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Observations on the biostratigraphy of Pliocene and Pleistocene diatomites from the Terrebonne district, Deschutes County, Oregon

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ABSTRACT: Some previous investigators have indicated that current lithostratigraphic evidence (including tephrochronology) suggests a Pleistocene age for the entire Terrebonne diatomite complex; however, biostratigraphic evidence from diatomites suggests that at least some of the diatomites in the complex are Pliocene. Because *Gomphonema occidentale* and *G. marginatum* (which have diagnostic, restricted stratigraphic ranges) and the indicative dominance of *Fragilaria* and *Nitzschia* in the "centric paucity" zone are present in diatomites from the eastern part of the Terrebonne area but are absent in diatomites from the western part, there can be little doubt that the former diatomites are older than the latter and are Pliocene in age. Since there is overwhelming evidence that the stratigraphic range of *Stephanodiscus niagarae* is from middle Miocene to Recent, claims of its first occurrence at about 1.8 m.y. (in the Tulelake core) are no longer tenable in considering age relationships in the Terrebonne diatomites. There are great differences between the eastern and western Terrebonne diatomites in respect to their paleoecology, lithostratigraphy, and biostratigraphy.

INTRODUCTION

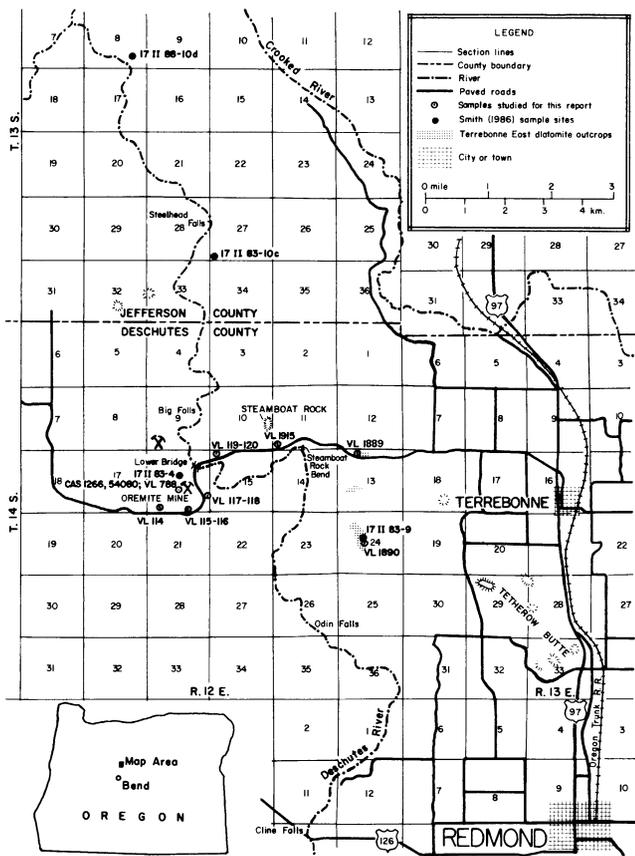
It has been common knowledge for many years that the purity and sustained mining of diatomite in the vicinity of Lower Bridge, near Terrebonne (text-fig. 1), probably make it the most important diatomite deposit in Oregon (Eardley-Wilmot 1928; Calvert 1930; Mulryan 1942) and one of the most noteworthy non-marine deposits in the United States, if not the world. It is interesting to note the comments of Edwards (1891) concerning the complexities of the diatomites from the Pacific Northwest (including those from the Columbia River and Deschutes River regions) and how J. W. Bailey (who conducted the first detailed examination of them) largely failed to recognize their distinctive character. Even though almost a century and a half have passed since Bailey's work, often modern investigators still have failed to see the significance of the distinctive nature of the diatomites from the Deschutes River basin, especially those from the eastern and western parts of the Terrebonne district. From the first discovery of the Terrebonne diatomites until the present, there has been ample controversy about their age, origin, and identification. Part of the explanation for this probably is the confusion of the Terrebonne diatomites (5 to 11 km west of Terrebonne) with other diatomites also in the Deschutes River basin, some of which are found in the Deschutes (Madras) Formation of late Miocene to early Pliocene age. Equally confusing is the fact that the Terrebonne diatomite complex (at least some parts of which evidently are considerably younger than the Deschutes Formation) includes three or more distinct beds in the outcrops west (hereafter referred to as Terrebonne West) of Steamboat Rock Bend and at least two beds in outcrops east (hereafter referred to as Terrebonne East) of Steamboat Rock Bend (text-fig. 1). In most cases the term "Terrebonne diatomite" has been used in the past to refer to the commercial deposits at the Oremite (or Dicalite) mine in sec. 16, T. 14 S., R. 12 E. and belongs to the Terrebonne West localities.

In referring to the Terrebonne diatomite complex, Mulryan (1942) indicated that, "Some geologists call it Pleistocene;

others classify it as Pliocene or late Miocene." Eardley-Wilmot in Calvert (1930) and Okuno (1956) designated a Miocene age for the commercial diatomite deposits at Terrebonne. The California Academy of Sciences (CAS) catalogue attributes a Pliocene age to diatomite samples CAS 54080 and 54081 from Terrebonne in the Hanna Diatom Collection. Such investigators as Stearns (1930), Moore (1937), and Peterson et al. (1976) assigned the Terrebonne diatomite complex to the Deschutes (Madras) Formation. Moore's (1937) Pleistocene age designation for the Terrebonne diatomites is in agreement with Williams (1957), Smith (1986), and Smith et al. (1987). However, there is good evidence that at least some of the Terrebonne diatomites (Terrebonne East) probably are pre-Pleistocene as VanLandingham (1987a) advocated and probably are somewhat older than the Terrebonne West deposits. Robinson and Stensland (1980) reported irregular masses of diatomite belonging to the Terrebonne East outcrops which were "interlayered with sedimentary rocks of Madras Formation." VanLandingham (1987a) assumed that some of the Terrebonne diatomites were in the Deschutes (Madras) Formation and proposed a Pliocene age for them on the basis of stratigraphic ranges of ten diatoms (all from Terrebonne West localities), at least four of which apparently became extinct before the Pleistocene. Evidently the lithostratigraphic evidence of Smith (1986) and Smith et al. (1987) presents a strong enough case to warrant probable extension of four of these diatom stratigraphic ranges into the Pleistocene. On the other hand, there are prominent problems with the rationale of the biostratigraphic assignment of not only these beds (Terrebonne West) but also the Terrebonne East beds to a Pleistocene age by Bradbury in Smith (1986) and Bradbury in Smith et al. (1987).

COMPARISON OF TERREBONNE EAST AND TERREBONNE WEST DEPOSITS

All of my taxonomic identifications from the Terrebonne diatomite beds were made from samples in Deschutes County,



TEXT-FIGURE 1
Map of the Terrebonne district in the Deschutes-Crooked River interfluvium and adjacent country in Jefferson and Deschutes Counties, Oregon.

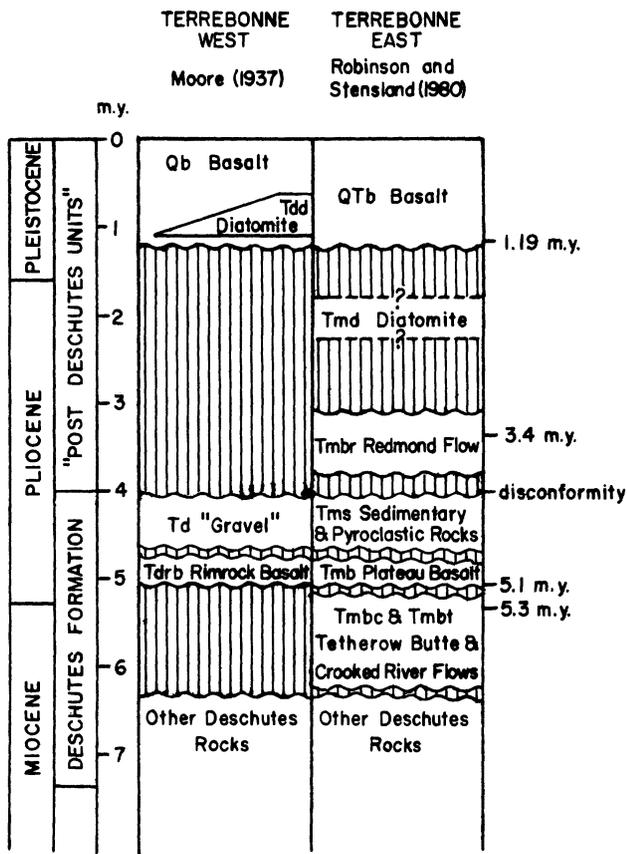
Oregon, at the following localities: CAS 1288 (collected by V. Eardley-Wilmot); CAS 54080 (collected by J. Fidiem); VL (VanLandingham) 114 in SW ¼ SW ¼ sec. 16, T. 14 S., R. 12 E.; VL 115 and 116 in S ½ SW ¼ SE ¼ sec. 16, T. 14 S., R. 12 E.; VL 117 and 118 in NE ¼ SE ¼ sec. 16, T. 14 S., R. 12 E.; VL 119 and 120 in N ½ NW ¼ sec. 15, T. 14 S., R. 12 E.; VL 788 probably in sec. 16, T. 14 S., R. 12 E.; VL 1915 in SW ¼ SW ¼ sec. 11, T. 14 S., R. 12 E.; VL 1889 in W ½ NE ¼ NW ¼ sec. 13, T. 14 S., R. 12 E.; and VL 1890 in NE ¼ SW ¼ sec. 24, T. 14 S., R. 12 E. The last two localities are from Terrebonne East and the remainders are from Terrebonne West (text-fig. 1). Samples and corresponding slides from all of the CAS and VL localities mentioned in this study already have been or will be deposited at the Geology Department, California Academy of Sciences, Golden Gate Park, San Francisco, California and/or Academy of Natural Sciences of Philadelphia, 19th and the Parkway, Philadelphia, Pennsylvania. Apparently great differences in environment of deposition (paleoecology), lithostratigraphy, and biostratigraphy can be noted in comparing the Terrebonne East with the Terrebonne West deposits.

