continued widening of the crack would have permitted coarser sediment to enter. The flow of sediment-laden water along the length of a crack would have produced the foreset-bedding structures frequently seen.

rence. In the non-Touchet cases, clastic dikes were observed in basalt and pre-Palouse loess. The Touchet dikes seen fit almost exclusively into Hayashi's composite category: both injection and infilling types. The dikes seen in basalt were simple. In one case the clastic dikes were intensely weathered and probably predate the late Pleistocene floods. The other clastic dikes in basalt were probably late Pleistocene.

Selected clastic dikes observed during this study are described in Appendix B.

The principal observations made in this study regarding the formation of clastic dikes in the Pasco Basin and associated valleys are that:

1. No clastic dikes penetrate unequivocally eolian deposits of Holocene age (This suggests a sub-aqueous development of most of the clastic dikes.).

2. The vast majority of clastic dikes occurring in the Pasco Basin and vicinity occur within the slackwater Touchet beds. However, "Touchet" dikes have been seen in basalts and pre-Palouse soils whose ages are far older than the 13 ka of the Touchet beds. Dikes have also been reported in the upper Ringold Formation. In all cases the dikes occur below the maximum level of the floodwaters, approximately 350 m.

3. The composite "Touchet" clastic dikes were formed during the deposition of the Touchet beds. The many examples of truncated dikes overlain by more Touchet sediments confirms this idea. Bedding-plane slippage occurred within the Touchet beds coincidentally with

the development of some of the clastic dikes.

4. Evidence has been found at the Cummings Bridge exposure for at least two major floods of late Pleistocene age. The rhythmites contained in the Touchet beds deposited by these two major floods do not represent numerous individual floods of sufficient size to have filled a lake the size of Lake Lewis. Instead they represent pulses into an existing lake. If Baker's (1973) conclusion about the duration of the last late Pleistocene flood is correct, then deposition of the Touchet beds and the formation of the enclosed clastic dikes must have occurred in a matter of weeks.

5. The time required for the deposition of the entire flood deposits was so short that freeze-thaw wedging of fissures or sub-aerial dessication could not have produced the numerous composite dikes. The ice-related clastic dike in tidal flats in northern Canada (Dionne and Shilts, 1974; Dionne, 1976) are features measurable in decimeters, not decameters, as in the Pasco Basin.

6. Most of the clastic dikes in the Pasco Basin taper downwards and were filled from the top. Instances of filling from below have been cited by Newcomb (1962), Black (1979), and in Appendix B, but there are few of these cases.

7. About 5 cm of slip along a fault occurred during the time of the late Pleistocene floods, as evidenced by slickensided clastic dikes and displaced basal flood deposits at Gable Mountain (Golder Associates, 1981).

Muir and Fritsche (1981) described earthquake-related features formed in sediments in California during the 1979 Imperial Valley earthquake. In saturated zones complex dikes were formed, while in unsaturated zones simple dikes were formed. This suggests that some clastic dikes in the Pasco Basin may be earthquake related. Woodward-Clyde Consultants (1980), in a study of reservoir induced seismicity (RIS), noted that man-made reservoirs that are either very deep (>150 m) or very large (>1 x $10^{10}$ $m^3$) are the most susceptible to reservoir induced seismic events. The ephemeral Lake Lewis, formed upstream of Wallula Gap during the late Pleistocene flood from glacial Lake Missoula, would have been both very deep (>250 m) and very large (2 x $10^{12}$ $m^3$). The RIS study concluded that seismic events were statistically more likely to be triggered if there were active faults present in the vicinity of the reservoir, and if the rate of filling of the reservoir was erratic.

If Baker's (1973) hydraulic model is valid, Lake Lewis both formed and largely disappeared within a period of two weeks. It is conceivable that reservoir induced earthquakes may have been associated with the rapid filling and draining of Lake Lewis.

Shaking resulting from seismic activity induced by the presence of Lake Lewis could provide a mechanism for the sliding of blocks of Touchet sediments and, the fissuring of Pasco Gravels, pre-Palouse loess, the Upper Ringold Formation, and basalt bedrock. However, the abundance and widespread occurrence of clastic dikes in the Pasco Basin, their composite natures, and the realtively short interval during which they formed all indicate that it is unlikely that earthquakes were the primary factor in their formation.

8. The exposure at the gravel pit just northwest of Kennewick shows a flat-lying composite Touchet clastic dike penetrating a thick calcrete developed on an older gravel (Figure D3-4). The dike is traceable near horizontally for over 5 m. No other such fissures have been seen in calcretes such as this. It is extremely unlikely that a flat-lying fissure would remain open with over 250 m of water above it while the clastic dike gently filled with sediment. (Hydraulic injection of sediment appears to be the most viable mechanism for the formation of this clastic dike. If clastic dikes can penetrate indurated carbonate-cemented conglomerate, then their injection into loose, saturated silts and sands would be easy.)

9. Clastic dikes reportedly created in fissures opened during folding in southern Chile (Winslow, 1977; Bruhn, 1979) are not similar to the composite Touchet dikes of the Pasco Basin. Their modes of origin must, therefore, be dissimilar also.

Summary - This Study

The lack of clastic dikes in eolian deposits and the predominance of clastic dikes in late Pleistocene flood deposits strongly suggest that they formed at the time of the flooding. This is confirmed by the frequent occurrence of truncated clastic dikes being overlain by younger flood deposits (Touchet beds).

Occasionally clastic dikes penetrate the entire sequence of flood deposits and extend downwards into basalt, Ringold, pre-Palouse loess and 200 ka cemented gravels.

High pressure injection is considered to be necessary to emplace dikes into the formations beneath the flood deposits, and this mechanism is regarded as the most plausible for the majority of cases, at least in the early phase of a dike's formation. Other processes, such as spreading of blocks of Touchet beds and liquefaction, presumably were also invoked as Black (1979) suggested, to continue the growth of the number of dikelets in a composite clastic dike.

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