The environment of deposition of the latter deposits has been described in great detail by Calvert (1930), Moore (1937), and Stockton in Mulryan (1942), while little has been said about that of the former except by Bradbury in Smith (1986) who reported it as a “shallow, warm, eutrophic environment of low salinity

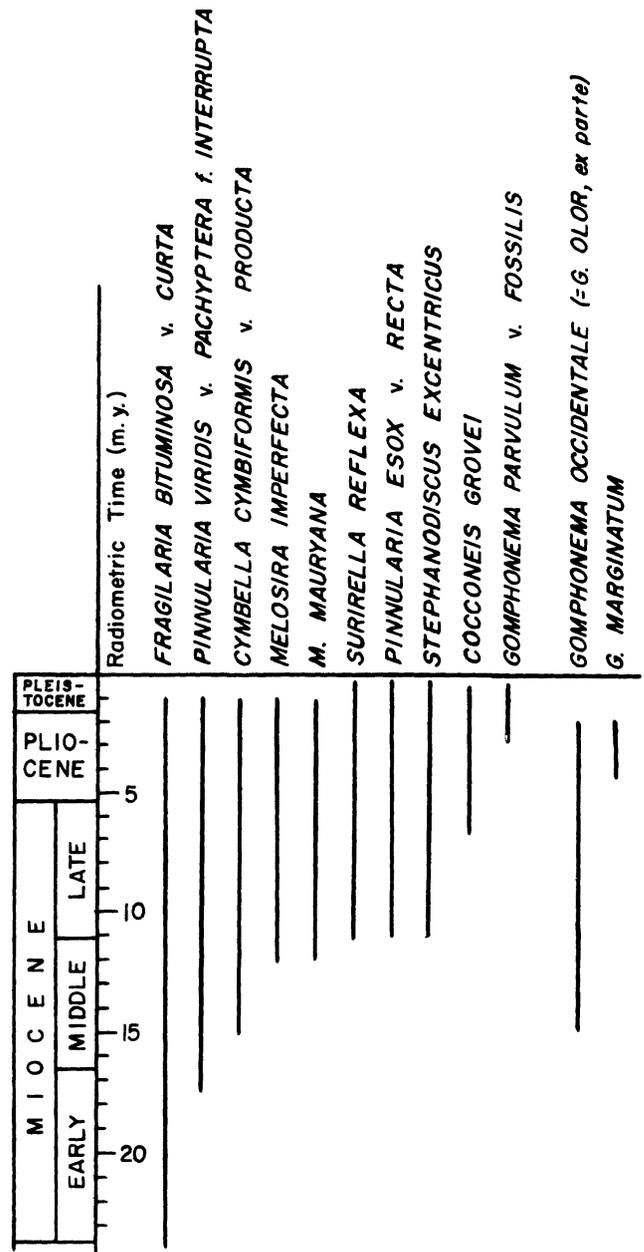
and moderate alkalinity.” My own assessment of the Terrebonne East assemblages indicates an environment of deposition similar to that given by Bradbury, except that his claim of “low salinity” for a lacustrine deposit of this nature which contains *Nitzschia romana* and *Fragilaria construens v. venter* as co-dominants seems doubtful since both of these taxa were characterized as leptomesohalobes (Baudrimont 1974) and since the latter diatom is described as oligohalobous to β mesohalobous (Werff and Huls 1957). Consensus of the literature indicates that neither of these taxa nor any of the taxa listed by Bradbury in Smith (1986) are truly halophobous (found in chloride deficient waters) or characteristic of “low salinity” (unless by this he intends to allude to fresh waters proper as being of “low salinity”). Research with CAESARS (continuous algal ecological spectral analysis reference system), a comprehensive computer retrieval pre-program based on approximately 3,000 publications with about 2 Mbytes of information on about 4,000 commonly and widely occurring diatoms (and other algae), revealed that in addition to having warmer waters, the Terrebonne East deposits were typified by more alkaline, mesosaprobic, and eutrophic conditions than the Terrebonne West deposits. All of the Terrebonne diatomites probably were deposited in shallow lakes, but the paleoecologic indications of taxa and the thin, delicate beds associated with the Terrebonne East lakes suggest that they were smaller and more short-lived than the Terrebonne West lakes.

The apparent lithostratigraphic relationships of the Terrebonne East and Terrebonne West diatomites are represented in text-figure 2. The “uncertain” stratigraphic position of the Terrebonne East deposits (indicated by Smith 1986) can be explained by the two following possibilities. First, the eastern diatomites appear to overlie the Pleistocene “QTb” basalt unit of Robinson and Stensland (1980), but if this were actually the case, these diatomites would be remains of Holocene or late Pleistocene lakes “perched” upon the Pleistocene basalt. However, this probably is not the case since taxa in the Terrebonne East deposits show even less similarity with any of the taxa from published assemblages of modern lakes in the region than the younger, Terrebonne West deposits (table 1). In addition, these Terrebonne East assemblages are quite different from the diatom assemblages found in modern Suttle Lake 40 km to the west in Jefferson County (VanLandingham, unpublished) and these Terrebonne East deposits have none of the common, extant, and endemic (to the Pacific Northwest) taxa with first occurrences in late Pleistocene that are found in modern lakes of the region listed in table 1. Second, the Terrebonne East diatomites may be older low-density material that was incorporated into or carried onto the surface of the younger high-density Pleistocene basalt as it was flowing. This invasive character of the basalt flows to cause “lifting” or “rafting” is not an unusual phenomenon on the Columbia Plateau as Carson, Tolan and Reidel (1987) and Smith (1988) have duly indicated (for example) with the Squaw Creek and Quincy diatomites in conjunction with the Roza lava flow of the Wanapum Basalt in south-central Washington. Because of reasons explained below, it is plausible that the Terrebonne East diatomite beds are at least slightly older than those of Terrebonne West as shown in text-figure 2.

The Terrebonne East beds possibly even may be related to the “Tms” unit (sedimentary and pyroclastic rocks) of Robinson and Stensland (1980), especially if this unit is considered to be near the top of the Deschutes Formation (text-fig. 2) which



TEXT-FIGURE 2
Idealized composite of stratigraphic columns of Terrebonne West (circa sec. 16, T. 14 S., R. 12 E.) and Terrebonne East (circa sec. 24, T. 14 S., R. 12 E.) diatomite localities. Interpretations of units, K-Ar dates (on far right), and nomenclature (on far left) are modified from Smith (1986) and my field notes of 18 July 1961, 13 October 1987, and 14 October 1988. Vertical lines in columns represent approximate time intervals not represented by rocks. The Tmd diatomite unit in questionable (?) position in the Terrebonne East column may be somewhat older than is indicated and more likely is part of the Tms (sedimentary and proclastic rocks) unit.



TEXT-FIGURE 3
Stratigraphic ranges of extinct diatoms in the Terrebonne diatomite complex. The first ten taxa are from Terrebonne West deposits and the last two are from Terrebonne East. *Cocconeis grovei* occurs in both the West and East deposits.

would have a time of deposition corresponding well with the indicative dominance of *Fragilaria* and *Nitzschia* (in relation with the "centric paucity" zone explained below) and with the stratigraphic ranges of extinct taxa from Terrebonne East (text-fig. 3). Diatomites in the Deschutes Formation (samples 17 II 83-10c and 17 II 83-10d of Smith 1986) are found in the vicinity of the Terrebonne district and are just to the north of the Terrebonne East and West diatomites (text-fig. 1). It is noteworthy that some assemblages in the Deschutes Formation, such as sample 17 II 83-5 (table 2) at Gateway and 17 II 83-10d at Steelhead Falls in adjacent Jefferson County (Bradbury in Smith 1986), also may be (like the Terrebonne East diatomites) in the diagnostic "centric paucity" zone.

Unless at least part of the Terrebonne West diatomites are older than Pleistocene, the implication by Smith (1986) that the "rafted" diatomite material at Terrebonne East (in his sample 17 II 83-9) was related to the Terrebonne West diatomites (in his sample 17 II 83-4) is not very likely for the following reasons. (1) The Pleistocene age of the Terrebonne East sample assigned

by Bradbury in Smith (1986) is somewhat young to compare favorably with the stratigraphic ranges of two Terrebonne East diatoms, *Gomphonema occidentale* and *G. marginatum* (table 1, text-fig. 3). (2) Except for *Cocconeis grovei* the 12 extinct diatoms in the Terrebonne East and West diatomites are different (table 1, text-fig. 3). (3) The Terrebonne East deposits have none of the 6 extant taxa with first occurrences in the late Pleistocene which are endemic (or essentially endemic) to the Pacific Northwest and which are found in the Terrebonne West deposits (table 1). (4) The diatom assemblages from Terrebonne West not only are much more closely related to modern Oregon lake communities than to the Terrebonne East assemblages, they also

TABLE 1

Comparison of Terrebonne East and West diatomite assemblages with published reports on Recent assemblages from regional lakes in Oregon. Samples from Crater, Diamond and (Upper) Klamath Lakes are from Sovereign (1958). Crater Lake assemblages include one from Emerald Pool. Davis Lake assemblage is for Messina-Allen and VanLandingham (1970). Swan Lake assemblages are from Tempère and Peragallo (1907-1915). Only the most important taxa are listed. Nearly all of the unlisted taxa are widely distributed or cosmopolitan extant forms and have their first occurrences in Miocene or Oligocene time. † = possibly extinct during Holocene or perhaps extant. * = Subendemic (or reported only rarely outside of the Pacific Northwest region). X = presence of taxon in assemblage. S = Subdominant. D = Dominant. C = Co-dominant. (*N. ludloviana* is subendemic.)

	TERREBONNE EAST	TERREBONNE WEST	CRATER LAKE	DIAMOND LAKE	KLAMATH LAKE	DAVIS LAKE	SWAN LAKE
RANGES OF EXTINCT TAXA	PLIOCENE: <i>Gomphonema marginatum</i>	X					
	MIOCENE TO PLIOCENE: <i>G. occidentale</i> (=G. olor ex parte)....	X					
	MIOCENE TO PLEISTOCENE: <i>Cocconeis grovei</i>	X	X				
	<i>Cymbella cymbiformis</i> v. <i>producta</i>		X				
	<i>Fragilaria bituminosa</i> v. <i>curta</i>		X				
	<i>Melosira imperfecta</i>		X				
	<i>M. mauryana</i> †.....		X				
	<i>Pinnularia esox</i> v. <i>recta</i>		X				
	<i>P. viridis</i> v. <i>pachyptera</i> f. <i>interrupta</i>		X				
	<i>Stephanodiscus excentricus</i> †.....		X				
	<i>Surirella reflexa</i> †.....		X				
PLIOCENE TO PLEISTOCENE: <i>Gomphonema parvulum</i> v. <i>fossilis</i>		X					
MOSTLY ENDEMIC TO PACIFIC NORTHWEST	MIOCENE: <i>Cocconeis klamathensis</i> *.....	X	X			C	
	<i>C. rugosa</i> *.....	X	X	S	S		
	<i>Gomphonema</i> (<i>Gomphoneis</i>) <i>scapha</i> *.....		X				X
	<i>Navicula aurora</i> *.....	X	X	X	X		
	<i>Nitzschia innominata</i> *.....		X	S	X		X
	<i>N. oregona</i> *.....		X	X	X		X
	<i>Opephora americana</i> *.....		X				X
	<i>Synedra mazamaensis</i> *.....		X	X	X	X	X
	PLIOCENE: <i>Navicula ludloviana</i>	X	X	X	X	X	
	<i>N. walkerii</i>		X	X	X		
	<i>Nitzschia columbiana</i>		X		X		
	LATE PLEISTOCENE: <i>Achnanthes lanceolatoides</i> *.....		X		X		
	<i>Fragilaria crotonensis</i> v. <i>oregona</i> *....		X		X		
	<i>Gomphonitzschia exigua</i>		X	X			
	<i>Nitzschia dissipata</i> v. <i>undulata</i>		X				
<i>N. fonticoloides</i> *.....		X	X			X	
<i>N. perspicua</i>		X					
NOT ENDEMIC TO PACIFIC NORTHWEST	EOCENE: <i>Fragilaria virescens</i>		X	X	D	X	X
	OLIGOCENE: <i>F. construens</i> v. <i>venter</i>	C	S				D X
	<i>F. pinnata</i>		X	S			S X
	<i>Nitzschia amphibia</i>	C	X	X	X	X	
	MIOCENE: <i>Cymbella cistula</i>	X	X	C	X	X	X
	<i>C. mexicana</i>	X	X	S	X	X	C
	<i>C. mexicana</i> v. <i>janischii</i>	X	X				C
	<i>Cymbellonitzschia diluviana</i>		X	S			
	<i>Epithemia sorex</i>	X	X	C	S	X	
	<i>Gomphoneis herculeana</i>	X	X	S	S	C	X
	<i>Nitzschia lancettula</i>	C		S	X		
	<i>N. romana</i>	C	X	X			
	<i>Rhopalodia gibba</i> v. <i>ventricosa</i>		X	X			C
	<i>Stephanodiscus niagarae</i>	X	D		X	C	
	PLIOCENE: <i>Gomphoneis ericense</i>	X	X	X	X	C	X
	<i>G. herculeana</i> v. <i>robusta</i>	X					X
	UPPERMOST PLIOCENE: <i>Surirella biseriata</i> v. <i>bicuspidata</i>		X				
	<i>S. linearis</i> v. <i>helvetica</i>		X	X	X		
PLIOCENE?: <i>Gomphonema rhombicum</i>	X		X	X			
Total samples studied.....	3	12	4	2	1	1	2
Approximate Pennate to Centric diatom ratio (H=high, L=low)...	400:1	1:3	H:L	H:L	58:1		
Total number of taxa in samples.....	67	117	113	104	56	82	110
Number of Terrebonne East taxa found in other assemblages.....		38	25	25	19	8	13
Number of Terrebonne West taxa found in other assemblages.....	38		72	59	38	20	28

TABLE 2

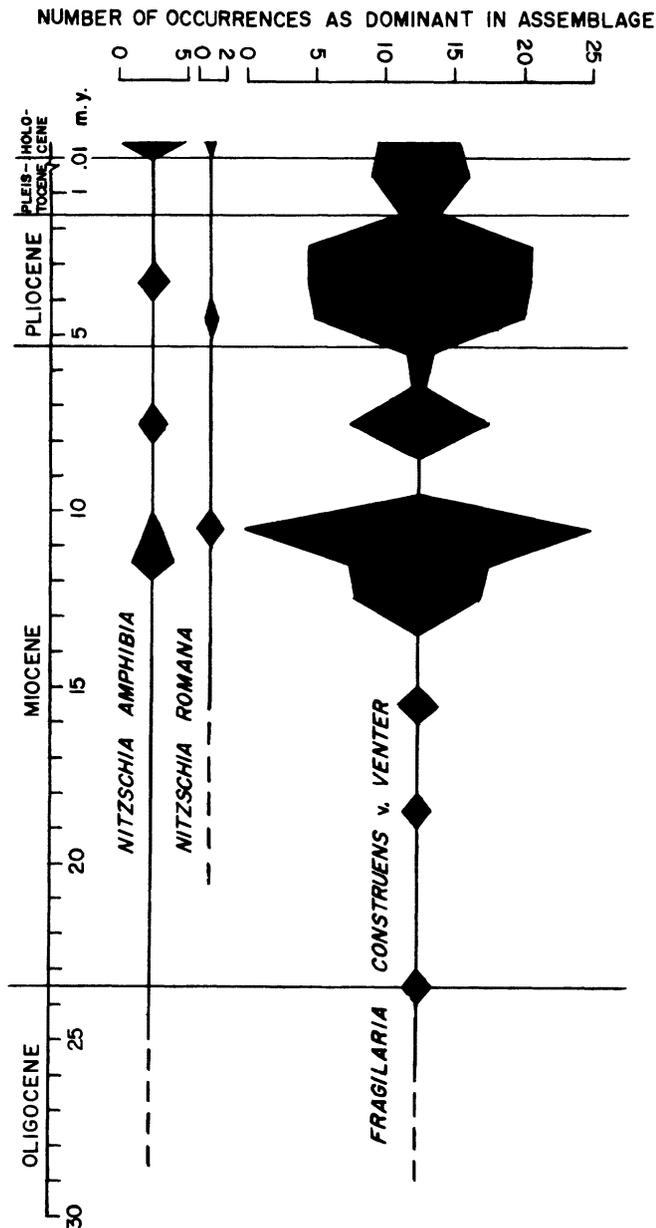
Approximate ages of Western Hemisphere assemblages with a paucity of centric diatoms. All localities are in the United States except those in nations designated with capital letters. All VL numbers in the references column are from unpublished work by VanLandingham. * = Subdominant. Note: Apparently all known (clearly fossil) assemblages in the "centric paucity" (CP) zone which are dominated by species of both *Fragilaria* and *Nitzschia* are Pliocene.

		LOCALITIES (formations in parentheses)	DOMINANT DIATOMS	REFERENCES	
HOLOCENE	0	Numerous Holocene deposits	<i>Pinnularia dactylus</i> , <i>P. major</i> , <i>Anomooneis serians</i> , etc.	Tempère & Peragallo (1907-1915), etc.	
	1	Arica, Tarapacá, CHILE (unspecified)	<i>Denticula elegans</i>	Dingman & Lohman (1963)	
PLIOCENE	2	Kettleman Hills, Fresno Co., California (Tulare)	<i>Epithemia turgida</i> , <i>Cymbella ventricosa</i> , <i>C. parva</i>	Lohman (1938, USGS diatom loc. 839)	
		Sierra Talc Mine, Inyo Co., California (Coso)	<i>Gomphonema longiceps</i> v. <i>subclavata</i> , <i>Nitzschia fonticola</i>	VL 1692	
		Yucca Mountain, Nye Co., Nevada (QTid unit of Swadley & Carr 1987)	<i>Denticula elegans</i> , <i>Epithemia argus</i> & vars.	Swadley & Carr (1987); VL 1567	
		Las Guayaverías de San Carlos, Mendoza, ARGENTINA (unspecified)	<i>D. valida</i> , <i>Nitzschia granulata</i> *, <i>Fragilaria peragalloi</i> *, etc.	Frenguelli (1934); VL 1963	
	3	Blanco Canyon, Crosby Co., Texas (Blanco)	<i>Fragilaria brevistriata</i> & vars., <i>Denticula elegans</i> *	Woolman (1892); VanLandingham (1988a)	
		Sevier, Sevier Co., Utah (Sevier River - Pliocene phase)	<i>F. brevistriata</i> , <i>Nitzschia denticula</i>	Callaghan & Parker (1962); Hintze (1965); VL 1893	
		Hillsdale, Garfield Co., Utah (Sevier River - Pliocene phase)	<i>F. brevistriata</i> , <i>F. construens</i> v. <i>venter</i> , <i>Nitzschia denticula</i>	Crawford (1951); Hintze (1973); VL 1881-1884	
		Benson, Cochise Co., Arizona (Quiburts or =)	<i>F. brevistriata</i> & vars., <i>Nitzschia denticula</i> , <i>Denticula elegans</i>	VL 1772	
		Mark West Springs, Sonoma Co., California (Sonoma Volcanics)	<i>F. construens</i> v. <i>venter</i>	VL 1640	
		Mulberry Canyon, Armstrong Co., Texas (Ogallala)	<i>F. construens</i> v. <i>venter</i> , <i>F. brevistriata</i> & vars., etc.	VanLandingham (1988a); VL 1489, 1491, 1493	
EARLY	4	Gate, Beaver Co., Oklahoma (Ogallala)	<i>F. brevistriata</i> & v., <i>F. construens</i> v. <i>venter</i> , <i>Nitzschia denticula</i>	VL 1856-1858	
	5	Gateway, Jefferson Co., Oregon (Deschutes)	<i>F. virescens</i> v. <i>producta</i> (no centric taxa listed)	Bradbury in Smith (1986, no. 17II 83-5)	
MIOCENE	6	Smith Valley, Lyon Co., Nevada (Wichman)	<i>Fragilaria virescens</i> , <i>F. construens</i> v. <i>venter</i>	VL 1698	
		Verdi, Washoe Co., Nevada (Coal Valley)	<i>Tetracyclus lacustris</i>	VL 50	
		Arabia District, Pershing Co., Nevada (Coal Valley or =)	<i>Fragilaria construens</i> v. <i>venter</i>	VL 1613	
	7	Panaca, Lincoln Co., Nevada (Panaca)	Conspicuous dominance is not specified	Mann in Westgate & Knopf (1932, sample 173, etc.)	
		Nevada Cement Claim, Lyon Co., Nevada (Coal Valley/Truckee or =)	<i>Fragilaria construens</i> v. <i>venter</i> , <i>F. virescens</i>	VL 1734	
		White Horse, Lyon Co., Nevada (Coal Valley/Truckee or =)	<i>F. construens</i> v. <i>venter</i> , <i>F. virescens</i>	VL 1733	
	LATE	8	Ione Valley, Nye Co., Nevada (Esmeralda)	<i>F. construens</i> v. <i>venter</i>	VL 1572
		Dicalite Mine dump, Mineral Co., Nevada (Esmeralda)	<i>F. lapponica</i> v. <i>rostrata</i>	VL 17	
		Grefco Mine, Mineral Co., Nevada (Esmeralda)	<i>F. construens</i> v. <i>venter</i> , <i>F. brevistriata</i>	VL 156	
		Crow Springs, Esmeralda Co., Nevada (Esmeralda)	<i>F. (Synedra) vaucheriae</i>	VL 1678	
	Gilbert, Esmeralda Co., Nevada (Esmeralda)	<i>F. brevistriata</i>	VL 1681		
	Bosalt, Esmeralda Co., Nevada (Esmeralda)	<i>F. brevistriata</i> , <i>Cocconeis placentula</i>	VL 1682		
	HCP 143, Mineral Co., Nevada (Esmeralda)	<i>Anomooneis sphaerophora</i> v. <i>polygramma</i>	VL 20, 21		
	Orizaba Mine, Nye Co., Nevada (Esmeralda)	<i>Fragilaria construens</i> v. <i>venter</i>	VL 1565		
	Weeks, Lyon Co., Nevada (Kate Peak or =)	<i>F. construens</i> v. <i>venter</i> & v. <i>subsalina</i>	VL 1556		
	Indian Valley, Adams Co., Idaho (Poison Creek or =)	<i>F. spp.</i>	Powers (1947, sample 132)		
MIDDLE	11	Blackwater River, British Columbia, CANADA (Hanceville/Chiloquin Ash or =)	<i>Epithemia argus</i> & vars.	Boyer (1926); VL 1503	
	14	Clan Alpine Mountains, Churchill Co., Nevada (Desert Peak or =)	<i>Pinnularia brebissoni</i> v. <i>microstauron</i>	VanLandingham (1988b); VL 1717-1718	
	16	Buffalo Canyon, Churchill Co., Nevada (Buffalo Canyon)	<i>Fragilaria construens</i> , <i>Cymbella turgida</i>	Smedman (1969, sample P2)	
		Pine Ridge, Sioux Co., Nebraska (Monroe Creek Sandstone)	<i>F. brevistriata</i>	Andrews (1971)	

are much more closely related to modern Oregon river communities. *Stephanodiscus niagarae* is very rare or absent in the samples from Terrebonne East, whereas it is the main dominant in the Terrebonne West samples (table 1). *S. niagarae* often is a co-dominant in the Snake River at Annex, Oregon (opposite Weiser, Idaho) and is frequently a very common or sub-dominant species in the Columbia River at Clatskanie and Bonneville, Oregon, and on the Klamath River at Keno, Oregon (Williams 1961).

(5) *Stephanodiscus hantzschii*, a very common dominant in such modern Oregon waters as the Columbia, Klamath, and Snake Rivers (Williams 1961), is present in the Terrebonne West diatomites but apparently is absent in the Terrebonne East diatomites, and it evidently is not known with certainty before Terrebonne East or late Pliocene time. (6) In every case the modern Oregon lakes in table 1 have at least twice as many diatom taxa in common with the Terrebonne West deposits as with the Terrebonne East deposits. With nearly three times as many diatom taxa in common, the diatom communities in the Terrebonne West deposits are much more closely related to

those from the modern Crater Lake (Klamath County, Oregon) than to those from the Terrebonne East deposits (table 1). In addition *Gomphonitzschia exigua* (a rare endemic heretofore known only from the type locality, Crater Lake) has been found in the present study in the Terrebonne West diatomites. It is remarkable that, with the exception of the report of Sovereign (1958), freshwater taxa of *Gomphonitzschia* evidently are not known in the Western Hemisphere. (7) The pennate to centric diatom ratio in the Terrebonne East deposits is $\geq 400:1$, but it is about 1:1 to 1:3 in the Terrebonne West deposits (table 1). It is clear that the former deposits belong in the "centric paucity" (CP) zone while the latter deposits do not. This zone (or series of zones) is associated with Miocene to Recent non-marine diatom-bearing sequences over the world in which centric diatoms are very rare or totally absent. VanLandingham (1988a) briefly referred to this CP zone. By definition the CP zone includes only fossil assemblages and may include some post-glacial fossil deposits but does not include active, living, and modern diatom communities. Examination of a total of almost 2000 diatomite and fossil diatom samples (from widely distrib-



TEXT-FIGURE 4
Principal pulses (acmes) in the stratigraphic ranges of *Nitzschia amphibia*, *N. romana* and *Fragilaria construens v. venter* from the Western Hemisphere. Recent and latest Holocene assemblages not included

uted localities over the world) from my personal collection, museums, and various publications yielded only about 120 in which centric diatoms were absent or very rare. Of the 120, about half were Pliocene or Miocene and in the remaining half nearly all were Holocene except for a very few in the latest Pleistocene. Table 2 lists known CP zone diatom assemblages from the Western Hemisphere. (8) Since CP zone diatom assemblages in the Western Hemisphere apparently are absent from the Pleistocene except for one in its latest part (table 2) and since the Terrebonne East deposits are in the CP zone and the Terrebonne West deposits are not, it is unlikely that the East deposits are Pleistocene and/or are of the same age as those of

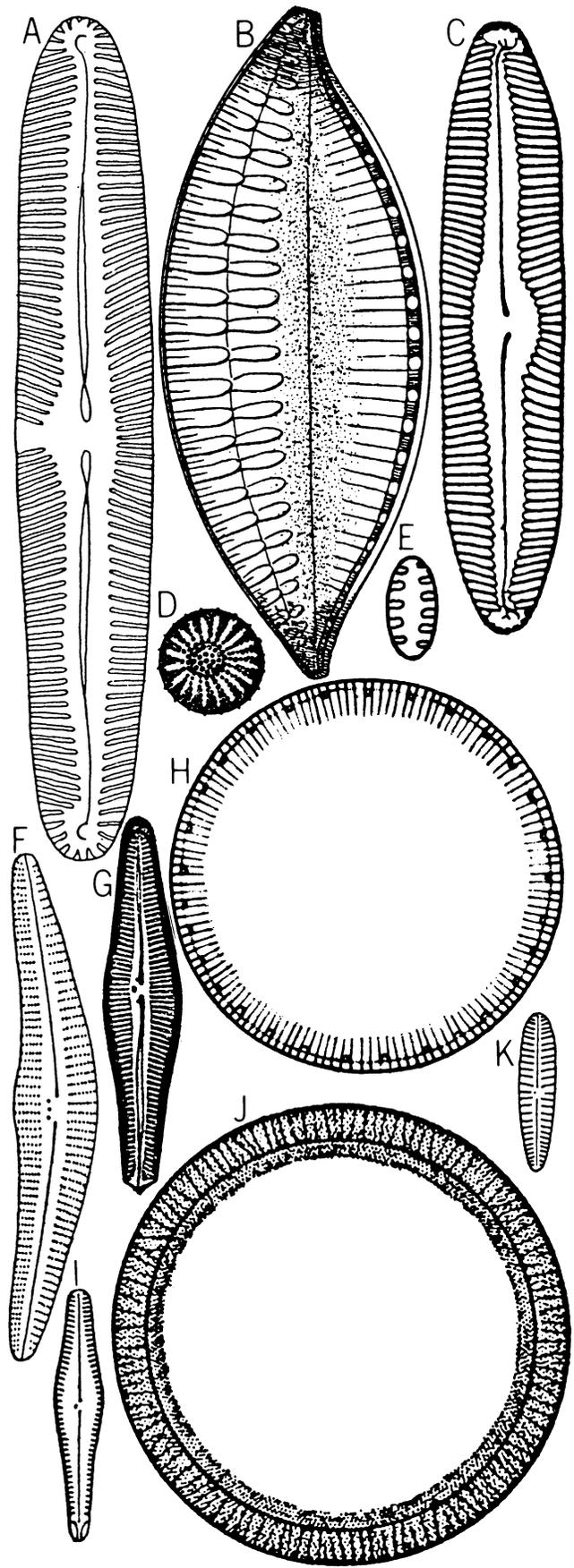
the West. The CP zone has three distinct phases, each separated by time gaps: post-glacial (or Holocene), Pliocene, and Miocene. It is not common for a post-glacial (Holocene) assemblage in the CP zone to have species of either *Nitzschia* or *Fragilaria* in abundance (or dominance). Unlike the Terrebonne East diatomites, apparently no post-glacial assemblages which are clearly fossil and in the CP zone are known to have species of *Fragilaria* and *Nitzschia* as the co-dominants (table 2). Except under special environmental situations (such as edaphic and periphytonic conditions), it is not common for active, living, and modern diatom communities to have a conspicuous paucity of centric taxa and/or to have species of *Fragilaria* and *Nitzschia* as co-dominants. Perhaps the main reason that it is unusual to encounter species of *Fragilaria* and *Nitzschia* as co-dominants in an assemblage is that these two genera in general have some fundamental ecological differences, the most noteworthy being that the latter has a much higher affinity for organic nutrients (and is more mesosaprobic) than the former. These differences are corroborated by CAESARS and Palmer (1969) among many other references. Most of the Pliocene assemblages in the CP zone have at least one dominant which is a species of *Fragilaria* or *Nitzschia* and often in such Pliocene assemblages both genera are represented with dominant species, such as at Terrebonne East. This *Fragilaria-Nitzschia* co-dominance is found also in assemblages from Sevier and Hillsdale, Utah, Benson, Arizona, and Gate, Oklahoma (table 2). Presumably all known (clearly fossil) assemblages in the CP zone which are co-dominated by species of *Fragilaria* and *Nitzschia* are Pliocene. Most of the Miocene assemblages in the CP zone have taxa of *Fragilaria* (usually *F. construens v. venter*) as dominants. Like the fossil post-glacial assemblages in the CP zone, none of these Miocene (CP zone) assemblages are known to have species of *Fragilaria* and *Nitzschia* as co-dominants, but unlike the fossil post-glacial assemblages (in the CP zone), no *Nitzschia* taxon is known to be dominant or abundant in them. For this and other reasons, the Terrebonne East diatomites are thought to be no older than Pliocene.

(9) If the Terrebonne East deposits are considered to be Pliocene, three of the four co-dominant species in them (*Fragilaria construens v. venter*, *Nitzschia amphibia*, and *N. romana*) correlate fairly well with the pulses (acmes) of these same species shown in text-figure 4, but these correlations do not occur if the Terrebonne East deposits are considered to be Pleistocene (like the Terrebonne West deposits). Except for its occurrence as a co-dominant in the Terrebonne East deposits, *N. lancettula* (not shown in text-fig. 4) does not seem to display a well developed dominance (acme) pattern and its only other occurrence as a dominant or co-dominant seems to be in latest Pleistocene or Holocene. (10) In comparing the Terrebonne East with the Terrebonne West deposits which have such dynamic biostratigraphic and paleoecologic differences, it probably would be logical to assume that there also would be noteworthy differences in their origin and lithostratigraphy. (11) *Gomphonema parvulum v. fossilis*, *Surirella biseriata v. bicuspidata* (= *v. rostrata*), and *S. linearis v. helvetica* (table 1) are found in the Terrebonne West (but not in the Terrebonne East) deposits, and all of these taxa have first occurrences which probably are younger than the Terrebonne East deposits.

STRATIGRAPHIC RANGES OF TERREBONNE DIATOMS

The indication by Bradbury in Smith et al. (1987) of the first appearance of *Stephanodiscus niagarae* Ehrenberg (pl. 1, fig. 1-12) at 1.8 m.y. in the Tulelake core from northernmost California is not significant in dating the Terrebonne diatomites. I have found *S. niagarae* for over 30 years in many samples (all older, some much older than the Tulelake occurrence) from Nevada, California, Washington, and Oregon, and these identifications have been confirmed with type material from public museum herbaria and with corroboration from many experts in the field. Many of these specimens were an excellent match for the illustrations of Theriot and Stoermer (1981) and for the F. Hustedt slides 11 (Eriesee, USA) and 19 (Isabol, Guatemala) of the Sovereign Collection at the California Academy of Sciences. Also the Cleve and Möller (1877-1882) exsiccata slide 40 (49) (*Stephanodiscus niagarae*) from Buffalo, New York (very near the type locality of Ehrenberg), compared very favorably with some of the Terrebonne and older specimens. With the exception of a very few large, damaged, and/or obscured specimens, all of the fossils that I identified as *S. niagarae* fitted well within most of the ranges of such criteria as diameter, fascicle count, areolae per 10 μm , number of striae per fascicle, spine count, labiate process count, central strutted process count, and mantle width given by Theriot and Stoermer (1984) for *S. niagarae* valves from 16 recent populations from the Great Lakes region. Evidently Cleve and Möller (1877-1882) had a concept of *S. niagarae* which compares favorable with modern consensus. If other specimens of *S. niagarae* edited by Möller (1892), such as those illustrated from his "Polycystinenmergel von Barbados" (Eocene) assemblage type plates, also are correctly identified, it would establish an age for this species over 20 times that of the Tulelake core and that of the oldest North American occurrence claimed by Bradbury in Smith et al. (1987) and Theriot et al. (1988).

There can be little or no doubt that the illustrations shown by the authorities in the next four references are indeed of *S. niagarae* and are from deposits which are probably as old or older than the 1.8 m.y. reference point in the Tulelake core. Servant-Vildary (1973) found *S. niagarae* to be abundant in the Pliocene deposits of Naala, Tchad, and Gasse (1977) reported it from Plio-Pleistocene lacustrine associations of central Afar (Ethiopia). Hanna (1951) reported it from Laguna Seca, Fresno County, California, with an assigned age of "Tulare Pliocene." Okuno (1952) recorded it in the Kumaki deposit (Miocene Tajiri Formation, Fugeshi Group), Kashima-gun, Ishikawa Prefecture, Japan, and from the late Pliocene of Kusu-gun, Oita Prefecture, Japan: in the Minami-Yamada deposit, in the Okabushi and



TEXT-FIGURE 5 →
 Extinct diatoms-found in Terrebonne diatomites: A. *Pinnularia viridis* v. *pachyptera* f. *interrupta*, B. *Surirella reflexa*, C. *Pinnularia esox* v. *recta*, D. *Stephanodiscus excentricus*, E. *Fragilaria bituminosa* v. *curta*, F. *Cymbella cymbiformis* v. *producta*, G. *Gomphonema occidentale* (=G. *olor* ex parte), H. *Melosira mauryana*, I. *Gomphonema marginatum*, J. *Melosira imperfecta*, and K. *Gomphonema parvulum* v. *fossilis*. All magnifications approximately X1000 except B which is X500 and E which is X2000. Figures C, J, and I are from Héribaud (1903a, 1908), B is from Wolle (1890), G is from Schmidt et al. (1899), K is from Manguin (1949), and all others are originals of diatoms from the Terrebonne diatomite complex. G and I are found in Terrebonne East and all others are found in Terrebonne West.

Okunameshi strata of the Nogami deposit, and in the Noda stratum of the Kita-Yamada deposit. In both the Okunameshi and Noda strata, *S. niagarae* accounted for 90% of the diatoms present. Based on planktonic foraminifera designations (*Globorotalia bykovae*-*G. menardii* zone) by Asano and Hatai (1967), the Tajiri Formation is contemporaneous with Onnagawa time and is included within the Serravallian (middle Miocene) as defined by Berggren (1971, table 52.30) and Berggren and Van Couvering (1974, fig. 1).

S. niagarae occurs in several samples from formations of Hemphillian or late Miocene age including the following localities in Nevada: VL 1576 from the High Rock sequence (Alturas Formation) at Duck Flat in SW ¼ SW ¼ sec. 20, T. 36 N., R. 19 E., Washoe County; VL 1672 from an unnamed Hemphillian formation in the Velvet district in sec. 1, T. 27 N., R. 28 E., Pershing County (pl. 1, fig. 11); and VL 1765 from the Thousand Creek Formation in SW ¼ sec. 28, T. 46 N., R. 27 E. in northwest Humboldt County (pl. 1, fig. 12). According to modern agreement and the COSUNA project, the Thousand Creek Formation is of Hemphillian age and probably is no younger than middle Pliocene (Wendell 1970; Hintze 1985). *S. niagarae* also has been found in VL 1499 (sec. 32, T. 23 S., R. 29 E., Harney County, Oregon) in the Danforth Formation which is approximately contemporaneous with the Thousand Creek Formation as defined by Wendell (1970). *S. niagarae* and *Coscinodiscus (Pontodiscus) gorbunovii* can be noted in sample VL 1916 from the upper Ringold Formation in N ½ sec. 12, T. 10 N., R. 28 E., Franklin County, Washington. The extinction of *C. gorbunovii* at circa 4 m.y. is in conformance with the 4.3 m.y. date of Krebs and Bradbury (1984) and the age range of 3.4 to 8.5 m.y. (of Fecht, Reidel and Tallman 1987) for the Ringold Formation.

The following occurrences in the upper Ringold Formation support the claim by Tedford and Gustafson (1977) and Waitt (1979) that the Ringold is no younger than 3.2 m.y.: (1) a reversed magnetic polarity sequence corresponding with the Gilbert Reversed Paleomagnetic Epoch (3.4 to 5.1 m.y.) (Packer and Johnston 1979), (2) microtine rodent fossils with an age of 3.7 to 4.8 m.y. (Repenning in Fecht, Reidel and Tallman 1987), and (3) a characteristic Blancan fauna (Gustafson 1978). *S. niagarae* also has been noted in Sonoma County, California, in the Petaluma Formation from VL 1792 in W ½ sec. 15, T. 6 N., R. 7 W. (pl. 1, fig. 10) and in the Sonoma Volcanics from VL 847 near Mark West Springs (pl. 1, fig. 2). A series of K-Ar and fission-track dates for the Petaluma Formation in Sonoma County ranges from 11.33±.88 to 6.93±.30 m.y. (Fox et al. 1985) and for the Sonoma Volcanics in the Mark West Springs 7 ½' Quadrangle, dates from 9.1±4.5 to 2.6±.3 m.y. (Wagner and Bortugno 1982). Modern consensus establishes the beginning of the Petaluma Formation in the late Miocene with its ending in the middle Pliocene and the Sonoma Volcanics as beginning in the latest Miocene and ending in the late Pliocene but somewhat before the Pleistocene (Wagner and Bortugno 1982). Large fragments of *S. niagarae* are not uncommon in sample VL 1800 (= U.S. Geological Survey diatom locality 3492) from the Barstow Formation in NW ¼ sec. 11, T. 32 S., R. 44 E., San Bernardino County, California. The youngest possible date for the Barstow Formation can be inferred from the range of K-Ar dates (13.8, 13.6, and 13.5±.1 m.y.) at the top of the Barstow Formation (Lindsay 1972; Burke et al. 1982) and from the 18–13 m.y. estimate for the entire formation by Glazner, Bartley and Walker (1989). Moiseyeva (1960), Jousé

(1966a, 1966b) and Proschkina-Lavrenko (1974) indicated a range for *S. niagarae* which extends well back into the upper half of the Pliocene in central Europe. The above summary of stratigraphic distributions should supply sufficient evidence for a comprehensive range back at least to middle Miocene for *S. niagarae*.

VanLandingham (unpublished) found *S. niagarae* from the Yonna Formation (or =) in samples VL 59 through 62, 1637, 1778, and 1839 from the Burney Falls-Pit River region of Shasta County, California (pl. 1, fig. 3, 4, 8, 9). It has been found also in the Yonna Formation in samples from localities VL 65 (NE ¼ sec. 18, T. 39 S., R. 9 E.), VL 67 (NW ¼ sec. 23, T. 39 S., R. 10 E.), and VL 74 (NW ¼ sec. 35, T. 34 S., R. 7 E.) (pl. 1, fig. 6), all in Klamath County, Oregon. Lohman in Moore (1937) found this species in diatomites (Yonna Formation) from the Kalmath Falls district and also illustrated this species from the recent diatomaceous oozes in Upper Klamath Lake. Since some of the samples above are very close to the general type locality (along the west side of Yonna Valley in T. 38 S., R. 11 ½ E.) of the Yonna Formation designated by Keroher (1966), any statement which might allude to the "poorly understood deposits called the Yonna Formation" probably is not appropriate in this situation, especially in view of the ample literature on this formation in this area. Even though the identity of the Yonna Formation has been complicated by structural problems and a wide range of lithologies, diatom assemblages from 48 widely scattered samples that I have collected from alleged Yonna Formation localities showed remarkable similarities in floristic composition and diagnostic extince species (VanLandingham, unpublished). Even more remarkable is the striking similarity in the spectral histograms of the paleoecology of all of these assemblages. Data supplied by CAESARS was employed in synthesizing the histograms. CAESARS was described and utilized in an ecological study by VanLandingham (1987b). Although the 2.3 m.y. isotopic age for the Yonna Formation of O'Brien in Bradbury and Krebs (1982) is from a lava flow faulted against diatomite and the stratigraphic position of the lava relative to the diatomite is uncertain, this age is compatible with the stratigraphic ranges of 47 extinct diatoms found in the 48 samples. Only 11 of these extinct forms have ranges which are known to extend past the Pliocene into Pleistocene, while 36 are known only from Pliocene and earlier times (and 13 of these 36 became extinct near the youngest Pliocene). The stratigraphic ranges of the 47 diatoms suggest a probable end to deposition of the Yonna Formation before the Pleistocene and a latest probable start of deposition around 6–3.5 m.y.

Fragilaria bituminosa v. *curta* Pantocsek (text-fig. 5E) is very common in fresh to brackish water deposits over the world and ranges from late Oligocene to its apparent extinction in late Pleistocene (text-fig. 3). The oldest known occurrence of this diatom is in rocks K-Ar dated at 23.6 ± .9 m.y. by McKee and Stewart (1971) from New Pass Summit (VL 1521 in E ½ sec. 32, T. 20 N., R. 40 E., Churchill County, Nevada). It is common in the brackish water European deposits of the Sarmatian and Tortonian.

The genus *Pinnularia* typically displays bilateral symmetry along both the apical and transapical axes. The distinct interruption of the costae on only one side of the central area which occurs in *P. viridis* v. *pachyptera* f. *interrupta* (Pantocsek 1903) VanLandingham, comb. nov. for *Navicula viridis* v. *pachyptera*

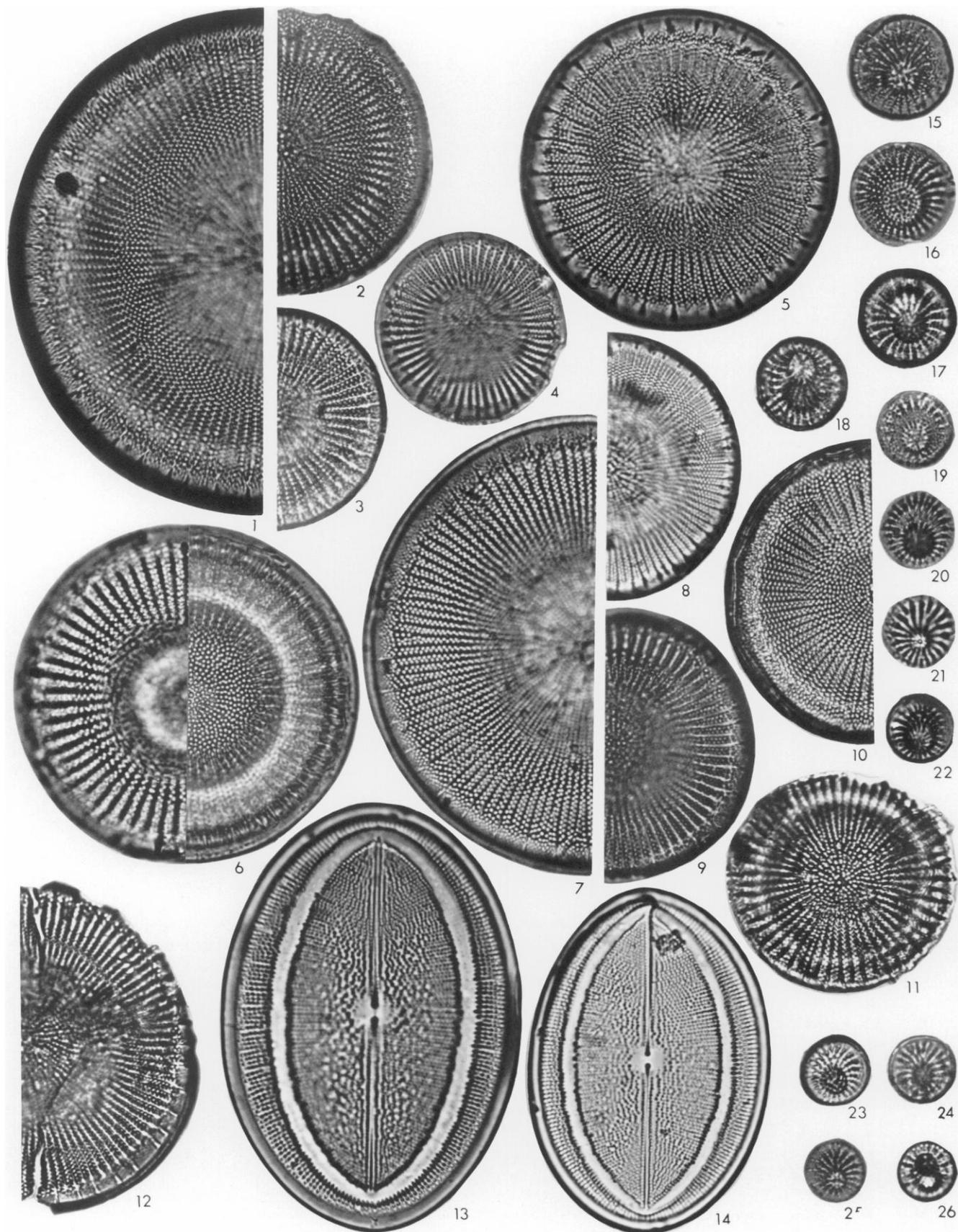
f. *interrupta* Pantocsek (1903), is considered by many prominent authorities to be a diagnostic feature and often justifies the recognition of a new species, or at least an infraspecific taxonomic variation of a type species in which the normal or typical population has uninterrupted costae on both sides of the central area (text-fig. 5A). By discounting my report of *P. viridis* v. *pachyptera* f. *interrupta* from the Terrebonne diatomites as "adventurous," apparently Bradbury in Smith et al. (1987) has been influenced by Hustedt (1930) who placed little diagnostic value on the interruption of the costae on one side of the central area in *Pinnularia*, evidently unaware that Hustedt obviously later did concede that this interruption can be a valid criterion for identification, if the interruption is found consistently in both valves of the cells within the same species population as exemplified by *Pinnularia ventricosa* Hustedt in Schmidt et al. (1934, pl. 389, fig. 3). In spite of any opinion of Hustedt or any other investigator, this interruption of the costae has been utilized by authorities listed below in numerous extinct *Pinnularia* taxa: *P. cymbelloides* Jousé (1952, 1966a, 1966b); *P. falax* (Pantocsek 1903) VanLandingham comb. nov. for *Navicula falax* Pantocsek (1903); *P. (Navicula) hemiptera* v. *gibba* Héribaud (1903a, 1903b), Tempère and Peragallo (1909), Lauby (1910a, 1910b), and Mills (1934); *P. hyppaei* Mölder (1939); *P. (Navicula) major* v. *andesitica* f. *interrupta* (Pantocsek 1903)

Reháková (1980); *P. (Navicula) martyi* (Lauby 1910a) Mills (1934); *P. meisteri* and f. *armenica* Poretzky ex Proschkina-Lavrenko (1950); *P. (Navicula) nodosa* v. *arverna* (M. Peragallo in Héribaud 1920) Mills (1934); *P. palibinii* Jouravleva (1936) and Proschkina-Lavrenko (1950, 1974); and *P. saga* v. *isostauron* and *undulata* Skvortzow (1937) and Okuno (1952). The stratigraphic range of *P. viridis* v. *pachyptera* f. *interrupta* (text-fig. 3) is from about early Miocene apparently to Pleistocene. It occurs in the following samples from Nevada: VL 1602, Truckee Formation or its = at center line between sec. 32 and 33, T. 19 N., R. 26 E., Churchill County; CAS 1302 and VL 1700, Esmeralda Formation near sec. 20 and in SW ¼ sec. 19, T. 2 N., R. 34 E., Esmeralda County; VL 1551, Truckee or Coal Valley Formation in W ½ sec. 2, T. 15 N., R. 25 E., Lyon County; VL 1555, Truckee or Coal Valley Formation in W ½ sec. 7, T. 16 N., R. 25 E., Lyon County; VL 1593, Truckee or Coal Valley Formation in NE ¼ sec. 10, T. 15 N., R. 25 E., Lyon County; VL 1617, Wichman Formation in NW ¼ sec. 19, T. 9 N., R. 27 E., Lyon County; VL 1467, unnamed formation of probable late Pliocene age in sec. 29, T. 14 S., R. 48 E., Nye County; CAS 1513, Esmeralda Formation in sec. 11 or 14, T. 9N., R. 30 E., Mineral County; VL 1710 and 1711, Esmeralda Formation or = in NE ¼ sec. 32, T. 10 N., R. 35 E., Mineral County; VL 1618, Middlegate or = unnamed formation immediately below a basalt dated 17.4 m.y. by Nosker (1981) near

PLATE 1

All magnifications ×1000

- 1, 5, 7 *Stephanodiscus niagarae* Slide VL 2201, sample VL 788, Terrebonne West, Deschutes County, Oregon.
- 2 *Stephanodiscus niagarae* Slide VL 1698, sample VL 847, Sonoma Volcanics, Sonoma County, California.
- 3, 4, *Stephanodiscus niagarae* Yonna Formation (or=), Shasta County, California. 3, 9, Slide VL 3565, sample VL 1637. 4, Slide 8, 9 VL 1695, sample VL 60. 8, Slide VL 1697, sample VL 62.
- 6 *Stephanodiscus niagarae* Slide VL 2220, sample VL 74, Yonna Formation, Klamath County, Oregon, at two different focal planes.
- 10 *Stephanodiscus niagarae* Slide VL 3874, sample VL 1792, Petaluma Formation, Sonoma County, California.
- 11 *Stephanodiscus niagarae* Slide VL 3415, sample VL 1672, unnamed Hemphillian formation, Pershing County, Nevada.
- 12 *Stephanodiscus niagarae* Slide VL 3819, sample VL 1765, Thousand Creek Formation, Humboldt County, Nevada. Focused to show marginal detail. Compare with figure 5.
- 13-14 *Cocconeis grovei* Slide VL 2201, sample VL 788, Terrebonne West, Deschutes County, Oregon. Note: The length to width ratio of 1.45:1 to 1.31:1 and a length of greater than 53µm in *C. grovei* distinguish it from *C. placentula* v. *intermedia* which has a length to width ratio greater than 1.47:1 and a length less than 53µm. Also, the submarginal unornamented band on the raphe valve is less ellipsoidal (and more pointed at the apices) in the former taxon. These taxa may grade into each other and both are present in the Terrebonne East and West deposits.
- 15-26 *Stephanodiscus excentricus* Terrebonne West, Deschutes County, Oregon. 15, 20, Slide VL 2205, sample VL 117. 16, 17, 24, Slide VL 2204, sample VL 116. 18, Slide VL 2201, sample VL 788. 19, 21, 26, Slide VL 2203, sample VL 115. 22, Slide VL 2206, sample VL 118. 23, 25, Slide VL 2202, sample VL 114.



Sou Hills in NE ¼ sec. 11, T. 26 N., R. 38 E., Pershing County; and CAS 1216, probably Coal Valley Formation near center S ½ sec. 9, T. 19 N., R. 18 E., Washoe County. It also has been reported in samples from VL 1490 through 1492 and 1494 from the Ogallala Formation in Mulberry Canyon, Armstrong County, Texas (VanLandingham 1988a). VanLandingham (unpublished) found it in VL 1440 in the lower part of the Mohawk Lake beds on the south bluff of the Feather River in SE ¼ NE ¼ SW ¼ sec. 9, T. 22 N., R. 12 E., Plumas County, California, and in CAS 1650, Alturas Formation at Fitzhugh Creek in sec. 31, T. 41 N., R. 13 E., Modoc County, California. Other California occurrences are from the Sonoma Volcanics in Sonoma County (VL 1462) and the Yonna Formation (or =) in Shasta County (VL 1839). This diatom has been found in the Bully Creek Formation of Oregon in VL 113, S ½ sec. 24, T. 19 S., R. 41 E., Malheur County and from the following samples in Baker County: VL 85, sec. 28, T. 8 S., R. 42 E.; VL 87, sec. 32, T. 8 S., R. 43 E.; and VL 88, SW ¼ sec. 34, T. 8 S., R. 43 E. The type locality of the synonym, *N. viridis* v. *pachyptera* f. *interrupta*, given by Pantocsek (1903) was from the andesite tuff (Sarmatian) at Szliács, Hungary. The synonym, *P. pseudopunctata* Lohman (1957), is found in USGS (United States Geological Survey) samples 3523 through 3525, "lower Virgin Valley Formation" at Opal Creek, Humboldt County, Nevada.

The stratigraphic range of *Cymbella cymbiformis* v. *producta* Pantocsek (text-fig. 3) apparently is from middle Miocene to Pleistocene (if the Terrebonne deposits are included). This taxon (text-fig. 5F) has been found at the following European Sarmatian deposits: Dubravica, Czechoslovakia (Pantocsek 1892, 1905; Tempère and Peragallo 1912; Řeháková 1971, 1980); Bory, Czechoslovakia (Tempère and Peragallo 1911); Kľebšchiefers of Lutilla, Czechoslovakia (Pantocsek 1913; Řeháková 1980); and Erdöbénye, Hungary (Tempère and Peragallo 1889-1895). VanLandingham (1988a) reported it from localities VL 1488, 1489, 1492 and 1493, Ogallala Formation from Mulberry Canyon, Armstrong County, Texas. VanLandingham (unpublished) found it at VL 18, Esmeralda Formation in the Mt. Montgomery-Basalt Station area in Mineral County, Nevada, at VL 1505, upper part of the Virgin Valley Formation in the Opal Creek area of the Charles Sheldon Antelope Range, Humboldt County, Nevada, and at VL 53, Yonna Formation (or =) in center S ½ sec. 18, T. 36 N., R. 4 E., Shasta County, California.

The stratigraphic range of middle Miocene to Pleistocene (text-fig. 3) for *Melosira imperfecta* Héribaud (text-fig. 5J) can be confirmed by the following occurrences: from rocks of Pontian age at Joursac, Cantal, France (Héribaud 1903a, 1903b; Lauby 1910a, 1910b); from Auxillac, Cantal, France, where it is abundant in Villefranchian beds (Tempère and Peragallo 1908); and from locality VL 148, 150 and 154, Esmeralda Formation north of the Monte Cristo Range in the Gilbert district in N ½, T. 4N., R. 38 ½ E., Esmeralda County, Nevada (VanLandingham, unpublished). Additional occurrences are from VL 84, Bully Creek Formation in SE ¼ sec. 29, T. 8 S., R. 42 E., Baker County, Oregon, and VL 78, Yakima Basalt in S ½ SW ¼ SE ¼ NW ¼ sec. 9, T. 14 N., R. 19 E., Yakima County Washington.

Melosira mauryana Héribaud (text-fig. 5H) ranges from middle Miocene to Pleistocene (text-fig. 3). In addition to the European occurrences in deposits from La Garde, Cantal, France

(Piacenzian) noted by Héribaud (1908), Lauby (1910a, 1910b) and Tempère and Peragallo (1912), VanLandingham (unpublished) recorded it from these localities: VL 1729, Esmeralda Formation northwest of Crow Spring in sec. 30, T. 5 N., R. 39 E., Esmeralda County, Nevada; VL 133, 134 and 1557, unnamed formation (probably Hemphillian age) in the Velvet district respectively in sec. 25, T. 28 N., R. 28 E., sec. 6, T. 28 N., R. 29 E., and SW ¼ sec. 34, T. 28 N., R. 30 E., Pershing County, Nevada; and VL 68, Yonna Formation in Poe Valley in NW ¼ NW ¼ sec. 12, T. 39 S., R. 10 E., Klamath County, Oregon.

The range of *Surirella reflexa* Ehrenberg (text-fig. 5B) from late Miocene to its probable extinction in post-glacial time (text-fig. 3) is supported by numerous published reports.

A compilation of numerous publications and my own observations indicated that *Pinnularia esox* v. *recta* (Héribaud) McCall = *Navicula olivieri* Héribaud (text-fig. 5C) arose sometime in the late Miocene and became extinct in post-glacial times (text-fig. 3).

The Oremite (Dicalite) mine at Lower Bridge (text-fig. 1) is the type locality of *Stephanodiscus excentricus* Hustedt (1952) (pl. 1, fig. 15-26; text-fig. 5D). The known stratigraphic range is from late Miocene to late Pleistocene or Quaternary (text-fig. 3), however it possibly could be extant. In examinations of the surface waters of Pyramid Lake on 9 July 1982 and 27 April 1985, I did not find *S. excentricus* or the "very similar species" mentioned by Bradbury in Smith et al. (1987) that "may be living today in Pyramid Lake." Also, Hanna and Grant (1931) mentioned no species of *Stephanodiscus* in their monograph on Pyramid Lake diatoms. VanLandingham (unpublished) found *S. excentricus* in the Yonna Formation (or =) in the following samples: VL 58, Lake Britton area in E ½ sec. 29, T. 37 N., R. 3 E., Shasta County, California; VL 73 and 75, Chiloquin area in SW ¼ sec. 19, T. 34 S., R. 8 E. and NW ¼ sec. 35, T. 34 S., R. 7 E., Klamath County, Oregon; and CAS 36100 and 36101, Dorris area in sec. 13, T. 47 N., R. 1 E., Siskiyou County, California. Other occurrences include: the Poverty Hills locality (VL 23) from the Quaternary lake beds in the Tinemaha Reservoir area in SW ¼ sec. 22, T. 10 S., R. 34 E., Inyo County, California; VL 52 from the Coal Valley Formation in NE ¼ NE ¼ SW ¼ sec. 17, T. 19 N., R. 19 E., Washoe County, Nevada; and VL 1792 from the Petaluma Formation in W ½ sec. 15, T. 6 N., R. 7 W., Sonoma County, California.

If the occurrence in the Terrebonne diatomites is included, *Cocconeis grovei* A. Schmidt (pl. 1, fig. 13-14) presumably ranged from late Miocene to Pleistocene (text-fig. 3). This is the only extinct diatom that was found in both the Terrebonne West and Terrebonne East deposits (table 1). Schmidt in Schmidt et al. (1894) originally described this species from samples of the Deschutes River (Terrebonne?) deposits in the Grove Collection. Hanna (1930) also reported it from the type locality. It has been found in the Sonoma Volcanics from Napa County, California, by Lohman in Kunkel and Upson (1960) in NE ¼ SW ¼ sec. 6, T. 5 N., R. 3 W. and by VanLandingham (unpublished) from: VL 1460 (S ½ NE ¼ sec. 32, T. 8 N., R. 5 W.); VL 1461 (SW ¼ sec. 33, T. 8 N., R. 5 W.); VL 1459 (NE ¼ SE ¼ sec. 32, T. 8 N., R. 5 W.); and VL 1458 (NE ¼ sec. 4, T. 7 N., R. 5 W.). Other occurrences in the Sonoma Volcanics are known from Sonoma County, California, near Mark West Springs (VL 847) and Goldstein Ranch (CAS 1245). I observed it in CAS 1695, probably from the Yonna Formation near the

southern end of Upper Klamath Lake, Klamath County, Oregon, and in VL 1770, "Pc" unit (middle to upper Pliocene diatomite) of Lydon, Gay and Jennings (1960) on the north flank of Antelope Mountain in NE ¼ sec. 7, T. 30 N., R. 13 E., Lassen County, California. Other localities in the Yonna Formation (or =) include VL 53, 55, 56, 58, 60, 1637, 1778, and 1839 through 1843, all in the Lake Britton-Pit River region of Shasta County, California.

The range of *Gomphonema parvulum* v. *fossilis* Manguin (text-fig. 5K) is uncertain, but current evidence indicates that it is from late Pliocene to late Pleistocene (text-fig. 3). Manguin (1949) originally described it from the lacustrine Pliocene-Pleistocene deposits of Ankaratra, Malagasy Republic.

Sustained, detailed observation and research have revealed that the tentative identification by VanLandingham (1987a) of *Gomphonema olor* Ehrenberg (= *G. occidentale* M. Schmidt ex parte) from the Terrebonne West diatomites is instead probably an extreme variation form of *G. erienne* or some other closely related taxon. However, *G. occidentale* does appear to be present in the Terrebonne East deposits (text-fig. 5G). I have not examined any specimens from the Yukon allegedly attributed to *G. olor* Ehrenberg (= *G. occidentale* M. Schmidt) by Kocielek ex Smith et al. (1987) and therefore cannot make a judgment concerning this claim. *G. olor* is very difficult to identify and easily can be confused with several other taxa which are known to inhabit modern waters. My own experience has taught that it is easy to make errors with such complicated species as *G. olor* (= *G. occidentale* ex parte) which obviously has occurred in attributing the statement, "jetztlebende Formen i. Nord-Amerika," made by Ehrenberg (1870, table 12, third row of taxa) for *Lithodontium nasutum* instead to *G. olor* in the second row of taxa in this same table. The text and table 12 of Ehrenberg (1870) indicated that *G. olor* was not "jetztlebende Formen i. Nord-Amerika." Bradbury in Smith et al. (1987) states, "Ehrenberg (1870), who described and named the species, said it was living in North America." According to information supplied by CEFDARS (continuous extinct fossil diatom age reference system), all of the 31 presently known localities of *G. olor* and *G. occidentale* are in a tight cluster with a 400 km radius centered at 41°13'15" N. Lat. × 118°47'40" W. Long. and indicate an age ranging from middle Miocene to extinction in the late Pliocene (text-fig. 3). Many of these localities of *G. occidentale* are discussed in VanLandingham (1985). Any locality in the Yukon would be over 1800 km away from the nearest locality in the cluster. Although it certainly is possible, the odds are against any such new record of occurrence.

Gomphonema marginatum Héribaud (text-fig. 5I) has a range from early to late Pliocene (text-fig. 3) and was found in the Terrebonne East but not the Terrebonne West deposits. Héribaud (1908) and Lauby (1910a) reported this species from the type locality at Mardansou, Haute-Loire, France. The age of late Miocene for the Mardansou deposit by Small (1946) is doubtful, but the consensus of modern stratigraphic nomenclature and research on the included diatom flora (which contains *Pinnularia huei* Héribaud and *Cyclotella charetoni* v. *gemmatula* Héribaud) do suggest an age no younger than early Piacenzian (or circa 2.5 m.y.) for the deposit.

CONCLUSIONS

There can be little doubt that the Terrebonne diatomite complex consists of at least two distinctly different groups of diatom deposits and that the Terrebonne East deposits are younger than Miocene but older than the Pleistocene Terrebonne West deposits. An unequivocal age determination based on tephrochronology for both the Terrebonne East and Terrebonne West deposits which might exclude the former from rocks as old as Pliocene would require more detailed work in the region than has occurred to date. There probably are ash beds in the region which not only have not been sufficiently studied but which are difficult to locate, describe and identify. It is likely that the Terrebonne West deposits are not part of the Deschutes Formation and are of Pleistocene age as Smith (1986) and Smith et al. (1987) avocated. On the other hand, the Terrebonne East deposits probably are somewhat older and may be related to the Deschutes Formation. If the age of the Terrebonne West diatomites is considered to be Pleistocene, it will require that the latest known times of occurrence be decreased slightly to Pleistocene for each of the following four diatoms (which previously had been known only from Pliocene and older times, according to VanLandingham 1987a): *Pinnularia viridis* v. *pachyptera* f. *interrupta*, *Cymbella cymbiformis* v. *producta*, *Melosira mauryana* and *Cocconeis grovei*. The basis for changing the ranges of these four extinct diatoms in the Terrebonne West diatomite deposits (in order to make them compatible with a Pleistocene age) should be on the basis of lithostratigraphy and/or factors other than those of Bradbury in Smith et al. (1987) in his discussion of diatom biostratigraphy. The belief of Bradbury in Smith et al. (1987) that CEFDARS is more concerned with affirming index fossils for the late Pliocene (or any preconceived time) is unfounded because the word "continuous" in the acronym indicates in CEFDARS that the system is being continuously updated and changed if new information so dictates.

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